For Earth, For Life
Kubota

# KUBOTA TECHNICAL REPORT

JANUARY 2021

54

ISSN 0916-8249

# KUBOTA TECHNICAL REPORT

No.54 JANUARY 2021

CONTENTS

# Our Efforts to Address the SDGs

## - Kubota Supports the Earth and People in the Fields of Food, Water and Environment -

The Kubota Group works on the SDGs, which are the common development goals for the international community, and is taking on the challenges to solve global issues through its business activities.

### What are the SDGs?

These are 17 goals set jointly by the nations around the world as issues to be tackled cooperatively.

The goals were adopted at the United Nations Summit in 2015 with 2030 set as the target for their achievement.

"Sustainable Development Goals" is abbreviated as SDGs, which is translated as “Jizokukanona Kaihatsu Mokuhyo” in Japanese.

### Association between the published articles and SDGs

| Primarily related field | | Closely related: ★ Related: ● |
|---|---|---|
| Food | Water Environment | Published article |
| ■ | | Development of AgriRobo Tractor MR1000A |
| ■ | | Development of the Head-feeding Combine Harvester DR6130A for Domestic Market |
| ■ | | Development of Small Rice Transplanter AW Series |
| ■ | ■ | Development of T90 Series Lawn Tractor for North America |
| ■ | ■ | Development of Two-stage Snow Blower SLA-1070ST |
| ■ | | Development of Spinach Conditioner NC301 |
| ■ | | Development of MU4902 Tractor for ASEAN Market |
| ■ | | Development of a High Speed Planter |
| ■ | | Development of SL Series Tractor with “Keeping Straight Function” |
| ■ | ■ | Development of 03･07･V3 StageV Engines |
| ■ | ■ | Development of Catalyst Technology for Particle Number Regulation |
| | ■ | Development of the CTL SVL65-2 for North America |
| | ■ | Development of Stand-On Type Mini Compact Track Loader SCL1000 |
| ■ | ■ | Development of Weathering Evaluation Technology |
| | ■ | Development of Flangeless T-pipes and Isolating Valves |
| | ■ | Development of Diagnostic Technology for Special Gate Valve for Petrochemical Plant |
| | ■ | Development of Combustion Analysis Technologies for Municipal Waste Incinerator |
| | ■ | Development of the Full-speed, Any-water Level Operation Function and Diagnostic Function for Pump Gate System |
| | ■ | Development of FILCERA HD -Ceramic Membrane Filtration Equipment for Drinking Water Treatment Plants |
| | ■ | Development of Plastic Single Stack Drain Fitting |
| | ■ | Introduction of Drainage Pump Vehicles to Assist Restoration Work Following Severe Flooding |
| | ■ | Introduction of Waste Treatment Operation at the Volume Reduction Facility of Futaba Town |


For more information on SDGs (Sustainable Development Goals),
please visit the website of the United Nations Information Center.
http://www.unic.or.jp/activities/economic_social_development/sustainable_development/2030agenda

| | SDG goals | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| | | ● | | | | | | ★ | ★ | | | | | | | ● | ● |
| | | ★ | | | | | | ★ | ★ | | | ● | | | | ● | ● |
| | | ★ | | | | | | ● | ★ | | ● | | | | | ● | ● |
| | | | | | | | | ★ | | | ★ | ● | | | | ● | ● |
| | | | | | | | | | ★ | | ★ | ● | ● | | | ● | ● |
| | | ★ | | | | | | ● | ★ | | | ● | | | | ● | ● |
| | | ★ | | | | | | ★ | ● | | | ● | | | | ● | ● |
| | | ★ | | | | | | ★ | | | | | | | | ● | ● |
| | | ★ | | | | | | ★ | ★ | | | | | | | ● | ● |
| | | | | | | | ★ | ● | | | ● | ● | ★ | | | ● | ● |
| | | ● | ★ | | | | ● | | ● | | | ★ | | | | ● | ● |
| | | | | | | | | | ★ | | ★ | | | | | ● | ● |
| | | | | | | | | ★ | | | ★ | ★ | | | ● | ● | ● |
| | | | | | | | | ★ | ★ | | | | | | | ● | ● |
| | | | | | | ★ | | | ★ | | ● | | | | | ● | ● |
| | | | | | | | ● | | ★ | | | ★ | | | | ● | ● |
| | | | ● | | | | ★ | | | | ● | ★ | ● | | | ● | ● |
| | | | | | | | | | ★ | | ★ | | ● | | | ● | ● |
| | | | ★ | | | ★ | | | | | | | | | | ● | ● |
| | | | | | | | | ★ | ● | | ● | ★ | | | | ● | ● |
| | | | | | | | | | | | ★ | | ★ | | | ● | ● |
| | | | | | | | | | | | ★ | ★ | ● | | | ● | ● |

# Inspiring Innovation to Provide Total Solutions

President and
Representative Director
Yuichi Kitao

Kubota delivers products that solve social issues in the areas of food, water, and the environment, thus enriching people's lives the world over. Yet, there remain many complicated issues that stem from low birthrates and longevity in developed countries, the ongoing spread of COVID-19, and global warming due to greenhouse gases. As one new issue after another presents itself, the global community is expected to become increasingly complex. Meanwhile, as technological innovation in the fields of ICT and IoT are catalyzing major changes in customers' business, we must definitively cater to their entire business, from upstream to downstream.

It is with this in mind that we have drawn up a new five-year Medium-term Plan that will kick off this year. Guided by the new Plan, we wish to be a company that offers total solutions to such issues by combining our proprietary technologies, products, and services. We have announced three directions to take in this regard. They are: 1. Enhancing productivity and safety of food, 2. Promoting recycling of water and waste resources, and 3. Improving urban and living environments.

I have been involved in the development of tractors and the operation of agricultural machinery business for 40 years, and there have been people that have insisted that the agricultural market has matured and will never grow again. Nonetheless, I tenaciously continued my research and development to help my customers to work out their difficulties. As a result, we have been able to help bring the agricultural market back to a growth trajectory, boosting sales of tractors and other agricultural machinery.

The "Customer First Principle" has long been ingrained in Kubota. After all, what we need for business is not self-centered thinking but to stay "On Your Side," that is, to stand by customers to discover their problems even before they do, so that we can lead their business to success.

It is also our desire that all divisions—R&D, Production, Sales, and Services—go beyond the boundaries of business domains and geographical regions to join together as "One Kubota," allowing us to offer new values that measure up to complicated social issues and diverse customer needs.

I believe that we can bring about innovation if we continue providing new values, and I take every opportunity available to tell everyone, "Without innovation, we cannot hope to grow." That said, it's not just new technologies that give rise to what I mean by "innovation." I have also told them that we can create synergies even with existing technologies and general-purpose products if we combine them in ways that were previously unimagined and that I would like to see them put together our in-house resources in the spirit of "One Kubota" and "On Your Side" to create a seamless string of innovations.

Meanwhile, it is true that, if we wish to create innovation in this modern age, it is important to develop new technologies by utilizing AI and other fruits of fast-paced technological innovation. For Kubota to sustain its business growth, in particular, advanced technologies in the fields of ICT/IoT, electric and other next-generation power sources, and biotechnology will play a vital role. Because these involve technical difficulties different from those associated with our more familiar technologies, such as casting, mechatronics, fluid control, and water/waste treatment, we are eagerly acquiring such technologies through our open innovation approach.

For instance, one research department is teaming up with an outside partner to study AI for next-generation agricultural robots, which perform harvesting—something that Kubota has yet to succeed in. Another department is jointly developing AI that uses videos to detect abnormalities in water infrastructure. This way, we are working with outside partners from both the private and public sectors for the future. Furthermore, at the Innovation Centers that we founded the year before last, we are gaining access to unique technologies and up-and-coming business schemes, such as a brand new pest control system/service that combines an insect database with meteorological information.

Kubota will remain committed to offering solutions to social issues and customers' businesses. To this end, we are transforming ourselves into a company that inspires innovation and offers total solutions. Please count on us!

# Development of AgriRobo Tractor MR1000A

Agricultural Tractor Engineering Dept. / Advanced Systems R & D Dept. Ⅰ /
Vehicle Base Technology Engineering Dept.



Japan's working population engaged in agriculture is declining due to the aging of farmers. As a result, the labor shortage is becoming more serious. On the other hand, farmland consolidation and scale expansion by certified farmers are increasing, and labor saving and efficiency improvement are required. To solve these problems, Kubota is promoting the development of smart agricultural technology. Kubota has already released into the market tractors, combine harvesters and rice transplanters with an autonomous driving system. To adapt to the needs of certified farmers we developed the new AgriRobo tractor "MR1000A", which is larger and more versatile than conventional AgriRobo tractors. Here we show the technical development of "MR1000A".

【Key Word】
Smart-agriculture, Tractor, Autonomous, Control, Detection System, GNSS

Related SDGs


## 1. Introduction

In Japan, the labor shortage in agriculture has grown severe. The underlying reasons include the aging of the agricultural workforce, which causes them to leave this sector. On the other hand, the consolidation of farmland by professional farmers has expanded the scale of the agriculture business and increased the area of farmland per capita of organizations. To maintain agricultural management efficient and stable, it is necessary to improve productivity and profitability. These requirements demand more efficiency and labor-saving using agricultural machinery. In response, Kubota, which promotes smart agriculture that achieves higher precision and efficiency and saves more on labor and effort, has developed the AgriRobo Tractor "MR1000A" capable of unmanned autonomous driving work (Fig. 1).

Fig. 1 AgriRobo Tractor MR1000A

## 2. Development concept and goals

### 2-1 Development concept

Tractors are capable of diverse types of work through the changing of implements. Each work task has different requirements for the vehicle speed, the timing at which the implement is raised and lowered, and the traveling route in the field. Therefore, the operator needs skills that vary depending on the work, and for efficient work, needs techniques and experience.

In addition, the vehicle operator is exposed to constant noise and vibration while having to keep the position appropriate to the work. All of this puts a great burden on the operator if the work is

prolonged.

Another aspect, there are several systems for obtaining positioning correction information with the use of RTK-GNSS (Real Time Kinematic-GNSS). The systems, the preference for which depends on the customer or region, require the versatility to support individual needs.

Considering all these circumstances, we based the development on the concept of "A highly versatile autonomous driving tractor that is advanced in precision and efficiency and contributes to safely saving labor and effort".



## 2-2 Goals

In order to achieve the creation of an AgriRobo Tractor that meets the development concept, we set the development goals as follows.

(1) Achievement of autonomous travel technology supporting many types of work

Achieve tillage by a rotary implement, soil puddling by a harrow, primary tillage by a stubble cultivator and fertilization by a broadcaster so that they are performed with the required accuracy independent of the operator's skills and experience and as well as the achievement of the generation of efficient work routes.

(2) Achievement of safety assurance in unmanned driving

Save on labor and effort with a reduced burden on the operator through unmanned autonomous driving work that is safely carried out under direct visual monitoring.

(3) Achievement of a highly versatile positioning system

Achieve a highly versatile positioning system by developing an RTK-GNSS unit for autonomous travel control that is compatible with the wide area base station system and with rough surface fields.

## 2-3 Overview of the AgriRobo Tractor

### 2.3.1 Devices mounted on the AgriRobo Tractor

The principal devices mounted to achieve autonomous driving include an RTK-GNSS unit for obtaining highly precise location information, an electronic power steering controller, a terminal monitor for registering work routes, condition settings and field contours, sensors for object detection, a camera for helping monitor the vehicle's surroundings, a remote control for starting or stopping work, and a tablet for obtaining vehicle information and changing settings.

### 2.3.2 Area worked on by the autonomous driving tractor

The applicable work area range for autonomous driving was defined to be the field's center area excluding the tillage area around the headland. Only in the case of rotary tillage, the innermost track of the tillage area around the headland was also defined as the area possible with tillage by autonomous driving. In the tillage area around the headland, in many cases, water intake valves, boundary stakes, drainage pipes and other low-height objects as well as concrete field ridges are present. Considering the risk of colliding with these objects, we excluded the tillage area around the highland from the applicable work area range for autonomous driving.

# 3. Technical issues to be solved

## 3-1 Issues in autonomous travel technology supporting many types of work

### 3.1.1 Extended work adaptability

Autonomous travel control is required to be situationally adaptive to the vehicle speed required for work and also the load on the tractor, which both vary depending on the type of implement used. More specifically, each implement has different characteristics; for example, the work with broadcasters often places more emphasis on efficiency than on accuracy, whereas the tractor does not respond quickly to the steering angle that the operator steers into to change the tractor's directions when working with stubble cultivators, which imposes loads with its claws hooked on the ground. So, our challenge was to develop autonomous travel control that supports these different implements accordingly.

3.1.2 Establishment of autonomous turning that does not damage headlands

Damaging a field with the tires or crawlers that stir up soil when the vehicle makes a turn in the headland lengthens the work time or degrades the finished quality of headland tillage. The size of the headland depends on the shape of the field and also the type of implement used.

Therefore, we faced the challenge of achieving automatic turning without damage to fields irrespective of the headland size. Another challenge we faced was to develop autonomous turning capability that takes into consideration not only wheel tractors but also power-crawler tractors, which require a greater diameter when making a turn.

3.1.3 Achievement of efficient route generation

After autonomous driving work finishes, the operator gets in the tractor and manually finishes up the remaining part of the field. Therefore, to improve the work overall in terms of efficiency and labor-saving, we faced the challenge of achieving the generation of autonomous driving routes, which not only improves efficiency for autonomous driving but also facilitates manual finishing work. More specifically, the issue to be addressed includes letting the tractor finish autonomous driving work at a location convenient for the operator to get in and also reducing the work time for finishing up the field by not leaving tire ruts on tilled land.

## 3-2 Issues in compatibility between safety assurance and versatility in unmanned autonomous driving

3.2.1 Safety requirements in unmanned autonomous driving

The most important thing in unmanned autonomous driving work is that not only the operator but also everyone in the vicinity can safely work with no injury to them. The guidelines for the assurance of autonomous travel safety published by MAFF[1)] stipulate, as part of the risk reduction measures for unmanned autonomous driving agricultural machinery, that tractors are required to be equipped with a system that detects surrounding objects and stops autonomously to avoid a collision with them. In addition, there is an international standard for the autonomous driving of agricultural machinery (ISO18497)[2)]. Based on all these stipulations, the inspection standard for agricultural robots and machinery by NARO[3)] was formulated. The inspection of agricultural robots and machinery requires the use of an 800 mm high object model made of layered cylinders as a representation of a crouching person and requires the unmanned autonomous driving tractor to be able to automatically stop before colliding with this model.

3.2.2 Safety assurance with many types of work

Tillage or soil puddling is performed at vehicle speeds of around 1-3 km/h. Contrarily, primary tillage or fertilization is commonly performed at vehicle speeds of 5 km/h or more. In addition, the implements attached differ in size and shape depending on the type of work. Given these circumstances, we faced the challenge of building an object detection system that lets the vehicle automatically stop with no collision with people and object models while maintaining the versatility to support high-speed vehicle work at 5 km/h or more and many types of implements.

## 3-3 Issues in the RTK - GNSS unit for autonomous travel control

To achieve a highly versatile RTK-GNSS unit for autonomous travel control, we faced the challenge of addressing wide area base station systems such as VRS (Virtual Reference Station). In addition, another challenge was to achieve the detection of the vehicle's location and direction with high precision at high rates even in rough surface fields.

# 4. Developed technology

## 4-1 Autonomous travel technology supporting many types of work

4.1.1 Optimization of steering control by work type

We achieved appropriate travel precision and efficiency by switching the allowable width and judgement items of the approach accuracy to the instructed work line variable depending on the implement type. More specifically, when the tractor does work that somewhat laps working tracks,

such as soil puddling by a harrow or broadcaster fertilization, the system tolerates vehicle misalignment during the approach to the start point of the instructed work line if the misalignment does not exceed the lapping tracks. In this way, efficient autonomous driving has been achieved with no wasteful moves in making a K-turn on the highland (Fig. 2).

On the other hand, stubble cultivators do not easily change direction when steering control is performed during the work. So, when they reach the start point of an instructed work line, the system checks the vehicle's misalignment in position and direction and also confirms if the amount of steering at the moment and the amount expected for the subsequent moment are within the allowable ranges. Only after that does the vehicle start the work.

With this, high accuracy has been achieved in stubble cultivator work (Fig. 3).

Thus, we have achieved highly precise and efficient autonomous driving with the selection of adequate travel precision according to the implement type.

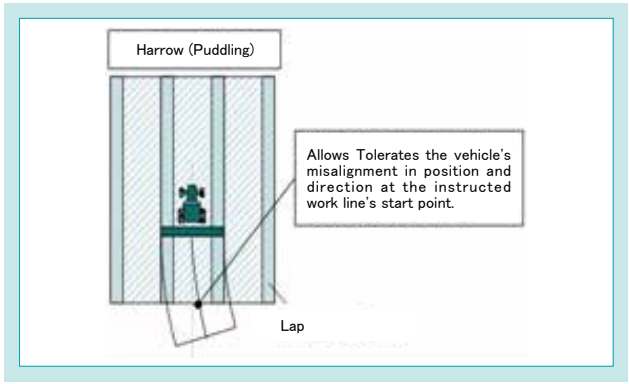



Fig. 2 Work Route of Harrow

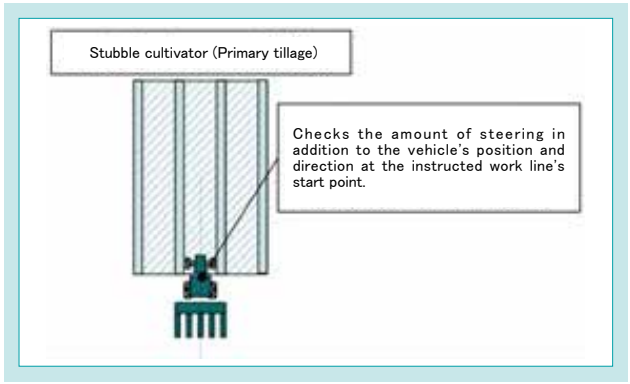



Fig. 3 Work Route of Stubble Cultivator

4.1.2 Autonomous turn and one-side braking controls that do not damage headlands

The vehicle obtains the information about instructed work lines through the terminal monitor beforehand. When the vehicle reaches the end point of an instructed work line, the system refers to the next instructed work line's starting position and line direction and the position in relation to the vehicle. Based on this referred information, the vehicle forms the turning circle for the approach into the next instructed work line. When the tractor turns, it travels along this turning circle. However, the headland area allowing the tractor to turn may be too small depending on the field shape and implement type. In this case, the vehicle will come close to the field ridge again and again if making attempts to directly go along the turning circle for the approach into the next instructed work line. This compels the vehicle to give an increased number of moves to make a K-turn and thereby causes damage to the headland. So, we programed an algorithm so that the system calculates the distance between the vehicle and the ridges at all times, and only if the vehicle approaches a ridge ahead, the vehicle reverses and makes a K-turn, and if a ridge is sensed on the side of the vehicle, the vehicle travels along the ridge a safely reasonable distance from it. Instead of the vehicle following a predetermined turning route, we programed an algorithm so that the vehicle heads for the turning circle and at the same time works around the surrounding ridges according to the vehicle's situation. In this way, the vehicle is capable of autonomous turning control with a minimized K-turn even in intricate fields (Fig. 4).

In addition, the diameter of the turning circle to the same steering angle is different between wheel and power-crawler specs. So, we made adjustments in the steering-angle and one-side braking controls to adapt them to each of the specs.

Through all these actions, we have achieved autonomous turning operation that does not damage headlands.

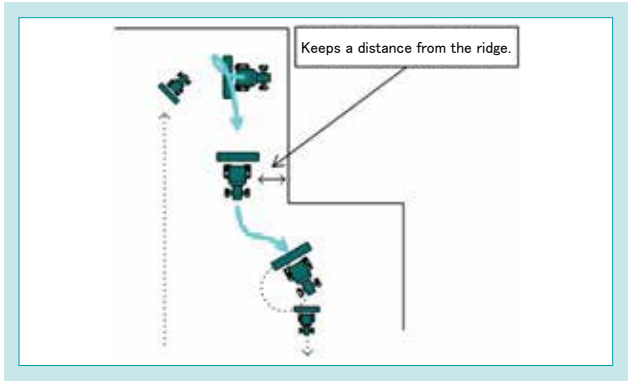



Fig. 4 Turning Route Along the Ridge

4.1.3 Efficient route generation that does not allow the vehicle to enter tilled land

If the vehicle has to follow a generated work route that focuses unconditionally on the minimum distance between the operator and the start and end point of tillage of the headland's inner perimeter, that is, the shortest possible distance from the field's entrance, the vehicle may enter tilled land near the start point when it reaches the end point (Fig. 5). If the vehicle enters tilled land, it creates extra work to eliminate tire ruts afterwards and therefore worsens work efficiency. So, we programed an algorithm so that the route generation control sets the start and end points of work in the innermost track to be in the corner that the vehicle encounters when it makes a left turn near the field's entrance. In this way, the operator can efficiently start manual headland tillage (Fig. 6).

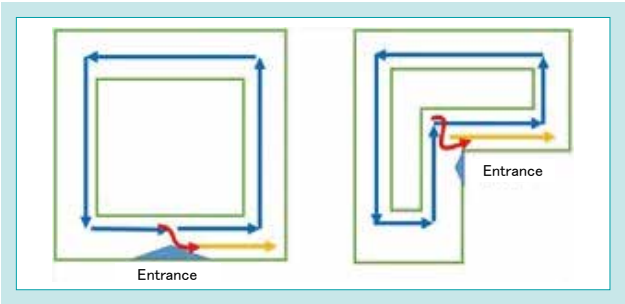



Fig. 5 Conventional Work End Point

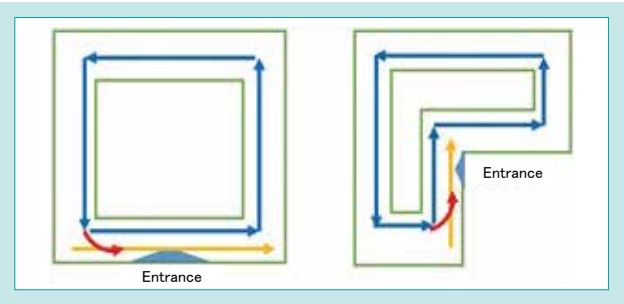



Fig. 6 Improved Work End Point

We have developed an algorithm that optimizes the length of the headland work line so as not to allow the vehicle's front tires to leave ruts on the center area's tilled land when the vehicle makes a right turn during the tillage of the headland's inner perimeter. More specifically, a turn judgment is processed at the end of each headland work line because the vehicle may enter the center area's tilled land only when it makes a right turn. A turn is judged as a left turn if the virtual line extended from the end point lies within the headland work's region that is one line outside of it, and if not, the turn is judged as a right turn (Fig. 7). The route is generated as follows: The line judged as a right turn is made short enough to allow its end point to come immediately preceding the point where the vehicle's front wheels arrive at the center area's tilled land. In addition to this, this line is further made shorter by the amount of the actually measured turning circle's radius. In this way, we have achieved a route that does not let the vehicle enter the center area's tilled land taking into consideration the vehicle's turn. (Fig. 8).

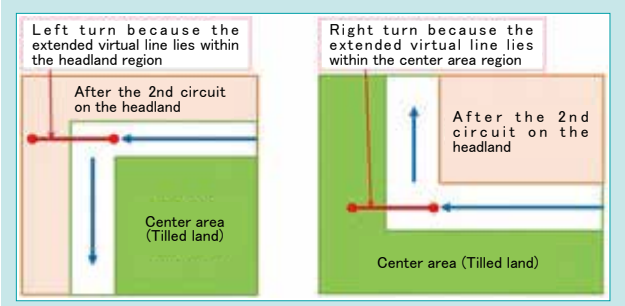



Fig. 7 Judgment of Left Turn or Right Turn

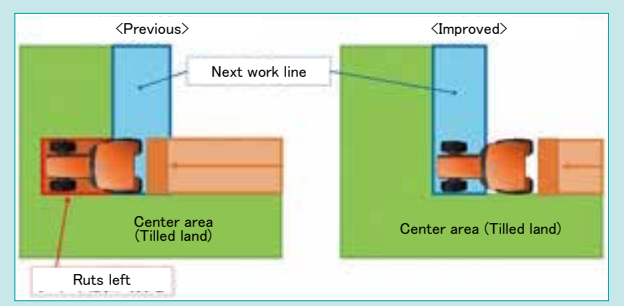



Fig. 8 Right Turn Route

## 4-2 Object detection technology supporting many types of work

### 4.2.1 Development of an object detection system supporting high-speed work

The MR1000A has an object detection system built with laser scanners and ultrasonic sonars as object detection sensors. The laser scanner selected features planar wide-angle scanning. A characteristic of the ultrasonic sonar is that although the detectable distance is short, the distances to objects in the peripheral space can be detected with relatively good precision.

As the vehicle speed is higher, the braking distance that the vehicle travels before coming to a stop becomes longer. Therefore, to bring the tractor to a stop with no collision with any object during high-speed vehicle work, braking needs to be initiated with the earlier detection of objects than with low-speed vehicle work.

In response, we have equipped the MR1000A with laser scanners at the front right and left of the vehicle, further towards the front than the hood, so that detection is possible when the tractor is sufficiently far away from objects.

For the detection in the right and left directions as well, the steering angle constraints in autonomous driving control have been eliminated by the sensors placed in the positions that can detect a third person approaching the tractor from the right or left side and that do not allow any steering angle to falsely detect the front tires as obstacles. Ultrasonic sonars were placed near the auxiliary steps which are the blind spots of the laser scanners and may have somebody present around it when the tractor starts (Fig. 9).

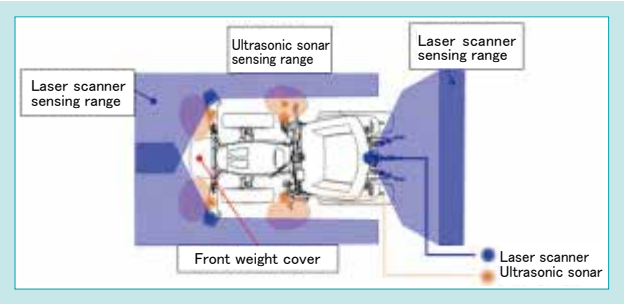



Fig. 9 Object Detection System

### 4.2.2 Detection area design supporting many types of implements

Tractors lose control of steering if the load on the front tires is too small. So, they need to put on as many front weights as appropriate for the implement used to keep the load on the front tires at 20% or more the total mass of the vehicle. The MR1000A has employed a front weight cover in order to reduce the object detection sensor's blind spot area range, which depends on the number of front weights to be placed (Fig. 10).

The laser scanners for the detection of objects behind the vehicle when it reverses have been adjusted to an installation angle that does not allow the implements to be falsely detected as obstacles when they are raised at the time of turning. In addition, we adjusted the sensing range of the laser scanners so as to detect only true obstacles instead of making a false recognition of obstacles regarding the ground when the vehicle is tilted or the second ears growing from the roots of grain that has been harvested once (Fig. 11).

In addition, we have developed a control system that switches the range of laser scanner detection according to the vehicle speed for the work and the implement size. With this, the tractor is capable of autonomous driving that does not allow field ridges to be falsely detected as obstacles when the tractor turns.

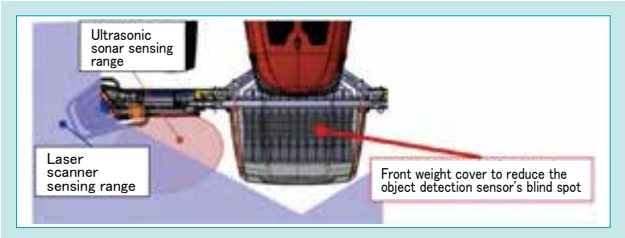



Fig. 10 Detection Area Near the Front Weight Cover

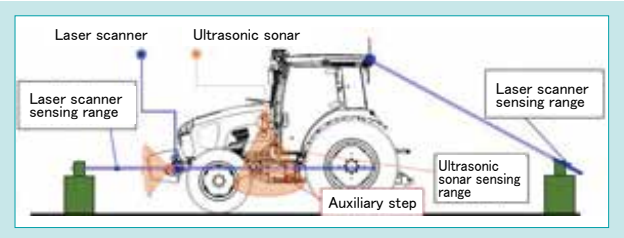



Fig. 11 Detection Area

## 4 - 3 RTK-GNSS unit technology

### 4.3.1 Addressing the wide area base station system

As the upgraded version of the integrated RTK-GNSS unit, which has been already commercialized for AgriRobo, we now have developed the RTK-GNSS unit best suitable for the autonomous travel of agricultural machinery. This is our own unique system capable of broader high-accuracy positioning by supporting the wide area base station system.

The previous RTK-GNSS unit has been offering services within 5 km in baseline length (between base station and mobile station) with the use of local base stations (transportable tripod types) or fixed base stations (installed in city halls or JA). This time, we selected a suitable receiver and developed our inhouse GNSS antenna so that we can provide broader and more versatile services and expand our service area with the support for the VRS system and long baseline length. With the support for the VRS system, RTK correction information can be received if within the mobile phone network, and the troublesome installation of the base station on the user side is eliminated. In addition, as support for the long baseline length (mainly for the use of simplified radio or N-Trip system at fixed base stations), the usable area has been expanded to within 10 km with the upgrading of the receiver, while previously limited to within 5 km from each base station (Fig. 12).


Fig. 12 Wide Area Base Station System

### 4.3.2 Highly accurate detection of positions and directions by hybrid maneuvering

Positions and directions can be output highly accurately and at a high rate even on rough surface fields due to the achievement of the GNSS/IMU hybrid maneuver with the use of the IMU (Inertial Measurement Unit) mounted on the integrated RTK-GNSS unit, into which all the constituent devices are united. Furthermore, the highly accurate and high rate detection of position (3 cm or below) and angle of direction (1° or below), which are essential for autonomous travel of agricultural machinery, has been achieved by its own unique calculation of optimum processing according to each travel status by using the vehicle's information (travel status generated from the vehicle speed, steering angle, map information, etc.).

## 5. Conclusion

The MR1000A has been developed as an autonomous driving tractor that is advanced in precision and efficiency and safely saves on labor and effort, along with high versatility with support for many types of work and the wide area base station system. This tractor has contributed to professional farmers being able to solve the labor shortage problem and reducing work burdens. From now on, we will proceed with the further enhancement of versatility based on market evaluations and requests. As future goals, we will advance the achievement of unmanned, complete automation and the action to strengthen KSAS (Kubota Smart Agri System) coordination.

## Contribution to SDG targets

8.2 Improvement in productivity through innovation
Contribution to the reduction of farmer labor with the unmanned autonomous driving tractor

9.2 Strengthening inclusive and sustainable industrial infrastructure
Contribution to the solution of labor shortages in agriculture

Reference

1) MAFF: Guidelines for the safety assurance of autonomous travel for agricultural machinery (Production former - No. 1897 notified on March 27, 2020 by Director-General, Agricultural Production Bureau, Ministry of Agriculture, Forestry and Fisheries)
2) ISO 18497: Agricultural machinery and tractors - Safety of highly automated agricultural machines
3) NARO: Major methods and standards for inspection of robotized/automated agricultural machinery -For robotized agricultural machinery (tractors)-

# Development of the Head-feeding Combine Harvester DR6130A for Domestic Market

Combine Harvester Engineering Dept.



In Japan's agriculture, farmland consolidation has accelerated due to a decline in the number of farms as a result of the aging of the population and the abandonment of farming. As the area of cultivated fields per farm increases, agricultural machinery is required to further improve work efficiency and save manpower and labor. To respond to such exigencies, Kubota has developed the Head-Feeding combine harvester "DR 6130 A" equipped with a large 130 horsepower engine. The harvester features an automatic operation assist function in addition to a major improvement in work efficiency. This paper describes (1) the development of a thresher with improved crop adaptability, (2) improvement of cleanability brought about by the side plate opening mechanism of the grain tank, (3) the automatic operation assist function.

【Key Word】
Combine Harvester, Adaptability, Cleanability, Autonomous Driving, Driving Control

Related SDGs


## 1. Introduction

In agriculture in Japan, while the number of farm households continues to decline, the government is taking the initiative in encouraging professional farmers to consolidate farmland and cultivate high-yield rice and rice for livestock feed. Due to this, the field area and crop varieties handled by professional farmers have increased and this has made combine harvester needs more diversified than ever. To contribute to making their agricultural business more efficient, we have developed the “DR6130A” combine harvester that saves more on manpower and labor with high performance in efficiency, durability and maintainability and also the autonomous driving assist function (Fig. 1).

Fig. 1 Autonomous Driving Assist Combine Harvester DR6130A

## 2. Development concept and goals

### 2-1 Development concept

To solve the management challenges of professional farmers (work efficiency, effort saving, manpower retention), we set the aim of the development model to make it a combine harvester that achieves more efficiency in agricultural business with an improvement in all aspects, which include work efficiency, cabin comfort, operability, maintainability, durability and ICT (Information and Communication Technology).

The development concept selected was “A flagship combine harvester that offers the No. 1 value in the country's industry to the next generation of professional farmers”.

This report describes the following three development items.

[1] Development of a thresher with enhanced crop adaptability

[2] Improved cleanability with a mechanism that allows the user to open the grain tank’s side plate

[3] Autonomous driving assist function

### 2-2 Development goals

The development goals are as follows.

(1) Improvement of thresher performance

Reduce threshing loss by 10% and straw contamination by 30% compared to that obtained with the current model in order to achieve a high-performance thresher that has the throughput that goes with the industry’s fastest harvesting speed and high adaptability for various crops.

(2) Improvement of cleanability

To improve the cleanability for crop type changeover, reduce the cleaning time for the grain tank’s inside by half.

(3) Manpower & labor saved by autonomous driving

Achieve efficient work with the autonomous driving assist function appropriate to the head-feeding combine harvester.

## 3. Technical issues to be solved

### 3-1 Extension of crop adaptability

A better thresher performance requires a reduction in harvest collection “loss” and “straw contamination” in collected harvests (Fig. 2). The increase in threshing cylinder speed or threshing beat force, which is a common means for reducing the losses due to harvests remaining unthreshed, encourages more straw contamination. These trends depend on crop conditions. So, to achieve a high-performance thresher, our challenge was to extend the crop adaptability that reduces both “loss” and “straw contamination” under various crop conditions.


Fig. 2 Sample Image of “Loss(Left)” and “Contamination(Right)”

### 3-2 Improved cleanability for crop type changeover

As there is a growing need for harvesting many types of crops with one combine harvester, thorough cleaning is required to prevent the unintended mixture of different types of grains. The previous model maintains cleanability with a cleaning opening provided on the machine’s underside. Nowadays, as cleaning is needed more frequently than ever before, we faced the challenge of achieving a structure that allows users to perform cleaning in an easier way.

### 3-3 Autonomous driving control technology unique to head-feeding combine harvesters

Ahead of all others in the industry, Kubota launched the autonomous driving assist function installed on the general purpose combine harvester "WRH1200A" (Fig. 3). This head-feeding combine harvester model employs map generation and travel control, which are our core technologies. However, we faced the challenge of dealing with the "row alignment" feature, which establishes an exact position alignment between the cutting part and the crop, and in addition, the "mud stir" problem where the mud squeezed out by the crawler pushes out the adjacent crop, both of which are typical issues of head-feeding combine harvesters.


Fig. 3 Autonomous Driving Assist Combine Harvester WRH1200A

## 4. Developed technology

### 4-1 High-performance thresher

4.1.1 Threshing chamber development

To reduce both "loss" and "straw contamination", the threshing chamber needs to minimize the production of straw waste, and at the same time, needs to thresh and collect the grain reliably. The threshing chamber of the development model aimed to improve the throughput to achieve "30% improvement in collection rate in relation to threshing loss" and "10% reduction in straw production" than that achievable with the previous model. To improve the throughput, we worked on the upsizing of the thresher and the optimization of parameters. The major specifications are shown in Table 1, and a schematic, in Fig. 4.

Increasing the length of the threshing cylinder has made an improvement in the collection rate. In addition, the previous model places the threshing teeth at the same height whereas the development model places lower and higher threshing teeth on the threshing cylinder's front and rear sides, respectively, so that the thresher is structured to minimize grain damage and straw production and to establish reliable threshing. Furthermore, the layer thickness of the of crop bundle was reduced by carrying the crop 20% faster, and this has reduced the production of straw. And, the number of times that the carried crop comes in contact with the threshing teeth has been made the same as that of the previous model by the optimization of the layout of threshing teeth. With all of these modifications, the threshing throughput has been secured.

With this, we have achieved "43% improvement in the collection rate in relation to threshing loss" and "11% reduction in straw production" than with the previous model's threshing chamber.

Table 1 Specifications of the Threshing Machine

| Item | Previous model | Development model | Change rate |
|---|---|---|---|
| Threshing cylinder length L [mm] | 1130 | 1300 | +15% |
| Threshing cylinder Diameter D [mm] | 424 | 454 | +7% |
| Crop speed [m/s] | 0.97 | 1.17 | +20% |

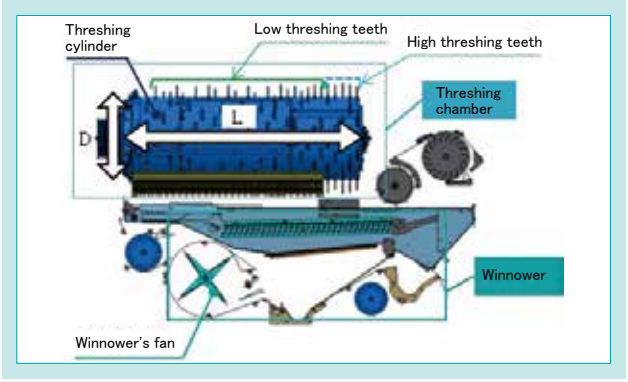



Fig. 4 Schematics of the Threshing Machine

4.1.2 Winnower development

To enhance the thresher, the improvement of the blowing performance of the winnower is indispensable. Many factors influence the airflow distribution in the winnower. So in this project, we conducted analysis by means of fluid analysis and quality engineering to develop an efficient winnower. We determined that the criterion for optimizing the airflow distribution is to expand the range in which appropriate airflow is maintained. So, we increased the height of the winnower and this increased the airflow from the winnower's fan by 20%.As results, this increased the range of the appropriate airflow in the winnower by 23% compared to the previous model and gave an optimized distribution of airflow in a wider range (Fig. 5). This modification has resolved the matter of excess range of airflow in the main winnower, which causes "loss", and the lack in airflow range in the rear winnower, which causes "straw contamination".

The results were reflected in the prototype machine, and through verification by real harvesting, "9% reduction in loss" and "13% reduction in straw contamination" have been achieved with only the modification of the winnower, compared to the previous model.

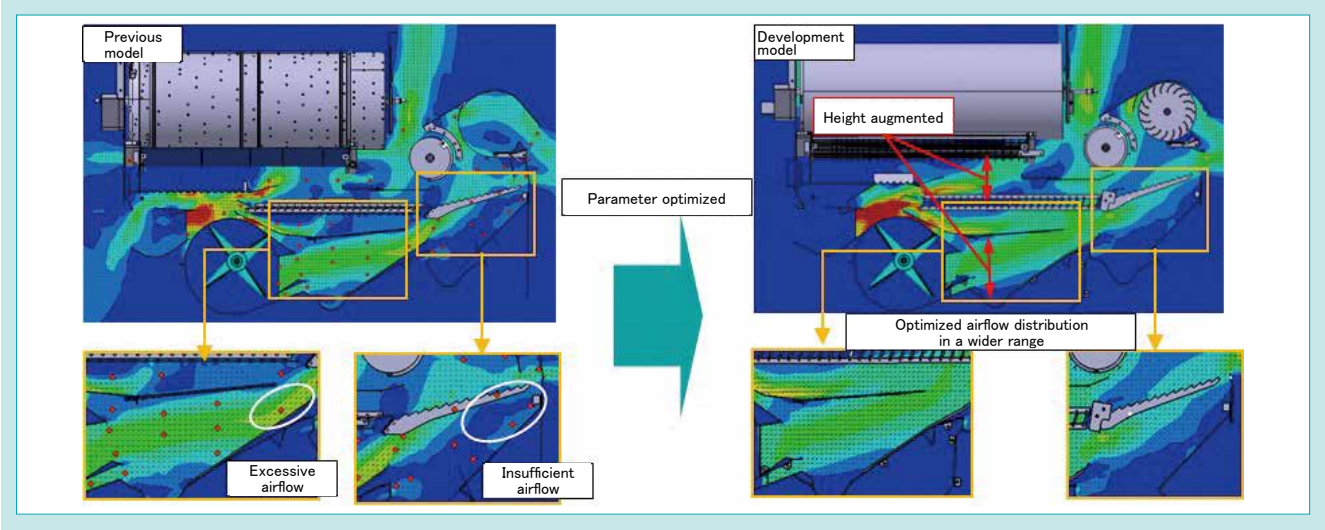



Fig. 5 Analysis Results

4.1.3 Results

To evaluate performance, we harvested real crops of various types all across the country and compared the previous model (6-row harvester, vehicle speed at 2.0 m/s) with the development model (6-row harvester, vehicle speed at 2.05 m/s). Part of the results is shown in Fig. 6.

(Data was compared not by absolute values but by percentages of totals.)

The development model has reduced both threshing loss and straw contamination, and remarkably, the straw contamination rate has been successfully reduced by 50% or more.

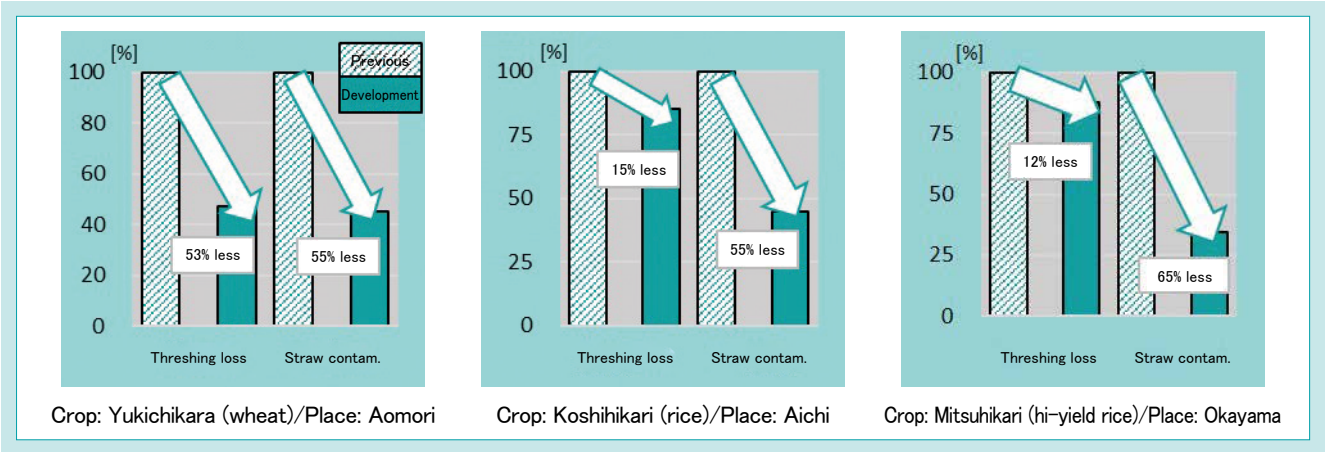



Fig. 6 Performance Test Results

## 4-2 High maintainability

Since more models increasingly support many types of crops, there is a growing demand for cleanability for the time of crop type changeover. Especially, the inclusion of rice for livestock feed results in quality degradation in the rice market. So, thorough cleaning is required. This section reports on the cleanability of the grain tank, which we have improved in this project.

With the previous model, the underside cleaning opening and the inspection opening on the machine's upper part are used, but these openings are small and so take a long time to clean. With the development model, we developed a new structure that enables access to the tank's inside with a single motion, allowing the user to open/close the grain tank's entire side plate with no use of tools. This has greatly improved cleanability (Fig. 7).

To achieve this new structure while securing strength by following the previous models' concept, we formed a lock structure by providing a support rod that we placed near the side plate so that it can be used as the junction to the side plate. However, because the entire side place is opened and closed, we needed countermeasures for the escape of chaff. To solve this issue, we formed a lock structure on the both upper and lower ends in addition to the support rod so that a tight enclosure can be ensured to prevent the escape of chaff even when subjected to the internal pressure that occurs during chaff packing (Fig. 8).

With this, while the previous model needed about 25 minutes for tank cleaning, the new structure has reduced it to about 6 minutes (75% reduction). In addition, even wet chaff, which sticks to the tank's wall surface, can be easily cleaned off.

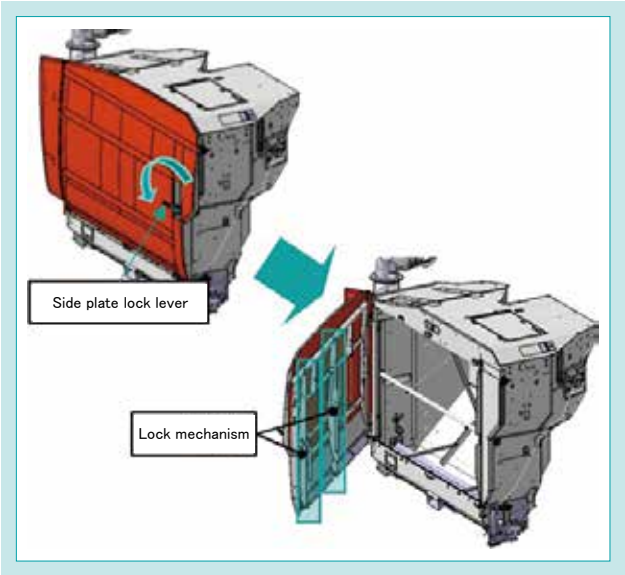



Fig. 7 Easy Maintenance of Grain Tank

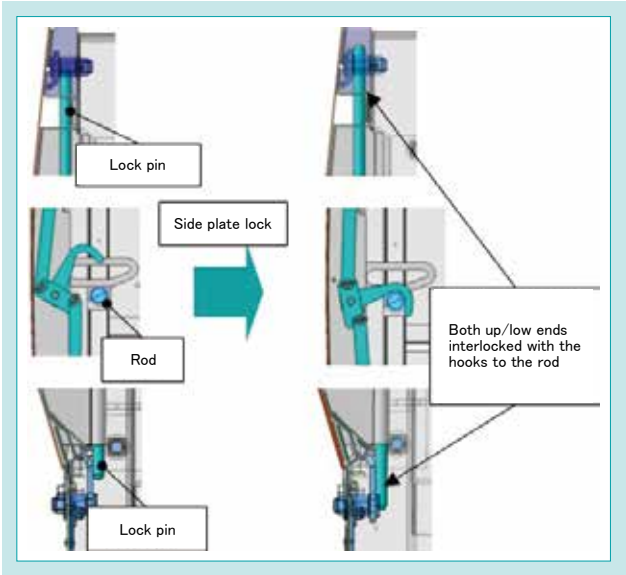



Fig. 8 Locking Mechanism

## 4-3 Autonomous travel control

4.3.1 Issues in the autonomous driving control of the head-feeding combine harvester

Kubota started the mass production of the general-purpose combine harvester WRH1200A equipped with the autonomous driving assist function in 2018. This function first calculates the outermost and innermost peripheries from the outermost locus points that is obtained after perimeter cutting is performed for two or three circuits. And from this result, the field's outline and unharvested region are calculated to let the vehicle harvest the unharvested region. Since this function was developed for the general-purpose model, we needed to make changes to convert it for use for head-feeding models, which have many differences from general-use models. For example, when harvesting, a general-purpose model can harvest using the entire cutting part, whereas a head-feeding model needs to have stalks confined between the dividers, which are located at the cutting part's ends (Fig. 9). In addition, the DR6130A has the cutting part's right end at the almost same position as the crawler's right end. For this reason, when "reverse harvesting", which leaves the crop left unharvested on the vehicle's right side, is used, the mud squeezed by the crawler may interfere with harvesting (Fig 10). So, unable to directly reuse the "artisan cutting", which is a type of travel control that we devised at the development of the WRH1200A, we needed to design the travel control intended for the head-feeding model.

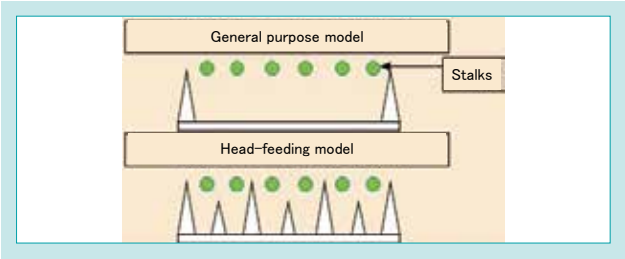



Fig. 9 Comparison Image of Reaper

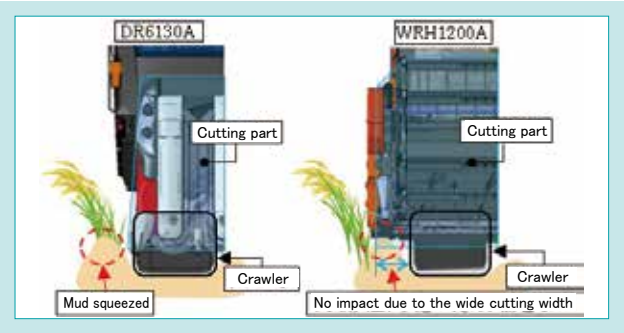



Fig. 10 Relative Position Between Reaper and Crawler

4.3.2 Achievement of multiple-row cutting

Since the interval of rice stalks varies by the country's region, we designed the system so that it can estimate row positions by the settings of planting direction and interval defined at the time of creating an autonomous driving route (Fig. 11). Based on this estimation, a route is generated so that the combine harvester always harvests 6 rows of stalks. In this way, lean harvesting has been achieved.

Because the combine harvester does not have the function of row detection, the system uses an assumption that stalks are planted at equal intervals when the operator performs multiple-row cutting. So, we needed to develop a function that allows the user to easily change the row setup if this assumption turns out to be incorrect after the route is generated. "Line shift function" is the function that we developed to solve this problem. The switch is provided on the posture hold grip so that the user can shift the travel line by 10 cm using the switch. With this, when a generated route splits up stalks, this function allows the user to shift the route so as not to permit a row split (Fig. 12).


Fig. 11 Display Image of Setting


Fig. 12 About New Function "LineShift"

4.3.3 Generation of efficient routes

Because of the position constraints of the cutting part and the crawler, we needed to design the head-feeding combine harvester so that it avoids reverse cutting wherever possible. To solve this issue, we programed the route generation as follows: the route to be generated will section the field according to the surface area worth the fill-up of chaff in the grain tank with the use of the "yield prediction" function so that harvesting can be done as if to draw blocks. In this way, the route can be made efficient with minimized reverse harvesting (Fig. 13). However, as the combine harvester works its way through this route, the diameter of the turning circle available is reduced, and in the end, it will have to harvest the adjacent line. Unlike tractors and rice transplanters, combine harvesters, whose turning circle is not small enough to be able to enter the adjacent line directly, need a K-turn according to the unharvested area. So, we developed two new patterns of K-turn while the WRH1200A has only one (Fig. 14). With the existing turning method, making a K-turn takes 40 to 45 seconds or so, whereas the newly developed method takes 30 to 35 seconds or so. Thus, this reduction has achieved efficient operation.

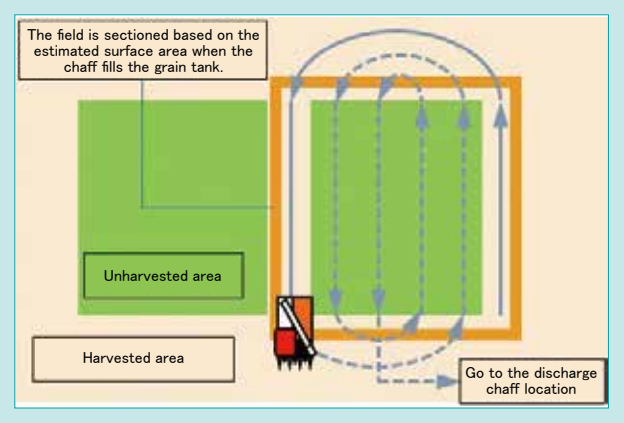



Fig. 13 Automatic Setting Area Using Yield Prediction

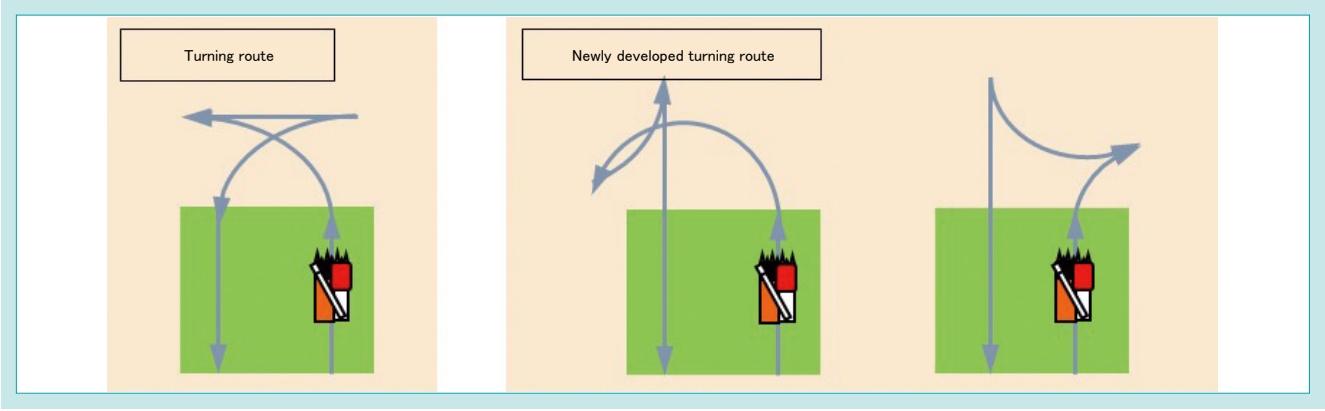



Fig. 14 New Machine Turns

## 5. Conclusion

To solve the issues of domestic farmers' agricultural management, we worked on this development based on the concept of "A flagship combine harvester that offers the No. 1 value in the country's industry to the next generation of professional farmers".

(1) With the developed thresher, we have achieved the development goals of 10% reduction in threshing loss and 30% reduction in straw contamination.

(2) Cleaning time has been shortened by 75% with the grain tank's side plate opening mechanism.

(3) We dealt with the issues typical of head-feeding combine harvesters through "line shift function" and "new patterns of K-turn" and thereby have achieved effort reduction regarding the complex operation of combine harvesters.

The combine harvester that we developed in this project, which is equipped with many other selling points than what this report has detailed, such as "increased comfort with a wide cabin space", a "new truck frame with enhanced durability" and "the opening structure of the straw removal chain-cutter rear cover", is such a machine that can make the agricultural business of professional farmers more efficient.

The current autonomous driving assist function needs the user to be in the driver's seat to monitor the safety of the surroundings and the work condition, but our final goal is the achievement of unmanned driving. For this goal, we need to come up with measures to solve various issues such as lower price sensors that can detect the differences between crops and obstacles as well as the clogging with crops.

To achieve unmanned driving, we have many challenges to overcome. However, the Kubota Group will make a unified effort to solve the important issues of domestic agriculture, including labor shortages and the aging of workforce.

## Contribution to SDG targets

2.3 Increasing agricultural productivity and income
Contribution to enhancing agricultural business efficiency through the industry's largest thresher and highly efficient combine harvesters

8.2 Improvement in productivity through innovation
Contribution to the reduction of farmer manpower and labor with the autonomous driving combine harvester

9.2 Strengthening inclusive and sustainable industrial infrastructure
Contribution to the solution of labor shortages in Japanese agriculture

# Development of Small Rice Transplanter AW Series

Transplanter Engineering Dept.



Although the total demand for rice transplanters in Japan is declining, the ratio of small-sized rice transplanters is an important class that continues to maintain about a 40% share of the market. Kubota has developed the AW series of fully remodeled machines with the aim of increasing the motivation of small machine users to continue rice cultivation and maintaining and expanding the business volume and market share of Kubota rice transplanters overall. Small-scale farmers who are small machine users are part-time farmers with a particularly high proportion of elderly people, who are consequently unfamiliar with machinery. Therefore, the rice transplanter was equipped with many automation functions based on the concept of simplicity, security, and comfort. This paper introduces (1) development of addition of "Super Yu Yu Turn" to our line of small class machines and (2) development technology of the lightest machine in its class.

【Key Word】
Rice Transplanter, Automation, Small-scale Farmer, Simplicity・Security・Comfort

Related SDGs


## 1. Introduction

While the ride-on rice transplanter market in Japan is on the decline, small size models, which retain around 40% of market share in the number of units sold, are placed in an important position (Fig. 1). In addition, small rice transplanters are sought in mountain-ringed regions, which accounts for 40% of domestic rice fields, because in these regions, fields are not easily centralized and so the use of upsized machinery is difficult.

As the development trends of Kubota's domestic medium/large rice transplanters, we have the NW series which started its sales in 2018. This series is equipped with advanced functions such as a GPS linear motion retention feature, which is targeted at professional farmers. On the other hand, the ZP-L series, was the important class as the main models in the small size category, featuring simple, manual rice transplanters targeted at small-scale farmers. This time, Kubota has developed the AW (ASWEL) series that has undergone a full model change to launch a competitive new model in the market (Fig. 2).

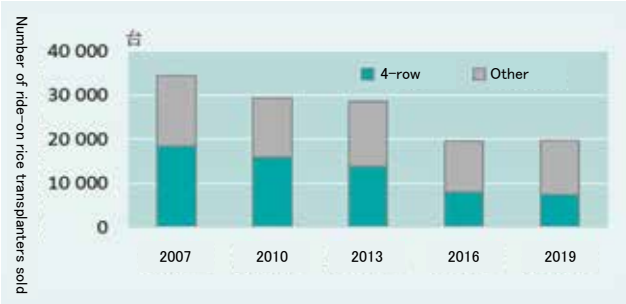



Fig. 1 Changes in Domestic Rice Transplanters


Fig. 2 Full Model Change Machine AW Series



## 2. Development concept and goals

### 2-1 Development concept

A high proportion of small-scale farmers, who are the target users of small rice transplanters, is made up of part-time farmers or elderly people who are not used to or are insecure about rice transplanter operation or find it heavy work to transplant rice seedlings. To serve the small rice transplanter users having these problems, we carried out development under the concept of "a reasonably priced small rice transplanter that makes the user feel the work is easy, secure and comfortable".

To achieve the concept, we worked mainly on the following development aspects.

[1] Modification of the manual lever into a power hand lever switch to achieve easy operation
[2] Mounting the super easy turn feature, which makes the user feel the work is easy, secure and comfortable when making a turn, onto the small size model
[3] Development of a light and balanced body to make the user feel secure when traveling in wet paddies
[4] Development of other new functions to achieve ease, security and comfort of work

### 2-2 Target values

(1) With new functions that make the user feel the work is easy, secure and comfortable, keep the sales price within up to 50,000 yen more than the price of the previous model to encourage the purchase by small rice transplanter users.
(2) Improvement of running performance
Develop a body that can travel more securely in deep muddy fields by reducing weight and improving the weight balance distribution.

Table 1 Development Goals

| | |
|---|---|
| Price | Increase by up to 50,000 yen more than the current model's price with many new functions |
| Mass | Lightest in the industry |
| Weight balance | +10% more front than the current model |

## 3. Technical issues to be solved

(1) Inhouse development of a small automated model

In this project, the automated functions including "super easy turn", which is installed on medium/large models, are to be implemented into the small model. The current small models, which are manually operated with a mechanical structure, need to have power operating parts. The inclusion of the same power mechanism as with medium/large models does not meet the specs and cost requirements of small models. So, our challenge was to develop a low-cost power mechanism appropriate to small model specs.

(2) Weight reduction and front-rear balancing

Weight reduction is required so that the wheels do not sink in wet paddies and the travel load is reduced. Also, the optimum front-rear balance is needed to prevent the body from being lifted by the reaction force that the body receives from the rear wheels' drive force when in the field. Therefore, we faced the challenge of developing a body that is lightweight and at the same time maintains the front-rear balance.

## 4. Developed technology

### 4-1 Technology for mounting the “super easy turn” feature on the small rice transplanter

#### 4.1.1 Technical issues in mounting the “super easy turn” feature on the small rice transplanter

“Super easy turn” is Kubota’s own unique feature that allows the user to make an easy turn with one single operation of the steering wheel.

Without “super easy turn”, making a turn requires the user to go through the following seven manual steps, which are a quite complicated set of tasks: [1] Deactivate the planting fork drive. [2] Raise the planting parts. [3] Make a turn with the steering wheel. [4] Lower the planting parts. [5] Align the planting start and end points. [6] Take out the line marker. [7] Start activating the planting forks. The function takes care of all of the above steps except for making a turn with the steering wheel (Fig. 3).

We hope to install the “super easy turn”, which has been the function only available for medium/large models, on small models, whose target users are not used to machinery work in many cases, including elderly users, who account for a high proportion of all users. The current small models, which use a mechanical structure requiring manual operation, has the following challenges to the installation of the “super easy turn”.

(1) Electrification of the raising/lowering of the planting parts and the turning on/turning off of the planting fork drive
(2) Electrification of the raising/lowering of the line marker
(3) Installation of control sensors and adjustment functions

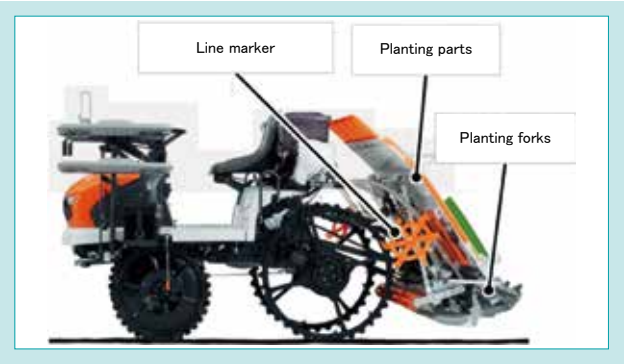



Fig. 3 Explanation of Each Part

#### 4.1.2 Technology solutions for the electrification of the raising/lowering of the planting parts and the turning on/turning off of the planting fork drive

The existing medium/large models use solenoid valve control and hydraulic cylinders to raise/lower the planting parts. Solenoid valves are not only used to raise/lower the planting parts but also to make the planting parts quickly react and follow the surface irregularities of the field with the adoption of high-speed responsive valves. Small models travel slower than medium/large models and so do not require the same high specs, which cost more. So, we developed a power mechanism optimized for small models.

Fig. 4 shows the mechanisms of the current small model and the development model. The current small model raises and lowers the planting parts using the manual lever to operate the mechanical valve’s spool, which actuates the hydraulic cylinders. The functionality of the planting part ascending and descending following the surface irregularities of the field is carried out with the mechanical valve cabled to a float, which senses the contact pressure against the field’s mud surface. In addition, the clutch rod, which moves together with the manual lever, turns on/off the planting fork drive.

As for the development model, we motorized the manual lever, which was based on the mechanism

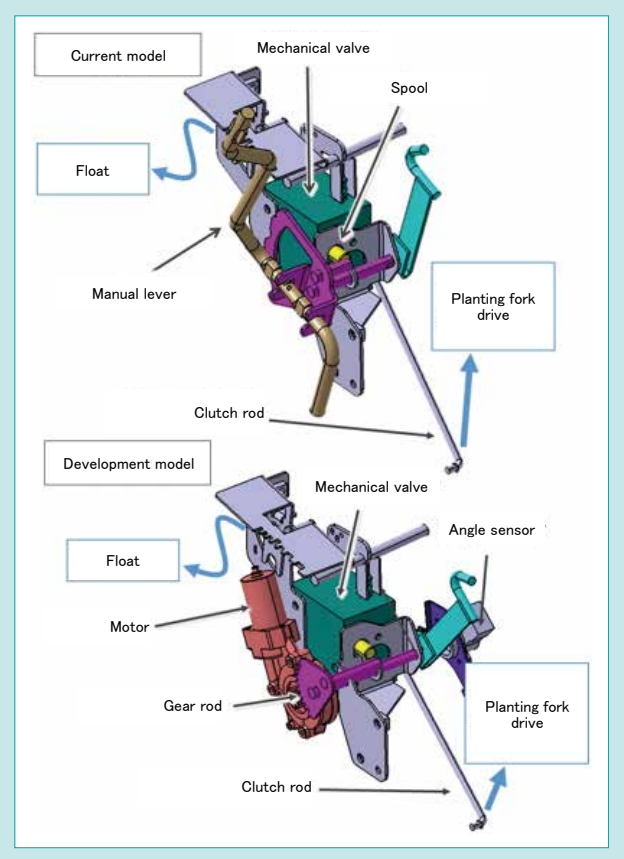



Fig. 4 Electrification Mechanism of Planting Part

of the current small model. For the ascent/descent of the planting parts following the field's surface irregularities, the current model's mechanism was reused. The power mechanism, which combined the mechanical valve with the motor, has achieved the electrification of the planting part's ascent/descent at a lower cost than with solenoid valves, while maintaining the ability to follow the field's irregularities that fits the vehicle speed of small models. Moreover, the electrification of the turning on/turning off of the planting fork's drive has been achieved at low cost. By reusing the current small model's mechanism, this drive of the development model operates on the same one motor whereas a dedicated motor is used for each on medium/large models.

4.1.3 Technology solutions for the electrification of the line marker's ascent/descent

As shown in Fig. 5, the existing medium/large models raise and lower the line markers using a motor's forward/reverse turns, and this motor is mounted on the right and left sides respectively. With regard to this structure, the project aimed at developing a power mechanism that is suitable for small models and can further reduce cost. which has a proven record. Cost reduction has also been achieved because the development model shares one motor to operate the right and left line markers through the reuse of the current small model's mechanism whereas the medium/large models have two motors each on the right and left.

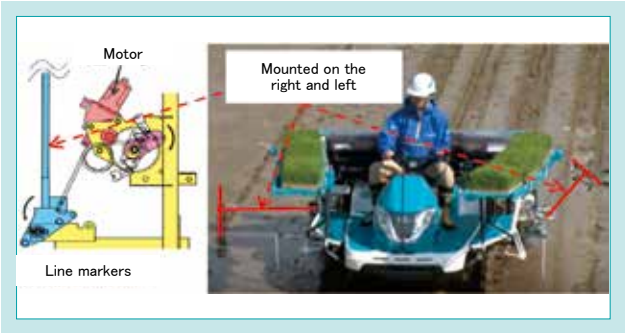



Fig. 5 Line Marker for Medium and Large Class

Fig. 6 shows the mechanisms of the current small model and the development model. The current small model lets one side of line marker descend under its own weight when the user unlocks it by [1] operating the manual lever so that [2] the green stay slides to [3] push the orange lock arm to unlock. And, by moving the manual lever to the other side, the line marker on the other side descends. The ascent is arranged to work with the planting parts; their ascent pulls up the line markers.

The development model reused the structure of the current small model and motorized only the areas that were under the control of the manual lever. This scheme has achieved electrification without changing the current model' basic structure,

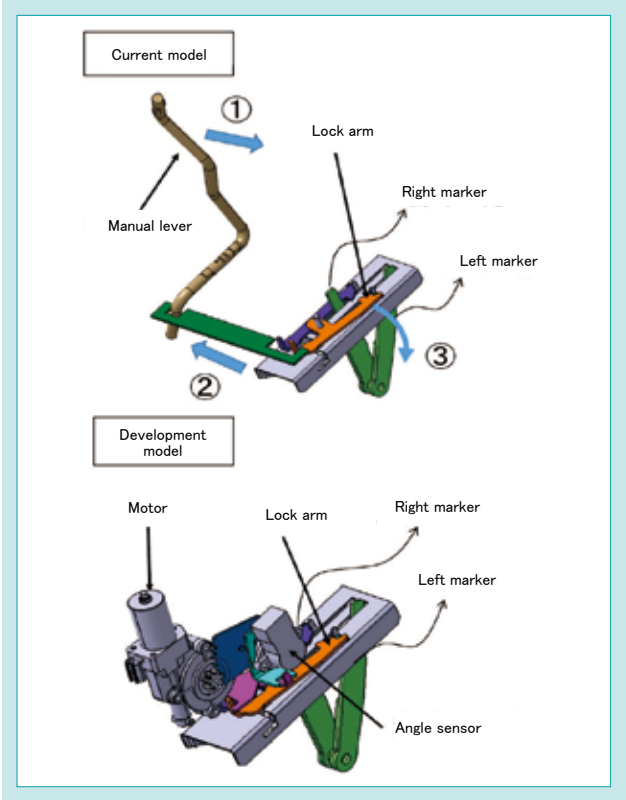



Fig. 6 Electrification Mechanism of Line Marker

4.1.4 Technology solutions for the installation of control sensors and adjustment functions

(1) Rear wheel count sensor

The rear wheel count sensor, which counts the turns of the wheel for detecting the distance the vehicle travels, was installed as in the medium/large models.

(2) Front wheel angle sensor

The front wheel angle sensor, which senses the steering angle to detect if the vehicle travels straight or is turning, is located on the underside of the vehicle of existing medium/large models as shown in Fig. 7. Small models, which have a low vehicle height, have higher risks with mud and so require anti-mud cases and seals. So, we developed a layout suited for small models and a low-cost sensor mechanism.

The development model has the sensor located in the space under the steering wheel, which is in an upper location of the vehicle, instead of the underside as shown in Fig. 7. The sensor is structured with only three parts: a spiral flute boss, a potentiometer sensor, an arm which is attached to this potentiometer sensor to detect the spiral flute position. With the linkage of the spiral flute boss to the steering shaft, the steering angle is sensed by the arm following the spiral flute. Cost reduction has been achieved with this simple structure along with the workaround to mud risks by placing the sensor in an upper location of the vehicle.

(3) Planting start timing adjustment function

With the existing medium/large models, the operator makes adjustments using the planting start adjustment switches and the ON/OFF switch while checking with the monitor (Fig. 8). The development model did not use a monitor but used a control knob and its label that indicates the adjustment level that the knob makes. By not using a monitor, it is cost efficient, and at the same time, the adjustment using a control knob is easier for small model users, who are often not used to machine operation. Cost was also reduced with the control knob, which can be set to the ON or OFF position, with no need to install a separate ON/OFF switch (Fig. 8).

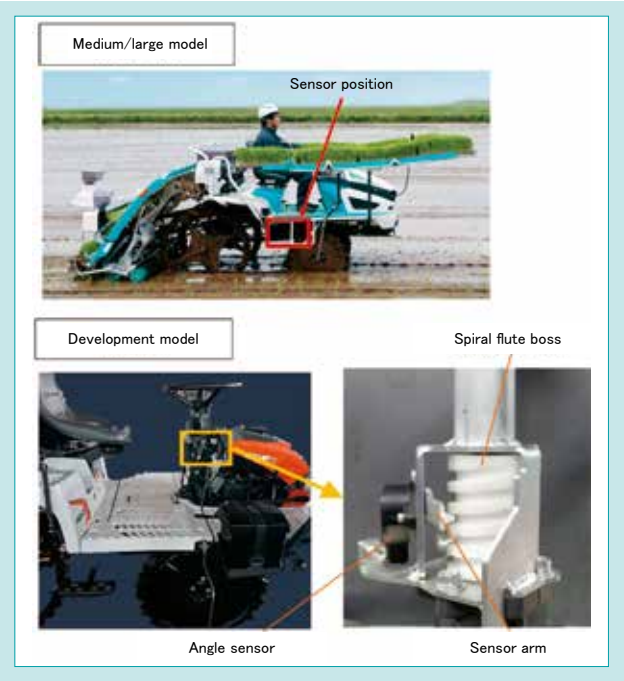



Fig. 7 Front Wheel Angle Sensor

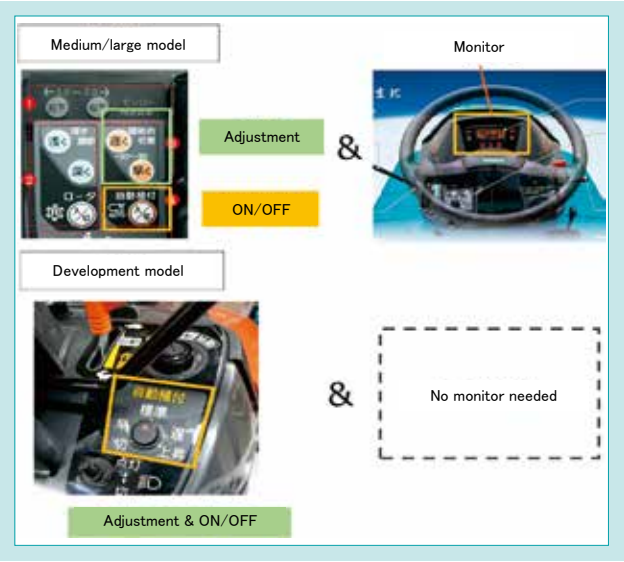



Fig. 8 Adjustment Function

## 4-2 Technical development of a light and balanced body

### 4.2.1 Technical issues in developing a light and balanced body

The challenge is to develop a body that is light and at the same time maintains a good balance distribution.

### 4.2.2 Solution for technical development of a light and balanced body

(1) Development of a body based on a model one size lower

To achieve weight reduction, we employed a body base whose vehicle size was one class lower. With the use of the lighter body base, we reinforced only the parts that needed a boost in strength. To confirm the effectiveness of light vehicle design, we performed ultimate strength and fatigue strength tests to verify the strength and durability.

(2) Securing balance

The front body of a rice transplanter can be lifted with its rear wheels serving as the lift's axis because of the reaction force that the body receives from the rear wheels' drive force when the field is deep (Fig. 9). This lifting is related to the distance between the rear wheels and the barycenter.

If weight reduction measures are only to reduce vehicle weight, the balance to the planting parts will be lost and this causes the barycenter to be positioned on the rear side. If a weight is added to the body's front area, it will improve the balance but will also increase the body weight and travel load. The development model positioned the barycenter more towards the front than with the current model by making the planting parts lighter by 15 kg with the use of aluminum and by increasing the wheelbase by 75 mm to arrange the layout so that the heavy parts such as the engine and transmission are positioned on the front side of the vehicle (Fig. 10). These modifications have achieved both lightness and balance. As a result, the vehicle has been made lighter 60 kg than the current model, and consequently has managed to become lighter than all other competitors' rice transplanters in the same class, surpassing them by 90 kg or more (Table 2). As a result of evaluation based on the barycentric position using our own unique index for the capability to prevent a lifting of the vehicle's front side, the development model has improved by 12% compared the current model and surpassed those of competitors by 23%.

This weight reduction contributes to also safety margin improvement for travel in wet paddies because the development model has improved the power-to-weight ratio (ratio of the vehicle's weight to the engine's rated power output) by about 14% compared to the current model while the engine output remains the same. With all of the above achievements in weight reduction and vehicle body balance, we have developed a rice transplanter that allows the operator to work with a feeling of security even when paddies are deep.

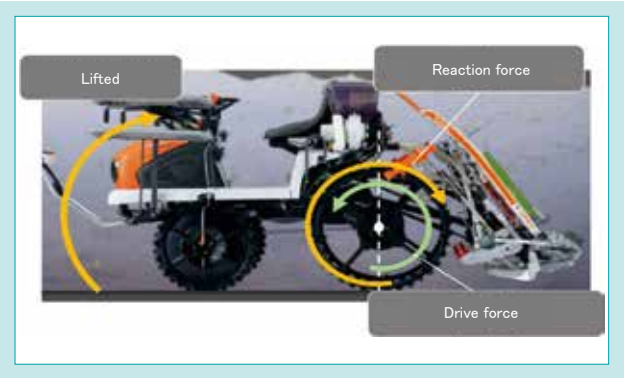



Fig. 9 Lifting of the Body due to Load

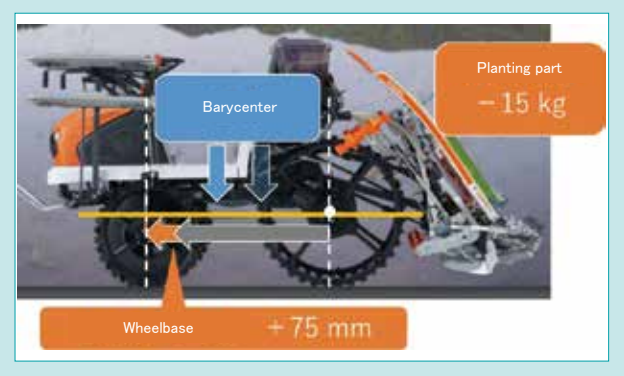



Fig. 10 Body Balance Improvement

| Planting of 4 rows with fertilization | Mass (kg) | Difference from the development model (kg) | Power weight ratio (kg/PS) |
|---|---|---|---|
| Kubota Development model | 365 | – | 46.2 |
| Current machine | 425 | 60 | 53.8 |
| Competitor's machine A | 455 | 90 | 59.1 |
| Competitor's machine B | 479 | 114 | 60.7 |

Table 2 Comparison of Weight and Power-Weight Ratio

## 5. Conclusion

Under the concept of "a reasonably priced small rice transplanter that makes the user feel the work is easy, secure and comfortable", we have developed the new small rice transplanter AW Series that keeps its price within up to 50,000 yen more than the current model's price while equipped with the "super easy turn" and "light and balanced body that can travel securely in deep muddy fields". In addition to these features presented in this report, the AW Series features the industry's first new functions including "3-way standby seedling stand" which are settable to a stacking or rail position and can slide back and forth (Fig. 11) and "easy planting parts ascent button" useful to plant seedlings as close as possible to the field edge (Fig. 12) as well as many other unique selling points such as "eStop", "Monroematic installed as standard", "new 2-lamp auxiliary LED" and "new resin step". Conventional small rice transplanters have been achieving ease of use with simple operation with a minimum of functions. On the other hand, the development model, which has automated the difficult work tasks which the user needs to get used to, has been polished up into a more comfortable, easier to use product for small model users who are often not used to machinery work, including elderly users, who account for a high proportion of all users.

Kubota will proceed with the development of new automation and other functions to build small rice transplanters that make users feel the work easier, more secure and comfortable and thereby support the "sustainable agriculture" of small-scale farmers.


Fig. 11 3-Way Spare Seedling Stand


Fig. 12 Easy Planting Stop Button

## Contribution to SDG targets

2.4 Achievement of sustainable and robust agriculture
Contribution to the sustainable agriculture of small-scale farmers

9.2 Strengthening inclusive and sustainable industrial infrastructure
Contribution to the solution of labor shortages in Japanese agriculture

# Development of T90 Series Lawn Tractor for North America

Turf Engineering Department North America ／ Turf Engineering Department



Through Kubota's market surveys, it was determined that despite the growing popularity of zero- turn mowers, there is still a large consumer base for lawn tractors in North America. Because of this, the T90-Series lawn tractor was developed as an updated version of the T80-Series. Over time, many of Kubota's competitors surpassed the T80-Series in performance and specifications. Therefore, the challenge of the design team was to create a high-quality lawn tractor that exceeded the performance of competitor machines and reignite sales of the T-Series. By redesigning almost every aspect of the T80-Series including the frame, engine, mower decks, steering and operator controls we were able to achieve our goal. Once the new T90-Series was introduced into the market in 2018, sales for the T-Series lawn tractors more than doubled compared to 2017 total sales.

【Keyword】
Lawn Tractor, Performance, Turning Radius, Comfort

Related SDGs


## 1. Introduction

The T90-Series was the first small lawn tractor model to be introduced by Kubota since the T80-Series in 2008. Due to the age of the T80, the lack of updated features and the rapidly growing popularity of zero-turn mowers, sales of the T-Series have seen a sharp decrease over the last several years. However, there is still a large market for lawn tractors in North America. Although zero-turn mowers can be faster and more efficient than traditional lawn tractors, the comfort of a steering wheel and foot pedals is still desirable by many customers as opposed to control levers. Also, it was determined that many customers who cut on hilly terrain often prefer a lawn tractor instead of a zero-turn mower because of the fixed steering system and easy ability to maintain a straight cutting path on slopes. The goal of the T90 development was to bring the T-Series up to date with Kubota's top competitors in the lawn tractor market. There were several issues with the current model T-Series that needed to be addressed in order to challenge the current competitor machines. The most important issues to be solved were cut quality, handling, and comfort.

Fig. 1 T80-Series

Fig. 2 T90-Series

## 2. R&D Concept and Target Value

### 2-1 R&D Concept

The development concept of the T90 project was to design a new T-Series that would outperform the competitors' lawn tractors and offer a high quality but affordable machine to homeowners in North America. The new tractor needed to achieve a very high level of cut quality, have great maneuverability and handling, be comfortable, easy to operate and also very durable. The T90 was developed as three different sub models with available 42-inch and 48-inch mower decks. The base model includes a 20hp Briggs & Stratton engine with 42-inch mower deck, ¾-inch rear axle and a standard seat with spring suspension. The mid-range model includes a 21.5hp Kawasaki engine with 42-inch mower deck, ¾-inch rear axle and an adjustable spring suspension seat with armrests. The top model includes a 21.5hp Kawasaki engine with 48-inch mower deck, 1-inch rear axle and an adjustable spring suspension seat with armrests.

### 2-2 Target Value

The target value of the T90-Series was a high-quality dealer grade lawn tractor that would be available to homeowners maintaining properties ranging from one to two acres. The warranty period was chosen to be 4 years or 300 hours, meaning the machine had to be very durable. The T90-Series was also designed to be versatile and perform many useful tasks for the operator including not only normal side discharge grass cutting but also mulching, bagging, leaf bagging, snow blowing, snow plowing, and pulling. Because the market for the T90 is residential customers, the cut quality of the mower decks was a top priority. Many homeowners in the US market put a great amount of value on the appearance of their home's lawns and landscaping. The T90-Series was designed to have the best cut quality of any competitor machine by producing the most even cut possible, leaving no patches or streaks of uncut grass.

## 3. Technical Challenge to be Solved

The main technical challenges associated with the T90 project were designing new fabricated mower decks, a new steering system and improving the layout of the seat and operator controls in a way that maximized comfort. The mower decks for the T90-Series were totally redesigned to be fabricated from sheet metal and feature a new single belt pulley structure. This style of deck was completely new for the T-Series, considering the previous T80 deck was a stamped design which had a stacked pulley belt configuration. The goal for the steering system was a best in class turning radius. Achieving this also meant the system used on the T80 needed to be totally redesigned. Another challenge was improving the operator comfort and controls layout. Because the T90 was using the same fender and bonnet design from the T80, the design team was limited with options for changing the operator platform layout.

## 4. Developed Technology

### 4-1 High Performance Single Belt Mower Decks

#### 4.1.1 Technical Challenge

The challenge of developing mower decks for the T90-Series included not only achieving great cut quality but also figuring out a way to drive the mower decks using a single belt instead of a stacked pulley design with multiple belts. In addition, the new decks were required to be fabricated from sheet metal in order to increase durability, more closely resemble the appearance of the Kubota ZTR lineup and reduce the upfront tooling cost.

#### 4.1.2 Solution of Challenge

The T90 mower decks were designed based off of the fabricated decks used on the Kommander series zero turn mowers. This decision was made mainly for the purpose of unifying the mower deck design of the turf lineup and also reducing the tooling cost of the deck to match the target EAU. Two mower deck sizes were chosen for the T90 which were a 42-inch and 48-inch cutting width. The 42-inch deck is a compact two-blade design that allows the operator to maneuver through small openings such as gates or around small garden areas. The 48-inch deck is a 3-blade design with a much wider cutting path for mowing large amounts of grass.


Fig. 3 48-inch & 42-inch Mower Decks

The challenge of achieving an even cut has many factors. The most important being the shape of the mower deck and internal baffles, the positioning of the blades, the speed of the blades and also the type of blades used. There are several types of defects which can be found in the cutting path of a mower deck. The most common is a rough cut or unevenness in the whole cutting path which is caused by poor lift, dull blades or a low blade tip speed. The next most common is streaking, which is identified by a thin strip of unevenly cut grass often in the center of the blade. This is often caused by poor blade position or baffle design.

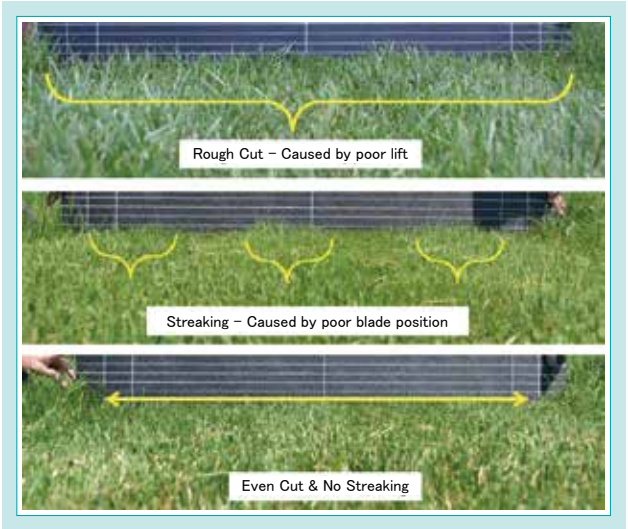



Fig. 4 Cut Quality Comparison

In order to prevent streaking in the center of the decks, the blades must be positioned in an offset and overlapping pattern. This is especially important when making tight turns where the blade overlap is reduced. However, increasing blade overlap also increases deck width, which in turn can affect turning radius and maneuverability. Through extensive testing and design consideration the T90 mower blades were positioned the optimal width which eliminates streaking in all cutting conditions while still maintaining minimum deck width.

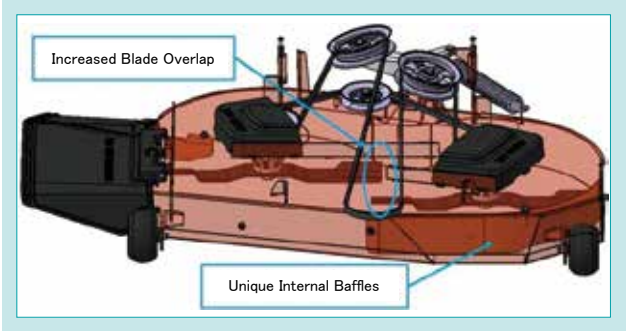



Fig. 5 Transparent View of 42-inch Mower Deck

The cut quality of the mower is also greatly affected by the shape of the baffles inside the deck. The baffles are used to direct airflow inside the mower and also help the blades create lift. The back of the blades are designed with a winged shape which stands up the grass as the mower passes over and allows the blades to cut the grass evenly. One of the issues created on a lawn tractor is the position of the front tires. As the machine drives forward, the front tires will lay down the grass just before it is passed over by the mower deck. This can cause a row of unevenly cut grass to form behind the tire path. In order to address this issue on the T90, we developed a unique baffle shape which concentrates lift specifically in the path of the tire. This allows the T90 to achieve an even cut across the entire width of the cutting path.

In order to reduce complexity, cost and service time, the T90 was designed to use a single belt driven mower deck instead of a stacked pulley two belt design like previous T-Series models. The challenge facing the design team was arranging the pulleys in a way which would allow the deck to be positioned at different cutting heights (1"- 4") while being able to sustain a long belt life at the required tension and speed necessary to produce a good cut. The solution to the problem was to use two angled pulleys at the rear of the deck which would direct the mower belt from the engine drive pulley, which is located in front of the deck, down to the blade drive pulleys. Because of the height the belt must change in order to reach each pulley, the angled pulleys needed to be positioned perfectly in order to keep the belt in the center of the pulley and prevent it from rubbing on the edge, which would reduce belt life. The pulley shape and size also play an important role in the design because of the large amount of belt angles the pulley must accommodate. Because of this, taller and deeper grooved pulleys were chosen as the angled pulleys on the rear of the deck.

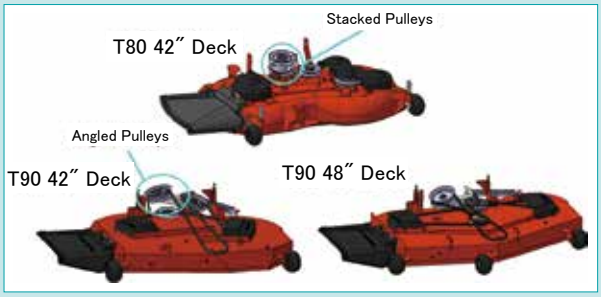



Fig. 6 T-Series Mower Deck Comparison

## 4-2 T90 Steering System

### 4.2.1 Technical Challenge

One of the most important aspects of a lawn tractor is its ability to make tight turns. This is especially true now in a turf market where traditional style lawn tractors are often competing with zero-turn mowers. The majority of customers cut their grass in rows. Therefore, the ability to make a tight turn at the end of a cutting row is critical. Also, it is important for the mower to be able to make tight turns around small obstacles such as trees or shrubs. Because of this, it was important for the T90-Series to have the best turning radius in its class. Considering the previous T80 model was already far behind current competitor machines, this was a huge challenge for the design team.

### 4.2.2 Solution of Challenge

In order to address the challenge of achieving a best in class turning radius, the steering system was entirely redesigned for the T90-Series. Our target was the top two competitor lawn tractor machines, which each had a turning radius of 16 inches. The T80 model was already far behind this at an 18-inch turning radius. Eventually, through extensive research and testing, we were able to realize our goal by achieving a 14-inch turning radius for the T90-Seires.

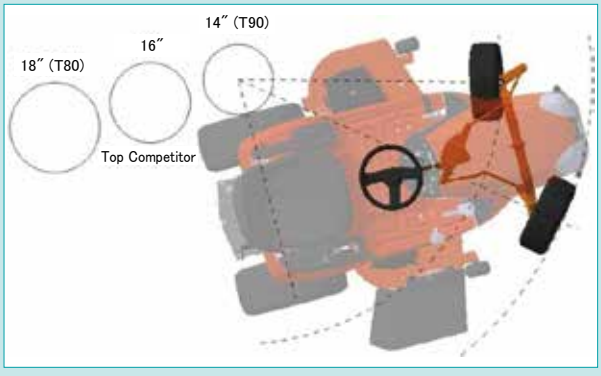



Fig. 7 Turning Radius Comparison

The T-Series steering utilizes a dual drag link system, which manipulates separate kingpins in the front axle. The front axle is a solid casting made from a high strength, ductile cast iron. The axle is fixed by a bushing in the center of frame, which allows it to pivot side to side. The kingpin flanges are located in bushings at each end of the axle. The drag links are fixed to a large sector gear, which is driven by a smaller pinion gear on the steering shaft.


Fig. 8 T90-Series Steering System

To achieve the 14" turning radius, the design team utilized principles of Ackermann geometry steering. The Ackermann geometry involves each tire being positioned at a different angle while turning where the center point of the rear axle and each front tire meets in a common location. In addition, caster and king pin inclination angles were incorporated into the front axle design. The caster and KPI alter the camber gain of each tire in the turn. Multiple iterations of these angles were tested and fine-tuned in real turf conditions in order to maximize traction, improve handling and allow the T90 to achieve the smallest turning radius possible.

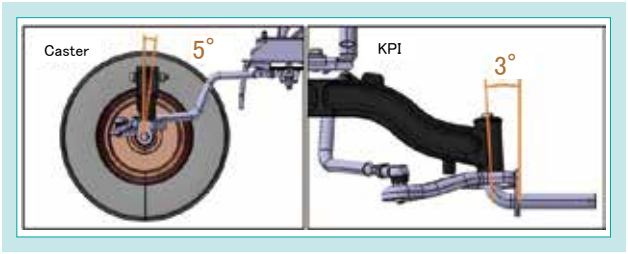



Fig. 9 T90-Series Caster and Kingpin Inclination

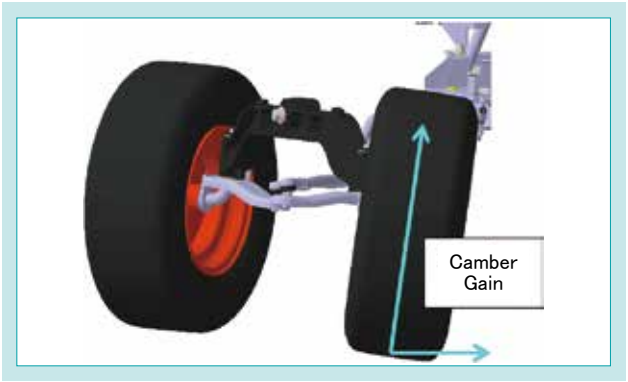



Fig. 10 T90 Camber Gain in a Turn

A major benefit of this steering geometry is the reduced tire slide while turning. Tire slide is the condition where the front tire is pushed forward during a turn. This causes the sidewall of the tire to dig into and damage the curfewed the T90-Series, the operator can make tight turns without fear of tire slide destroying the lawn.

## 4-3 T90 Comfort and Ergonomics

### 4.3.1 Technical Challenge

Because the T90-Series is mostly targeted towards customers who are not comfortable operating a zero-turn mower, the comfort, ergonomics and operation forces of the machine were extremely important factors in the new design. This was a challenge to the design team because the fender, bonnet and panel from the previous T-Series were to be used to reduce cost. This limited the design team's ability to easily move the seat, steering wheel and controls of the machine into positions that were more ergonomic and comfortable.

### 4.3.2 Solution of Challenge

It was determined through dealer and customer feedback that the T80 seat base and steering wheel position needed change to improve rider comfort. The steering wheel was too close to the operator's legs and would often cause interference while turning with the steering wheel. In addition, due to the shape of the fender, the seat was angled downward, which would cause the operator to feel like they were sliding out of the seat. For the T90, the steering wheel has been raised up 100mm from its original position closer to the operator to add clearance. Not only does this create more legroom for the operator but it also reduces the distance the operator must extend their arms to reach the wheel.

In addition, the T90 seat base was designed to be lifted up at the front of the seat so that the seat sits level with the floor pan. This eliminates the feeling of sliding out of the seat and gives the operator an overall more comfortable seating position.


Fig. 11 T80 vs T90 Operator Comfort

The T90 has also been fitted with a new high back seat with optional armrests, which provide more support to the operator than the previous low back seat. The design team also designed a new adjustable 4-link spring seat suspension specifically to fit the T-Series fender and seat. The seat suspension is fully adjustable to accommodate operators up to 300lbs. In addition, a premium steering wheel reduces vibration felt by the operator and improves grip while steering.

The entire mower linkage system of the T80 has been redesigned for the T90 to feature a fender mounted dial cam. The reason for this change is to make the dial-cam within reach of the operator without having to bend down. Using the new system, the operator can easily adjust the cutting height while comfortably sitting upright in the seat.


Fig. 12 T80 vs T90 Mower Lift Operation

In order to lower the steering force to a level acceptable to a wide range of customers, the T90 steering system utilizes a lower gear ratio in the sector and pinion gears that reduces the overall steering force by an average of 10% compared to the T80.

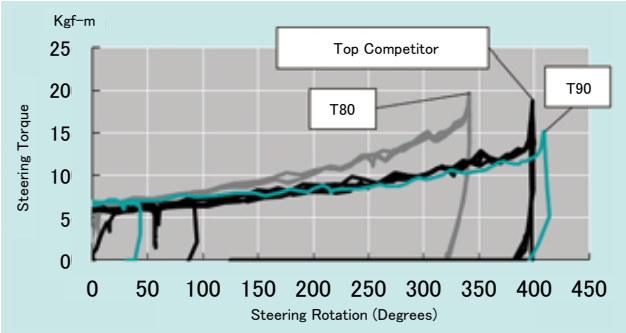



Fig. 13 T90 Steering Force Comparison

## 5. Conclusion

The T90-Series has achieved the goal of a modern high-quality lawn tractor by offering the customer the best in cut quality, handling and comfort. Exceptional cut quality is achieved with new fabricated mower decks, while the new steering system offers the market's best in handling. New seat and controls layout greatly improve rider comfort and ease of operation compared to the T80-Series. Since the new T90-Series was introduced into the market in March of 2018 sales of the T-Series have more than doubled compared to that of 2017 total sales. Similar numbers are projected for 2019 sales which show a strong positive reception of the T90-Series.

## Contribution to SDG Targets

8.2 Improvement in productivity through innovation
Contribution to the increase in efficiency and quality of homeowners and landscaping maintenance personnel in the care of their properties.

11.7 Access to sustainable green and public spaces
Contribution to the sustainability of green spaces and gardens.

# Development of Two-stage Snow Blower SLA-1070ST

Farm Machinery Implements and Products Engineering Dept. /
Farm and Industrial Machinery R&D Dept. Ⅱ



In cold regions of Japan with heavy snowfall, snow removal work during the winter months is extremely hard work. With the mechanization of snow removal work, the use of Two-stage snow blower has become common in ordinary households that used to remove snow with shovels.

Kubota also developed the Snow Slalom Series of Two-stage snow blower in 2016, and sales have been increasing steadily. However, snow removal work is often done early in the morning before going to work, and it is necessary to consider the effect of noise on neighboring residents. In addition, a user who is unfamiliar with machine operation is prone to hitting the snow blower against the curb during snow removal, and breaking the shear bolt of the snow removal section (bolt that protects the power transmission system of the snow removal section) , and therefore having to replace the shear bolt in cold weather. To solves these problems, Kubota has developed the Snow Slalom SLA-1070ST, which is equipped with a mechanism to reduce noise and mitigate the impact even if it hits the snow removal section.

【Key Word】
Two-stage Snow Blower, Snow Slalom, Engine Cover, Blower Noise Reduction, Torque Limiter

Related SDGs


## 1. Introduction

The Snow Slalom Series Two-stage Snow Blower was developed in 2016 with the concept of being easy to operate as well as allowing the user to work effortlessly as the target users include those who are not familiar with machine operation.

In cities, however, users remove snow early in the morning in many cases, and to show consideration for the neighbors, noise reduction is required. In addition, because the machine is used often by those who are not used to machine operation, they break a shear bolt and have to do the replacement work in the cold by interrupting their snow removal work.

To solve these challenges, we worked on the development of the Two-stage Snow Blower SLA-1070ST, which has eventually achieved the reduction in noise and in the frequency of shear bolt breakage.

## 2.Development concept and goals

### 2-1 Development concept

The Two-stage Snow Blower of the Snow Slalom Series is being developed as a machine whose target users include those who live in cities and are not used to using machines.

Users are satisfied with the ease of operation and ability to work, including the power side clutch, power auger lift and the mechanism to maintain a constant handle height, as well as the price.

We conducted the development on the concept of addressing the unsolved challenges as a product series machine: (1) Reduce engine and blower noise; (2) Reduce the frequency of shear bolt breakage though the mitigation of impacts by adopting a torque limiter structure in the snow removal part.

### 2-2 Target values

In order to reduce engine and blower noise, the development target values were set as follows. The evaluation was done with the engine turned on and the blower running, while the engine noise and the blower noise were separately addressed.

- Noise with the auger running: -3 dB (A) compared to the previous model

For the improvement of maintainability and ability to work, the development target value to reduce the frequency of shear bolt breakage is as follows. The frequency of shear bolt breakage is evaluated by measuring the time the shear bolt takes to break with the intentional bumps of the auger against a simulated curb.

- Time the shear bolt takes to break with curb collision: 30 seconds or more.

## 3. Technical issues to be solved

### 3-1 Reduction of noise

Snow removal in cities early in the morning needs the user to be considerate to their neighbors regarding the engine and blower noise of the machine (Fig. 1).

The issues were individually addressed for the engine noise and the blower noise respectively, while the evaluation was done with the engine turned on and the blower running.

#### 3.1.1 Reduction of the engine noise

As a measure for engine noise reduction, just covering the engine does not achieve the goal. The noise source created by the engine needs to be covered effectively. To be able to do this, we conducted investigation into the sound sources of the engine noise. In addition, we faced another challenge that the heat produced from the engine remains in the cover and so the temperature in it rises if the engine is covered. If this temperature rises past a certain point, the engine overheats and stops and the machine is no longer able to work. To avoid this, heat countermeasures needed to be taken to prevent the temperature from rising in the cover.

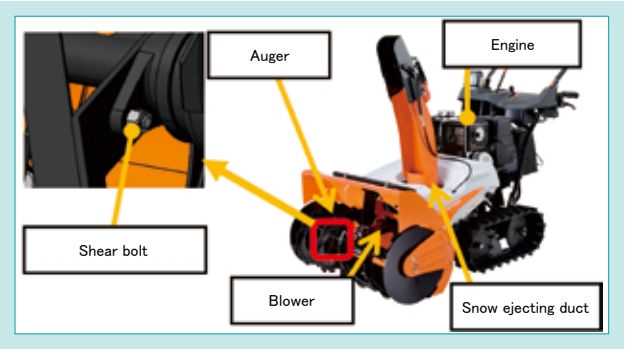



Fig. 1 Two-stage Snow Blower SLA-1070A

#### 3.1.2 Reduction of the blower noise

The previous model produced significant wind noise when the blower was running. To identify the source of this, fluid analysis was used. Where there is significant noise, the pressure variation is great. We needed to identify the area where pressure variation was great and modify the shape of the area to make the variation uniform. With the previous model, the structure from the blower to the snow ejecting duct is formed by molds and then welded. So, noise reduction measures need to be taken by reviewing the structure around the blower having the reuse of the molds in mind.

### 3-2 Reducing the frequency of shear bolt breakage

The shear bolt breaks frequently when the auger is subjected to an impact load during snow removal due to the user not being used to machine operation. The shear bolt acts as a protector by breaking when the snow removal part is subjected to an impact. The breakage serves to reduce the impact load applied to the power transmission system in the auger gear case.

However, once it breaks, the machine is unable to perform snow removal and the user is compelled to do the replacement job in the cold.

That's why this development intends to reduce the frequency of shear bolt breakage by adding a torque limiter structure, which releases an impact load if applied over a certain level to the auger in the snow removal part, but we need to set the appropriate triggering torque range of the torque limiter, which is triggered when snow removal is ongoing if the range is too low and is not triggered and permits the shear bolt to break if too high.

On the other hand, increasing the parts to be mounted on the snow removal section causes snow to accumulate there during snow removal work and compels the user to remove snow if they want to keep working. So, the size reduction of the torque limiter also needs to be addressed.

## 4. Developed technology

### 4-1 Effects of noise reduction

4.1.1 Reduction of the engine noise

To consider the structure of the engine covering , we conducted investigations into sound sources of the engine noise. To investigate the sound sources, the engine noise is measured by microphones from the four directions in a semi-anechoic chamber. The sound pressure is shown in contour view to visualize its distribution (Fig. 2). The contour view shows locations with great and small levels of sound pressure in red and blue, respectively. The sound pressure distribution at the sound source showed that there was significant noise around the muffler and the lower part of the engine.

In response, we decided to attach the upper and lower covers around the engine to reduce engine noise (Fig. 3).

The engine, which is a general-purpose part, does not accept the installation of the covers on its body. So, we divided the cover into the upper and lower parts and attached the lower cover to the sheet metal part of the engine mount so that it serves also as the fastener of the upper cover. The upper cover is made of resin for weight reduction and design. The lower cover is fastened and the upper cover is made removable so that they as a whole make a structure that takes into consideration the maintainability as well.

The upper cover structure is provided with defensive measures against the heat. The rise of temperature at the engine is prevented with the muffler covered with a sheet metal part fastened in the upper cover and with the internal use of insulating material. As a countermeasure against the heat around the engine, the exhaust opening was made larger to release the heat produced (Fig. 4).

In addition, a sound absorbing material was used inside the upper cover.

Table 1 shows the effectiveness of noise reduction with the use of the upper and lower engine covers. At the time of measurement, the engine is turned on, but the blower is not running. Compared with the previous model, the use of the engine covers produced a reduction effect of -4 dB (A).

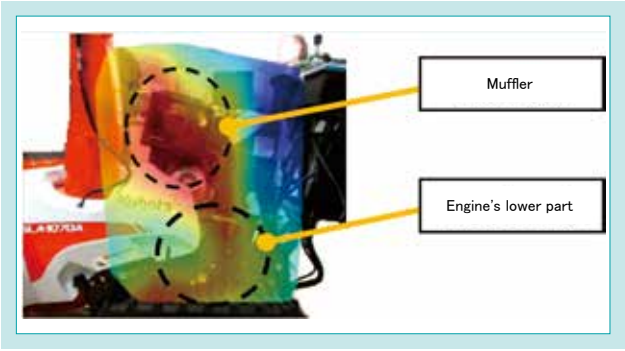



Fig. 2 Sound Pressure Distribution

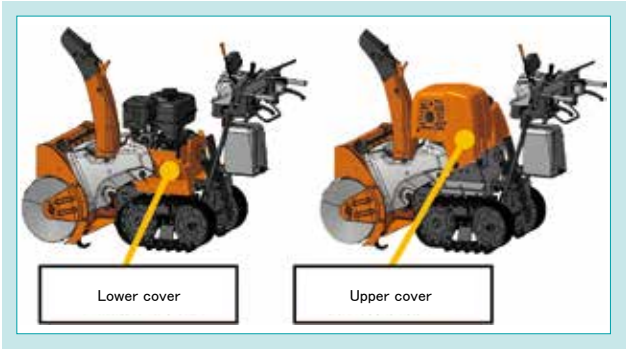



Fig. 3 Engine Cover Structure

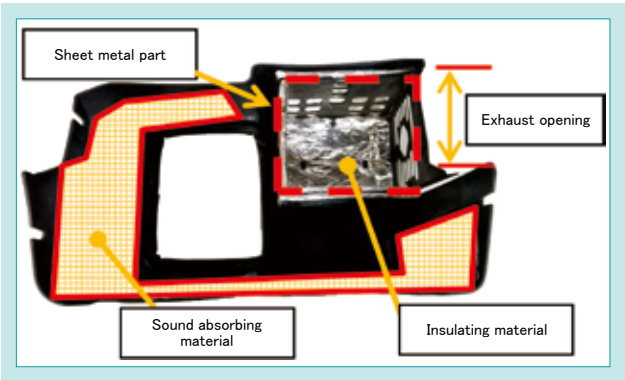



Fig. 4 Engine Top Cover Internal Structure

Table 1 Noise Results when the Engine Cover is Attached

| | Previous model | Development model | Noise reduction |
|---|---|---|---|
| Average noise in the right and left ears [dB (A)] | 85 | 81 | −4 |

4.1.2 Reduction of the blower noise

For the reduction of blower noise, the noise source was identified by fluid analysis. Noise is produced where the pressure variation is significant. So, we conducted analysis with the snow removal section's blower running as with the actual machine circumstances and evaluated the pressure variation (Fig. 5). The analysis results confirmed that the tongue of the blower case had the highest pressure variation and so we identified it as the noise source (Fig. 6).

In response to this finding, we prepared several shape patterns of the tongue of the blower case and conducted an analysis using these tongues. The results revealed that the establishment of a smooth connection between the blower case and the snow ejecting duct using a rounded shape of tongue was able to reduce the pressure variation 55% from about 900 MPa to about 500 Mpa. Since the blower is also responsible for snow casting, we considered a possible deteriorating effect that the change in the blower case's tongue shape may have on the snow casting performance. To check on the snow casting performance, we conducted a fluid analysis on the distribution of air velocity and confirmed that the air velocity at the blower case's discharge port was not reduced in the comparison before and after the change.

The above results show that we have established a blower configuration that reduces noise without affecting the snow casting performance.

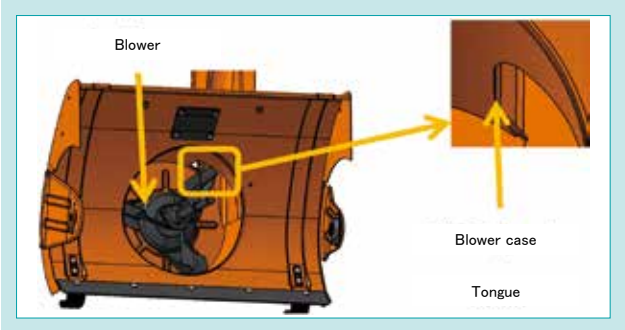



Fig. 5 Snow Removal Part Analysis Model

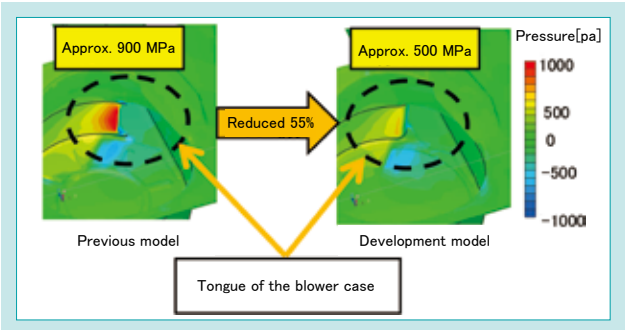



Fig. 6 Blower Case Analysis Result

Next, we considered the fabrication method for the blower case. The blower case was molded as a single piece for the previous model, and it has been made possible to reuse these molds for the machine under development with the employment of a structure that adds notches to the blower's upper part and the snow ejecting duct and welds the rounded component obtained from the analysis onto the snow ejecting duct (Fig. 7).

Table 2 shows the effectiveness of noise reduction at the blower. Under the measurement condition where the engine was turned on without the upper and lower engine covers and the blower was run, we succeeded in making the noise measured at the operator's ears -4 dB (A) compared with the previous model.

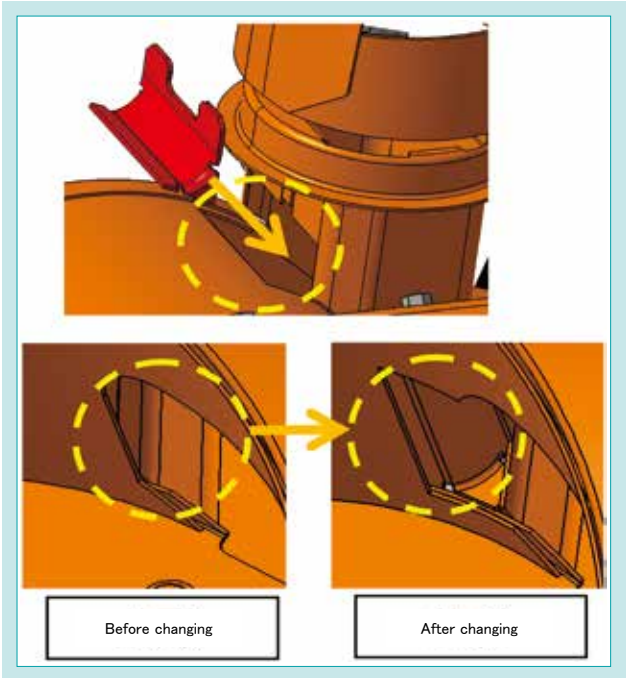



Fig. 7 Blower Case Shape Change

Table 2 Noise Results after Changing the Shape of the Blower Case

| | Previous model | Development model | Noise reduction |
|---|---|---|---|
| Average noise in the right and left ears [dB (A)] | 88 | 84 | −4 |

4.1.3 Tonal improvement

A market research revealed that manyvc users feel the snow blower's high-frequency noises are annoying. To make a tonal improvement, a sound absorbing material was added in the engine cover and this has successfully cut the high tones of the engine. Also, the elimination of wind noise by changing the shape of the blower case's tongue has lowered the high tones. Fig. 8 shows the results of noise frequency measurement comparing the previous model and the development model. The development model proved to have lower noise values in the high tones. Also, sensory evaluation results showed that the high tones hard on the ears were clearly lower compared with those of the previous model.

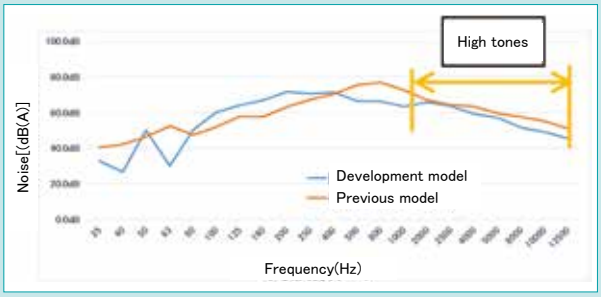



Fig. 8 Noise Frequency Comparison

4.1.4 Total noise reduction achievements on the machine

To see the total effectiveness in noise reduction of the machine, noise measurement was conducted. Table 3 shows the results. At the time of measurement, the engine was turned on and the blower was running with the use of the upper and lower engine covers. The noise measured at the operator's ears with the development model was 83 dB (A), which is a reduction of -6 dB (A) compared with the previous model.

The upper and lower engine coverings and the modification of the blower case configuration, which we carried out for noise reduction measures, have attained the noise reduction goal that this development project originally set up.

Table 3 Noise Reduction Effect

| | Previous model | Development model | Noise reduction |
|---|---|---|---|
| Average noise in the right and left ears [dB (A)] | 89 | 83 | −6 |

## 4-2 Reduction of shear bolt breakage

For the purpose of protecting the power transmission from an overload, a shear bolt is provided between the gear case and the auger in the operating part of the snow blower. If the shear bolt breaks during snow removal, it deprives the machine of the power transmission ability and thus forces the user to discontinue the work. The replacement job of the shear bolt, which needs to be done in the cold if the user wants to continue the work, is hard. The Slalom Series developed by Kubota is intended for general users, and in many cases, they are not familiar with machines and so often needed the customer support call service for the replacement job, which was not easy for them. This is why there was a market demand for such measures.

Possible cases are that the shear bolt breaks when the machine bumps against the user's curb during snow removal or when the auger, if a stone jams in it, comes in contact with the ground due to the snow removal section having been excessively lowered. From the fact that, in either case, an impact load causes the shear bolt to break, we aimed for the installation of a torque limiter mechanism that lessens the impact in order to reduce the frequency of shear bolt breakage (Fig. 9).

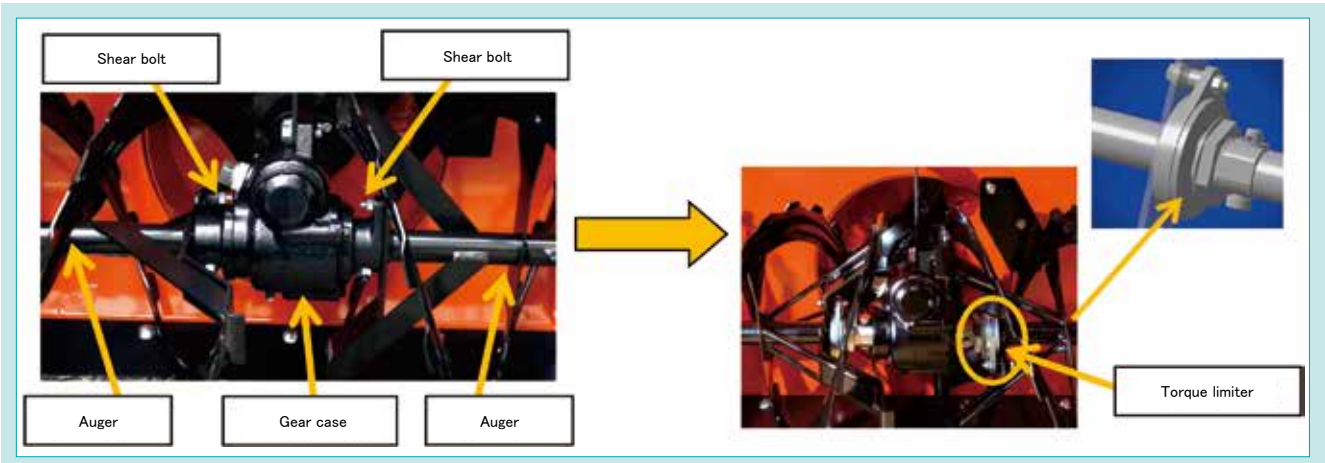



Fig. 9 Structure of Snow Removal Part

4.2.1 Torque limiter structure

In this development, to use the same the gear case as the previous model, we devised a structure that has the torque limiter attached outside the gear case instead of incorporating it into the gear case. A typical torque limiter is often incorporated into the gear case, in which the gear held with disc springs slips to dissipate any excessive torque applied, whereas the development model did not use gear parts but employed a structure in which the shear bolt's installation flange held with disc springs slips to dissipate any excessive torque applied. In this structure, two torque limiters, one each on the right and left augers respectively, are required. This raises concerns about an increase in cost. In this development, we did away with the use of friction pads, which are used in common torque limiters. Since the torque limiters used in snow blowers are not in a position where they may be triggered all the time, they do not seize up with frictional heat as frequently as with other common torque limiters.

So, instead of friction pads, we opted to form a new structure, which is simple and cost effective, by adopting a flange that slips, then providing this flange with a grease hole and filling it with grease, as the measure to prevent seizure.

Next, we worked on the size reduction of the torque limiter. With the previous model, the torque limiter is fastened to the drive shaft with a key and hollow set screw. With this structure, the torque limiter is made larger and so collects snow easily during snow removal work. So, we changed the structure so that the drive shaft and the torque limiter are fastened with a pin. The elimination of the key enabled the reduction of the diameter of the torque limiter and with it the size of the disc spring as well. With this change, the external diameter of the torque limiter has been successfully reduced (Fig. 10).

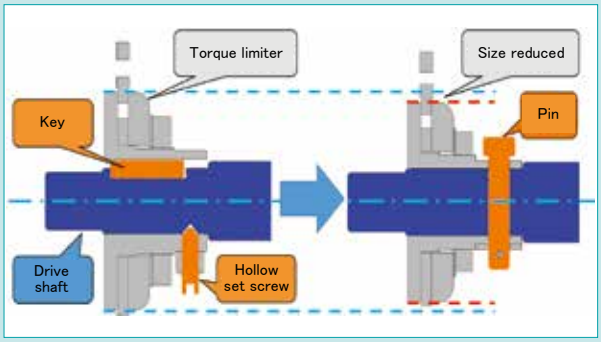



Fig. 10 Considering Miniaturization of Torque Limiter

4.2.2 Setting of the triggering torque

To determine the setting values of the torque limiter's triggering torque, we actually cleared snow in several regions and measured the torques resulting from snow removal work and from shear bolt breakage.

The torque resulting from the shear bolt breakage during snow removal work was 320 N·m. So, the upper limit value was set at 300 N·m.

The lower limit value was set at 110 N·m, which is the maximum torque for snow removal work, because ease of work is lost if the torque limiter is triggered in the usual snow removal work. As for the operating range of the torque limiter, it was set at 110 to 300 N·m.

4.2.3 Results of the performance check

Since the shear bolt breaks in many cases when an impact load is applied to the auger, we, as a check of the torque limiter trigger, measured the time the shear bolt took to break using a jig that simulated a curb, with which the operating part was brought into continuous contact (Fig. 11).

Table 4 shows the results. We performed the trigger check three times. On the previous model, the shear bolt broke after around 1 to 2 seconds, whereas on the development model on which torque limiters were mounted, no breakage occurred for more than 1 minute in all three attempts. Thus, as these results show, we have attained our goal.

The check on the torque limiter trigger resulted in the torque limiter being triggered only when the operating part was locked, and was not triggered when not in an overload condition and thus proved to have no effect on normal snow removal work.

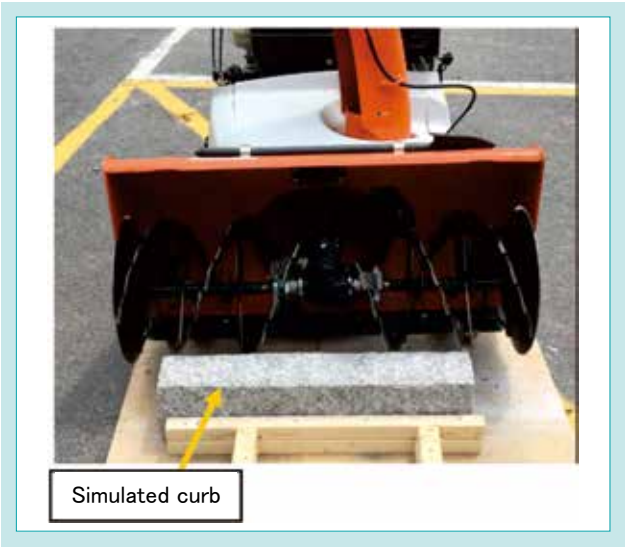



Fig. 11 Torque Limiter Operation Test

Table 4 Results of Shear Bolt Breakage Time

| | Shear bolt broken or not | Shear bolt breakage time in seconds |
|---|---|---|
| Development model SLA-1070ST | No | Set 1: No breakage for 1 minute |
| | | Set 2: No breakage for 1 minute |
| | | Set 3: No breakage for 1 minute |
| Previous model SLA-1070A | Yes | Set 1: 1 second |
| | | Set 2: 1 second |
| | | Set 3: 2 seconds |

## 5. Conclusion

This development model, which took into consideration the use in housing estates as well, has achieved noise reduction through the engine coverings and the blower case configuration. In addition, the development of the machine's own unique torque limiter has contributed to increasing the ease of workability and maintenance by widely reducing the frequency of shear bolt breakage compared with the previous model.

This machine saves on the effort that users have to put in every winter during snow removal work.

From now on, by taking advantage of the technology that this development achieved, we will work on saving on the effort required in snow removal with the further enrichment of the Slalom Series lineup so that it can contribute to the users who are in trouble with heavy snow in extreme weather.

## Contribution to SDG targets

9.1 Development of a high-quality, sustainable and resilient infrastructure
Contribution to reduced noise and effort in snow removal

11.a Support for connections between urban and rural areas
Contribution to an improvement in the ease of snow removal work

# Development of Spinach Conditioner NC301

Post-Harvest Products Engineering Dept.



Processing of soft leafy vegetables such as spinach (removal of unnecessary roots, cotyledons, and lower leaves) accounts for 44%[1] of the total working hours (from seeding to shipping), and the work is carried out by employed workers. On the other hand, since the processing of soft leafy vegetables requires delicate handling, there is a conventional machine for this purpose, but it has been difficult to save labor by mechanization.

Therefore, we aimed to reduce the labor component of manual processing and improve work efficiency by maximizing the root cutting accuracy and the cotyledon and lower leaf removal rate by developing a machine for this task. This paper describes the features and processing work performed by the spinach conditioner. At the same time, we will introduce the development technology.

【Key Word】
Spinach, Soft Leafy Vegetables, Processing, Removal of Lower Leaves, Removal of Cotyledons, High Efficiency

Related SDGs


## 1. Introduction

### 1-1 Background of the development

Soft leafy vegetables deteriorate quickly right after being harvested, and spinach is a representative example. For spinach, due to its very perishable nature, all the processes from sowing to harvest and also packaging have been mechanized, but the processing of spinach is still done manually in most cases. The work takes up 44% of the total hours required for the entire process and relies on part-time workers in large production regions, where, however, it is becoming difficult to retain this workforce in recent years. To save on labor in the conditioning of soft leafy vegetables, Kubota, in response, developed spinach conditioner NC300 jointly with the National Agriculture and Food Research Organization ("NARO") as an "urgent development project for agricultural machinery, etc." ("urgent project"), and obtained the commercialization rights in 2000. However, the processor for spinach, which requires a delicate touch, could not satisfy the market demands due to a lack of ability. In addition, Japanese agriculture in recent years has been increasingly concentrated around professional farmers with more than 10 hectares of farmland due to more famers distancing themselves from agriculture or outsourcing the work due to their aging populations. Spinach farmers, who are also on the increase in the per-farmer hectarage of planting, had been requesting a more highly efficient conditioner to be developed.

Given this background, Kubota again launched into joint research as an urgent project with NARO[2], and with the achievements of the project, developed the new machine "NC301" (Fig. 1).

Fig. 1 Spinach Conditioner "NC301"

### 1-2 Method for spinach processing

Spinach is processed by cutting off the unnecessary part of the root with 5 to 10 mm left, and then removing the cotyledons (1 to 2 leaves/plant) and lower leaves (2 to 4 leaves/plant), which cause discoloration or rot (Fig. 2). The purpose of the soft leafy vegetable processing is to automate these processes.

Note that the "cutting length of the root" in this report refers to the "length of root left from where the root ends and the stems begin after the cutting process".

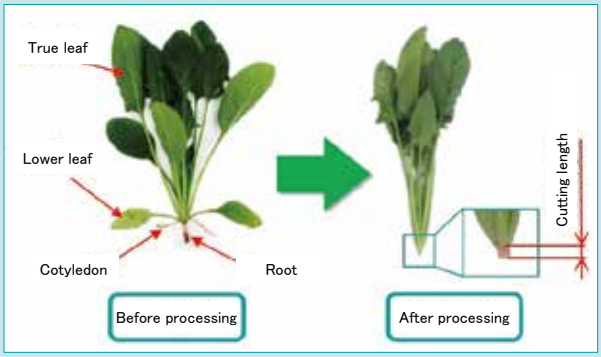



Fig. 2 Processing of Spinach

### 1-3 Conditioner structure and work flow

Spinach conditioner comprises the feeding, processing and unloading units (Fig. 3).

The work flow is described below using the photos of the development model.

(1) The feeding worker places plants of the crop onto the feeding conveyor one by one. When placing them, let the plant base of the crop follow the plant base guide.

(2) The crop is carried on the feeding conveyor and reaches the processing unit.

(3) In the processing unit, the footing holding conveyor and the feeding conveyor carry the crop while holding the true leaves not requiring removal. Then the root is cut and the cotyledons and lower leaves that are not held are removed automatically (Fig. 4).

(4) The crop ejected from the processing unit is passed to the unloading conveyor of the unloading unit.

(5) At the unloading unit, the finishing worker removes true leaves that have insect holes or discoloration. At the same time, the worker removes the roots and lower leaves that the machine failed to remove.

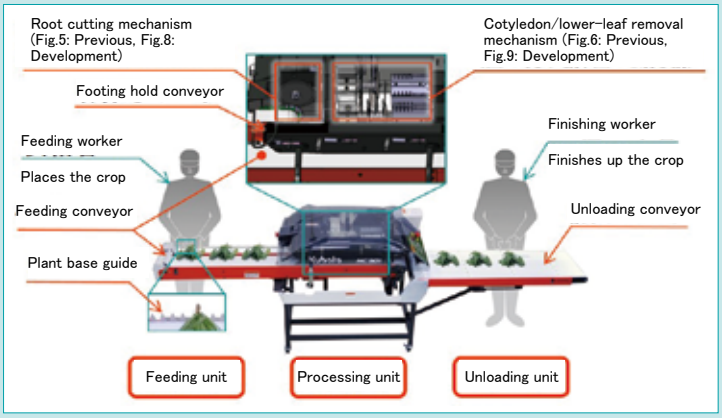



Fig. 3 Constitution of Conditioner

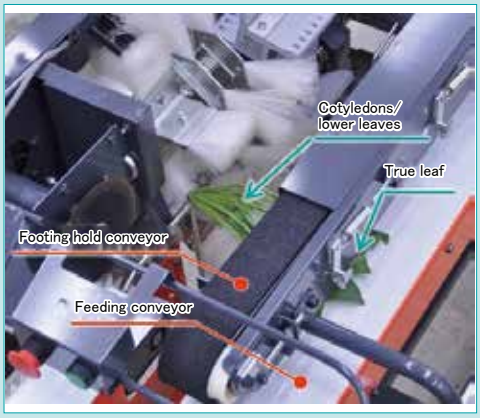



Fig. 4 Crop Flow Inside the Conditioner

## 2.Development concept and goals

### 2-1 Development concept

To make the processing process efficient, the machine needs to decrease the effort required of the finishing worker to reprocess the roots and lower leaves that the machine fails to cut or remove. While achieving 100% in processing accuracy is not easy because soft leafy vegetables differ in shape and condition depending on the type and cultivation timing, we set the goal to improve the accuracy of cutting roots and of removing cotyledons and lower leaves to the greatest extent possible to lead to the improvement of work efficiency with a reduction in the effort for reprocessing.

Also, the retention of experienced workers is recently becoming difficult. Manual practice requires skilled technique, and the finished quality varies if processed by inexperienced workers. In response, we aimed for a spinach conditioner that allows anyone to produce stable finished quality through easy operation.

## 2-2 Target values

The following development goal was set to achieve the concept.

Work hours for processing 30% less than with the current machine

The indispensable prerequisite for this development goal is the reduction of the effort required for reprocessing, and thus we set the following values to achieve the processing accuracy targets.

(1) Accuracy of root cutting
 [1] Average cutting length 5 - 10 mm
 [2] Standard deviation 2.0 mm or less
(2) Accuracy of cotyledon/lower-leaf removal
 [1] Rate of cotyledon/lower-leaf removal 90% or more
 [2] Rate of true leaf loss (incorrect removal) 5% or less

# 3.Technical issues to be solved

## 3-1 Issues for improving the accuracy of root cutting

The value of spinach delivered for fresh consumption places great importance on the after-processing appearance as well. So, spinach roots must not be cut at an angle in addition to meeting the earlier mentioned cutting accuracy requirements. On the other hand, the previous cutting mechanism pushes the crop downwards with its cutter to make the crop hang down at the moment of cutting moment. Due to this, the machine had the issue that it produced variations in cutting length or angled the cut surfaces of roots (Fig. 5). Those incorrectly cut roots need to be reprocessed manually and this takes time and effort.

To eliminate the need of root reprocessing, this development got down to working on this challenge by reviewing the structure from when the crop is carried onto the feeding conveyor to when it reaches the cutting process.

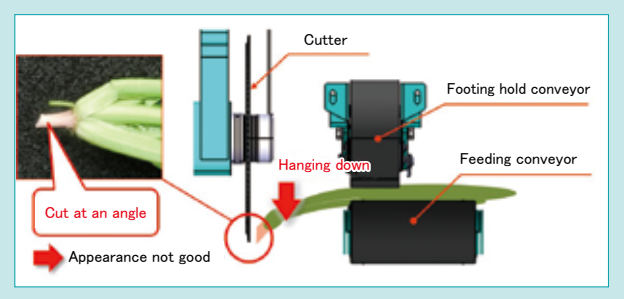



Fig. 5 Mechanism of "NC300" for Cutting Roots

## 3-2 Issues for improving the accuracy of cotyledon/lower-leaf removal

The previous mechanism for the removal of cotyledons and lower leaves has the lower-leaf removal brushes and rolls alternately aligned (Fig. 6). In this mechanism, the lower-leaf removal brushes pick up cotyledons and lower leaves in the root direction and then the lower-leaf removal rolls, which are made of sponge and rotate at low speed, entangle and tear them off to remove. This method had one issue to be solved in that it left the petioles (the portions that look like stems connecting from the lower leaves to the plant base) unremoved at the plant base and required the worker to reprocess them.

In this development, to improve on this issue, we tried to develop a new mechanism that can remove the lower leaves reliably from the plant base.

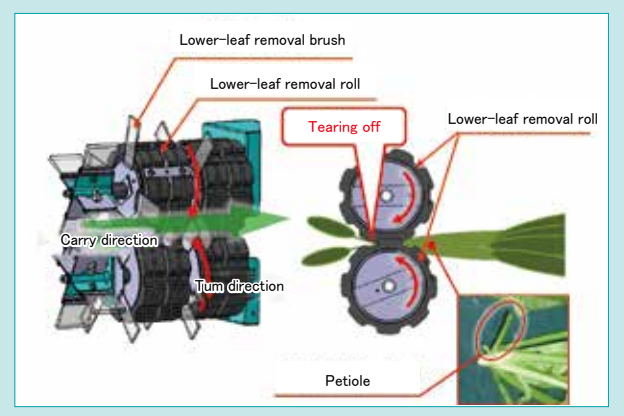



Fig. 6 Mechanism of "NC300" for Removing Cotyledons and Lower Leaves

## 4. Developed technology

### 4-1 Improvement of root cutting accuracy

4.1.1 Stabilization of crop feeding at the feeding unit

In considering the improvement of root cutting accuracy, we worked on it by reviewing the feeding unit, which is responsible for aligning the plant base of the crop, and the root cutting mechanism in the processing unit.

At the feeding unit, as mentioned earlier, the feeding worker places plants of crop onto the feeding conveyor one by one, and at that time, needs to let the plant base of the crop follow the plant base guide. So, the plant base of the crop may be positioned slightly far apart from the plant base guide depending on the feeding worker's competence, and this increases the root cutting length by the amount of distance apart.

The machine developed, in response, has tilted the plant base guide 1° with respect to the feeding conveyor (Fig. 7). With this, as the crop travels further by being carried on the feeding conveyor, the plant base guide is drawn closer to the plant base of the crop, and thereby this tilt arrangement can correct the crop feeding position a maximum of 10 mm or so. This structure, which lets the machine accommodate variations in the feeding position, enables the improvement of root cutting accuracy. It also reduces the effort required of the feeding worker to pay attention to the feeding position of the crop in comparison with the previous model. This improvement in feeding speed leads to the improvement of work efficiency as well.

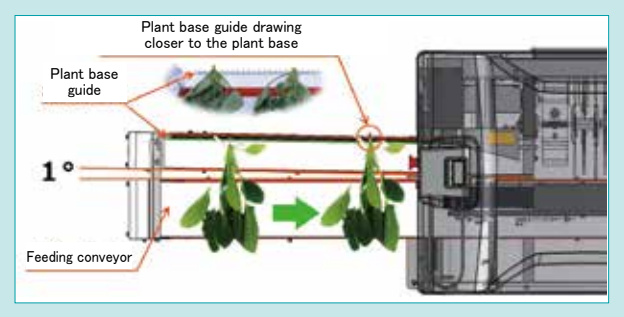



Fig. 7 Conveyor Arrangement of the Feeding Unit of "NC301"

4.1.2 Improvement of the root cutting mechanism in the processing unit

In the cutting process of the development model, the root of the crop is supported from underneath with the gear rotor provided close to the plant base guide (Fig. 8). The plant base of the crop, which has been carried along the plant base guide, is supported by lying closely against the gear rotor. This structure allows the cutting length to be uniform. Also, it can result in a good appearance as it can cut the root vertically by preventing the crop from hanging down at the cutting moment. These results indicate we have achieved a root cutting accuracy that requires almost no manual reprocessing.

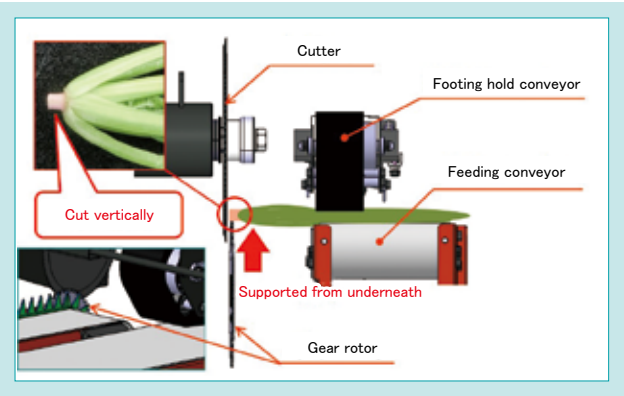



Fig. 8 Mechanism of "NC301" for Cutting Roots

4.1.3 Results

Table 1 compares the accuracy of root cutting between several types of crops cut by the development model and by the previous one. Seeing the average cutting lengths and standard deviation averages of the machines, the previous model recorded an average cutting length of 9.7 mm and a standard deviation of 3.0 mm whereas the development model recorded an average cutting length of 6.5 mm and a standard deviation of 1.2 mm. These results show that the development model is able to cut shorter with less variation than with the previous model. Also, the attainment in all types as to the target values, which are an average cutting length of 5 to 10 mm and a standard deviation of 2.0 mm or below, indicates the machine has achieved stable finished quality irrespective of the type of spinach.

Table 1 Evaluation Results Related to Root Cutting Accuracy

| Spinach type | Region | Ave. cut length (mm) | | Standard dev. (mm) | |
|---|---|---|---|---|---|
| | | Development | Previous | Development | Previous |
| Target value | | 5〜10 | — | 2.0 or below | — |
| Sun Hope Seven | Gifu | 5.7 | 10.1 | 1.0 | 3.0 |
| Super Star | Iwate | 6.6 | 9.1 | 1.0 | 2.1 |
| Sun Hope Seven | Gifu | 5.1 | 9.1 | 1.1 | 3.4 |
| Scoop | Gunma | 8.6 | 9.9 | 1.4 | 2.9 |
| Justice | Gunma | 6.5 | 10.1 | 1.4 | 3.4 |
| Average | | 0.5 | 9.7 | 1.2 | 30 |

## 4-2 Improvement of the cotyledon/lower-leaf removal accuracy

### 4.2.1 Development of the mechanism for cotyledon/lower-leaf removal

The mechanism for the removal of cotyledons and lower leaves that the development model provides comprises the lower-leaf removal brushes and blades (Fig. 9). The lower-leaf removal brushes, which are equivalent to those of the previous model, consist of two each on the upper and lower parts which are adjacent to each other, and thereby produce a continuous effect to reliably pick up cotyledons and lower leaves in the root direction.

The lower-leaf removal blades, which have been newly adopted in the development model, are made of EPDM-base sponge rubber and are attached in a set of four each on the rotary shaft in a windmill-like manner. Each set is placed up and down and turns at a high speed of up to 900 rpm to remove cotyledons and lower leaves. The blade edges apply an impact repeatedly only to the bases of lower leaves and change shape to go along the plant base shape and thereby can chop off the lower leaves reliably from their bases (Fig. 10).

The lower-leaf removal blade edge takes different shapes in the upstream and downstream (Fig. 11). The upstream is intended to remove mainly cotyledons and lower leaves and is provided with deep slits to help the lower-leaf removal blade change shape easily along the plant base shape of the crop and also provided with the “flaps” and grooves that serve to reliably catch the lower leaves. On the other hand, the downstream has shallower slits to give more durability to the lower-leaf removal blade, and a set of blades form a brush-like shape to serve to polish up the plant base.

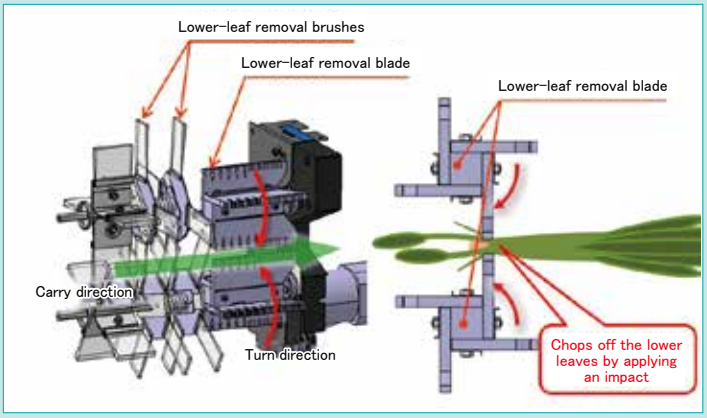



Fig. 9 Mechanism of “NC301” for Removing Cotyledons and Lower Leaves

Fig. 10 Blade for Removing Cotyledons and Lower Leaves

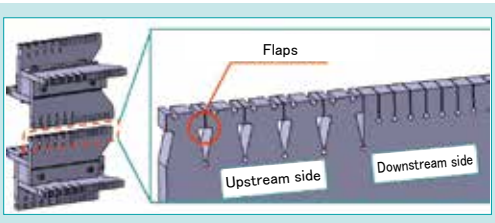



Fig. 11 Tip Shape of Blade

4.2.2 Results

Table 2 compares the accuracy of cotyledon/lower-leaf removal between several types of crops cut by the development model and by the previous one. The rate of cotyledon/lower-leaf removal, which is an evaluation index, was determined with the division of the weight of cotyledons and lower leaves removed by the machine by the weight of the overall cotyledons and lower leaves that should have been removed. The rate of true leaf loss was determined with the division of the weight of true leaves, which were damaged or incorrectly removed by the machine, by the weight of the whole plant complete with the conditioning process.

Seeing the averages of cotyledon/lower-leaf removal and true leaf loss rates of each of the machines, the rate of cotyledon/lower-leaf removal is 92.3%, which indicates that the target value of 90% or more was attained. The improvement by 13.6 than with the previous model raises our hopes for the improvement of work efficiency through the reduction of the effort required for reprocessing. The rate of true leaf loss is 1.0%, which indicates the satisfaction of the target value of 5% or below, resulting as a reduction of 2.3 from the previous model. This has proved that the development has brought effectiveness in the reduction of crop damage and thus in yield improvement as well.

Table 2 Evaluation Results Related to Cotyledon and Lower Leaf Removal Accuracy

| Spinach type | Region | Cotyledon/lower-leaf removal (%) | | True leaf loss (%) | |
|---|---|---|---|---|---|
| | | Development | Previous | Development | Previous |
| Target value | | 90 or more | — | 5 or below | — |
| Sun Hope Seven | Gifu | 93.7 | 67.2 | 0.0 | 0.1 |
| Super Star | Iwate | 90.5 | 88.4 | 0.1 | 1.1 |
| Sun Hope Seven | Gifu | 90.0 | 85.0 | 0.5 | 14 |
| Scoop | Gunma | 96.5 | 74.6 | 3.4 | 4.5 |
| Fortissimo | Gifu | 90.6 | 78.1 | 0.8 | S3 |
| Average | | 92.3 | 78.7 | 1.0 | 3.3 |

## 4-3 Work efficiency improvement and user evaluation

4.3.1 Work efficiency improvement

Table 3 shows the results of comparison in processing work efficiency between the previous model and the development model. Seeing the averages with each of the machines, the development model recorded 927 plants/(person per h), which is an improvement of approximately 65% compared with the previous model, which recorded 563 plants/(person per h). That is to say, the work hours have been reduced approximately 40%.

The machine developed has improved the accuracy of root cutting and of cotyledon/lower-leaf removal, and with the reduced work in manual reprocessing, the throughput per hour has improved and thus the number of finishing workers can be reduced.

Table 3 Evaluation Results Related to Work Efficiency

| Spinach type | Region | Work efficiency (plants/person per h) | | Improvement (%) | Work time reduction (%) |
|---|---|---|---|---|---|
| | | Development | Previous | | |
| Sun Hope Seven | Gifu | 897 | 570 | 57.3 | 36.6 |
| Super Star | Iwate | 956 | 556 | 71.9 | 41.7 |
| Average | | 927 | 563 | 64.7 | 39.3 |

4.3.2 Improvement of usability

The development model worked on various improvements in the usability aspects as well. An example is the lines printed on the unloading conveyor for the purpose of identifying the sizes of the crop (Fig. 12). The finishing worker sorts the crop into delivery standard sizes such as "S", "M" and "L". Previously, crops were commonly measured using a scale, and this was reducing work efficiency. This modification, which allows the finishing worker to recognize the sizes of crop at a glance, has led to the improvement of work efficiency.

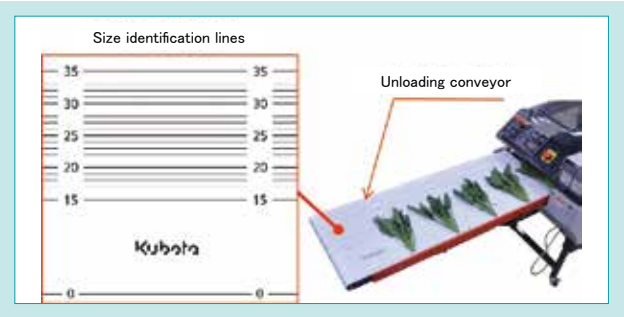



Fig. 12 Crop Size Identification Line

4.3.3 User evaluation

A total of 1,000 hours or more went into the verification tests of the machine developed. The work efficiency greatly improved than with the previous model has been evaluated very positively by users. Users commented that "the automatic root and lower-leaf removal, which gives neat finished quality, has reduced our time and effort". In addition to such a performance evaluation, we had comments also on operability such as that "beginners are able to do the processing job if using the machine". Commonly, spinach is planted more than once throughout the year, and so farmers need to deal with the sowing and upkeep at the same time as the processing. A user mentioned the prospect of producing higher quality crops, commenting that "the reduction in the time for processing helps us dedicate more time and energy to go to the field and produce higher quality crops than ever before".

## 5. Conclusion

In this project focused on spinach and other soft leafy vegetables, we developed spinach conditioner NC301 to improve wok efficiency through the mechanization of these vegetables' processing, which consumes the most time and manpower of the entire cultivation process. The machine developed has greatly improved the accuracy of root cutting and cotyledon/lower-leaf removal and thereby has successfully reduced approximately 40% the work hours taken for the processing process compared with the previous model.

We expect this product to contribute to solve the shortage of experienced workers, make the processing process more efficient with less effort, and help customers expand the hectarage of their planting land and produce higher quality crops.

Soft leafy vegetables include various types such as shungiku (edible chrysanthemum) and mizuna (Japanese mustard greens) in addition to spinach and komatsuna (Japanese mustard spinach) and they are processed in a wide variety of ways. As our next steps, we will work on the technical development to be able to support more types of perishable vegetables based on customer requests.

## Contribution to SDG targets

2.4 Achievement of sustainable and robust agriculture
Contribution to increased productivity by reducing the work hours for processing approximately 40% compared to the previous model

9.5 Promotion of scientific research and innovation
Contribution to the promotion of mechanization in vegetable cultivation

Reference

1) Ministry of Agriculture, Forestry and Fisheries: "Agricultural management statistical survey, 2007 Management statistics by product" 1-6, (2007) https://www.maff.go.jp/j/tokei/kouhyou/noukei/hinmoku/ (Reference on 2020-10-01)
2) Yuichi Kobayashi et al.: "Development and performance of a high efficiency spinach conditioner", 80-6, (2018), pp. 434-439, Journal by Japanese Society of Agricultural Machinery and Food Engineers

# Development of MU4902 Tractor for ASEAN Market

KUBOTA Research and Development Asia Co., Ltd.



In recent years, under the policy of the government, the transition from rice cultivation to dry crop cultivation was making progress in Thailand. While rice has been the largest harvested area by crop, the harvest area occupied dry crops (sugar cane, cassava, corn) is expected to increase due to the Thai government encouraging farmers to change to crops other than rice and also the growing demand for bioethanol.

As a result, there has been an increasing demand for heavyweight tractors for dry field farming away from conventional lightweight tractors used in paddy fields.

Moreover, looking at other ASEAN countries, in Cambodia, in addition to the two consecutive seasons of rice cultivation (dry field / paddy field), cassava was also a major crop. In Myanmar and Laos, in addition to rice (dry rice fields), beans and cassava were major crops. It was thought that the market for heavyweight tractors for dry crops was expanding. Against this background, KUBOTA Research and Development Asia (KRDA) has developed a tractor for ASEAN dry-crop farming. Clarify the tractor specifications required for ASEAN dry-crop farming tasks and introduce the required development technology.

【Keyword】
Heavyweight Tractor, Dry Field, Operating Speed, Fuel Consumption, Local Development

Related SDGs


## 1. Introduction

Rice is the main crop in ASEAN. Kubota tractors has been evaluated by small and medium-sized rice farmers who are also working as contractors, for its light weight, compactness, and good work efficiency, and have had an overwhelming share in the 41-50 horsepower range. However, even with the same rice, in the dry fields rice and dry crops farming markets, competitor's heavyweight tractor which exceeds the traction force

were increasing the sales. As the harvested area of field crops is expected to increase in the future (see Table 1), it is hoped that tractors will be introduced into the heavyweight tractor market, which Kubota does not have product lineup. (Fig. 1)

This time, developing a new tractor at KRDA, a local development base and developing tractor implements in Thailand where is the main market of the tractors in ASEAN.

Basic performance was important because the functions were limited to introduce an inexpensive tractor. Here, introducing how have achieved the basic performance by taking advantage of the merits of local development.

Table 1 Crop Area in Thailand 2014 vs 2019

| Production | 2014(a) | 2019(b) | (b)-(a) |
|---|---|---|---|
| Primary rice | 62.79 | 55.96 | ▲6.83 |
| Secondary rice | 12.55 | 12.05 | ▲0.50 |
| Sugarcane | 8.37 | 12.37 | +4.00 |
| Cassava | 8.98 | 10.74 | +1.76 |
| Maize | 7.50 | 8.71 | +1.21 |
| Para rubber | 18.58 | 18.00 | ▲0.58 |
| Palm | 4.41 | 3.55 | ▲0.86 |
| | | | |
| Rice total | 75.34 | 68.01 | ▲7.33 |
| Other total | 47.84 | 53.37 | +5.53 |
| Total | 123.18 | 121.38 | ▲1.80 |

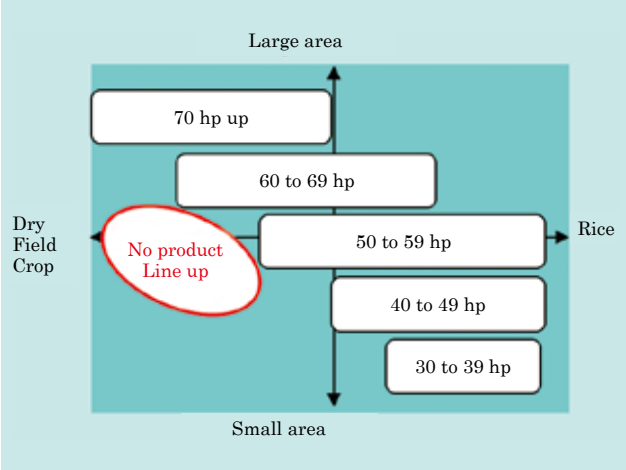



Fig. 1 Positioning Map for Tractors in ASEAN

## 2. R&D Concept and Target Value

### 2-1 R&D Concept

Customers were small and medium-sized dry crops farmers, so low-priced products were desired. Competitors were introducing standard low-cost tractors with simple transmissions and no electronic controls. Therefore, need to develop it as a basic tractor with limited functions and realize a reasonable price.

Because it was a basic tractor, it was difficult to differentiate it from competitors in terms of functionality, so the goal was to overwhelm with basic performance such as fuel efficiency, work efficiency, and workability.

Fig. 2 MU4902 Tractor for ASEAN

### 2-2 Target Value

1. Weight setting for heavyweight tractors
   - Determining the optimum weight
   - Optimal front-rear balance setting
2. Fuel efficiency and work efficiency superior to competitors
   - Addition of shuttle function
   - Speed setting for improvement
3. Realization of high operability
   - Shuttle lever position and operating power
   - Arrangement of front dozer lever
   - Arrangement of position lever

## 3. Technical Challenge to be Solved

### 3-1 Technical Challenge for Best Weight Setting

The weight of the tractor was an important factor in achieving an appropriate traction force in dry crops farming work. However, if just adding the weight, additional costs will be required for its material cost and the additional reinforcement cost to keep same durability against the weight increase, and the price unnecessarily was increased.

In addition, the weight balance between the front and rear of the vehicle body was important for achieving stable running and ensuring a constant tillage depth during each actual work.

It was necessary to suppress unnecessary weight increase and realize the optimum front-rear balance of the tractor at a reasonable price.

### 3-2 Technical Challenge for Better Fuel Consumption and Working Efficiency

In Thailand and other ASEAN markets, it was common to work in the range of 1800 to 2000 rpm engine speed, regardless of the engine rated speed.

It was possible to consider that this was because, in the past, many used oversea major tractors were imported which were equipped with low-speed (rpm), high-torque engines with large displacements. Anyway it's hard to change this habit because it comes from the idea that customers want to save on fuel costs and don't want to work with high rpm because customers want to use their tractors for as long as possible.

Therefore, it was necessary to achieve fuel efficiency and workability that surpassed the competition in the work of each implement with the engine speed range of 1,800 to 2,000 rpm, which was the actual customer operation range.

### 3-3 Technical Challenge for Better Operability

In Thailand and other ASEAN markets, there was a lot of work with front dozers. During the work, the blade was constantly moved up and down, so keep right hand on the operating lever. Also, because of leveling work, there were many cases of switching forward and backward. If customers can switch the shuttle lever while holding the steering wheel, they can work without releasing their right hand from the dozer lever, and they do not have to switch right hand from steering wheel to dozer lever. It leads to reduction of operator fatigue.

In addition, Operators do not use the draft function when working with rotary, disc harrow, disc plow, etc., always put their right hand on the position lever and operate the rear implement up and down so that the tractor speed become constant.

It was necessary to arrange each lever at the optimum position and reduce the load on the operator by improving operability.

## 4. Developed Technology

### 4-1 Technology for Best Weight Setting

4.1.1 Weight Setting of the Tractor

We developed MU4902 at KRDA which was developing tractor implements for ASEAN market. Took this advantage and decided that set the weight of tractor including the implements. The weight was set including the front dozer (about 450 kg) that was 90% installed in the market, and the traction force was comparable to that of competitors. By comparing the work performance with competitors not only with the tractor catalog specifications but also with the actual operating weight, have realized a more reasonable tractor price without extra weight increase.

Fig. 3 FD190 Front Dozer for MU4902

4.1.2 Solution of Weight Balance

Implements like a front loader, which increase weight load to the front wheels during work, were not common in the ASEAN market. Therefore, it was not necessary to add weight to the rear wheels if appropriate traction force was generated.

On the other hand, there were heavy and large overhang implements such as a disc harrow. So, by making the front of the tractor as heavy as possible, the front and rear balance was improved, and can achieve stable running and traction force during operation.

Therefore, considering attaching a weight to the front end. However, at this time, as mentioned earlier, co-attachment with the front dozer becomes important.

For the front dozer, it was better to locate the blade as close to the tractor to get the big departure angle and to reduce the offset amount, which was advantageous in terms of strength.

This time, we examined how to attach the front weight and devised a way to reduce the offset amount of the front dozer as much as possible. The weight of the front bracket was set to the weight obtained by subtracting the weight of the hanger weight added in advance to realize the weight required in 4.1.1. The dozer was fitted with a cylinder to raise and lower the blade. If the hanger weight was attached as usual, there will be no space to attach the cylinder and it will interfere, so the structure was such that the spacer was sandwiched only in that part and the weight was not attached.

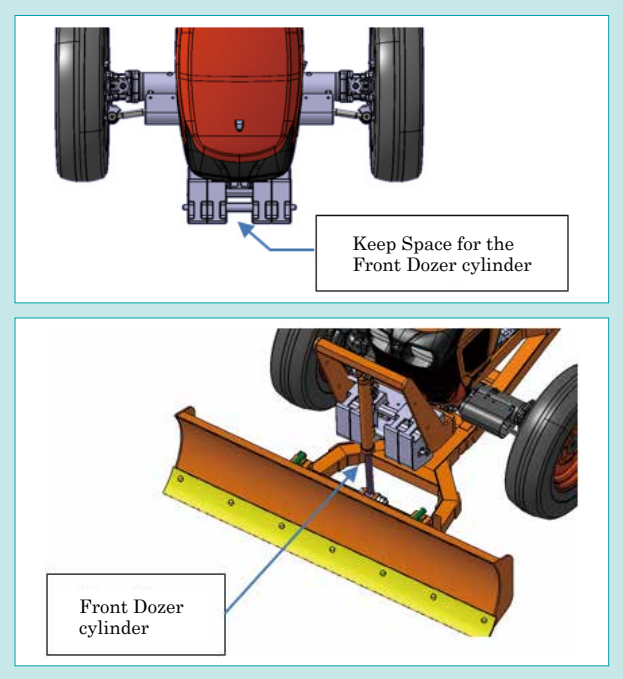



Fig. 4 Positioning of Front Weight and Front Dozer

## 4-2 Technology for Better Fuel Consumption and Working Efficiency

4.2.1 Solution of Challenge for Better Fuel Consumption and Work Efficiency

A shuttle mechanism was adopted to facilitate forward / backward switching that was frequently performed in front dozer work. A synchro type shuttle was adopted to keep costs reasonable. In order to handle the increased weight and reduce the shifting operation force of the shuttle lever, we adopted one size bigger synchro system comparing with the same horsepower range.

Next, the optimum tractor speed was considered to realize the customer's work speed for improving fuel efficiency, it was conceivable to increase the number of gearshift and increase the vehicle speed range that can be selected. However, with this method, the number of parts such as gears increases, resulting in cost up.

This time, we considered to cover as much tractor speed as possible with a total of 8 speeds, 2 speeds for auxiliary transmission (constant mesh) and 4 speeds for main transmission (synchro mesh). Customers' working implements were mainly rotary, plow, harrow and dozer, and these four implements cover 80-90 percent of tractor working time. Therefore, we targeted the vehicle speed setting that was optimal for these work speeds. The Fig. 5 shows the vehicle speed range of the four implements. As mentioned above, these tractor speeds should be achieved at an engine speed of 1800 rpm according to the customer's behavior. Design target was establishing four speeds between 4 and 9km / h. As a device on the low speed side, in ASEAN countries, the rotary work speed was relatively fast, so the rotary speed setting has been made faster so that it can be used for plow work. And as a device on the high speed side, since there was no heavy towing by the trailer, H-1 speed could be increased and set to be optimal for harrow work. In addition, there were many sandy field in cassava and sugar cane planting area. Harrow work was performed at high speed in these areas. By lowering the speed of the H-2, this speed range was covered. Relatively the L-2 speed became slow, but there was no problem because there were no implements used in this speed range. As mentioned above, in order to achieve the required tractor speed, we changed the speed setting that was considered unnecessary, and made it possible to use four speeds, which were half

of total eight speeds. (See Fig. 5)

Fig. 7 shows the results of measuring the fuel consumption and work efficiency in the disc plow work. MU4902, which has four speeds in the working speed range, has many vehicle speeds to choose from, and it can be said that it was advantageous in fuel efficiency and work efficiency because customer can work at the optimum speed compared to other companies that have only three speeds.

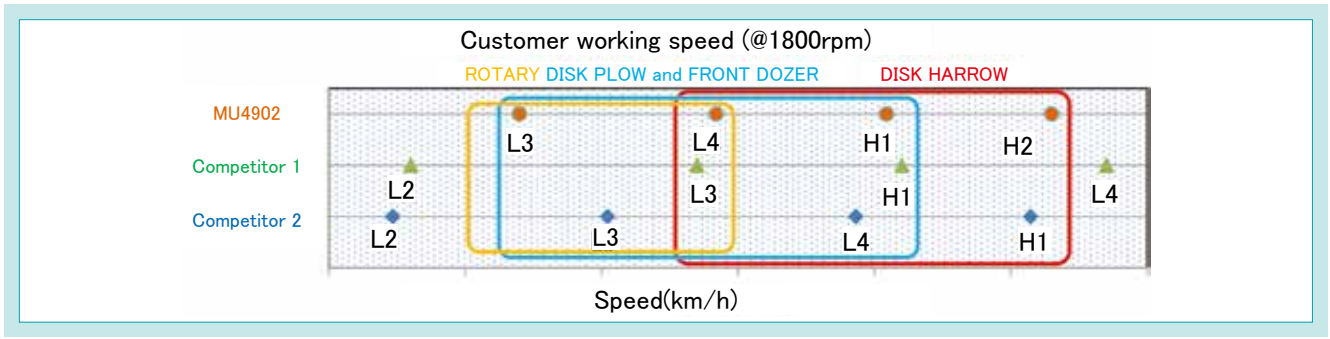



Fig. 5 Tractor Speed and Operating Speed for the Implements

Fig. 6 Disk Plow Operation


Fig. 7 Fuel Consumption and Work Capacity

## 4-3 Technology for Better Operability

4.3.1 Technical Challenge for Shuttle Lever.

As shown in Fig. 8, the lever was arranged so that it could be operated while the thumb was placed on the handle. In addition, since the operation was performed only by the other fingers, the operating force had to be low. By reviewing the detent shape of the shifter and changing the strength of the detent spring, the operating force was reduced. The Fig.9 shows the results of comparison of operating power with competitors. 30% lower operating power was achieved comparing with competitors.

Fig. 8 Position of Shuttle Lever

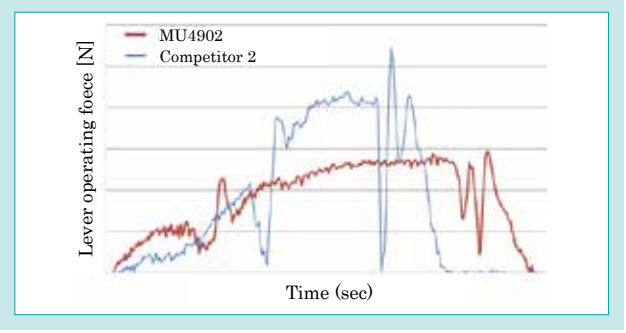



Fig. 9 Operating Force of Shuttle Lever

4.3.2 Technical Challenge for Other Levers.

There were position lever that adjusts the height of the rear implement, draft control lever, a main shift lever, and a front dozer operating lever on the right side of the operator.

The first thing to consider was the operability of the position lever. Customers do not rely on draft control for the rear implement, and always adjust the tillage depth of the implement with the position lever to achieve stable tillage. It could be said that customers did not release the position lever during tilling work. Therefore, it had to be placed in the best position to reduce the load on the operator. The best position was selected based on ergonomics. In addition, the range in which the customer operates the lever in actual work has been adjusted to match the easy-to-use lever operation range.(Fig. 10)

The next important lever was the front dozer lever. KRDA defines the arrangement range of the operating lever position based on past experience values. (Refer to Fig. 11) However, this area was the space for the position lever and the main shift lever. This time, the best position of the front dozer lever was secured by shifting the position of the main shift lever to the front side. The position lever and dozer lever determined in this way were further improved by repeating the user survey and set as the final position.

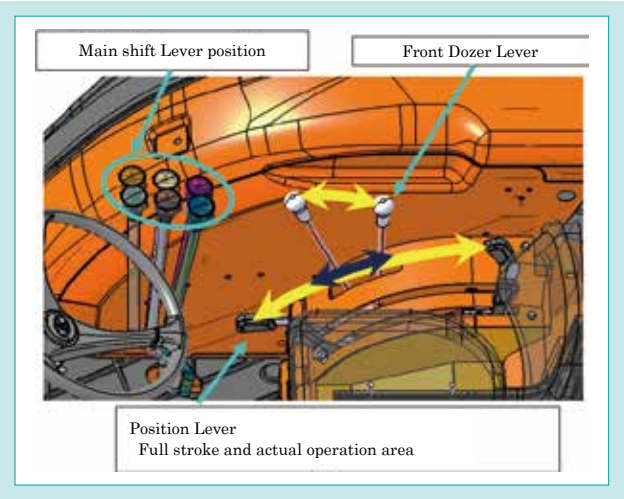



Fig. 10 Positioning of Operating Levers

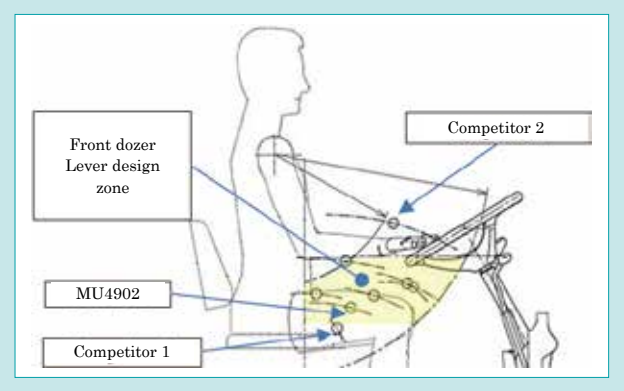



Fig. 11 Front Dozer Lever Design Zone

## 5. Conclusion

By developing a tractor at a local development base KRDA, we believe that it was possible to develop more "On your side" tractor by being able to develop at the same time as the implements, easily performing on-site performance tests, and listening to the voices of customers. In addition, because it was a basic tractor aiming for a low price, we focused on the basic performance of fuel consumption, work efficiency, and operability. By setting the tractor speed according to the needs of local customers, we were able to reduce fuel consumption and improve work efficiency, and we were able to differentiate ourselves from other companies. In addition, we were able to reduce the load on the customer by optimizing the lever arrangement and reducing the operating force.

In the future, based on the experience of this development, which was the first local development of tractors, we are going to develop tractors to expand the product lineup aiming to become a Global Major Brand and contributing to agriculture in ASEAN and around the world.

## Contribution to SDG Targets

2.3 Increasing agricultural productivity and income
Contribution to the increase in income of farmers in ASEAN through improvement in work efficiency and fuel consumption.

8.2 Improvement in productivity through innovation
Contribution to the productivity by achieving the optimum tractor speed.

Reference

Thai Agricultural Research Journal, 2019

# Development of a High Speed Planter

R&D KVG Soest



Climate change and in consequence a shorter time period for optimum planting conditions demanding an efficient solution. Instead of using more planters the possibility to improve situation, is a machine, which is able to plant at high speed. Hence development of high speed planter was required and the traditional speed range of 7 to 9 km/h was raised up to 18km/h. Beside the speed target higher precision in respect of spacing (planting distance from one seed to the other) was achieved. To reach this task the Optima planter was changed from a vacuum system to a pressure system. The new system, Optima SX, is highly efficient and does not need complicated techniques. By increasing the working speed customers get 30 to 40 % more efficiency without additional resources. A high level of standardization puts KVG in a position to reach proper margin at attractive prices for our customers.

【Keyword】
High Speed Planter, Spacing, Interrupter, Pressure System, Vacuum System

Related SDGs


## 1. Introduction

Kverneland (KV) Optima maize planters (Fig. 1) are the most important products in the Soest factory. Yearly 6000 sowing units are sold in average, which represents approximately 1000 complete machines and 30% market share of EU. Optima planters are popular for their reliability, preciseness of seed spacing and outstanding options like GEOCONTROL. The main task of a precision drill is to achieve the preset spacing (Fig. 2). It is important that the distance from one seed to the other is exact same, and one seed only in one position with no doubles and no misses. The planting depth has also to be accurate. This parameters need

Fig. 1 Optima SX TFprofi

to be correct at any speed (5-18 km/h) at different spacing's (3 -120 cm) and planting depth (1-10 cm). This must work with a wide range of seed, from oilseed rape seed to beans (granule diameter 2 mm-18 mm,) and their varieties. Seed shape are not following norms and every year seed shape is changing and the coating as well. Pneumatic vacuum precision drills have mainly replaced mechanical systems today, except those for sugar beets.

The main principle of a vacuum system is explained in Fig. 3. Vacuum let seed move onto disc. (There are different discs for seeds/ diameter of holes and spacings/ number of holes). An electric motor drives the seed disc. Disc revolutions depending on forward speed of machine and preset spacing. In case, more than one seed sits on a hole, the adjustable scraper makes sure one seed stays on the hole only. At a certain position the interrupter stops vacuum influence and seed falls down by gravity through a channel into furrow. The correct spacing is depending of exact timing of this process and the fixing of seed in the ground. In average every second 20 seeds are planted.

Fig. 2 Spacing

Fig. 3 Vacuum System

## 2. R&D Concept and Target Value

### 2-1 R&D Concept

The concept was defined by the main requirement of high speed planting without decreasing spacing performance. R&D started with the idea to improve existing seed heart. The reason has been to make use of well performing components and save therefore time to market. In addition to this approach, it guarantees a high level of standardization. The new seed heart must fit into the existing row unit to make it available for most of the Optima models. Furthermore several components need to be reinforced because of massive force increase by doubling forward speed.

### 2-2 Target Value

The new Optima SX is supposed to be the high end planter of KV portfolio fulfilling planting speeds up to 18 km/h with minimum same performance than actual model does at a speed of 8 km/h. This is valid for maize, sunflowers, sugar beet, soya and oilseed rape just to mention the core crops. To avoid a second product line and keep cost reasonable, a high level of standardization was requested. Accessories and options like GEOSEED (all seeds of a complete field aligned triangular or in squares) must fit to existing and new planters. The benefit for customers is an increase of efficiency by 30% to 40% by investing approximately 20% more money for this technology.

## 3. Technical Challenge to be Solved

Doubling the planting speed with an existing vacuum system is not possible because the spacing is not acceptable. There are more than one challenge, but in general we have always undefined shape, diameter and roughness of seed surface which will vary year by year. In other words we need a less sensitive system regarding the seed characteristic and technical wise components which allow a more precise timing:

- Reliable engagement of seed at holes of the seed disc
- Accurate singling
- Precise timing getting the seed off the disc
- Improve transport of seed into furrow
- Fix the seed within the furrow

This has to be possible at rate of 40seeds/s, which is a big challenge. On the other hand the system must be easy and quick to adjust for an optimum result. Due to short planting period (Europe approximately 3 weeks) machine must be absolute reliable and easy to maintain.

## 4. Developed Technology

### 4-1 Technology

#### 4.1.1 Technical Challenge

The timing of the complete process from seed bin into furrow must be always the same in best case to bring the timing deviation to nearly zero was one main target. In a first step we identified the weak points within a vacuum system.

#### 4.1.1.1 Interrupter

The deviations in releasing time, the different seeds show to get off the disc, were too high. First target has been to make this process uniform. Every seed must move off the disc at the same position and time (Fig. 4). Therefore a new interrupter with automatic setting was designed to guarantee a quick, full closing of hole at backside of disc (Fig. 5) to achieve a sudden stop of airstream.

Therefore, it is necessary to keep the disc clean, which is proven by rotation of interrupter.

This interrupter disc itself touches the seed heart housing where the drive comes from. The spring load of interrupter is acting lateral and tangential. There have been minor improvements on timing but reliability was increasing very much. For the spring load system of interrupter a patent was granted.


Fig. 4 Interrupter (Work)

Fig. 5 Interrupter (w.o. Disc)

#### 4.1.1.2 Seed Bouncing in Channel

Seed is dropping off the disc into the channel (Fig. 6). Different speed of disc, seed shape and coating and also weight of seed determine the flight curve into and within the channel. Ideally, the seed should not touch channel inside. In practice we find this behavior but also any kind of bouncing within the channel. This is a knock out criterion for the timing process. Testing channels with different inserts did not perform (Fig. 7). We need a technology for a homogenous movement of seed. There have been ideas of elevator belt (Fig. 8) with boxes or meters with one box per seed. This should pick seed coming from singling disc and release it at furrow (Fig. 9). Improvements could be seen but release into furrow was undefined and depending on circumference speed of meter. Disadvantage on top has been meter boxes need to be aligned to size of seed. This solution did not perform and was too complicated.

Fig. 6 Seed Channel

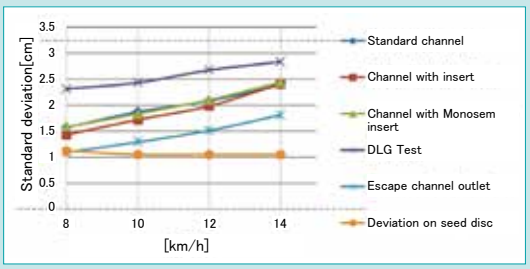



Fig. 7 Test Row Different Channel Insert

Fig. 8 Elevator Belt

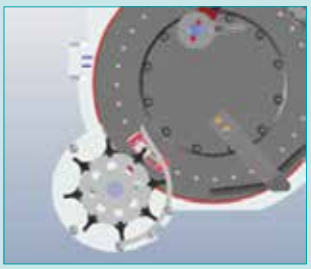


Fig. 9 Box Meter Solution

4.1.1.3 Placement in Furrow

The seed passes the outlet of the channel with a certain energy. When touching down into the furrow, the seed might move forward, depending on furrow shape, organic material and speed of seed. (Fig. 10) If forward speed of planter is not identical with speed of seed it will move within the furrow. Not too seldom it was observed, that a seed overtakes the next one by rolling down the furrow, which causes a bad spacing result obviuosly. All improvements made before in the process are made obsolete at this point. To prevent the seed movement in the furrow a press wheel was placed directly behind the channel outlet to stop the seed at once (Fig. 11). Tests in field have confirmed that this is the right way forward. To fulfil this function, press wheel must be put a extremly narrow to the outlet. This causes very often the danger of chopping or soil building up. At least press wheel stops, which is even worse and not for use in practice.

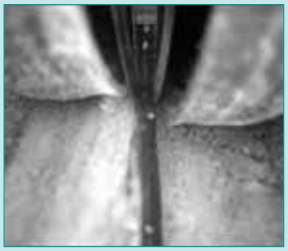


Fig. 10 Furrow

Fig. 11 Wheel

4.1.2 Solution of Challenge

The general solution to solve issues mentioned above was a transition from a vacuum operated system to a pressurized system. The operation air pressure is about 60 to 80 mbar. Instead of vacuum, we make use of air pressure force to attach seed on disc and use this force again in addition to gravity force to unstick seed off the disc. The principle is shown in Fig. 12, where the arrows indicate the flow direction of air pressure unit. The escape of air follows through holes of seed disc or through the tube leading seed to the furrow.

Fig. 12 Air Flow

4.1.2.1 Solution for Interrupter

Improved interrupter (Fig. 5) performed well and no further change was necessary.

4.1.2.2 Solution for Channel Bouncing

Instead of the channel, a 20mm diameter tube is responsible for seed transport from disc to furrow. Within the new developed pneumatic system there is an excess pressure of approximately 65 mbar. This force takes the seed as soon interrupter is working off the disc and transporting it with speed of 20 m/s through the tube (Fig. 13). We achieved two things here: Improving the process to get the seed off the seed disc due to the additional force instead of just using gravity. With the additional force the influence of seed size, shape and coating decreased.

Secondly bouncing inside the tube is no longer a problem. The air stream drives the seed into the center of tube. A special developed interchangeable seed guidance (patent granted) supports this process. The seed stays in the center of tube until it comes down into the bended outlet part (Fig. 14). Within the bend of the tube seeds glides smoothly along the tube wall. There is a minor loss of preciseness, because transport forces are much higher than friction forces and in addition, every seed show the same behavior; hence the possible deviation of timing is based on different friction which depends on seed size, shape and weight.

Fig. 13 Modified Unstick Area

Fig. 14 Tube

4.1.2.3 Solution for Placement in the Furrow

At the outlet of the tube seeds reach speeds between 60 and 80 km/h. Hence it is mandatory to have an application to catch the seed and fix it into ground (Fig. 15). We had already some experience with a press roller and this time we could allow more space between outlet and catch/press wheel. To prevent the seed from damage, process of catching and fixing must be as soft as possible. On the other side this "catch/press wheel must work trouble free in stony and wet conditions. To fulfill a proper catching, we need to cover complete furrow profile and seed must not rebound when hitting the wheel. To find the right composition of rubber and geometry was not easy (Fig. 16). If rubber is too soft lifetime is limited. Stones cut the tyre surface and soil is getting inside the system and stops working immediately. If tyre is too hard, there is a risk of seed damage, rebounding of seed and blocking in sticky soil.

Therefore, a good flexing behavior of tyre is requested.

Fig. 15 Outlet Section with Catch Wheel

Fig. 16 Catch Wheel Evolution Phases

A rubber wheel with soft and high sidewalls perform to all demands. The angle of outlet to point of impact is shallow, so that the seed is jammed between tyre and soil. (Fig. 17) The flexible sidewalls of wheel bulging outwards under (weight) pressure. The furrow is therefore closed and no seed is able to pass the wheel (Fig. 18). This process of active stopping the seed have the biggest impact on increasing the speed. Even more this solution is responsible for optimum spacing results at high speed a vacuum system never reached at 9 km/h.

Fig. 17 Outlet

Fig. 18 Bulging Catch Wheel

## 4-2 Challenge and Solution to Reach a High Level of Standardization

Precision seeders are highly customized and the number of different parts are always at the limit. To avoid a complete new range we stressed the fact of multiple use of parts. The advantage of existing parts are, they need not to be tested and can save time and costs in the development process. While developing the new seed heart the row unit body of the Optima was under value engineering in parallel (Fig. 20-22).

This gave the opportunity to reinforce the body due to higher forces at high speed and make it fit for the two seeding hearts. On top a saving of approximately. 10% costs of a complete standard unit was reached. The seed heart itself stayed on the drum principle (Drum consist of back half of seed heart; and seed disc (Fig. 19). The sealing surface is comparatively to other systems small; this causes less friction and in consequence, less torque for disc drive. (USP)). Scraper, interrupter, seed disc and complete option list stay the same. Even the existing fan fits for vacuum and pressure system. We achieved a standardization level of 80%.

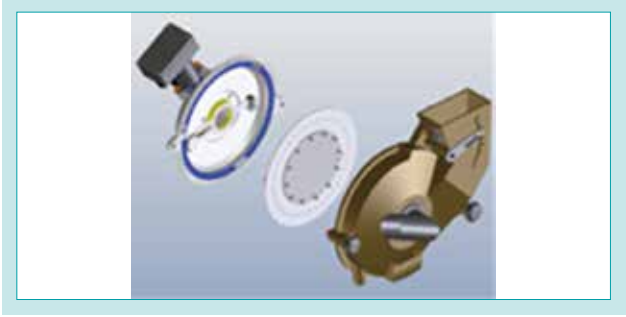


Fig. 19 Seed Heart (Drum Principle)

Fig. 20 Optima Before Value Engineering

Fig. 21 Optima HD (Vacuum)

Fig. 22 Optima SX (Pressure)



## 5. Conclusion

The change from a vacuum processed system to a pressurized system showed big advantages. Though the principle of using the pressure difference within the system stays the same, the result is exceedingly better. Using the positive pressure for getting the seed off the disc and transport down to the furrow the weak phases of a vacuum system could be eliminated. In general the planting distance is significantly better and also the rate of double seeds or missing seeds are reduced. Depending on crops and conditions planting speeds up to 18km/h are possible. For the farmer it means better planting performance and higher speed (Fig. 23). This saves seed by 3 to 5% as a result of less doubles and misses, exact spacing and optimum timing of planting. High speed allow to increase the output by 40%. This is saving money for operation per ha. A high ratio of standardization keeps surcharge for an Optima SX high speed planter relatively low (+15%). The Optima SX is in full series and show an outstanding field performance.

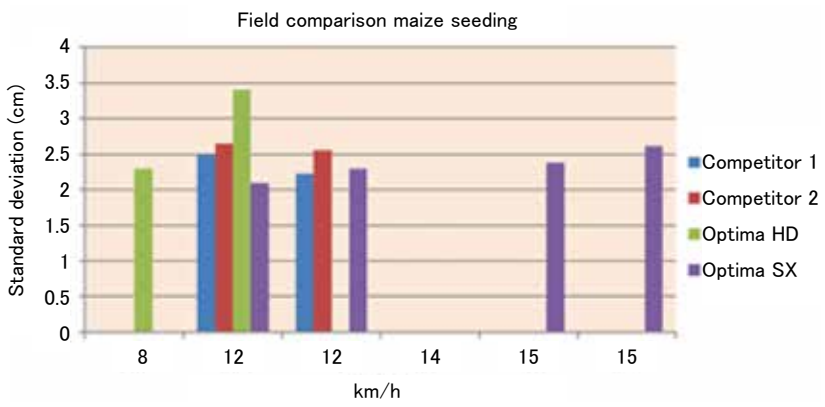



Fig. 23 Standard Deviation of Placing

## Contribution to SDG Targets

2.3 Increasing agricultural productivity and income
Contribution to the increase in income through improvement in work efficiency.

8.2 Improvement in productivity through innovation
Contribution through saving natural resources in this case seed.

Reference

https://ien.kverneland.com/Seeding-Equipment/Precision-Drills/Kverneland-Optima-SX-sowing-unit
https://www.youtube.com/watch?v=vuYJ9UYezLk

# Development of SL Series Tractor with "Keeping Straight Function"

Compact Tractor Engineering Dept. / Farm and Industrial Machinery R&D Dept. I



KUBOTA released a new lightweight tractor with the "Keeping Straight Function" in Jan. 2020, in response to an increased demand for labor saving and efficiency in the farming sector.

This new model SL series tractor features the "GS" specification ("GS" stands for "Go Straight", Keeping Straight Function). This model satisfies the needs of a broad range of customers by providing an enhanced range of options that enrich the line-up such as a cabin model, ROPS model, power crawler model, wheel model in 21-44 kW (28-60 PS), and by supporting multiple implements. This paper describes the new technology added to the model.

【Key Word】
Robot, Automatic Steering, GNSS

Related SDGs


## 1. Introduction

The development concept of the new SL Series GS specs is that it allows anyone to use the GS (Go Straight) keeping straight function easily, safely and effortlessly while being highly functional. We set our sights on making the GS function widely accepted by diverse farmers engaged in various forms of work in both rice and other crops by including this function in the specs in almost all horsepower categories of the new SL Series and also by expanding the applicable implement types.

## 2. Presentation of the technology

### 2-1 Intuitively controllable operation/display system and setting flow

In the new SL-GS specs, the settings and operations required to use the GS function are made easy with many new features, including the multi-function switch and other new switches, the GS monitor, and the refinement of the setting flow (Fig. 1). Just enough functions for the SL Series users are packaged in a simple interactive setting procedure. Without confusion even in the first use, the users can complete the setup and start GS driving. We have changed the image of high-functionality tractors of recent years and the existing linear motion retention retrofit products so that even beginners can use the GS function through intuitive operation.


Fig. 1 SL-GS Layout, Setting Screen

## 2-2 Turn assist guidance and color fill guidance that contribute to agricultural efficiency and labor-saving

**Turn assist guidance**: Achieved with the vehicle's location and direction measured with a good accuracy through the GPS (Global Positioning System) unit, which measures where the vehicle is located, and the IMU (Inertial Measurement Unit) unit, which measures the direction of the vehicle. Turns to the next pass are supported with guide lines that appear at set intervals (Fig. 2). The monitor is placed in the best position to see in the direction of travel so that this guide is easily visible while the operator looks in the direction of travel. This is particularly useful for indirect tillage, etc., where it is difficult for the operator to get a sense for the vehicle's turn.

**Color fill guidance**: Visualizes the tracks that have been already worked on (Fig. 3). Easy to operate by selected functions to the minimum necessary. This is particularly useful for the after-mentioned puddling and broadcaster work, which make it difficult for the operator to distinguish the tracks that have been already worked on.

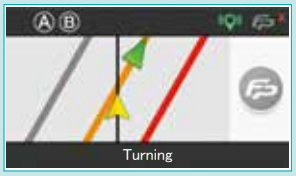



Fig. 2 Turn Assist Guidance


Fig. 3 Color Fill Guidance

## 2 - 3 Supporting diverse types of work to popularize GS tractors

To maximize the ease of use of the display and operation, we took a survey of a wide variety of opinions from many operators in various positions throughout Japan and expanded the types of machinery that can support diverse forms of work. The new SL Series has enriched tow use and paddy field implements in particular. In addition, to aim for the use of the GS function by customers in a wider variety of situations, we also considered a GS function for travel in reverse, which had been highly demanded in the market. The types of work that have been expanded from the new SL-GS specs are described below (Fig. 4).

**<Tow implements>**

**Plow-soiler, stubble cultivator**: Due to the nature of the work that is faster but rougher than with rotary implements, the steering speed was adjusted properly. With this natural assist, both straight-line accuracy and safety have been balanced.

**<Paddy field implements>**

**Levee Plasting Machine**: The biggest challenges were the slow vehicle speed for the work and the vehicle's delay in following the work due to the reaction force from ridges but they have been cleared by enhancing the steering sensitivity with respect to the vehicle's angle of direction.

**Soil puddling harrow**: To support the vehicle's movement typical of wet paddies, in which for example tires are trapped in a rut, we enhanced the responsiveness to be more instantaneous to external perturbations than with rotary implements, which are similar to harrows.

**Broadcaster**: Due to the characteristics of the broadcaster which is installed in an elevated position away from the ground and operates at high speed, the vehicle is susceptible to external perturbations and steering control. To achieve natural, smooth steering, we minimized unnecessary steering control by setting a smaller upper limit for the azimuthal angular velocity instruction.

**Travel in reverse**: When making ridges in a narrow field, the tractor goes back into the previous position in reverse and then starts ridging the next row. This method is used to avoid entering the space that is going to be formed into ridges. Reflecting the market request on the GS function for travel in reverse, we implemented this request as our own unique function that other companies do not offer. To maintain both safety and operability, we put our energy into the study on the maximum vehicle speed for the work, the reporting function that lets the operator confirm safety during travel in reverse, and the easy-to-operate layout of switches.


Fig. 4 Supports for Multi Implement

## 3.Conclusion

The SL-GS specs models launched their sales in January 2020. These models made a solid start, selling about 500 units by September, which accounts for 18% of the entire sales of the SL Series. However, we still have many challenges, including the further enrichment of machines that can be supported and the goal of offering greater convenience. Looking ahead to the future, in which the GS function that we have presented in this report will grow to be the new standard, we continue reflecting farmers' opinions in our development.

## Contribution to SDG targets

2.1 Elimination of hunger
Contribution to increased food supply with the reduction of labor in agricultural production

8.2 Improvement in productivity through innovation
Contribution to increased agricultural productivity with the use of GPS as agricultural technology

9.5 Promotion of scientific research and innovation
Contribution to the spread of advanced agriculture

# Development of 03・07・V3 StageV Engines

Engine Engineering Dept.



Our leading product, 03･07･V3 series which are Kubota vertical water-cooled diesel engines covering the power range of 19-56 kW are installed on many machines. In Europe, where these engines have penetrated the market, a new emission regulation (StageV) came into effect from 2019. Accordingly, we have developed new models that comply with StageV and improved product appeal in response to customer's requests for conventional models. Here we describe our approach to meeting customer's requests by expanding the line-up, and by decreasing downtime.

【Key Word】
StageV, Expansion of Engine Line, Increase in Engine Output, Decreasing Downtime, DPF

Related SDGs


## 1.Introduction

The 03, 07 and V3 series engines, which cover the output range of 19 kW or more and below 56 kW, are mounted on Kubota's agricultural and construction machinery and on many other domestic and international industrial machinery. Also, they are the dominant models of Kubota's vertical water-cooled diesel engines. In Europe, in which these engines are widespread, the Stage V, which is the world's most stringent emission standards, started to be effective from 2019, and to comply with them, the engines were required to change models.

The previous engines, which were launched in the market in 2013 where we were still under the previous emission standards, enjoyed great popularity with a wide range of lineup. On the other hand, to improve the appeal of the products that carry this engine, making the engine package compact and higher output and torque had been called for. In addition, while these machine manufacturers need to replace engines to comply with Stage V, the design changes with the replacement should be minimum and it is important to be compatible with previous models in installation aspects. So, we needed a system of engine supply that could expand the existing lineup and perfectly fit customers' machines.

In addition, we had also a high demand for the reduction of downtime. The downtime referred to in this report is periods of time in which the machine that carries the engine is unable to operate. Machines that are used in the rental market in many cases require a high level of operational availability. At the same time, the installation of a DPF (Diesel Particulate Filter), which is a device for emission aftertreatment, is mandatory for compliance with Stage V, and we needed to reduce the downtime that this device may produce depending on how it is used.

## 2. Development concept and goals

### 2-1 Development concept

Kubota started to adopt DPFs since 2012, and our DPF-mounted engines have been used in many products. So, making use of the experience that Kubota has built up in DPF-mounted engines, we set the following two development concepts.

[1] To have installation compatibility with the existing lineup, develop new high-output specifications based on the existing models.
[2] Develop engines that improve the operational availability of customer machines with reduced DPF-attributable downtime.

### 2-2 Target values

In this project, we developed engines of 12 models in total, consisting of four new models of high-output specifications added to all 8 models of the existing lineup. As an example of high-output specifications, Fig. 1 shows the external view of the 03 Series Engine D1803-CR-TIE5, and Table 1 shows the main specifications of representative models. We set the following two development goals.

[1] By adding an intercooler to the turbocharger of the existing model, improve the development models in the rated output by 5 to 14% and the maximum torque by 20 to 26%.
[2] Reduce the development models' DPF-attributable downtime by half compared with the existing model.

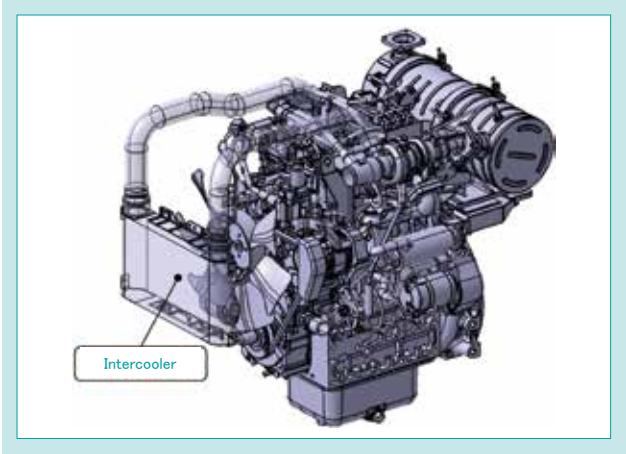



Fig. 1 External View of D1803-CR-TIE5

Table 1 Engine Specifications

| Model | D1803-CR-TE5 | D1803-CR-TIE5 | V3307-CR-TE5 | V3307-CR-TIE5 | V3800-CR-TE5 |
|---|---|---|---|---|---|
| Type / Cylinders | Vertical / 3 | Vertical / 3 | Vertical / 4 | Vertical / 4 | Vertical / 4 |
| Aspiration (T/C : Turbocharged) | T/C | T/C+ Intercooler | T/C | T/C+ Intercooler | T/C |
| Bore × Stroke [mm] | 87.0 × 102.4 | 87.0 × 102.4 | 94.0 × 120.0 | 94.0 × 120.0 | 100.0 × 120.0 |
| Displacement [L] | 1.826 | 1.826 | 3.331 | 3.331 | 3.769 |
| Output [kW / rpm] (Gross intermittent) | 37.0/2700 | 42.0/2700 | 55.4/2600 | 55.4/2600 | 55.4/2400 |
| Maximum torque [N・m/rpm] (Gross intermittent) | 150.5/1600 | 182.7/1600 | 265.0/1500 | 335.0/1400 | 310.0/1500 |
| Rated fuel consumption [g/kW・h] | 243 | 227 | 242 | 227 | 245 |
| Dimensions [mm] (Length × Width × Height) | 746 × 536 × 735 | 746 × 536 × 745 | 878 × 562 × 753 | 878 × 562 × 753 | 844 × 580 × 851 |

* Dimensions: No fan or intercooler (Because specifications vary depending on the customer's machine)

## 3. Technical issues to be solved

### 3-1 Technical issues related to engine lineup expansion

[1] Installation compatibility

To achieve higher output and maintain installation compatibility, we need to inherit the basic structure and visual layout of the previous models, wherever possible, to minimize the increase in the overall engine size.

[2] Securing reliability

Engine reliability needs to be secured because higher output increases the maximum combustion pressure in the cylinder (Pmax), resulting in more burdens on the components.

### 3-2 Technical issues related to downtime reduction

[1] DPF regeneration in the low-load region

The DPF device employed in this project consists of a DOC (Diesel Oxidation Catalyst) and a DPF, which traps the PM (Particulate Matter) in exhaust gas (Fig. 2). This DPF device has a function called DPF regeneration, which periodically removes trapped PM. However, DPF regeneration, which works by means of catalysis of the DOC, is not activated to remove PM if the DOC is conditioned below the temperature of catalytic activation. If this condition continues, the operator needs to stop working to carry out a special operation to force the DPF to activate regeneration, resulting in downtime. So, we need to establish an environment that enables DPF regeneration during a low-load run as well, in which the temperature of the exhaust gas tends to drop.

[2] Prolongation of periodic DPF maintenance interval

In a DPF, various deposits besides PM are formed, including the metallic substances composed of the calcium, magnesium, etc. contained in the engine oil ("ash"). Ash, which is generated with the combustion of the slight amount of engine oil that intrudes into the combustion chamber through the small space between the piston and cylinder, moves to the DPF together with combustion gas and gets deposited there but cannot be removed by DPF regeneration, unlike PM. After ash is deposited, the DPF needs to be serviced for periodic maintenance by the dealer where the DPF is detached and ash is removed, and during this service period, the operator is not able to engage in work, resulting in downtime. So, we need to prolong the interval of periodic DPF maintenance.

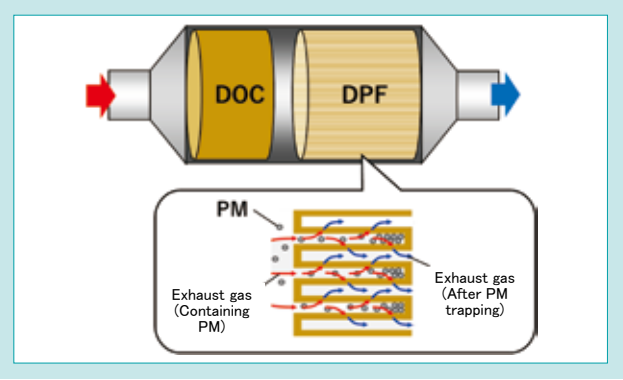



Fig. 2 DPF Device

## 4. Developed technology

### 4-1 Installation compatibility

Fig. 3 shows the external dimensions of the D1803-CR-TIE5, which is of high-output specifications. In the development model, output enhancement has been achieved with the an intercooler that increases power density by cooling the air, which is heated up to a high temperature because of the supercharging of the turbocharger. The resulting increase in engine size was minimized to only 10 mm higher than the previous model with the help of the change in the DPF muffler's fastening parts. At the same time, installation compatibility is maintained because we did not change the basic structure including the engine mount. In addition, fuel injection control was optimized and this resulted in a great improvement in the rated output and maximum torque, which have been increased by 14% and 21%, respectively, compared to the previous model. Similarly, the 07 Series Engine V3307-CR-TIE5 also has improved the maximum torque by 26% with the an intercooler, while installation compatibility is kept.

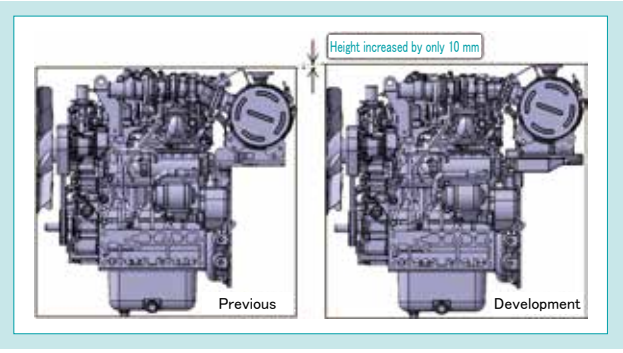



Fig. 3 Comparison of External Dimensions

### 4-2 Technology for reliability improvement

To secure engine reliability in relation to Pmax, which tends to increase when output is enhanced, this project worked to decrease this value as much as possible, but at the same time, worked to improve the peripheral parts to accommodate the grown Pmax. The following section reports how we approached the V3307-CR-TIE5.

4.2.1 Optimization of combustion

It is generally known that by retarding the fuel injection timing, combustion becomes slow and Pmax can be reduced. On the other hand, the reduction of Pmax induced by retarded timing is in a tradeoff relationship against fuel economy and PM, and so it is difficult to achieve all of them. So, we worked on the decrease of Pmax through

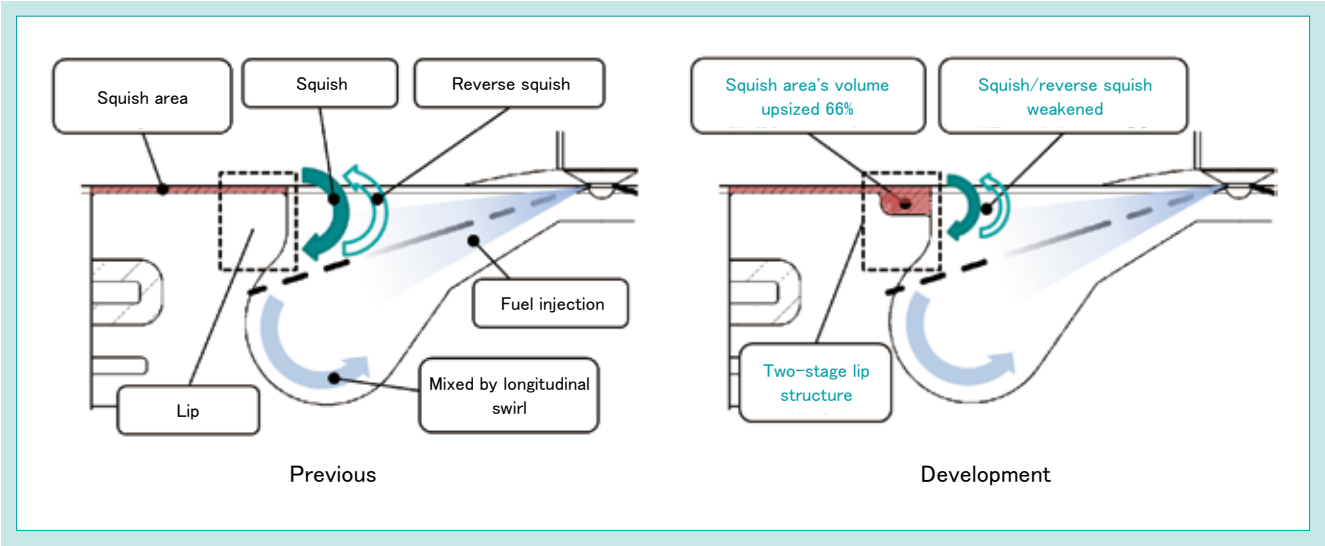



Fig. 4 Optimization of Combustion Chamber Geometry

the optimization of combustion by improving the combustion chamber.

As the first approach, we decreased the compression ratio of the piston by 3% and thereby decreased Pmax by 7%. In addition, this lowered compression ratio, which reduced the compression end temperature, extended the time ignition takes after fuel is injected, and thereby made the mixture of fuel and air uniform. As results, NOx (nitrogen oxides) and PM, which are substances restricted in the emission standards, were reduced at the same time. To deal with low-temperature startability, which tends to degrade with a lowered compression ratio, we optimized the multi-step fuel injection control and thereby secured reliable startability under a low temperature environment.

As the second approach, we optimized the configuration of the combustion chamber. Fig. 4 shows the geometry of the piston combustion chamber. The combustion chamber of the previous model has a space called a squish area between the lip's upper part and the cylinder head. In the compression process, a squish flow, which heads for the combustion chamber from the squish area, is generated, and in the expansion process, a reverse squish flow, which heads for the squish area from the combustion chamber, is generated. A fuel that is injected at high pressure into the combustion chamber forms a longitudinal swirl along the combustion chamber's wall surface to get burned while being mixed with the air in the combustion chamber. In the combustion chamber of the previous model, the reverse squish flow that counters the flow of combustion gas is strong because of its small squish area, and so the high-temperature combustion gas concentrates around the lip[1]. As results, a locally high-temperature region emerges, where NOx is generated by reaction with airborne nitrogen. An effective countermeasure for this problem is establishing uniform combustion by weakening the reverse squish flow. So, by employing a two-stage lip structure that has a dent on the top of the combustion chamber, this project has widened the squish area by 66%. With this structure, the reverse squish in the expansion process was weakened and the generation of NOx was suppressed. In addition, the minimized generation of PM was achieved with this two-stage lip combustion chamber that uses the air present in the squish area to burn the fuel that flows out of the combustion chamber.

These approaches, combined with the optimized fuel injection control, have reduced the rated fuel consumption by 7% while suppressing Pmax (Fig. 5).

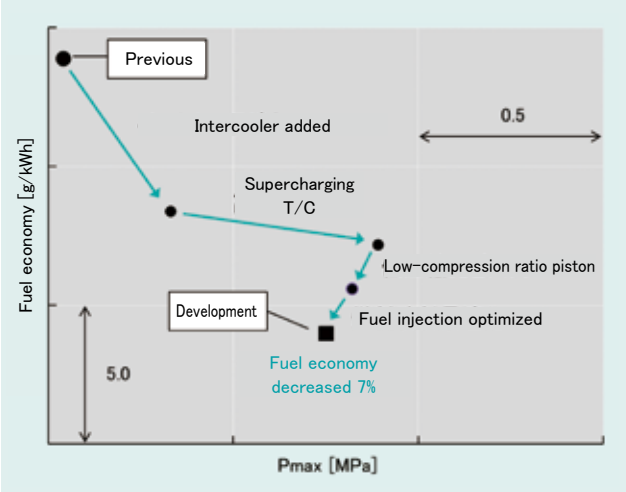



Fig. 5 Suppression of Pmax and Improvement of Fuel Efficiency

4.2.2 Securing piston reliability

The explosion load that the piston receives from the combustion chamber is transmitted to the connecting rod via the piston pin positioned in the pin hole. Although Pmax was successfully minimized as described in 4.2.1, the fact is that Pmax has become greater than with the previous model. In relation to this increase, we conducted the stress and bare unit tests of the previous model's piston, and the results revealed that the pin boss, which gets in contact with the piston pin, lacked strength. As the countermeasure, we tapered the pin boss to give a greater surface area to accommodate the increased application of pressure and thereby mitigate the stress on the pin boss. (Fig. 6). With this modification, piston reliability has been secured.

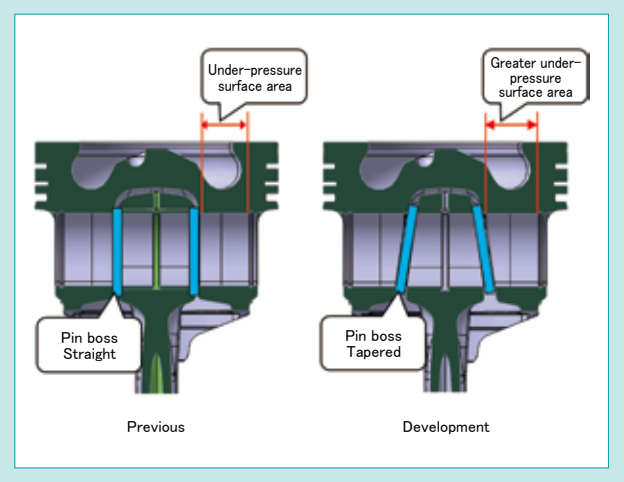



Fig. 6 Tapered Pin Boss

## 4-3 Technology for DPF regeneration in the low-load region

To enable DPF regeneration in the low-load region, the temperature of exhaust gas needs to be increased, and commonly, the effective countermeasure is the reduction of the amount of air intake by adjusting the intake throttle valve (Fig. 7). On the other hand, this method involves the risk of flame loss caused by no ignition of fuel owing to lack of air intake. So, we investigated a method that can prevent the risk of flame loss and at the same time increase the temperature of exhaust gas.

In this project, we optimized the injection pressure of fuel. During DPF regeneration, the swirl (lateral swirl generated around the central axis in the cylinder) is reduced because the intake throttle was turned down and the resulting reduction in the amount of air intake lowers the air density in the cylinder. When in this condition, if the cylinder receives a high-pressure injection, the penetrating force of the injected fuel grows relatively higher than with the normal operation, and this causes the fuel to be adhered onto the cylinder and the combustion chamber's wall[2], resulting in incomplete combustion that increases a higher risk of flame loss. So, to improve combustion, we optimized the pressure of injection at the time of DPF regeneration, and as results, this measure successfully suppressed the risk of flame loss. In addition, the temperature of the exhaust gas was successfully raised with the optimization of multi-step fuel injection control including the post-injection process, which is effective for increasing the exhaust gas temperature.

The following paragraphs report on the effectiveness of all these approaches. Fig. 8 shows the region in which the D1803-CR-TE5 is capable of DPF regeneration and also the region of operation of a representative customer machine that runs under low load most of the time. In the graph, the load factor refers to the ratio of the engine's maximum torque to the required torque. The load factor of the customer machine is an average of 18%. The development model enables DPF regeneration in almost the entire region of the customer machine that runs under a low load most of the time. In addition, once the conditions to enable DPF regeneration are met, the DPF can keep being ready for regeneration even after the machine has been in the region of no regeneration temporarily, because the temperature of the DOC only lowers slowly. Thus, the downtime associated with DPF regeneration has been eliminated from almost all customer machines.

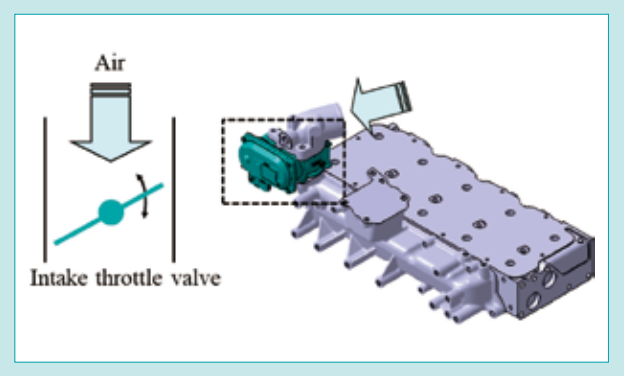



Fig. 7 Intake Throttle Valve

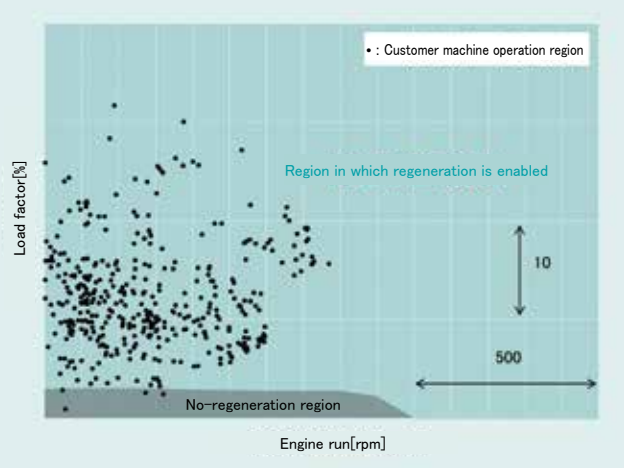



Fig. 8 DPF Regeneration Area of Low-load Region

## 4 - 4 Technology for prolongation of periodic DPF maintenance interval

To extend the interval of periodic DPF maintenance, we need to raise the limit of the amount of ash deposit by increasing the DPF's volumetric capacity or lower the amount of ash deposit by decreasing oil consumption. As the drawback of increasing the DPF's volumetric capacity is that it causes an increase in engine size, which reduces the degree of flexibility in installation and increases the cost as well. So, turning our attention to the improvement of the oil scraping performance of the piston's oil ring, we aimed to reduce the oil consumption of the development model while curbing an increase in cost. For the specifications of the oil ring to be newly adopted, we aimed at increasing the coefficient of followability as expressed by the following equation.

$$K_p = \frac{3 \cdot F_t \cdot (d_1 - a_1)^2}{E \cdot h_1 \cdot a_1^3 \cdot k}$$

$K_p$: Followability coefficient, Ft: Tension (N), d1: Nominal diameter (mm),

E: Elasticity ($N/mm^2$), h1: Width (mm), a1: Thickness (mm),

k: Cross-sectional coefficient rate

The followability coefficient is an index indicating the static followability of the piston ring to the cylinder deformation, and it is known that the larger the followability coefficient is, the smaller the oil consumption[3]. With reduced width and thickness, the followability coefficient of the oil ring of the new specs has been improved by more than 80% compared with that of the previous model. As results, oil consumption was reduced by 38%, and the amount of ash deposit, by 24% (Fig. 9). Since the oil ring of the new specs uses reduced amount of wire rod material, the cost has been reduced by 24% per cylinder.

In addition to these approaches for improvement, we added a new function that accurately estimates the amount of ash deposit in the DPF and notifies the operator of the status. In total, the interval of periodic DPF maintenance has been prolonged up to two times longer than that of the previous model (Fig. 10).

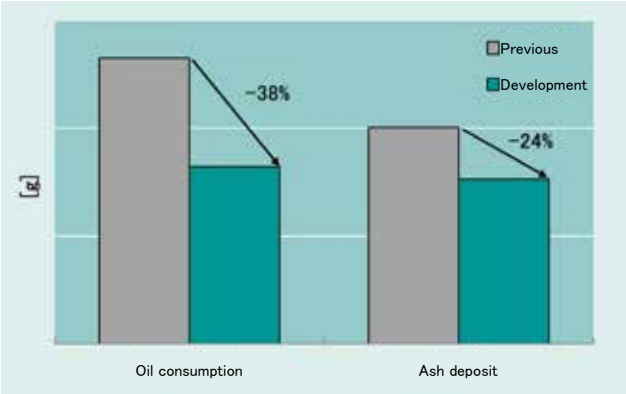



Fig. 9 Reduction of Oil Consumption and Ash Deposits

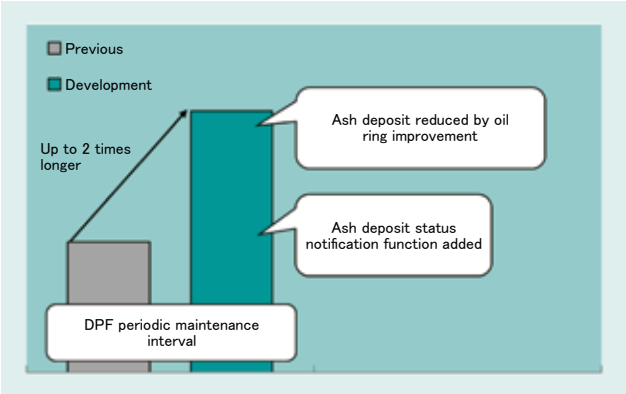



Fig. 10 Extension of DPF Periodic Maintenance Time

## 5. Conclusion

In the output range of 19 kW or more and below 56 kW, we have developed the 03, 07 and V3 Series Engines, which comply with the Stage V, which started to be effective from 2019. In addition, realizing the performance improvement that meets the market requests that we learned with the previous models, these new models have contributed to improving the product performance of customer machines.

(1) Developing new models that maintain installation compatibility and at the same time have higher output and reliable durability, which are balanced in a higher form of technology, we have widened our lineup with these newly added high-output models.

(2) DPF regeneration now has been made available in the low-load region, and in addition, the interval of periodic DPF maintenance has been extended. With these, the new models have minimized the operator's downtime.

We will roll out the technology that we developed in this project to other models and will strengthen the product capabilities of Kubota engines by developing more models that further improve fuel-economy and maintainability.

## Contribution to SDG Targets

7.3 Improvement of energy efficiency
Up to 7% reduction in fuel economy compared to previous models

13.2 Policy formulation as to climate change measures
Compliance with the Stage V, more stringent emission standards

Reference

1) Kim Sang-kyu, Kazunori Hirabayashi, Makoto Namba, Masahiro Miyazaki, Tsuyoshi Onishi, Daisuke Shimo: "Development of new 1.5L low compression ratio clean diesel engine (Report No.2)", pp. 172-177, 2015 Spring meeting academic lecture presentations (2015), Society of Automotive Engineers of Japan, Inc.

2) Kazuhisa Inagaki et al.: "Low emissions and high-efficiency diesel combustion using highly dispersed injection with restricted in-cylinder swirl and squish flows" https://www.jstage.jst.go.jp/article/jsaeronbun/42/1/42_1_219/_pdf (reference on 2020-10-6)

3) "Piston ring for automobile" Editorial committee: "Automotive engineering series automotive piston rings", (1997), pp. 30, Sankaido

# Development of Catalyst Technology for Particle Number Regulation

Engine Engineering Dept.



In order to resolve the environmental problem of emissions in to the atmosphere, the emission regulations on harmful components in exhaust gas from diesel engines are being strengthened year by year. Especially, in the EU, particulate number (PN) regulations were implemented from StageV for non-road diesel engines. In order to comply with PN regulations, it is necessary to improve the diesel particulate filter (DPF) performance in collecting the particulate matter (PM) from diesel engines. In our development, we achieved compliance with the PN regulations by improving the substrate and the catalyst of the DPF which are related to the collecting performance and combustibility of PM, without any degradation in engine performance and mountability.

【Key Word】
Air Pollution Reduction, Diesel Engine, PM2.5, Particulate Number (PN) Regulation, Exhaust Gas Treatment System, Diesel Particulate Filter (DPF)

Related SDGs


## 1. Introduction

Since diesel engines have high fuel efficiency, torque and durability, they are widely used not only in the automobile industry but also in various industrial fields including agricultural machinery, construction machinery and generators. On the other hand, from the viewpoint of global environmental conservation and health, the regulations on the emission of harmful components in exhaust gases such as carbon monoxide (CO), hydrocarbon (HC), nitrogen oxides (NOx) and PM are enforced all over the world. Fig. 1 shows the diagrammatic illustrations and photos of a diesel engine and exhaust gas treatment system. Particularly in developed countries, the installation of exhaust gas treatment systems such as diesel oxidation catalyst (DOC) and DPF is indispensable.

Next, the trends in the emission regulations for industrial diesel engines in Europe are shown in Table 1. In Europe, where concern for the environment and health is particularly high, PN restrictions were newly introduced under the Stage V non-road emission standards that were enforced in order to further reduce PM emissions in 2019 in addition to the reinforcement of the conventional weight restrictions (PM weight restrictions). A further reduction of PM emissions is required of manufacturers as these standards are applicable to all industrial diesel engines of 19 kW or more destined for Europe. This technical report presents PM emission reduction technology for PN restrictions.

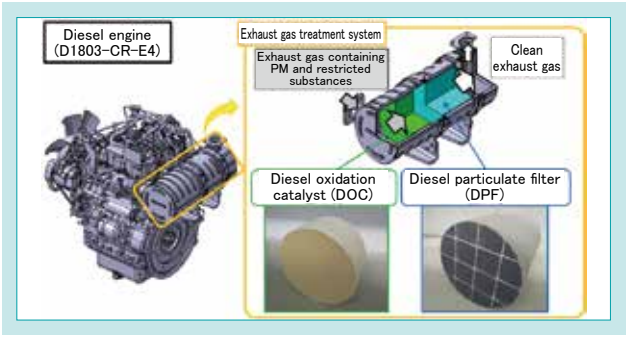



Fig. 1 Diesel Engine, D1803-CR-E4 and Exhaust Gas Treatment System

Table 1 Emission Regulations in Europe for Non-road Diesel Engines

NOx(+HC)[g/kWh]/HC[g/kWh]/PM[g/kWh]/PN[n/kWh]

| Power (kW) | Year | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
| 8–19 | No regulation | | | | | | | | | Stage V 7.5//0.4/ | | |
| 19–37 | Stage 3A 7.5//0.6/ | | | | | | | | | Stage V 4.7//0.015/1x10$^{12}$ | | |
| 37–56 | Stage 3A 4.7//0.4/ | | | | Stage 3B 4.7//0.025/ | | | | | Stage V 4.7//0.015/1x10$^{12}$ | | |
| 56–75 | Stage 3A 4.7//0.4/ | | Stage 3B 3.3/0.19/0.025/ | | | Stage 4 0.4/0.19/0.025/ | | | | Stage V 0.4/0.019/ 0.015/1x10$^{12}$ | | |
| 75–130 | Stage 3A 4.7//0.3/ | | | | | | | | | | | |
| 130–560 | | Stage 3B 2.0/0.19/0.025/ | | | Stage 4 0.4/0.19/0.025/ | | | | | Stage V 0.4/0.019/ 0.015/1x10$^{12}$ | | |

## 2. Development concept and goals

### 2-1 Development concept

PM whose diameter is ultrafine, which is difficult to measure by PM weight restriction schemes, is allegedly a health hazard[1]. Under these circumstances, PN restrictions have been introduced and manufacturers are required to reduce the emission of ultrafine PM.

Diesel engines, which have achieved a wide reduction in PM emissions with the employment of electronic fuel injection, need to have a DPF additionally installed to comply with the resent stringent PM weight restrictions. Fig. 2 shows the schematic of DPF. A DPF features a ceramic porous filter (DPF's substrate) whose adjacent channels are alternately closed. A catalyst made of precious metal as a main ingredient is coated on this filter to trap PM when exhaust gas passes through the DPF's wall. Conventional DPFs have been compliant enough with the PM restrictions but are insufficient when it comes to the reduction of ultrafine PM emissions. So, in this project, we pursued to develop a DPF highly capable of trapping ultrafine PM by improving DPF specifications.

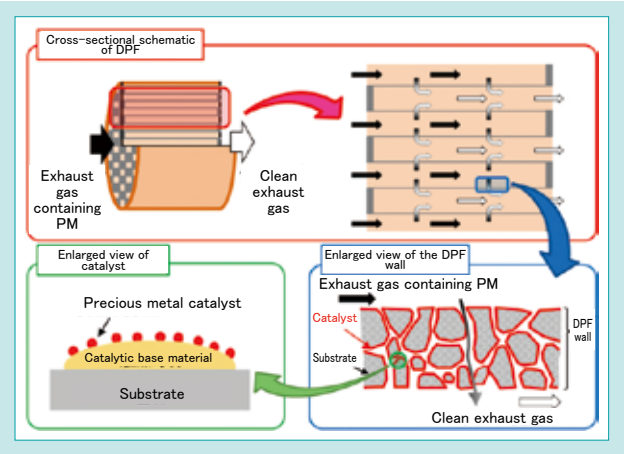



Fig. 2 Schematic Diagrams of a DPF

### 2-2 Target values

We set the goal of letting the new DPF meet the PN restriction ($1.0\times10^{12}$ particles/kWh) under the European Stage V non-road emission standards in all our diesel engine models of 19 kW or more destined for Europe without sacrificing the mountability to the engine as well as DPF differential pressure and DPF regeneration performance that relates to engine performance.

## 3. Technical issues to be solved and solution principles

The technical issues to be solved and solution principles for this development are described below.

Issue 1: Achieving performance both in PM trapping and DPF differential pressure

Develop a technology that achieves performance both in PM trapping and DPF differential pressure to pursue more efficient PM trapping without sacrificing engine performance and mountability.

Issue 2: Catalyst deterioration

From the viewpoint of resource saving and the stabilization of exhaust gas emission, develop a technology that suppresses catalyst deterioration and minimizes the amount of catalyst supported

## 4. Developed technology

### 4-1 Technology that achieves performance both in PM trapping and DPF differential pressure -DPF substrate improvement-

#### 4.1.1 PM trapping performance and DPF differential pressure with the improved DPF substrate

Typically, the PM trapping performance of DPFs is higher as the pore size and porosity of the DPF substrate are made smaller. Yet in that case, DPF differential pressure is increased, causing the degradation of fuel economy and other engine performance. On the other hand, increases in DPF size can decrease differential pressure but lowers mountability and increases costs. So, we tried to enhance PM trapping performance by reducing the pore size, and at the same time, reduce DPF differential pressure by making the DPF's wall thinner approximately 18%. Fig. 3 shows the diagrammatic illustrations of DPF substrates before and after its improvement. As to the DPF differential pressure after a certain amount of PM has been trapped, Fig. 4 shows the results of DPF substrates before and after its improvement. The results show that the reduction of pore size increased the DPF differential pressure 10%, but the reduction of wall thickness lowered the differential pressure by 3% compared to the current specs. Fig. 5 shows the PN measurement results under a steady-state test (Ramped Modal Cycle; RMC) where the current DPF and the DPF improved with smaller pores and a thinner wall were mounted. The results show that emission PN was reduced 75% with the reduction of pore size and wall thickness.

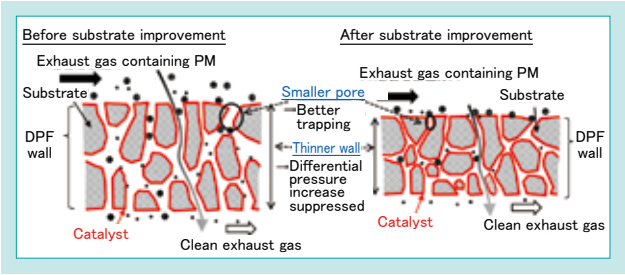



Fig. 3 Schematic Diagrams Before and After Improving the DPF Substrate

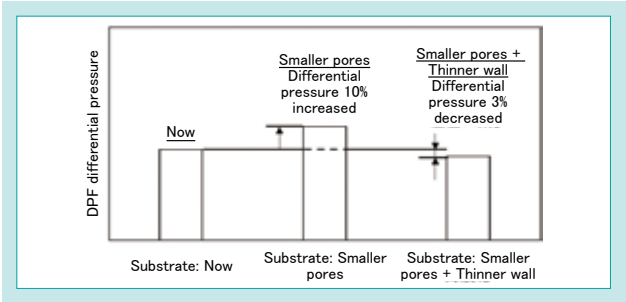



Fig. 4 DPF Differential Pressures Before and After Improving the DPF Substrate

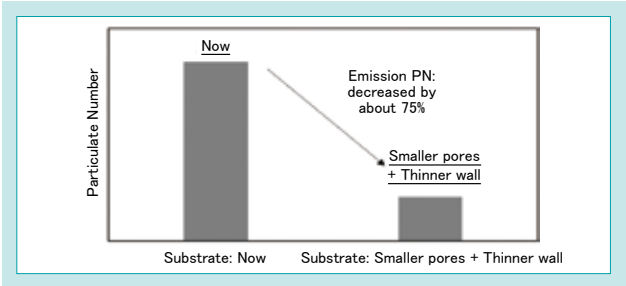



Fig. 5 PN over RMC Before and After Improving DPF Substrate

4.1.2 Durability of the improved DPF substrate

At the same time, there is a concern about the reduction of wall thickness because it possibly causes a reduction in DPF strength. The fracture of DPF substrates is caused by a thermal shock due to temperature differences inside the DPF. The greatest thermal shock in the real use is produced by the soot that accumulates in the DPF, which instantaneously burns up if the oxygen concentration in the exhaust gas suddenly rises when DPF regeneration or a high-load operation switches to idling operation. To produce this thermal shock, we simulated the PM that would be accumulated under the real use conditions, and using the DPF with this PM, we carried out the DPF regeneration process. And, immediately after the PM in the DPF started burning up, we switched operation to idling and measured the maximum temperature inside the DPF in this moment. Fig. 6 shows the results. The results revealed that the DPF improved with the reduction of pore size and membrane thickness was less likely to reach the temperature that cracks or melts the substrate; in other words, it was more resistant to thermal shock. We also conducted a long-time endurance test under the engine's high-load operation condition to see if the DPF substrate was endurable to engine operation. Fig. 7 shows the results of an X-ray CT scanning of the DPF taken after the endurance test.

Showing no cracking or melt, the CT images verified that the substrate could sufficiently withstand an extended time of engine operation.

The above results have shown that the DPF substrate mounted on the engine successfully maintained both performance in PM trapping and DPF differential pressure.

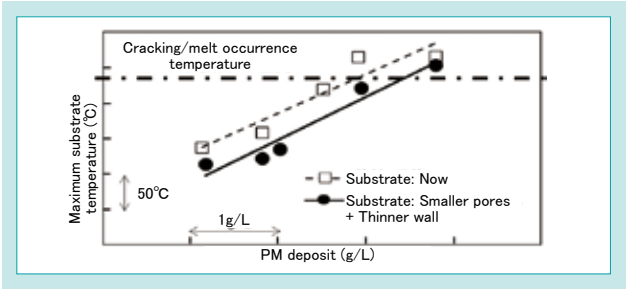



Fig. 6 Maximum Temperatures by the Thermal Shock Experiment

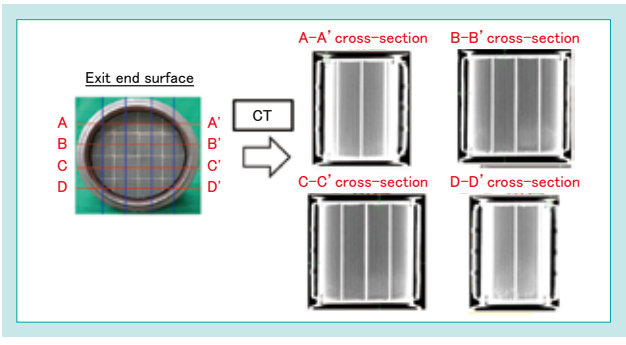



Fig. 7 CT Images for the DPF After Diesel Engine Endurance Test

## 4-2 Technology that achieves performance both in PM trapping and DPF differential pressure -Development of a new catalyst that improves PM trapping performance-

4.2.1 DPF's PM trapping mechanism

As described above, the reduction of pore size and wall thickness can improve PM trapping performance and at the same time keep up DPF differential pressure. However, it was found that some engines did not clear the development target values. Even though the improvement of PM

trapping performance requires more reduction in pore size and porosity, it is obvious that doing so increases DPF differential pressure. Making the wall even thinner to decrease DPF differential pressure is not a good idea from the viewpoint of durability. Also, if the DPF size is changed, it will lower mountability. So, other than the improvement of the DPF substrate, we needed to develop a technology that achieves performance both in PM trapping and DPF differential pressure.

Fig. 8 shows the results of PN measured under a steady-state operation that was performed after DPF regeneration was switched to idling operation. The point is that, after DPF regeneration, that is, when PM does not accumulate in the DPF, if idling operation is started, a small particulate number of matter leaks constantly. Then, after the engine switches to a loaded steady-state operation, a sudden rise in PN is detected. After this, the PN gradually decreases until almost no PN is detected. Various researches on PM trapping mechanisms of DPFs are being made[2) 3)]. This research reports that after going through depth filtration, during which PM deposits inside the DPF, the process shifts to surface filtration, during which PM deposits on the DPF substrate surface, and in addition, PM trapping performance remarkably improves during surface filtration. These research results led us to surmise that the PN (I in Fig. 8) in a loaded steady-state operation shown in Fig. 8 is observable in the early periods of depth filtration and surface filtration.

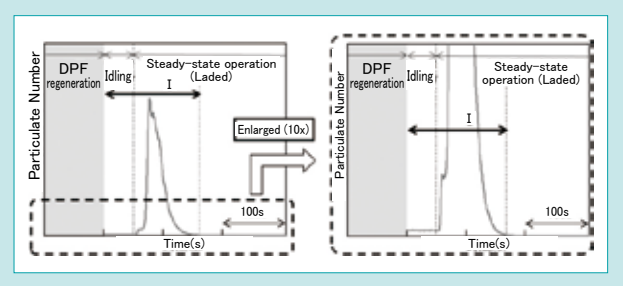



Fig. 8 PN After the DPF Regeneration

### 4.2.2 New catalyst that improves PM trapping performance

From the above results and considerations, we devised a structure that causes a rapid shift to surface filtration. Fig. 9 shows the diagrammatic illustrations of a conventional DPF (before catalyst improvement) and the devised DPF (after catalyst improvement). Previously, the precious metal catalyst was evenly coated on the DPF wall, and there was another catalyst that was composed of the catalyst substrate. This structure has been changed so that a catalyst is coated concentratedly on the surface layer of the DPF wall. To achieve surface filtration with a thin layer of PM deposit, we tried to use this structure to form a catalytic layer on the DPF surface. Fig. 10 shows the cross-sectional analysis results of the DPFs before and after catalyst improvement. In the analysis, they each were measured at the same position using an electron probe microanalyzer (EPMA) and scanning electron microscope (SEM). The white regions in the EPMA images show the presence of a precious metal catalyst. The analysis revealed that the improved DPF has more catalyst coated on the DPF wall surface (IN side of Fig. 10) than the pre-improvement DPF.

Next, Fig. 11 shows the analysis results of the DPFs before and after improvement, where PN was measured under a steady-state operation that was performed after DPF regeneration was switched to idling operation. The results of the improved DPF show that PN is smaller at the peak and that the time PN takes to decrease is shorter. This is surmised to be because the catalytic layer helped surface filtration take place with a thin layer of PM

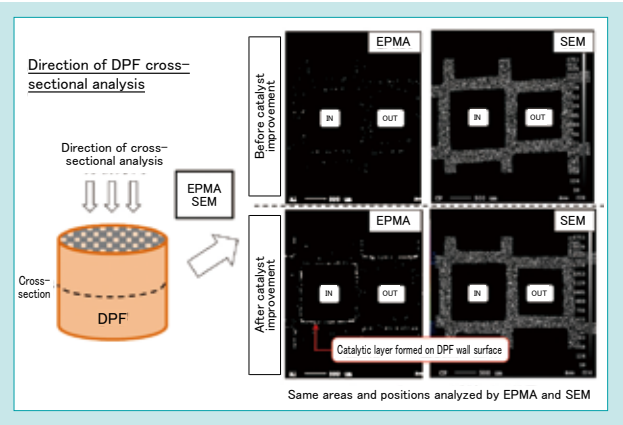



Fig. 10 EPMA and SEM Images Before and After Improving the DPF Cross Section

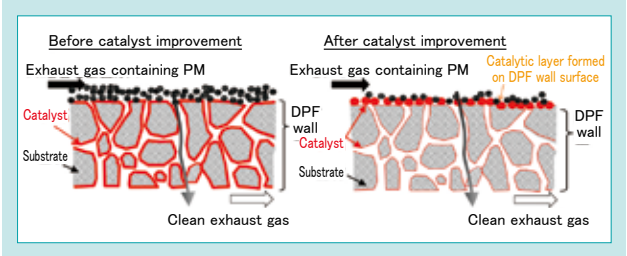



Fig. 9 Schematic Diagrams Before and After Improving the DPF Catalyst

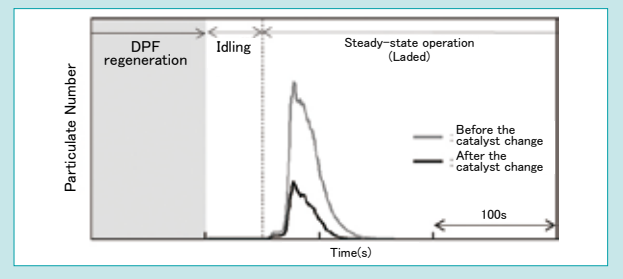



Fig. 11 PN after DPF Regeneration Before and After Improving the DPF Catalyst

deposit. In addition, Fig. 12 shows PN measurement results and DPF differential pressures in the RMC. The results show that the emission PN in the RMC is decreased by about 70% Also, for the DPF differential pressure as well, the increase has been successfully suppressed. This is surmised to be because the amount of catalyst inside the substrate was decreased by the amount of the catalytic layer formed on the DPF wall surface.

The above results show that the catalyst that can greatly reduce emission PN while suppressing the increase of DPF differential pressure has been achieved.

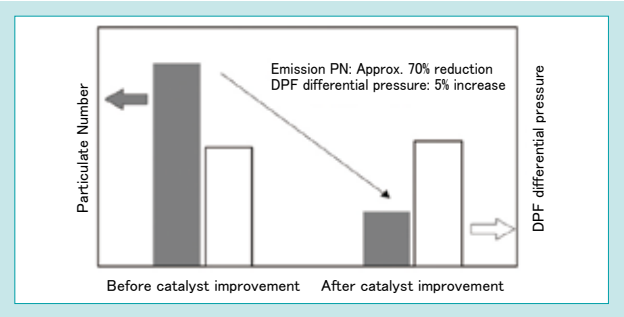



Fig. 12 PN and DPF Differential Pressures over RMC Before and After Improving the DPF Catalyst

## 4-3 Technology for suppressing catalyst deterioration

### 4.3.1 Relationship in DPFs between engine operation time and PN

Fig. 13 shows the relationship between engine operation time and PN in the RMC. The results show that PN emission tended to decrease as the operation time increased. This is surmised to be because the PM trapping of the DPF has become more efficient due to the following factors.

[1] The pores get smaller due to the deposition of metallic substance (ash) derived from engine oil.

[2] The lowered catalytic activity reduces the combustibility of PM, and this promotes the formation of a PM deposit layer.

The issue that arises in the early periods of engine use is a high PN emission for the reason opposite to the above. Thinking of issue [2], the reduction of the DPF's catalytic activity, that is, the reduction of the catalyst can solve the problem. However, the catalyst of a DPF, which is greatly related not only to PN but also to continuous combustion of PM, DPF regeneration, and exhaust gas emission overall, is indispensable for promoting chemical reaction. On the other hand, manufacturers determine the type and amount of a catalyst from the viewpoint of being able to ensure these emission requirements for an extended period of time while taking the catalyst's deterioration into consideration, and this is why catalysts deliver excessive catalytic activity at the early stage.

In view of the above, we needed to develop techniques for lowering the catalytic activity of the early stages within the bounds of meeting other exhaust gas emission requirements to decrease PN, and at the same time, for maintaining the catalytic activity for a long time when the engine is in operation.

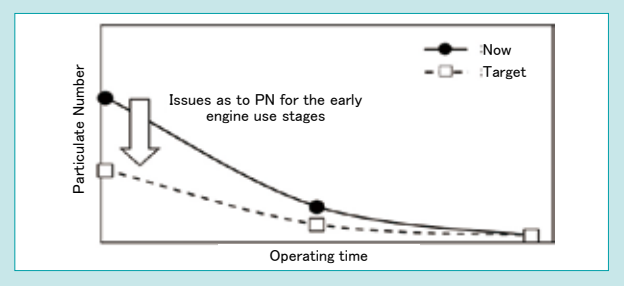



Fig. 13 Operating Time for a Diesel Engine and PN over RMC

### 4.3.2 Mechanism of catalyst deterioration

As described earlier, the catalyst of a DPF, which is composed of a precious metal catalyst and a catalytic substrate, works mainly to promote the combustion of soot trapped by the DPF and promote the oxidation of HC and CO, which are generated during PM combustion, into $CO_2$. Since these promoting reactions occur on the surface of the DPF catalyst, the specific surface area and particle size of the catalyst are important factors for the performance. On the other hand, it is generally known that catalyst deterioration is caused by the heat from engine exhaust gas and a catalyst poison contained in it[4]. Fig. 14 shows the schematic diagram of the thermal deterioration of a DPF catalyst. Thermal deterioration or degradation of catalyst performance due to heat is caused by sintering, which aggregates catalyst particles with the reduction of specific surface area and the change of physical properties. Therefore, we see that the reduction of catalytic activity can be suppressed with the inhibition of sintering.

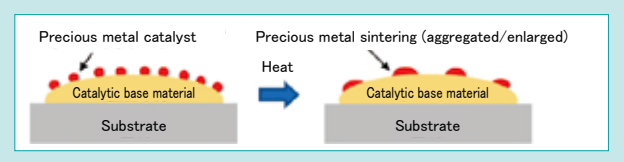



Fig. 14 Schematic Diagrams on Thermal Deterioration for DPF Catalyst

4.3.3 Suppressing catalyst deterioration

Platinum (Pt), which is highly catalytic and stable, has been used as a main ingredient of DPF catalysts. It has been reported that the addition of palladium (Pd) to this Pt inhibits the sintering of catalysts to minimize the reduction of catalytic activity[5]. On the basis of this report, we added Pd to Pt to adjust the ratio of catalyst. After conditioned under a thermal endurance environment at 750°C for 50 hours, the specific surface area of each catalyst was examined. Fig. 15 shows the results. The results show that the addition of Pd increased the specific surface area of the catalyst after thermal endurance. In other words, the sintering of the catalyst was inhibited. Fig. 16 shows the CO oxidation activity of these catalysts before and after thermal endurance. Before thermal endurance, activity was higher with more Pt, whereas after thermal endurance, activity was higher with the addition of Pd. This is surmised to be due to the inhibition of sintering with the addition of Pd.

With the above measures, we successfully optimized the catalytic activity of first periods by [1] suppressing catalyst deterioration with the optimization of the amount of added Pd and the catalyst preparation conditions, and [2] optimizing the early-period catalytic activity with reduced amount of catalyst.

Fig. 17 shows the results of PN measurement over the RMC before and after the change of catalyst in the early stages of engine use, that is, when catalyst deterioration has not progressed. Comparing the PN before the change of catalyst, we successfully have reduced PN by 20%. On the other hand, due to the change of the specifications of the catalyst, there is a concern that [1] PM removal rate during DPF regeneration and [2] reduction in the oxidizability of CO and HC during regeneration. Figs. 18 and 19 show the evaluation results as to these two issues. Fig. 18, which graphs the PM removal ratio by DPF regeneration after thermal endurance, shows that the results after the catalyst change were almost the same as the performance the catalyst evinced before the catalyst change, which has been proven in the market, and also satisfied the required level of Kubota standard. In Fig. 19, which graphs the CO and HC emissions during DPF regeneration, the results before thermal endurance show that the emissions before catalyst change are less than those after catalyst change, but after thermal endurance, these results were reverse. This is surmised to be because the thermal endurance properties were reduced after catalyst change. After catalyst change, the emissions were on the decrease due to thermal endurance. This is surmised to be because oxidation was promoted because the concentration of CO and HC decreased momentarily due to the slowing of PM combustion speed after thermal endurance.

In summary, we have suppressed catalyst deterioration and thereby have successfully achieved the three goals of this project-keeping a high degree of DPF regeneration performance for a long time, resource saving in precious metals, and the stabilization of exhaust gas emission.

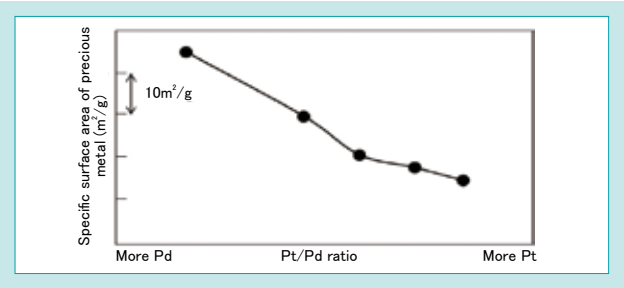



Fig. 15 Surface Area for Noble Metal and Pt/Pd Ratio

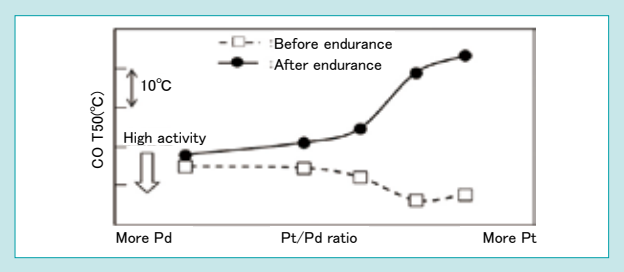



Fig. 16 CO Oxidation Activity and Pt/Pd Ratio

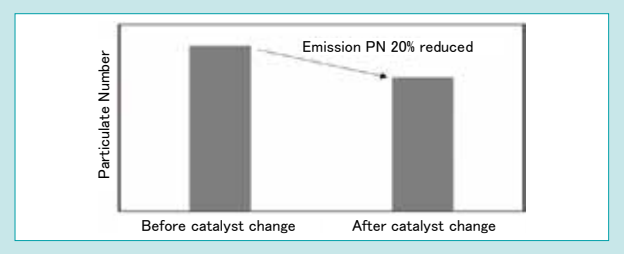



Fig. 17 PN Results over RMC Using Less Aged DPF

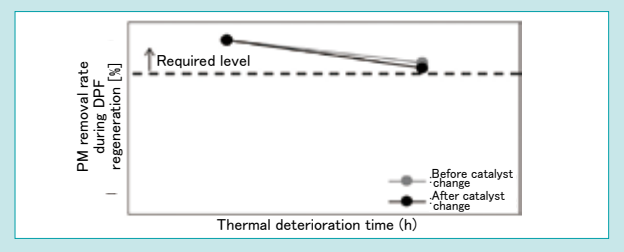



Fig. 18 PM Removal Ratio by DPF Regeneration

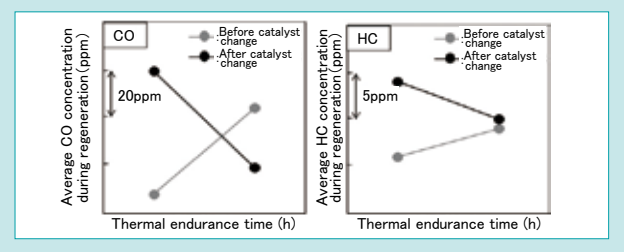



Fig. 19 CO and HC Emissions During DPF Regeneration

## 5. Conclusion

In this project, we developed the above three technologies related to DPF substrates and DPF catalysts. By combining them, we have produced a DPF that contributes to resource saving and has higher PM trapping performance and exhaust gas purification performance than conventional DPFs. Furthermore, with this DPF, all diesel engine models of 19 kW or more destined for Europe meet the PN requirements. In addition to this success, this project has also contributed to global environmental conservation and our sales expansion in the European market.

We will expand our sales channels while paying attention to the global environment with sure compliance with the PN regulations that will be introduced throughout the world. As our future goals, we aim to achieve further resource saving and improve fuel economy through the improvement of DPF regeneration performance and through the technology that enables the automation of all-region DPF regeneration so that we will create an exhaust gas treatment system with low environmental impact and high added value.

## Contribution to SDG targets

3.9 Reduction of deaths and diseases caused by hazardous chemical substances, and air, water and soil pollution
Wide reduction of particulate matter hazardous to health

12.2 Sustainable management and efficient use of natural resources
Resource conservation of precious metals

Reference

1) Morawska, L. et al. Ambient nano and ultrafine particles from motor vehicle emissions: characteristics, ambient processing and implications on human exposure. Atmos. Environ. 2008. 42, 8113-8138
2) Shuichi Kubo et al., Collection mechanism in DPF, The Japan Society of Mechanical Engineers papers, 2006, vol. 72, no. 721
3) Daisuke Suzuki et al., Collection performance of diesel particulate filter and deposition process of carbon particles, papers of Society of Automotive Engineers of Japan, Inc., 2016, vol. 47, no. 6
4) Calvin H. Bartholomew. Mechanism of catalyst deactivation. Applied Catalysis A. 2001, 212, 17-60
5) Kaneeda M. et al. Improvement of thermal stability of NO oxidation Pt/Al2O3 catalyst by addition of Pd. Applied Catalysis B, 2009, 90(3-4), 564-569

# Development of the CTL SVL65-2 for North America

Construction Machinery Engineering Dept.for Loader / Kubota North America Corp.



A compact track loader (CTL) is a compact construction machine that is used in the North American market. It has good running ability on rough terrain, high mobility and versatility. In addition, it can perform a wide variety of attachment tasks. In recent years, this market has continued to expand, and Kubota has also steadily expanded its sales volume since launching the CTL in 2010. This time, Kubota released the SVL65-2, the lightest in the Kubota range in order to expand CTL's product line. Its weight is significantly reduced while maintaining excellent habitability as good as that of SVL75-2, which is the current model in the upper class. Moreover, SVL65-2 can perform smooth simultaneous movements of loader arm, bucket, and AUX hydraulics because we developed a highly evolved hydraulic circuit and an advanced multifunction valve that are superior to those of the SVL75-2.

【Key Word】
Compact Track Loader, Weight Reduction, Advanced Multifunction Valve

Related SDGs


## 1. Introduction

CTLs are types of small construction machinery predominantly popular in the North American market (Fig.1). With their features, including "turning on a pivot", "use of a wide variety of attachments (Fig. 2)" and "high performance at crawler travel over rough terrain and steep roads", they are used in many applications including moving soil, digging and land preparation in diverse scenes such as construction, upgrading of infrastructure, agriculture, etc.

Especially in North America, under the circumstances of the high versatility of CTLs and the soaring demand for homebuilding, the CTL market is now still expanding and grew about 80% between 2014 and 2018 (Fig. 3).

Kubota entered the CTL market with the release of the SVL75 and SVL90 in 2010. After that, going through changing models to support the market needs and comply with the North American Tier 4 emission standards, we now have the SVL75-2 and SVL95-2S in the market. As results, in the combined total for the two models in 2018, our market share in the number of units sold in the North American CTL market increased about 16% (surveyed by Kubota), which was the third place in the industry. Aiming at expanding the lineup so as to gain more market share, Kubota has developed the SVL65-2, the lightest model in Kubota's CTL history.

Fig. 1 SVL65-2

Fig. 2 Example Attachments

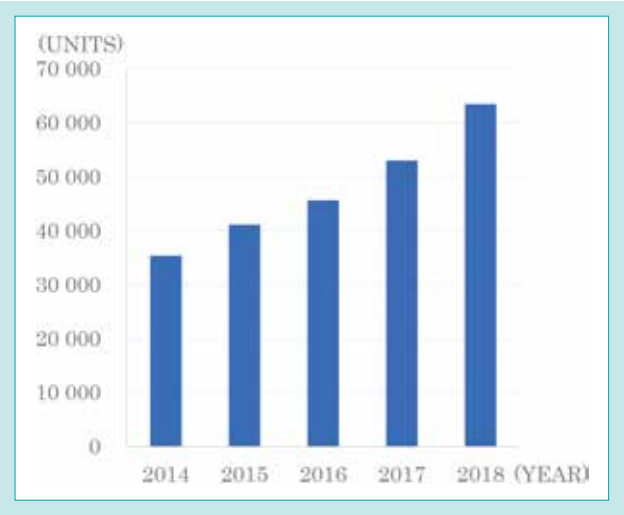



Fig. 3 CTL Sales (in U.S.A.)[1]



## 2. Development concept

The CTL market conditions are displayed in the graph (Fig. 4). Fig. 4 classifies the North American CTL market by Rated Operating Capacities called ROC (Rated Operating Capacities), which is depends on vehicle size class and weight (that the loader can safely lift).

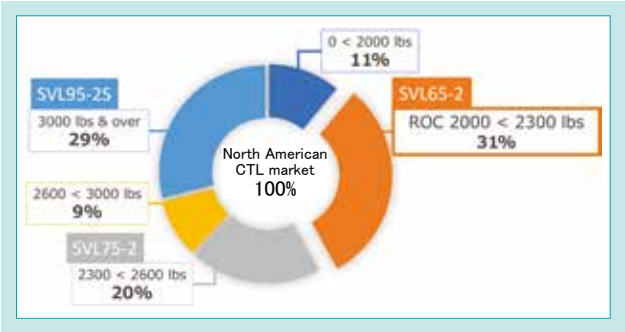



Fig. 4 North American Market for CTL

The competitors in the CTL market distribute many types of lineups (10 or more models by some manufacturers) throughout all the class ranges to cover a wider product market. Contrarily, Kubota now competes with only two models, which are the SVL75-2 and SVL95-2S, and has no product launched in the class range of ROC 2,000 to 2,300 lbs (907 to 1,043 kg), which is the greatest market in 2019. So, we have developed a product that matches this class range and draws on the strengths of Kubota's CTLs so that we will gain further share in North America.

Next, the points that our surveys have revealed to make our product match this class range are described below. Generally, a CTL is loaded on a trailer, and this trailer is towed by a truck to be transported to the destination. In the U.S., to transport a machine having a heavy weight vehicle, a special transporter license called CDL (Commercial Driver's License) is needed. This license needs to be renewed periodically after obtaining it , and the survey shows that the users who want to avoid this effort tend to select CTLs of a Rated Operating Capacities (ROC) of 2,000 to 2,300 lbs (907 to 1,043 kg) in particular. So, we set our sights on offering users a product having the vehicle weight that does not require this license, while keeping the cabin comfortable, which is a strength of Kubota's CTLs.

On the other hand, the higher model SVL75-2, which is the previous base model, SVL75-2 of this development model, had the characteristic of a hydraulic actuator not capable of simultaneous operation under some conditions. In this regard, the highest model SVL95-2S has been made capable of hydraulic simultaneous operation under any conditions, owing to the installation of the LS system[2]. For the lightest model SVL65-2, which is under severe weight and cost requirements, we did not employ this LS system that was used in this highest model but tried to improve the hydraulic system to make it a simple and inexpensive system that can deliver smooth hydraulic simultaneous operation as with the LS system. Under these circumstances, we set the following product concepts.

**<Product concept>**

[1] Keep the vehicle weight under the limit that does not require a transporter license while inheriting the cabin comfortable, which is a strength of Kubota's CTLs.

[2] Achieve a low-cost system that enables smooth hydraulic simultaneous operation.

Note that this report presents some examples of points that helped the weight reduction of large worked-steel parts to solve the issues in achieving concept [1], as well as the technology (Advanced Multifunction Value) developed to achieve consept [2].

## 3. Technical issues to be solved and goals

### 3-1 Technical issues

3.1.1 Weight reduction

In the target class range of this development, the weight that does not require the special transporter license is legally 10,000 lbs (approx. 4,536 kg) or below in a combined total with a trailer. The difference of the trailer's weight from 10,000 lbs is the maximum weight allowed for the carrying of the CTL body. Because the SVL75-2, which is the previous base model, SVL75-2 of this development, and has a vehicle weight of 8,874 lbs (approx. 4,025 kg), exceeds 10,000 lbs (approx. 4,536 kg) when combined with a trailer, we needed to achieve a weight reduction to make up for this excess.

In addition, we decided to keep the wide driver's seat space and the flip-up front door (Fig. 5) because these two features produce a good comfort, which is a strength of Kubota's CTLs.

Fig. 5 Flip-up Door

3.1.2 Hydraulic simultaneous operation

The hydraulic simultaneous operation in this report refers to the operation of the Loader, which consists of an arm and bucket, simultaneously with the AUX (the hydraulic source for the actuation of the attachment). An attachment is used by connecting its hydraulic hose to the AUX coupler provided on the arm (Fig. 6). The required rate of flow, which depends on the attachment type, can be adjusted by operating the AUX slider provided on the hand grip (Fig. 7).

Grapple bucket operation is one of this simultaneous operations (Fig. 8).

This operation is to grab and carry lumber or other objects in forestry, etc.; The angle of the entire arm is operated by the arm cylinder (lower left blue arrow in Fig. 8), the angle of the entire bucket is operated by the bucket cylinder (upper right green arrow in Fig. 8), and the claw unit is opened/closed by the cylinder with the use of AUX (upper right yellow arrow in Fig. 8). With a general series circuit, which cannot operate the arm, bucket and AUX simultaneously in a particular operation, the angle of the arm and bucket cannot be changed at the same time while letting the claw hold lumber, for example, and so the operator is compelled to perform these operations in turns, resulting in a loss of work time. In addition, because the claw cannot keep holding lumber when making an angle change of the arm or bucket, the lumber may slip out of place and fall out if the bucket angle is moved, resulting in an additional loss of work time. The reduction of these work time losses was our challenge.

Fig. 6 AUX Coupler

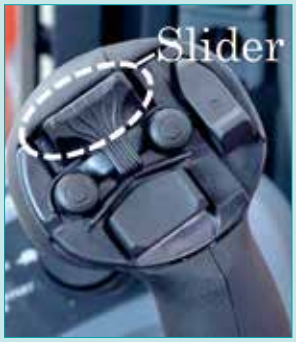



Fig. 7 AUX Slider

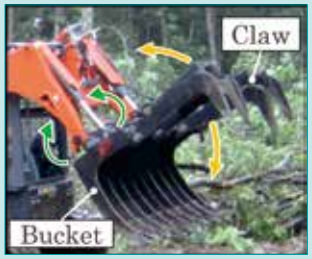




Fig. 8 Grapple Bucket

### 3 - 2 Target settings for the issues

[1] Weight reduction

Keep the advantages and features of the SVL75-2, and at the same time, be 934 lbs (424 kg) lighter than the SVL75-2 to weigh below 7,940 lbs (3,601 kg), which is the vehicle weight that does not require a special transporter license.

[2] Improvement in hydraulic simultaneous operability

Make possible the simultaneous operation of the Loader and AUX under any conditions.

## 4. Developed technology

### 4-1 Method for weight reduction

Before selecting the parts that can contribute to weight reduction, we thought about functional parts versus structural parts, which constitute the CTL. The functional parts are the engine, hydraulic system, and other parts that are responsible for the basic functions and so cannot be eliminated and not is so easily reduced in weight. On the other hand, the structural parts, which account for 40% or more of the entire CTL's weight (Table 1) and are used to hold or protect parts, can be possibly reduced in weight if the layouts or shapes are optimized.

Table 1 Weight of Structural Parts(SVL75-2)

| | Weight in kg | Weight % |
|---|---|---|
| Total of large structural parts | 1685 | 42 |
| Body overall | 4025 | 100 |

We approached the weight reduction of the structural parts with the following three points.

- Optimize the shape (layout).
- Project an outlook on strengths with structural analysis.
- Review and redesign the supporting structure by taking advantage of the reduced carrying weight.

In the development process of the SVL75-2, there were many additions of reinforcement parts to secure the strength of structural parts. So before starting the parts optimization for this project, we reviewed all such structures of the SVL75-2. Then we analyzed strength under the condition that these additional parts are removed. As an example, Fig. 9 shows the hitch structure. With the SVL75-2, the hitch had a complex welded structure shown in blue, whereas, with the development model SVL65-2, we optimized it into a simple, cylindrical shape as a result of layout review (Fig. 10). Besides this, the development model SVL65-2 has achieved a weight reduction of 270 kg (595 lbs) by optimizing the shapes of large structural parts (Table 2).

In addition, because the Rated Operating Capacities (ROC) of the development model SVL65-2 was changed to 2,100 lbs (approx. 953 kg) from that of the previous base model, SVL75-2, which is 2,300 lbs (approx. 1,043 kg), this reduced the load on the structural parts, also lessened the required engine horsepower and so we were able to reduce the weight of the engine unit.And, in the end, the overall reduction of vehicle weight reduced the load on the truck parts such as the crawlers and idlers shown in Fig. 11 and so allowed us to reduce the weight of these parts as well.

All these measures helped the development model SVL65-2 achieve a weight of 7,871 lbs (3,601 kg) for the vehicle, attaining more than the target weight of 7,940 lbs (approx. 930 lbs (422 kg) lighter than the SVL75-2).

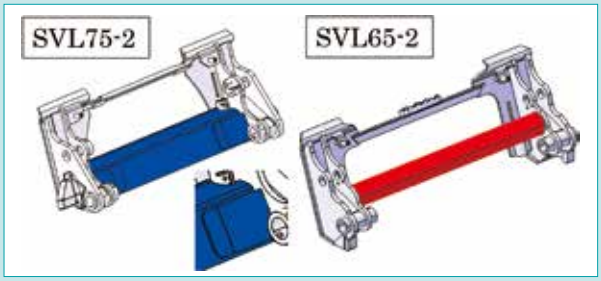



Fig. 9 Hitch

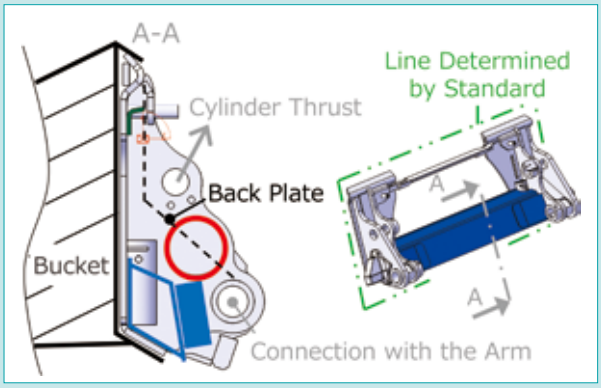



Fig. 10 Structure of Hitch

Table 2 Weight Reduction of Structural Parts

| | | Weight reduced in kg |
|---|---|---|
| Large structural parts | Frame | 130 |
| | Arm | 56 |
| | Link | 29 |
| | Hitch | 20 |
| | Hood | 18 |
| | Cab | 17 |

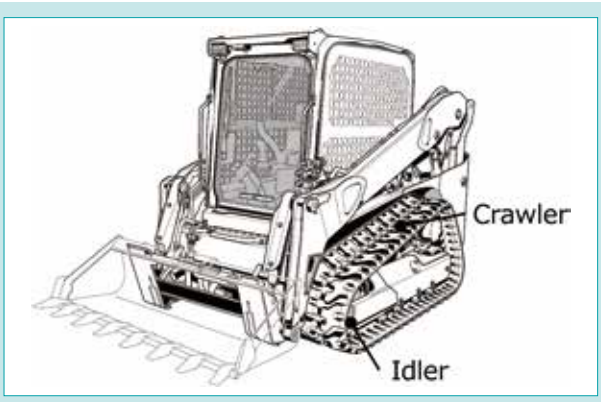



Fig. 11 Truck Parts

## 4-2 Improvement in hydraulic simultaneous operability

As for target [2], the loader and AUX function don't work at the same time in same conditions on the previous base model, SVL75-2. The reason is attributed to the hydraulic circuit of the previous base model, SVL75-2 (Fig. 12), which is a series circuit.

A series circuit sends the hydraulic oil that leaves the pump to the first actuator and sends the return oil from this actuator to the next actuator as indicated by the arrows in the diagram. Each actuator is operated with the movement of the spool (rod notchd to switch the oil passage), which works to switch the flow of oil in response to the user's operation (dashed lines in Fig. 12). The movement of the spool causes a move of the spool's notch in order to increase or decrease the hydraulic oil passage surface area to produce smooth operation.

An advantage of using this series circuit is that a relatively smaller pump can be used to run the machine than with multiple actuators used in parallel. As a drawback, as with the case that we faced in this project, if there is a rise in the downstream actuator's pressure (AUX's area A in Fig. 12), the oil, which has lost a place to drain, raises the pressure of the adjacent upstream actuator's bottom side as well (bucket cylinder's area B). So, even if the oil is sent to the rod side (area C), the difference in surface area prevents cylinder operation. Similarly, the operation of the further upstream actuator (arm cylinder) is also prevented.

On the other hand, the hydraulic circuit of a competitor (Fig. 13) uses a tandem circuit to feed hydraulic oil to AUX.

A tandem circuit sends the hydraulic oil that leaves the pump to the upstream actuator with priority. As indicated by the arrows in the diagram, while the upstream actuator operates (bucket cylinder in Fig. 13), the oil is not sent to the downstream actuator (AUX in Fig. 13). An advantage of this method is that the upstream actuator can always be operated even if pressure rises in the downstream actuator. However, as a drawback, while the upstream actuator is in operation, the downstream actuator cannot be operated. So, the SVL65-2 implemented a hybrid circuit in which a tandem circuit was added to the series circuit (Fig. 14). By adding new oil passages to the spools, this circuit established the function of a tandem circuit that can allow adjusts the amount of oil that returns to the tank, without needing to have additional hydraulic valves.

With this, even when there is a rise in the downstream actuator's pressure (AUX's area A in Fig. 14), the midstream actuator (bucket cylinder) can operate with the return of the hydraulic oil from the added tandem circuit (B) to the hydraulic tank. At the same time, even when pressure rises in the midstream actuator, the actuator (arm cylinder) furthest upstream can operate.

However, a new issue arose in another operation (Fig. 15).

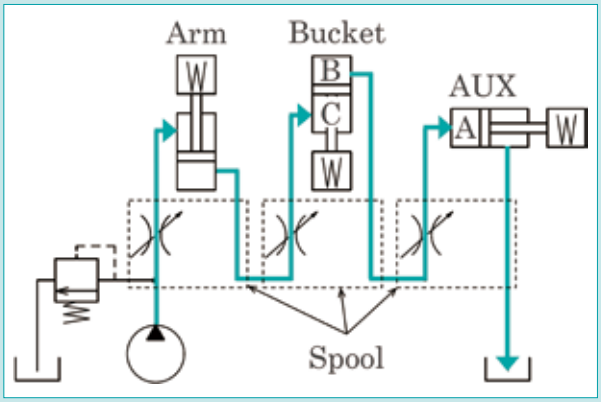



Fig. 12 Hydraulic Circuit (Previous base model, SVL75-2)

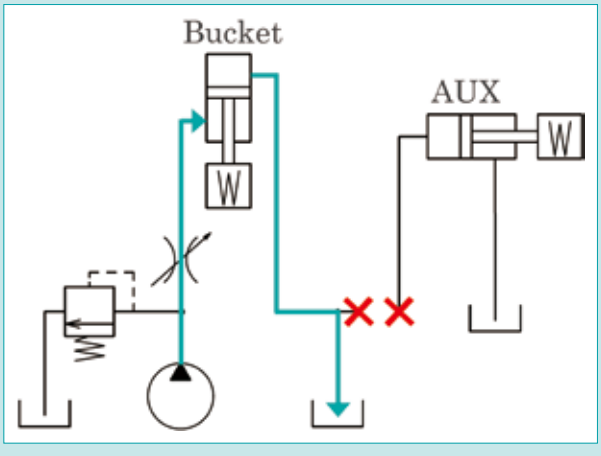



Fig. 13 Hydraulic Circuit 2(Competition)

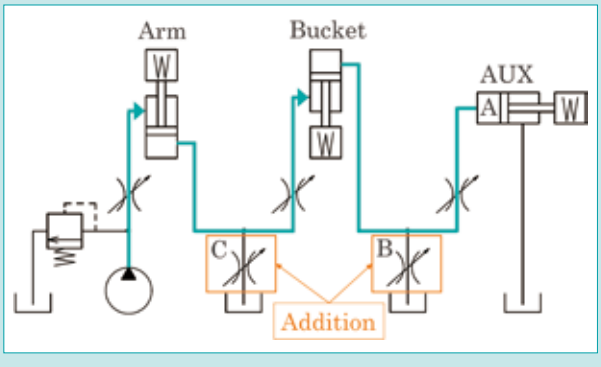



Fig. 14 Hydraulic Circuit 3(Hybrid)

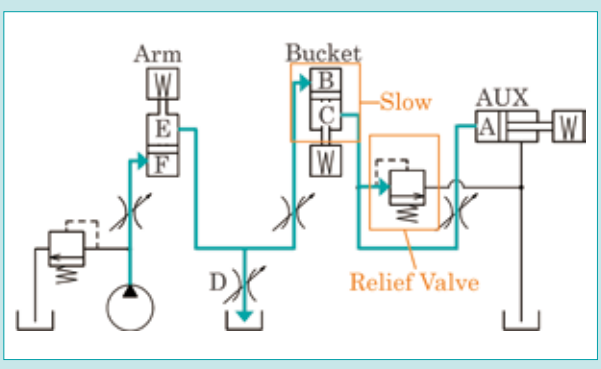



Fig. 15 Hydraulic Circuit 4(The New Challenge)

In this operation, the direction of the two actuators' movement (arm and bucket) is the reverse of that shown in Fig. 14. In this stage of development, we encountered the issue that the speed of midstream actuator operation (bucket cylinder in Fig. 15) was lost due to some problems including the insufficient amount of oil sent to this actuator. We first saw a issue in the added tandem circuit (D). When the actuator (AUX) furthest downstream is put under load and its bottom side's pressure (area A) rises, it causes the pressure in the midstream actuator's rod side (area C) to increase as well, resulting in an increased resistance on the operation of the midstream actuator. When this condition arises, the oil sent to the midstream actuator's bottom side (area B) produces the resistance that increases the circuit pressure, and this increases the amount of oil that leaks from the tandem circuit (D) to the hydraulic tank. Consequently, the oil that moves the midstream actuator is reduced by this amount. On the other hand, when the actuator (arm cylinder) furthest upstream is moved in the arm's expanding direction, because its rod side (area E) has a smaller surface area than that of the bottom side (area F), the amount of oil sent to the midstream actuator is reduced. Contrarily, the midstream actuator, which has a greater volumetric capacity on the bottom side, requires a great rate of oil flow for its operation. All of these factors combined resulting in the above mentioned issue. To solve this issue, we added a regenerative circuit, which returns the hydraulic oil from the midstream actuator's rod side to the bottom side (Fig. 16).

A regenerative circuit makes the oil from an actuator retrun again and be merged with the oil that is fed from the pump, and by increasing the flow rate of the hydraulic oil on the actuator's feed side, the cylinder speed can be augmented. With this function, even when the pressure in the most downstream actuator (AUX) is increased, the midstream actuator (bucket cylinder) can operate with no loss in its speed. This technique obtained two patents each in Japan and the United States.

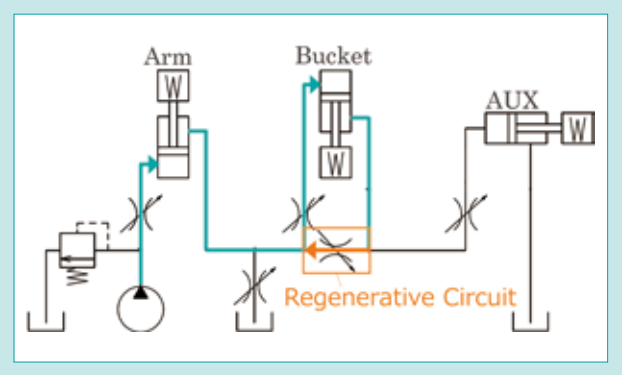



Fig. 16 Hydraulic Circuit 5(AMV)

## 5. Conclusion

Through the efficient use of structual analysis and the adoption of AMV, the SVL65-2 has achieved the concept that we initially set up. This projects success has provided a new option of machine, which is smaller than the previous base model, SVL75-2 and better in operability, to users who were considering the purchase of a machine in the class range of 2,000 to 2,300 lbs (907 to 1,043 kg). The SVL65-2 has been highly appreciated in the market and is robustly growing in sales. Consequently, our market share (three models) in the number of units sold as of August 2020 has increased to about 20% (surveyed by Kubota).

From now on, we will roll out the weight reduction technique and hydraulic technology that we implemented in this project to other models and thereby contribute to the expansion of the industry by promoting research and development toward the new value creation.

## Contribution to SDG targets

9.2 Strengthening inclusive and sustainable industrial infrastructure
Contribution to industry development with the provision of machinery that can be easily transported

11.3 Strengthening of inclusive and sustainable housing planning and management capabilities
Contribution to infrastructure development in North America with the realization of low-cost hydraulic simultaneous operation

Reference
1) YENGST ASSOCIATES (2019)
2) Kubota Technical Report No.51 "Development of the CTL SVL95-2S for North America" (2017)

# Development of Stand-On Type Mini Compact Track Loader SCL1000

Great Plains Manufacturing, LP Engineering



The SCL 1000 is Kubota's entry into the growing market of Compact Utility Loaders (CUL). A CUL, also known as a stand-on skid steer, is a power unit that has the ability to work in tighter spaces than a traditional skid steer or compact track loader. In North America, the CUL market is growing rapidly for both commercial and rental applications, replacing traditional skid steers on some job sites. This market is new for Kubota and the natural desire to exceed the features of competitor machines led to several technical challenges. The key features that add value to Kubota's SCL 1000 are wide tracks on a narrow frame, a 25 Hp turbo-charged engine, light machine with high ROC (rated operating capacity) and vertical lift plus operator features such as comfort and control logic.

【Keyword】
Compact Utility Loaders, Stand-on Skid Steer, Wide Tracks, High ROC

Related SDGs


## 1. Introduction

The compact utility loader (CUL) machine is basically a small, stand-on compact track loader. The need for these small machines to perform landscaping and small construction projects in residential neighborhoods, or even commercial areas, continues to increase. The appeal of the CULs is their relative ease of use and their expanding line of attachments to enhance their versatility.

Kubota's entry in the CUL market is the SCL 1000, which features a 25 Hp engine and 1,000 pound rated operating capacity. This is a unique machine developed by USA engineers for the North American market. Designing, sourcing, manufacturing and selling the SCL 1000 in the same market area saves wasteful shipping.

Some initial environmentally friendly and technically challenging features designed into the SCL 1000 include: (1) wide tracks on a narrow machine for minimal turf damage;

(2) incorporating a turbo charged engine for low noise;
(3) a light machine with high operating capacity for low fuel consumption and
(4) operator comfort to minimize operator fatigue.


Fig. 1 Appearance of SCL1000

Table 1 Specifications of the SCL1000

| Main Specifications | Unit | Value |
|---|---|---|
| Rated Operating Capacity | lbf | 1000 |
| Machine Weight | lbf | 3050 |
| Overall Width | in | 35.8 |
| Overall Length | in | 108 |
| Overall Height | in | 55 |
| Gross Engine Horsepower | hp | 24.8 |
| Track Width | in | 9.8 |
| Ground Pressure | psi | 4 |
| Ground Pressure | in | 108 |



## 2. R&D Concept and Target Value

### 2-1 R&D Concept

Although the SCL 1000 has many innovative and market leading features. This article focuses on four key concepts that contribute positively to the environment.

(1) Reduce damage to turf in residential yards.

A common use for CUL machines is to drive through a narrow gate, enter into the back yard of a residence and do work. Damaging the turf while working with a CUL requires additional work to reshape and or re-plant the turf. The concept is to design a narrow machine with wide tracks to minimize ground pressure and reduce damage to the turf.

(2) Reduce engine noise and vibration felt by the operator.

Through our customer surveys, we learned the operators complained about the loud engine noise and vibration endured when operating the competitive machines for many hours. The concept is to satisfy the customer with a machine that operates quieter and smoother when compared to the competition.

(3) Optimize the balance between maximum rated operating capacity and low overall weight.

The objective for this concept is to get the highest lifting capacity out of a machine with 25 Hp engine yet keep the machine light to reduce fuel consumption.

(4) Minimize operator fatigue.

Typical construction and landscaping jobs are toilsome work for the operator. To make the operator's job more enjoyable, the machine needs intuitive and ergonomic controls that allow the operator to work safely and efficiently.

### 2-2 Target Value

(1) We measured many gates in residential areas and found the smallest gates to be 36" wide. We set our goal to have a machine width of less than 36" allowing our machine to drive through these gates. We set the track width at 10" each to achieve the lowest possible ground pressure.

(2) We checked competitive machines and found all competitors have noise levels near the operator at or above 92 Db. We set our goal to be less than 90 Db. To achieve this goal we used a turbo-charged engine that will provide 25 Hp at a lower engine speed. With lower engine speed, we can achieve less noise and reduced vibration.

(3) The target early on for this goal was to have the machine rated at 1,000 pounds or more. The heavier the machine, the easier it is to achieve high rated operating capacity. But heavy machines consume more fuel. We had a target

to keep the machine weight at or below 3100 pounds.

(4) We evaluated larger machines, and asked customers what they prefer for controls. Many suggested integrating auxiliary controls in the loader joystick to keep hands on the controls at all times and move around less. A multifunction joystick became the design goal for reducing operator fatigue.



## 3. Technical Challenge to be Solved

To meet the marketplace demands of this new machine and fit into our market "niche", we identified the following design hurdles:

(1) Optimize layout with challenging width constraints.
Creative solutions and multiple layout iterations were necessary to meet the width constraints.

(2) Maintain performance with turbo engine and prevent excessive stalling.

(3) Meet ROC target and minimize weight.
With the low weight target, loader arm lift geometries were critical to meet the ROC target.

(4) Developing easy-to-use auxiliary controls.

## 4. Developed Technology

### 4-1 Address Space Limitation Problems

4.1.1 Solve Design Challenges Related to Narrow Width

We encountered three major challenges where space was limited due to the narrow width and the wide tracks:

1) Areas between the two tracks were extremely restrictive, and if conventional frame designs were used, it would be impossible to fit an engine in the machine.

2) The short distance between the two drive motors limited engine placement options.

3) The oil filter limited engine placement variability.

4.1.2 Narrow Width Design Solutions

To be able to fit an engine in the machine, we designed a T-shaped frame. The design allowed the wide tracks to be housed in exterior "track wells", and provided room for the wider upper portion of the engine.

The next challenge was to fit the flywheel housing between the two drive motors. We could find no other solution to this problem besides drastically offsetting the sprocket from its mounting shaft. A tapered or conical sprocket shape allowed us to pull the drive motors towards the outside of the machine as much as possible, while still maintaining clearance for the drive motor hoses and track lugs.

Lastly, we needed to place the engine oil filter in a location to keep the engine low and as far forward as possible, but still maintain serviceability. We placed the engine to where the filter was right behind the track well, and included an access panel for easy service.

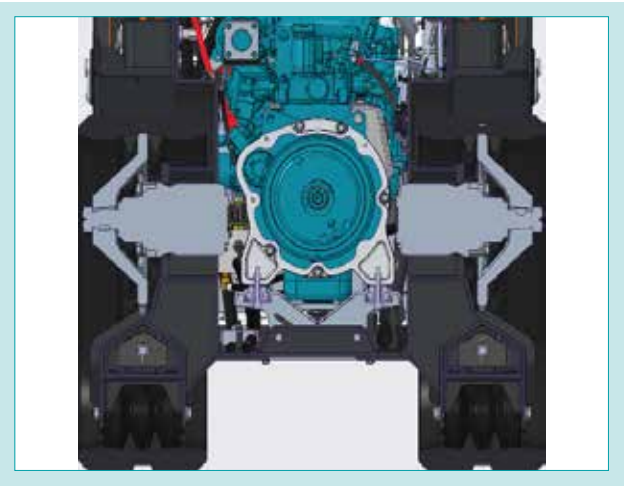


Fig. 2 Drive Sprockets and Motors

## 4-2 Powertrain Design for Turbo Engine

### 4.2.1 Maintain Performance with Turbo Engine and Prevent Excessive Stalling

Lower engine speed is good for reduced engine noise and vibration, but lower engine speed creates another challenge. The lower speed of the turbo engine with a conventional engine flywheel would produce less rotational momentum. Less rotational momentum will lead to more engine stalls while performing demanding work.

### 4.2.2 Increase Rotational Mass and Limit Power Demand

The first countermeasure was to increase the rotational momentum by increasing the rotational inertia of the flywheel offsetting the negative effects of the speed reduction. With the machine already being compact with no room, the small space needed to be used efficiently.

The second countermeasure was to reduce parasitic losses in the hydraulic system by following plumbing best practices. The design team collaborated with a hose routing expert, and utilized their experience to optimize hose routings and hydraulic system design. Figure 3 shows the hose routings designed near the operator's station.

We also focused on controllability of the machine. All other machines in this class used a direct lever-type control valve for the loader, but the Kubota machine used all hydraulic pilot controls.

Pilot operated drive and loader control joysticks gave the customer excellent controllability and response with feedback, which leads to fewer engine stalls and improved operator satisfaction.

Fig. 3 Hydraulic Hose Routings

## 4-3 Meet the ROC Target and Limit Weight

### 4.3.1 Balancing ROC and Machine Weight

The challenge for meeting a high ROC target is difficult when weight limitations are on a machine. Care must be taken to optimize the machines center of gravity and loader travel path.

### 4.3.2 Calculate Center of Gravity and Design Vertical Lift Path

Using our modeling software, we calculated the center of gravity of our machine and confirmed it with a prototype. We based our loader design on Kubota's popular and proven CTL loader arms. We used our modeling software's mechanism analysis package to determine the optimum pin locations on the CUL's loader arms. Loader measurements, shown in figure 5 including lift height (Q), bucket reach at the top of the path (H), breakout force, and bucket position were all weighed against one another. To achieve the target ROC, the bucket position had to be considered the priority.

ROC from ISO 14397 is defined by the equation below:

ROC (Rated Operating Capacity) = 0.35*Tipping Load

Tipping Load: The load at the centroid of the bucket with the loader at maximum reach at which the machine tips. This spec strongly correlates with the bucket pivot pin position, which is mapped in the figure and approximated by the equation y= 4.64e^(0.34x).

Many iterations were made to get the optimum loader performance, but the goal was realized with a 1000lb ROC, best-in-class reach (H), and best-in-class lift height(Q).

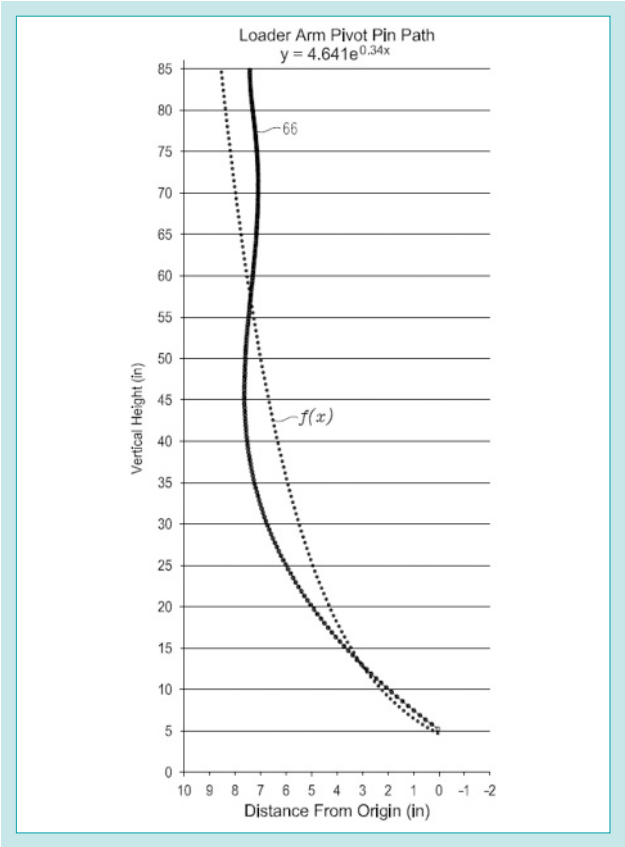



Fig. 4 Pivot Pin Path

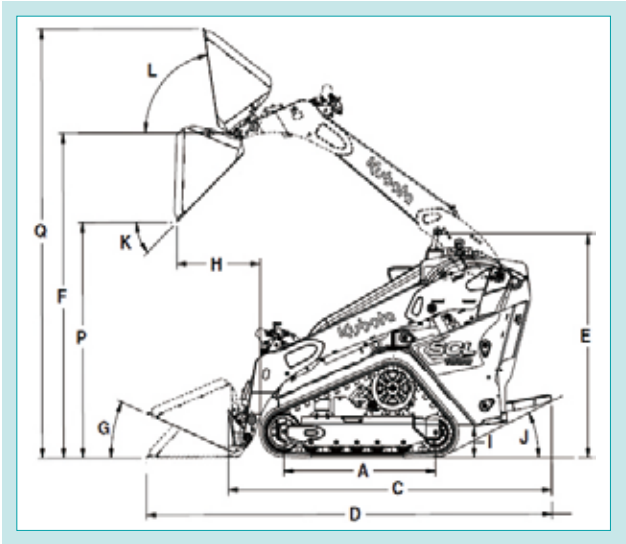



Fig. 5 Loader Dimensions

## 4-4 Developing Easy-to-use Auxiliary Controls

4.4.1 Technical Challenge

At the time, a multifunction joystick with integrated auxiliary controls would be a unique new feature in the stand-on compact loader market. This type of auxiliary control required an electrical interface between it and the hydraulic valve solenoids controlling the auxiliary flow. In a very compact machine, that electrical system must be as simple, serviceable, and compact as possible.

Auxiliary controls must allow the operator to momentarily or continuously actuate an attachment in forward or reverse. These controls must be easy to learn to accommodate frequent new operators. The capabilities for the auxiliary controls must be as follows:

- For momentary control, output hydraulic flow from the auxiliary coupler proportional to the user input from the auxiliary control.
- For continuous control (also known as auxiliary hold), either lock the output hydraulic flow to the auxiliary coupler in its current state or hold at maximum flow.
- For either momentary or continuous control, be able to stop or reverse flow immediately.

A mechanical valve lever would make this quite simple, but a multifunction joystick demands more complexity. Using only basic components for a simple electrical system, integrating the logic for the auxiliary controls would require multiple relays and switches. In a compact unit, there would not be enough space for the bulk of multiple relays near the control panel.

4.4.2 Solution of Challenge

A chip or integrated circuit (IC) is very small with programmable logic suitable for low current applications. With only a few wires and potentially two relays, depending on the current ratings of the IC, the whole electrical interface between the multifunction joystick and the hydraulic valves could be a cost-effective system contained within a compact space less than 10 cu. in.

Further analysis of the demands of the remaining electrical components of the stand-on compact loader revealed that an I/O module would be the most efficient use of cost, space, and reliability. An I/O module would centralize all the sensor and output signals. It would provide a programmable logic platform to handle everything from engine startup controls to the multifunction joystick auxiliary controls.

Another goal of the electrical system was to present runtime information to the operator. Traditionally this is done with indicator lights and gauges in an instrument cluster. An instrument cluster would occupy a large area on the control panel and the space behind.

Instead, a display could present the runtime information, consolidate the auxiliary controls logic, all the sensors, engine controls, and other I/O into a single, compact device. The SCL1000 features a solid state I/O expansion module and a color display. The display consists of a 4.3in. color LCD screen, 5 tactile buttons, and overall dimensions of only 4.66x4.98x2.06in. including the connector. The I/O module mounts flat and slim against the sidewall of the frame away from the control panel providing plenty of I/O for the machine.

The auxiliary control buttons on the multifunction joystick input to the display, the display communicates with the I/O module via CAN, and the I/O module sends PWM outputs to the auxiliary valve solenoids according to the programmed logic following the simple initial momentary and continuous control requirements. The additional benefit of consolidating all other machine controls into these two devices are the ability to modify for continuous improvement with simple software updates. This completes the interface between an easy-to-learn, low-fatigue multifunction joystick and the auxiliary valves for controlling hydraulic flow to the attachment in a compact form.

## 5. Conclusion

We successfully developed, tested and sourced components for the SCL 1000 in North America for the North American market. Introduction this new Kubota CUL at the 2019 Kubota National Dealer Meeting in Grapevine, Texas resulted in much excitement from Dealers. The SCL 1000 achieves the design targets and customer expectations learned during market surveys. The narrow width and wide tracks are innovative and sure to spare damage to yards. Using the turbo charged engine reduces noise and vibration providing the operator comfortable conditions. Optimizing the balance between maximum operating capacity and minimum weight will reduce fuel consumption. Integrating auxiliary controls in a multifunction loader joystick reduces operator fatigue and increases productivity.

## Contribution to SDG Targets

8.2 Improvement in productivity through innovation
Developed a small machine for both tight maneuverability with low weight, low ground pressure, fast travel and loader cycle times, and high lift capacity for its size.

11.6 Reduce environmental impact
Improved work efficiency in residential areas and reduce turf damage.

12.2 Management and efficient use of natural resources
Powered by less than 25HP Tier IV diesel running at lower engine speed for low fuel consumption.

# Development of Weathering Evaluation Technology

Materials Center



In recent years, in addition to a product's work performance, a quality appearance is becoming an important evaluation point for users of both agricultural and construction machinery. Among them, the weather resistance of the coating is the most important factor for retaining a quality appearance. In order to prevent deterioration of the appearance of products that are used over an extended period of time, it is important to examine the types of coating, and the coating systems, and furthermore to evaluate the durability (weatherability) correctly. However, since a long-term outdoor exposure test takes too much time, it is necessary to perform an accelerated test that is highly correlated with outdoor exposure. This time, we have defined a unique KUBOTA accelerated test method by examining the test conditions using a xenon accelerated testing apparatus.

【Key Word】
Coatings, Appearance Quality, Weatherability, Outdoor Exposure, Accelerated Test

Related SDGs


## 1. Introduction

The previous industrial machinery primarily valued work performance and tended to neglect visual qualities such as discoloration and rust. However, with the times visual quality carries more weight, and what is important is not only the visual quality at early stages of use but also maintaining the durability over time. For coating particularly, which is greatly responsible for visual quality, the types and properties of the paint used need to be considered and also it is important to determine durability over time (weather resistance) by reliable and rapid evaluation techniques. While general weatherability evaluation uses a weathering test with outdoor exposure, it takes too much time to predict longevity in weatherability when we think of the recent advance of coating technology and the speedup in product development. So, manufacturers need to perform accelerated tests that have a high correlation to outdoor exposure. Various accelerated test methods have been proposed and each has its own characteristics.

Aiming at acceleration and correlation higher than those specified in ISO and JIS standards, we determined Kubota's own unique accelerated weathering test conditions by considering the load factor of water, the temperature of test panels (in chamber) and other test conditions[1)] using a xenon testing apparatus.

## 2. Description of the technology

### 2-1 Development concept

Xenon testers, which use a wavelength distribution of light similar to that of sunlight, are dependable in terms of correlation. However, the standard test conditions for xenon tests defined in ISO and JIS standards do not suffice in acceleration. The test results of a layer of enamel urethane resin coating exposed in Miyakojima and Arizona suggested that water (rain) had the particularly greatest effects on acceleration among four major deterioration factors: 1) light, 2) water, 3) temperature and 4) oxygen (Fig. 1).
(Arizona has a desert climate with more solar radiation but less rain than Miyakojima.)

In this project, we investigated the test conditions (mode) while factoring in the effects of increase in the load factor of water and the temperature of test panels (in chamber) in terms of acceleration (Fig. 2).
(The numbers enclosed in □ are mode numbers.)

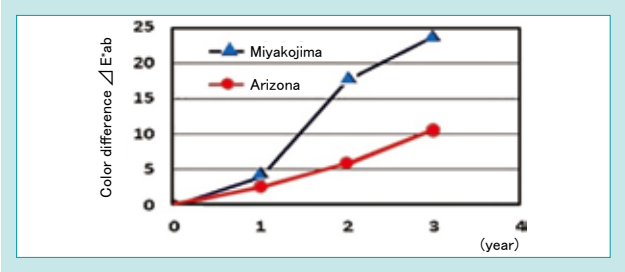



Fig. 1 Change in Miyako (blue) and Arizona (red)

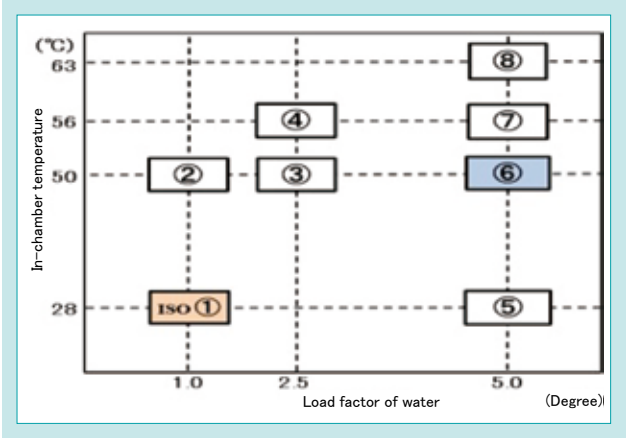



Fig. 2 Diagram Showing Relationships of Test Conditions

### 2-2 Selection of test conditions

Of the test conditions shown in Fig. 2, mode [6] shows the highest acceleration and correlation, and so we selected this as Kubota's own unique test conditions. A layer of red coating was tested with outdoor exposure in Miyakojima and with an accelerated test in mode [6], and the acceleration and correlation results are shown in Fig. 3.

The results showed that the weather deterioration of a layer of enamel urethane resin coating (red) was approx.11 times more accelerated than with the outdoor exposure in Miyakojima (approx. six times more accelerated with ISO mode [1]), and also proved a good correlation. With other colors (blue, black, yellow) as well, deterioration was accelerated around 10±1 times more, and the correlation was good.

The results of a layer of blue coating are shown as an example (Fig. 4).

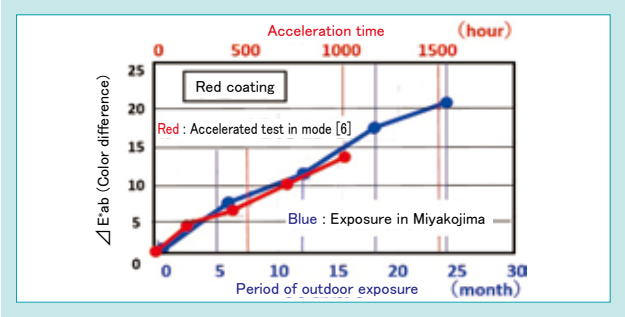



Fig. 3 Comparison of Change in red color between Miyako (blue) and Xenon (red)

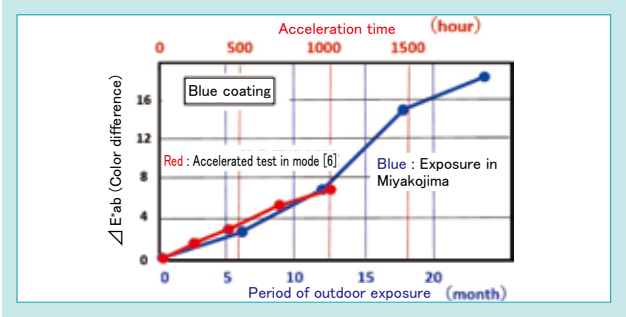



Fig. 4 Comparison of Change in blue color between Miyako (blue) and Xenon (red)

## 3. Conclusion

Since outdoor exposure depends on the weather and is much time to evaluate, the effective use of acceleration tests is searched.

In this project, the xenon test that is said to have the highest correlation was used and we were able to enhance acceleration, which was a weakness of the usual test. We are hoping to roll out these test conditions to the clear coatings as well, which have good weather resistance, in order to speed up their weatherability evaluation.



## Contribution to SDG targets

8.2 Improvement in productivity through innovation
Contribution with rapid accelerated testing for outdoor exposure evaluation (2 years)

9.5 Promotion of scientific research and innovation
Contribution to sharing of research themes through academic presentations, etc.

Reference

1) Masahiko Akahori, Hiroyuki Kimoto: The 30th research presentations, Materials Life Society, Japan Lectures, p. 39-42 (2019)

# Development of Flangeless T-pipes and Isolating Valves

Pipe Systems Networks R&D Dept. / Intellectual Property Dept.



A lot of damage to T-pipes located in water pipelines have been reported in investigations conducted after the 2011 Tohoku earthquake and 2016 Kumamoto earthquake. On the other hand, the use of earthquake-resistant joints has become widespread, but conventional flange joints are still predominantly used where the T-pipe branch joins another pipe. It was thought that the cause of the damage was that the joint strength and water tightness required during earthquake was insufficient. Isolating valves have to be replaced when performance deterioration occurs because these valves are vitally important in order to cut off water pressure in an emergency. That being the case, large-scale construction works were needed, and consequently there are some issues related to construction.

In order to address these issues, we developed flangeless T-pipes and isolating valves with high-strength joints sufficient to resist an earthquake and with an easy valve replacement function.

【Key Word】
T-pipe, Isolating Valve, Flangeless Joint, Lateral Load, High Pressure Water Sealing Performance, Construction Method for Replacing Isolating Valve

Related SDGs


## 1. Introduction

Large-scale natural disasters, including earthquakes and torrential rainfalls, have occurred frequently in recent times, and so there is a demand for the water supply facilities in Japan to be further strengthened. With this factor in place, no damage has been reported in past large-scale earthquakes as to the earthquake-resistant ductile iron pipes used in water pipelines, which thereby have been proven to be highly earthquake-resistant. On the other hand, it cannot be stated that auxiliary equipment such as air valves and fire hydrants have sufficient earthquake resistance compared with pipelines, and in fact, many cases of damage to air pipes, in particular, were reported in the surveys[1)2)] conducted after 2011 Tohoku earthquake and 2016 Kumamoto earthquake (Table 1).

Table 1 Ratio of Equipment Damaged During Large Earthquake

| Category | Equipment | Earthquake | Damage rate See Note) 1 | Number of damages | Total installations (or distance) |
|---|---|---|---|---|---|
| Pipeline | Earthquake-resistant ductile iron pipe | 2011 Tohoku earthquake | 0/km | 0 | (1780km) |
| | | 2016 Kumamoto earthquake | 0/km | 0 | ( 628km) |
| Auxiliary equipment | Air valve | 2011 Tohoku earthquake | 1.72% | 148 | 8,627 |
| | | 2016 Kumamoto earthquake | 4.31% | 114 | 2,646 |
| | Fire hydrant | 2011 Tohoku earthquake | 0.03% | 18 | 55,970 |
| | | 2016 Kumamoto earthquake | 0.06% | 11 | 18,414 |

Note) 1. Pipeline damage rate: Damages/Installation distance km, Auxiliary equipment damage rate: Damages/Total installation qty × 100

The breakdown of these cases of damage to auxiliary equipment shows many cases of foreign material clogging and the internal component breakage of air valves and also shows there were many water leaks from flanges (Fig. 1).

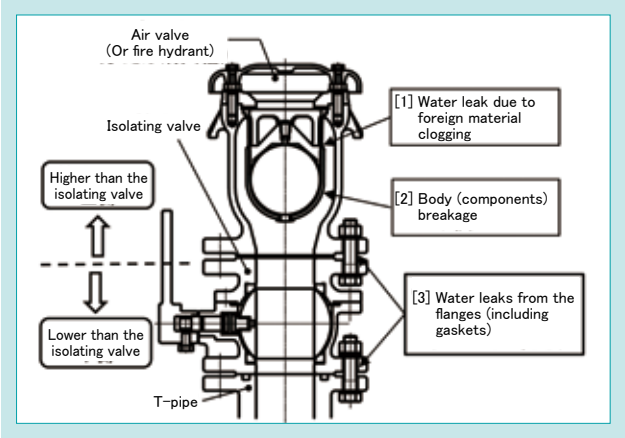



Fig. 1 Main Damage During Large Earthquake

Among these water leaks, those occurring above the isolating valve can be shut off immediately by closing the isolating valve, but those below are not easy to shut off. In response, Kubota, turning our attention to these isolating valves' underside flanges, have developed a new flangeless joint that can endure a possible large earthquake.

The isolating valves, which play an important role in emergency cases, need replacement according to the circumstances without delay because they deteriorate over an extended period of use after installation or may have malfunctions or water leaks due to foreign material inclusion, etc. However, if we wish to replace isolating valves under pressure, it will require the use of a dedicated large apparatus and the securing of a wide work space together with a high cost for land work. To work out these great issues, we decided to add an easily replaceable structure to the earlier mentioned flangeless joint.

The introduction of the flangeless T-pipe and isolating valve (Fig. 2), which have a joint endurable to earthquakes and are easy in isolating valve replacement, can raise the level of earthquake resistance performance of auxiliary equipment to the same level as pipelines and thereby can widely reduce the water leak damage during an earthquake. The details of the development are reported below.

Fig. 2 Flangeless T-pipe and Isolating Valve

## 2. Development concept and goals

### 2 - 1 Development concept

The development concept for the flangeless T-pipe and isolating valve is described below.

(1) The shut-off performance of the joint can be kept under the conditions in which it is subjected to a lateral load (caused by the collision with the valve box) and/or high water pressure (caused by the impact pressure produced in the air valve), which are expected when an earthquake occurs.

(2) The replacement of the isolating valve is possible without needing to suspend water supply and do land work for valve box removal, etc.

### 2 - 2 Target values

The joint (T-pipe's branch pipe) to be developed is in one size, 75 in nominal diameter, which accounts for 80% or more of the total uses. As shown in Table 2, the development targets were decided to agree with the shut-off performance believed to be necessary for the joint to tolerate an earthquake by reference to the recent investigations, as well as the standard size valve box installed with the T-pipe.

Table 2 Target of Development

| Item | | Development goals |
|---|---|---|
| Joint size (branch pipe) | | Nominal diameter 75 |
| Joint performance | Basic performance | Equivalent to GX joints |
| | Water shut-off performance with lateral load | Water shut-off possible when bent (at 1.5° ) |
| | | Water shut-off possible with a bending moment load of 20 kN·m |
| | High pressure water shut-off performance | Water shut-off possible with impact pressure (5.0 MPa assumed) |
| Isolating valve replacement | | Water supply suspension. Replaceable in the valve box (standard size). |
| | | Work within 60 minutes |

## 3. Technical issues to be solved

### 3 - 1 T-pipe joint structure

While water pipelines are being made earthquake-proof, the T-pipes are still connected with flange joints in most places to this day. Many case examples[3] about past large-scale earthquakes report that fire hydrants and air valves joined to T-pipes collided with their valve boxes and resulted in water leaks from the flange joints (Fig. 3).

The reports also included a case where the shaking during an earthquake caused a sudden change in the water pressure in a pipe, and with this, an impact pressure was locally produced in the air valve, then the water pressure instantaneously rose, and the flange gasket popped out. Therefore, we need a joint that can keep its shut-off performance when subjected to a lateral load and/or high water pressure, which are expected when an earthquake occurs.

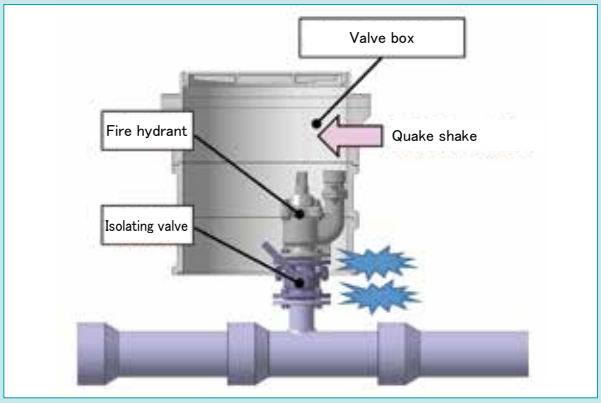



Fig. 3 Collision with Valve Box

### 3-2 Method of isolating valve replacement

Ductile iron pipes are made of ductile cast iron that is excellent in corrosion resistance and coated with anti-corrosive coatings, which have been improved with recent years' new specifications for enhanced longevity (100 years or so). On the other hand, isolating valves may malfunction due to foreign material inclusion or other troubles characteristic of valves, and therefore the average lifetime is shorter than that of ductile iron pipes. Now that the upkeep of water pipelines is emphasized these days, it is predicted that the demand for replacing only isolating valves will increase from now on, and consequently, there is a strong demand for easy techniques of isolating valve replacement that do not require a suspension of water supply and land work.

The most common size applicable to the valve boxes for T-pipes is 600 mm in inner diameter. If an isolating valve has to be replaced without a suspension of the water supply, excavation will be necessary to remove the valve box and to secure working space (approx. 1,200 mm in square width) because dedicated large equipment needs to be placed (Fig. 4).

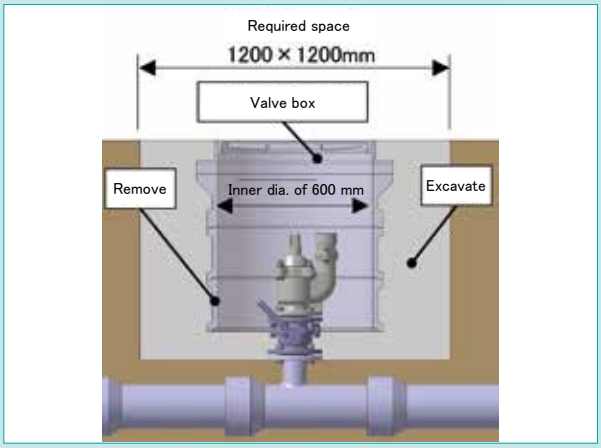



Fig. 4 Space Required for Conventional Method

## 4. Developed technology

### 4-1 T-pipe flangeless joint

4.1.1 Structure of flangeless joint

Fig. 5 shows the flangeless joint structure that we developed.

(1) Water shut-off structure

The inserting end, which is installed at the end of the isolating valve, is inserted into the receiving end on the T-pipe, and the rubber ring is placed as the water shut-off function. For this rubber ring, we employed a shape similar to the T shape that has been proven to work with ductile iron pipes in order to enhance the shut-off performance that can endure a bending stress.

(2) Slip-out resistant structure

A dividable split ring is fitted to the projections

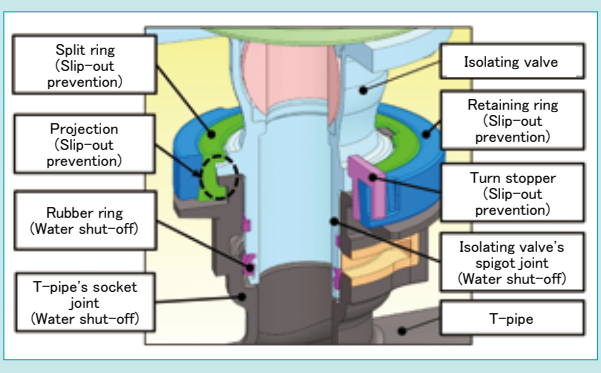



Fig. 5 Structure of Flangeless Joint

provided on the T-pipe and isolating valve and is fastened with a retaining ring and turn stopper. With this structure, slip-out resistance performance was secured without relying on the tightening force of bolts and nuts.

Next, the joining procedure is shown in Fig. 6. No special tools are required for the joining work. As the result of a joining test conducted using real products, the joining work was completed within about two minutes.

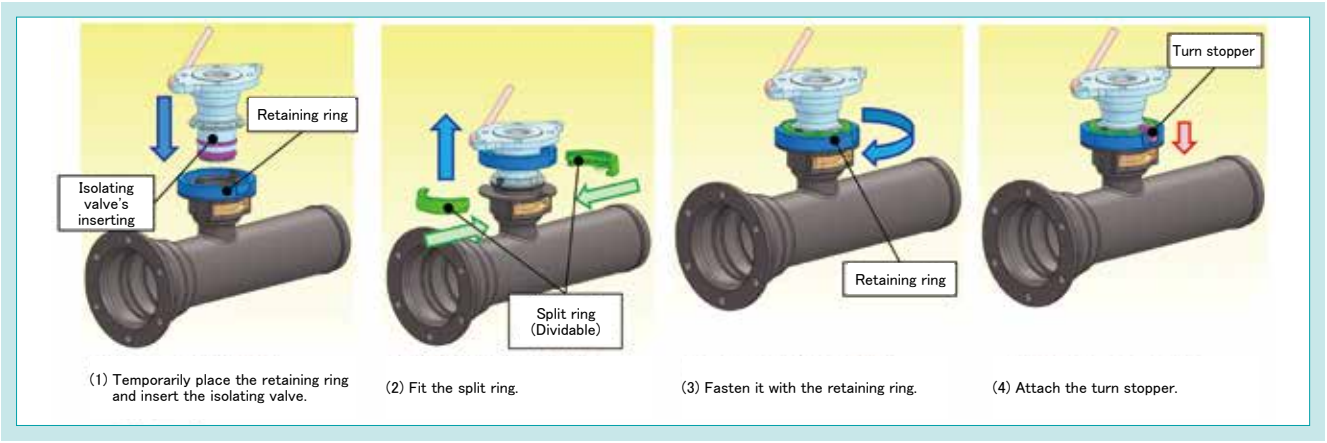



Fig. 6 Procedure for Jointing

4.1.2 Basic performance of the joint

To evaluate the basic performance of our developed flangeless joint, we tested water tightness, slip-out resistance and bending strength. Test conditions were decided based on the standards for earthquake-resistant ductile iron pipes (Water supply GX ductile cast iron odd-form pipes, JWWA G121).

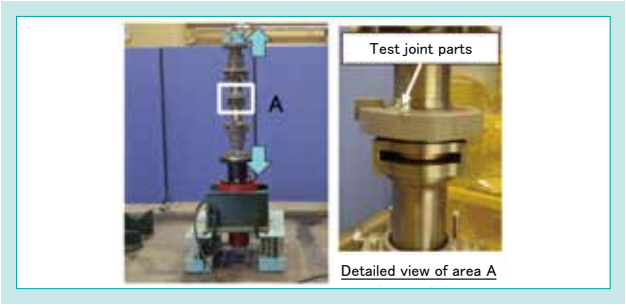



Fig. 7 Aspect of Slip-out Resistance Performance Test

4.1.3 Water shut-off performance with lateral load

To evaluate the water shut-off performance of the T-pipe with a lateral load on it, we attached a short pipe to the isolating valve's upper part and applied a load in the lateral direction to bend the joint using a hydraulic cylinder. Then a water tightness test was conducted (Fig. 8).

Revealing no water leak from the joint and

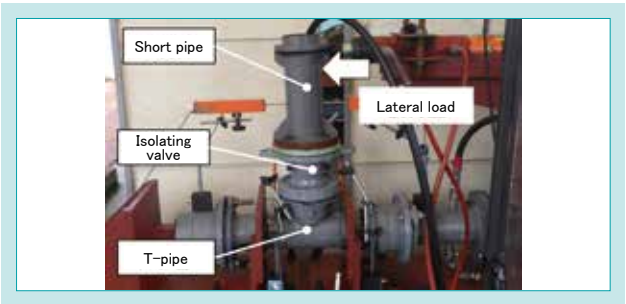



Fig. 8 Aspect of Lateral Load Test

In the tests of slip-out resistance and bending strength, the test piece was placed on the tester after being joined with test joint parts, and then predetermined loads were applied (Fig. 7). Table 3 shows the test conditions and results. We had good results in all tests.

Table 3 Result of Fundamental Performance Test

| Test | Condition | Result | |
|---|---|---|---|
| Water tightness test | 2.0 MPa kept for 5 minutes | No water leak | ○ |
| Slip-out resistance performance test | Slip-out resistance force 225 kN load | No joint abnormality | ○ |
| Bending strength test | Critical bending moment 4.4 kN · m load | No joint abnormality | ○ |

no other abnormalities under all the conditions that were set, the results showed that this joint structure met the development goals (Table 4). From this result, we concluded that this joint structure possesses sufficient water shut-off performance endurable to a lateral load simulated on the assumption of a large-scale earthquake.

Table 4 Result of Lateral Loading Test

| Condition | | | Result | |
|---|---|---|---|---|
| Lateral load condition | Water pressure | Holding time | | |
| Bending at 1.5° | 5 minutes | No water leak | No joint abnormality | ○ |
| Bending moment 20 kN · m | 5 minutes | No water leak | No joint abnormality | ○ |

4.1.4 High pressure water shut-off performance

We conducted a water tightness test under a high water pressure (5.0 MPa) that simulated an impact pressure on the assumption of an earthquake. Revealing no water leak from the joint, the results showed that this joint structure possesses sufficient water shut-off performance under high pressure (Table 5).

Table 5 Result of High Pressure Sealing Test

| Condition | | Result | |
|---|---|---|---|
| Water pressure | Holding time | | |
| 5 MPa | 15 seconds | No water leak | ○ |

## 4-2 Method of isolating valve replacement

4.2.1 Investigation for the construction method

To replace the isolating valve with no suspension of water supply, the water pressure between the T-pipe and isolating valve needs to be shut off. To achieve this purpose, we considered a water shut-off structure in which a work valve is horizontally attached to the underside of the isolating valve. We employed the following designs for the T-pipe and the work valve, which needs to be compact and lightweight to enable its assembly work in the valve box.

(1) An opening for the work valve is created at the T-pipe's receiving end in advance (Fig. 9), and the T-pipe is provided with an inner space that allows the work valve's disc to pass.

(2) The assembly of the work valve, which is dividable into two pieces, is completed by turning its both sides' bolts 90° and tightening them with the two nuts (Fig. 9).

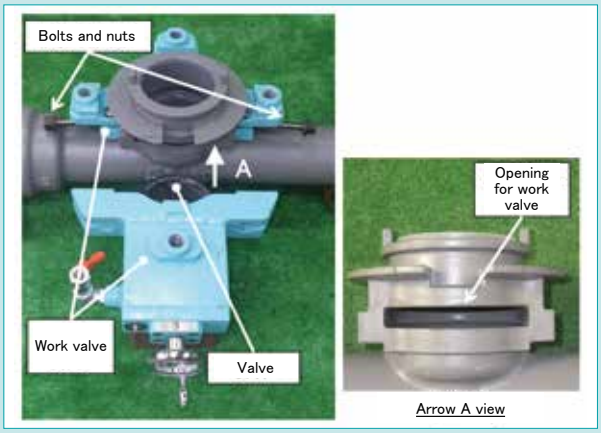



Fig. 9 Structure of Working Valve

4.2.2 Replacement procedure

The work procedure for the method of isolating valve replacement is shown in steps (1) to (4) below and Fig. 10.

(1) Fit the dividable work valve to the T-pipe's both sides and tighten them with the bolts and nuts on the both ends.

(2) Fasten the work bolts at the work valve's both sides and tighten these bolt's upper nuts to lock the isolating valve. With this, the isolating valve is prevented from moving upward with the pull-out force of water pressure.

(3) Remove the joint parts (turn stopper, split ring, retaining ring) to clear the fastening function of the T-pipe and isolating valve. Then, pull up the isolating valve to the specified position by loosening the nuts. Note that the isolating valve automatically moves upward by water pressure if the nuts are loosened.

(4) Operate the work valve to close in order to check if it shuts off water. Then, remove the nuts and fully pull up the isolating valve to remove.

To install a new isolating valve, follow the removal steps in reverse; using the work bolts and nuts, insert the isolating valve's inserting end, and assemble the joint parts. With this procedure, isolating valve replacement can be completed.

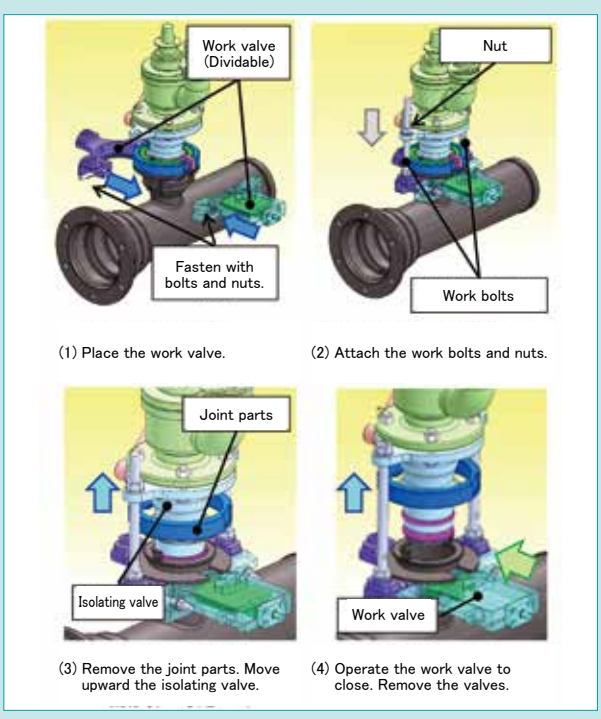



Fig. 10 Replacement Method Procedure

4.2.3 Verification test for aboveground workability

The ease of work of this method was verified. First, in a sufficient aboveground space, we performed isolating valve replacement using real facilities. The replacement, which completed within about 22 minutes, proved that there was no problem in the ease of replacement work (Table 6).

Table 6 Replacement Work Time

| Work | Time taken | Total time |
|---|---|---|
| Work valve placement | 4 minutes | 22 minutes |
| Joint parts disassembly/Work valve operation/Valve removal | 6 minutes | |
| Isolating valve placement/Joint part assembly | 6 minutes | |
| Work valve disassembly/Fire hydrant placement | 6 minutes | |

4.2.4 Verification test for ease of work in valve box

To verify the ease of replacement work in the valve box, we installed real facilities on a water pipeline meeting the conditions shown in Table 7. Then, we replaced the isolating valve (Fig. 11).

The results show the work time taken was about 33 minutes. Although, compared with work with a sufficient space, about 1.5 times more time was taken, we have attained the development target (within 60 minutes). However, there was still an unresolved issue regarding the ease of work because the manual removal and reinstallation of the isolating valve in a limited space of the valve box requires a certain degree of skill. To solve this issue and improve the ease of work, we launched a dedicated jig (Fig. 12) with which all the replacement work can be done above ground without needing to put a hand in the valve box. With the use of this dedicated jig, work time was able to be shortened about 12% (33 minutes without the jig, 29 minutes with the jig).

Table 7 Test Condition

| Item | Installation conditions |
|---|---|
| Pipeline size | Nominal diameter 150 |
| Branch pipe size | Nominal diameter 75 |
| In-pipe water pressure | 0.38 MPa |
| Covering soil | 800 mm |
| Inner diameter of the box | 600 mm |

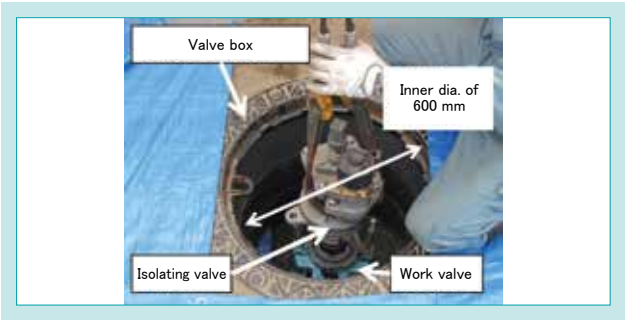



Fig. 11 Replacement Work Inside Valve Box


Fig. 12 Example of Specialized Tool

## 5. Conclusion

The development reported above has successfully led us to commercialize the flangeless T-pipe and isolating valve. The characteristics of the product are summarized below.

(1) Passing the joint performance tests under the same conditions required as earthquake-resistant ductile iron fittings, the product has been confirmed to have performance equivalent to those stipulated.

(2) The product is equipped with the water shut-off performance that can endure the lateral load and high water pressure expected during an earthquake.

(3) The product has the joint structure that does not use bolts and nuts and does not require any special tools to join it. So, this structure allows the joining work to be done easily and in a short time.

(4) With no suspension of water supply, the isolating valve can be replaced in a valve box which has an inner diameter of 600 mm.

This product started its sales from 2018 and is steadily rising in the number of units sold. In addition, its functions have been highly appreciated by some water supply utility organizations that used the product.

The damage to auxiliary equipment during past large-scale earthquakes included many cases of "damage to the internal parts of air valves" in addition to "water leaks from flange joints". Damaged parts ranged widely and were not distributive in the market, and these factors served as the cause of the retardation of water supply pipeline restoration. Investigating to get to the root of these circumstances and look for countermeasures, Kubota is making use of the findings obtained and knowledge into the improvement of air valves[4].

We believe that the above-reported development of the flangeless T-pipe and isolating valve and the improvement of air valves contribute to minimizing the damage to the auxiliary equipment of water supply pipelines when earthquakes occur.

We will continue to be committed to developing earthquake-resistant products and technologies for water supply pipelines overall to contribute to making the domestic water supply facilities more resistant.

## Contribution to SDG targets

6.1 Strengthening access to safe and affordable drinking water
Contribution by providing an inexpensive isolating valve replacement method

9.1 Development of a high-quality, sustainable and resilient infrastructure
Contribution by providing a T-pipe and isolating valve resistant to natural disasters

Reference

1) Status report on damage to pipes and auxiliary equipment in the 2011 Tohoku earthquake, Japan Water Works Association
2) Report by the investigation group for water supply facilities damage, etc. in the 2016 Kumamoto earthquake, Fact investigation group for water supply facilities damage, etc. in the 2016 Kumamoto earthquake
3) Kazuo Sugawara, et al.: pp. 598-599, "Verification of water supply facilities damage in earthquakes (II)", The 48th national water supply research presentations
4) Takuya Hongo et al.: "Investigation of the cause of damage to water supply rapid air valves in the 2011 Tohoku earthquake, and countermeasures", 2013 National Conference (Water supply research presentation meeting), pp. 700-701

# Development of Diagnostic Technology for Special Gate Valve for Petrochemical Plant

Pumps and Valves Manufacturing Dept. / Advanced Systems R & D Center

Special gate valves for petrochemical plants (hereinafter, SG-V) are the main export products of the valve business, and only two companies globally have been licensed by U.S. Lummus Technology to use the Catofin ® Process. The company has so far supplied products to 14 plants in 6 countries with a global share of 60%. In recent years, in concert with the increase in the number of years of plant operation, preventive maintenance activities to minimize the product life cycle cost have been increasing. This report describes efforts to develop diagnostic technology to diagnose the condition of the valve while the plant is in operation and to perform appropriate maintenance at an appropriate time.

【Key Word】
Petrochemical Plant, Diagnostic, Preventive Maintenance, High Temperature



Related SDGs


## 1. Introduction

PDH (Propane Dehydrogenation) plants generate propylene with the removal of hydrogen from propane at high temperature. A typical plant consists of eight reactors, and one reactor has eight SG-V units of different types. So, the total number of SG-V units is 8 × 8 = 64 units. Fig. 1 shows the positions of SG-V units installed on a reactor. These eight valves have an important role in controlling reactions. The valves, which perform their opening/closing operation every 20 minutes, are used at a design temperature of up to 704°C, which is a very severe condition. Therefore, the plant is shut down about every 2 to 3 years and the valves are removed from the pipes to perform maintenance on them. However, the maintenance of all 64 units in a limited maintenance period of usually 1 to 1.5 months is not possible. Therefore, appropriately and efficiently selecting the valves that truly require maintenance is very important. We have developed technology for the analysis of internal conditions of valves while they are under operation so that it can contribute to the stable operation of customers' plants with appropriate maintenance at an appropriate time.

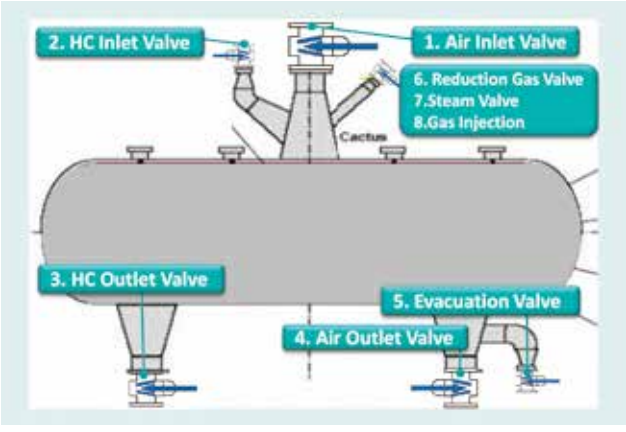



Fig. 1 SG-V Location of Reactor for PDH Plant[1)]

## 2. Development concept

This section reports the current practice with which Kubota has been providing services to customers and the new practice based on this project's diagnostic technology development.

[Current practice]

· As shown in Fig. 2, after plant shutdown, the flanges of valves are removed to determine the valves requiring repair based on the valve internal inspection (Window Inspection).

[Problems]

1). Sufficient repair is unavailable if damage is found immediately before the planned maintenance because there is little capacity room regarding the quantity of spare parts and process schedule.

2). Visual checking is limited to detecting visual valve damage and so the valves requiring maintenance may be overlooked.

[New practice]

· As shown in Fig. 2, while the plant is in operation, valve data is periodically retrieved for follow-up observation and valve condition diagnosis. Combined with the current practice, the valves requiring repair are comprehensively determined using the diagnostic results.

[Effect 1]: While the plant is in operation, we can perform periodic valve diagnosis and refer to results to grasp the overview of the valves requiring maintenance. With this, customers can prepare for the required repairs.

[Effect 2]: The accurate selection of valves requiring maintenance is improved with the comprehensive judgment of visual check and diagnostic results.

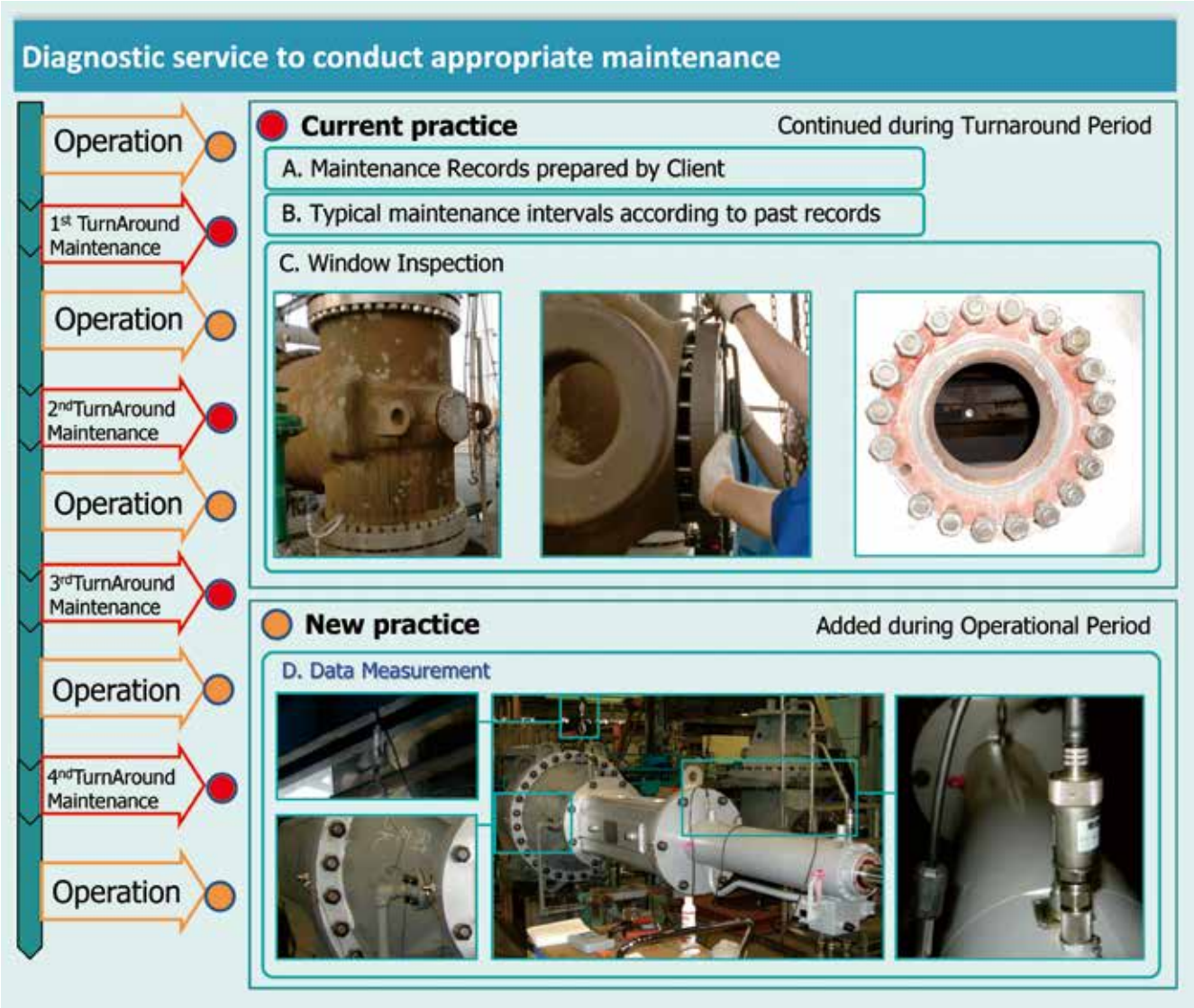



Fig. 2 Current Practice and New Practice

## 3. Technical issues to be solved

Fig. 3 shows the external view of the SG-V used in this project. Using a hydraulic gate valve, this valve performs the opening/closing operation every 20 minutes under a corrosive environment with a high temperature of up to 704°C. Because of the use in such a severe environment, deformation progresses due to the wear and thermal stress at the sliding area (indicated as "Guide, Seat" in Fig. 3). The remedial work for resulting sealing performance deterioration is the primary objective of periodic maintenance to restore stable operation.

As an example of the damage that prevents stable operation, the disc guide, which is a core component, is shown in the lower part of Fig. 3. To achieve stable operation over a long period of time, this component's sliding surface is processed with a cobalt-base special Hardfacing material called Tribaloy T800®, which is extremely durable in a high-temperature environment. However, if operated for a long time without replacement, T-800 is worn by sliding and the wear of the base material is accelerated rapidly as shown in the lower part of Fig. 3.

Our challenge is to solve the issues in development of technology that can estimate and identify the damage progressing inside the valve, as in the above case example, by externally taking data measurements while the plant is in operation in order to determine the sealing performance and stable operation, which are the most important elements of valves.

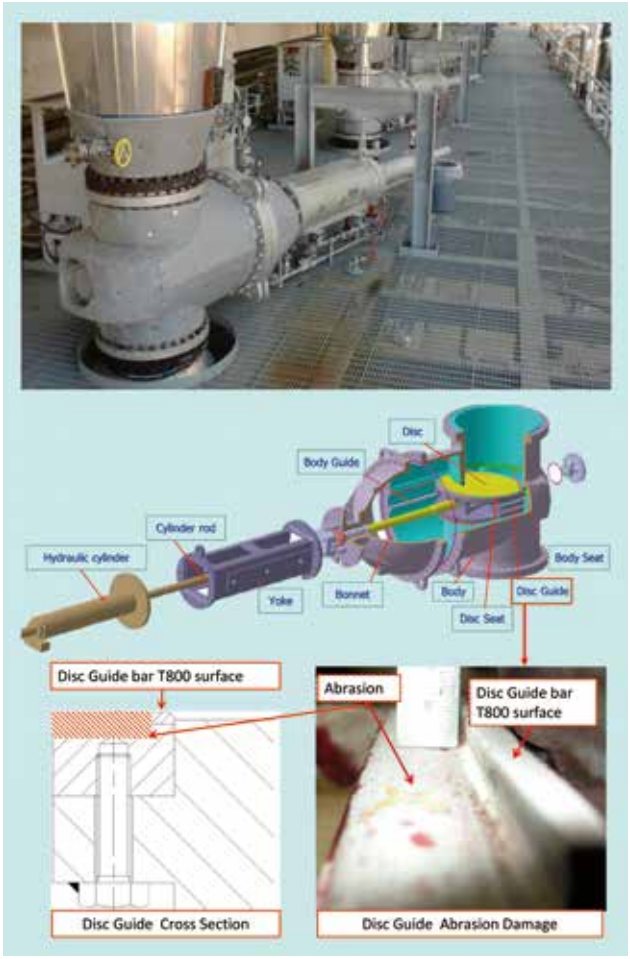



Fig. 3 Overview of Special Gate Valve and Typical Damage

### 3-1 Technical issues

[1]-1. Selection of data to be measured and accumulation:

As shown in Fig. 4, we retrieved the data of physical quantities (temperature, pressure, vibration, flow rate) that can be safely measured externally while the valve is operating and we set them as measurement items. Out of the data retrieved, the data that can be used for diagnosis is decided and accumulated.

[1]-2. Drawing up the statistical evaluation indexes for measurement data:

An example of measured data is shown in the lower part of Fig. 4. The graph shows the changes over time of a. hydraulic pressure and b. N2 bonnet pressure when the valve is closed. Raw measurement data is converted into evaluation indexes to make it in a data form that can be used for data analysis to verify and grasp the correlations and trends of the conditions of in-valve damage.

[1]-3. Verification of correlations between evaluation indexes and real conditions of damage:

Without the correlations between evaluation indexes and real conditions of damage, the diagnostic results cannot be accurately derived. So, the correlations between the evaluation indexes drawn up in [1]-2 and the real conditions of damage are verified to determine the indexes that can be used for diagnosis.

[2]. Making data analysis activities efficient:

The calculation of evaluation indexes drawn up in [1]-2 is time-consuming and so there is quite a time lag before results can be ready after measurements are taken. Results need to be ready on a timely basis on the spot where data measurement takes place.

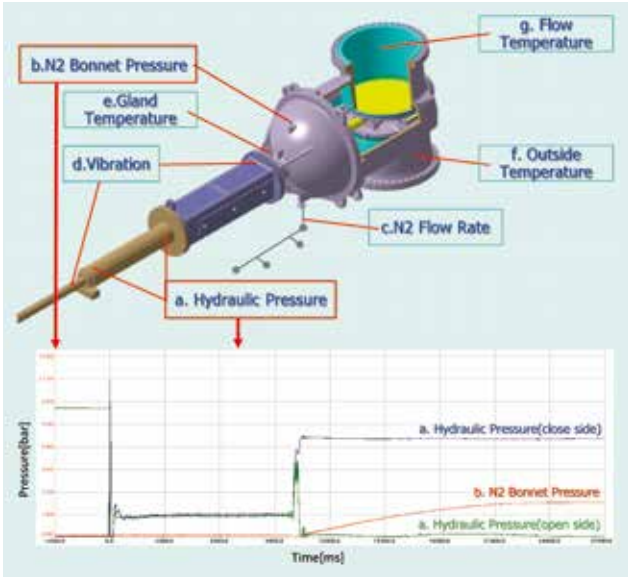



Fig. 4 Extracted Target Data for Measurement

## 4. Developed technology

### 4-1 Diagnostic technology

4.1.1 Evaluation indexes

To solve the technical issues raised in section 3, which are "[1]-1. Selection of data", "[1]-2. Drawing up evaluation indexes" and "[1]-3. Verification of correlations between evaluation indexes and conditions of damage", we need to run a cycle of measurement and evaluation and so we actually carried it out in real plants. Now that this cycle has been continued in multiple plants for about four years, we judge that these three challenges are ready to be verified at this stage, and so this section reports what has been decided for the development.

To select the data to be measured as discussed in challenge [1]-1, we took data measurements within the bounds of measurement available for test purposes. Based on them, we decided on hydraulic pressure and N2 bonnet pressure, which are relatively easy to measure and with which we can verify the correlations of sealing and stable operation performance, which has the greatest effects on valve performance (Fig. 4).

As the statistical evaluation indexes for measurement data discussed in challenge [1]-2, we identified amounts of characteristics A and B. We have confirmed a certain degree of correlations of these amounts of characteristics with the real conditions of in-valve damage discussed in challenge [1]-3.

Amount of characteristic A: [Index correlated with stable operating performance]

The differential pressures of the operating pressures measured from the hydraulic cylinder are calculated and the average movement difference is obtained. Then, thresholds are determined on the basis of the Hotelling statistics in the operation zone that is not under the influence of the cylinder cushioning. The values that deviate from these thresholds are counted as outliers (the number of red dots). The thresholds are set according to the type and diameter of the valve. In order to improve accuracy, the system is updated as deemed appropriate according to the accumulated data measurements. Fig. 5 shows the data of a valve that actually had a problem versus a valve that is operating normally. The diagram has confirmed that the outlier counts and pulse rises can be specifically classified.

Amount of characteristic B: [Index correlated with sealing performance]

As shown in Fig. 6, the friction coefficient is calculated with N2 bonnet pressure P2 and the average P1 of the operating pressure at the time of disc pullout. Based on this, the P2 value and the friction coefficient value are used as the index to evaluate sealing performance. Actual measurement has confirmed that amount of characteristic B has a correlation with C. N2 flow rate (N2 flow rate), which directly connects to the sheet performance shown in Fig. 4. Thus, amount of characteristic B has been confirmed to be appropriate as the index to evaluate sealing performance.

4.1.2 Diagnosing

As shown in Fig. 7, the amounts of characteristics are measured every six months to diagnose the internal condition.The valves that require repair are prioritized based on information, such as maintenance history, operating years and plant operation records, and also based on accumulated data, and then, the valves to be maintained are identified as shown in Fig. 8 so that appropriate maintenance can be performed at an appropriate time, thereby minimizing product life cycle costs.

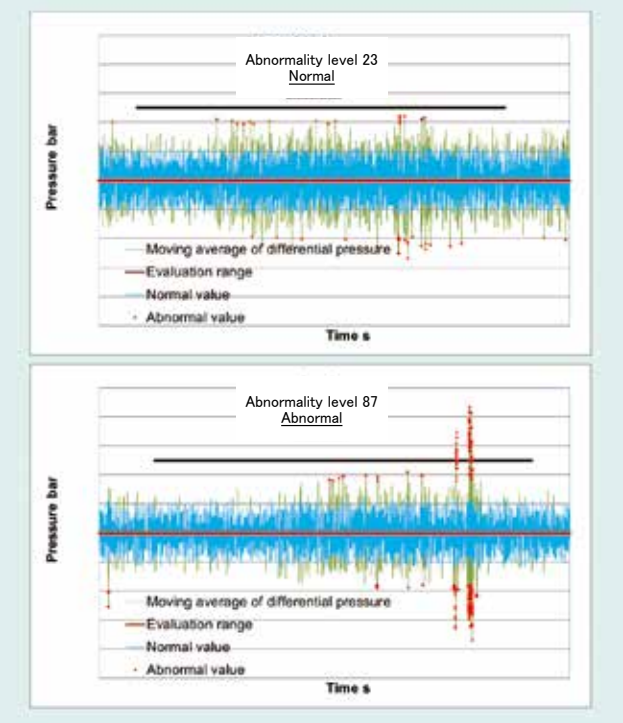



Fig. 5 Evaluation Factor for Valve Operating Function

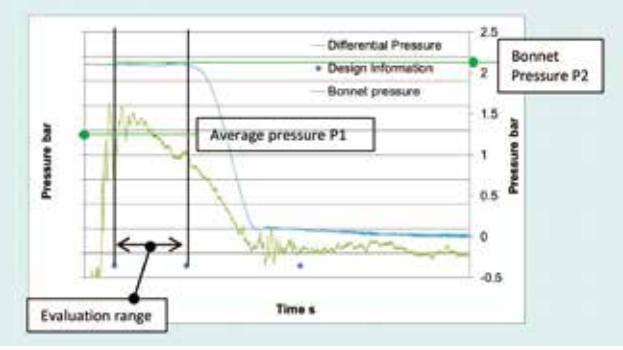



Fig. 6 Evaluation Factor for Valve Sealing Function

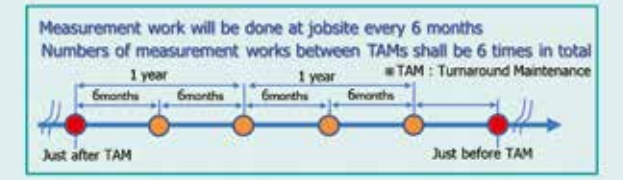
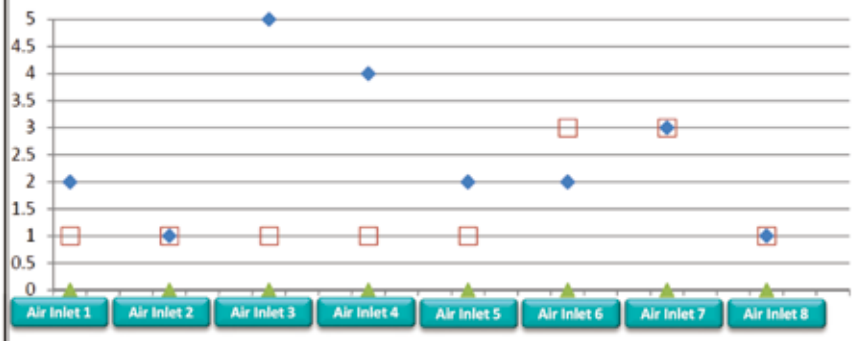



Fig. 7 General Diagnostic Interval

Evaluation and Recommendation that is based on analysis of measurement data ※

| Valve location and Reactor No | Air Inlet 1 | Air Inlet 2 | Air Inlet 3 | Air Inlet 4 | Air Inlet 5 | Air Inlet 6 | Air Inlet 7 | Air Inlet 8 |
|---|---|---|---|---|---|---|---|---|
| Body and Disc seat condition ◆ | 2 | 1 | 5 | 4 | 2 | 2 | 3 | 1 |
| Body and Disc guide condition □ | 1 | 1 | 1 | 1 | 1 | 3 | 3 | 1 |
| Result of Window Inspection ▲ | - | - | - | - | - | - | - | - |
| Priority levels of maintenance (1 Good – Bad) | 3 | 2 | 6 | 5 | 3 | 5 | 6 | 2 |
| Recommendation Result ※ | ○ | ○ | △ | △ | ○ | △ | △ | ○ |

Good 1 – Bad




○ No concern △ Recommendation of maintenance at next TAM
× Recommendation of Early Maintenance

※ These results are prepared for reference only.

Fig. 8 Priority Level Sample for Maintenance

## 4-2 Automation technology for diagnosis

### 4.2.1 Development of automation technology for diagnosis

In order to efficiently analyze data (see 3. Technical issues [2]), we have developed a system that can deliver diagnosis results at measurement sites by applying and expanding the KSIS diagnostic common platform[2]. Fig. 9 shows system configuration. Instead of a commercial data logger, a tablet PC (KSIS tablet) is used as the device handled at the site. In this way, we aimed for both flexible function addition and high portability. This KSIS tablet has already started its experiments and trial operations as a diagnostic tool for rotary machinery and bearings with the use of an acceleration sensor. As a SG-V dedicated application, we have added new functions, including automatic measurement triggering, high-speed pressure sampling, data retrieval at any intervals, precision diagnosis by statistical processing, measurement history checking, etc.

Right after the worker, who enters the site with the tablet, sets parameters, the tablet executes two types of diagnosis (sealing performance and operating performance) and uses an alert LED to report as to whether the diagnosis has identified any trouble in each of the diagnoses. Fig. 10 shows an example of a diagnostic screen on the KSIS tablet.

Diagnostic data can be wirelessly transferred to the cloud diagnostic server from the site. This method can be used as a tool for an experienced engineer to remotely check the actual condition of the site and provide support. In the future, by accumulating medium- to long-term data, more possibilities can be expected, such as the improvement of diagnostic logic accuracy and the coordination with AI and machine learning.

In addition, a permanently-installed diagnostic system, which is now under development with the KSIS diagnostic common platform, can be applied to the continuous monitoring and diagnostic system for SG-V as well.

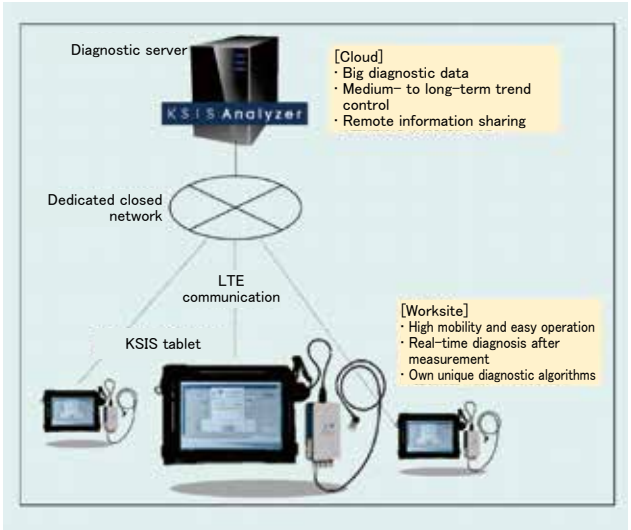



Fig. 9 KSIS Platform System Diagram

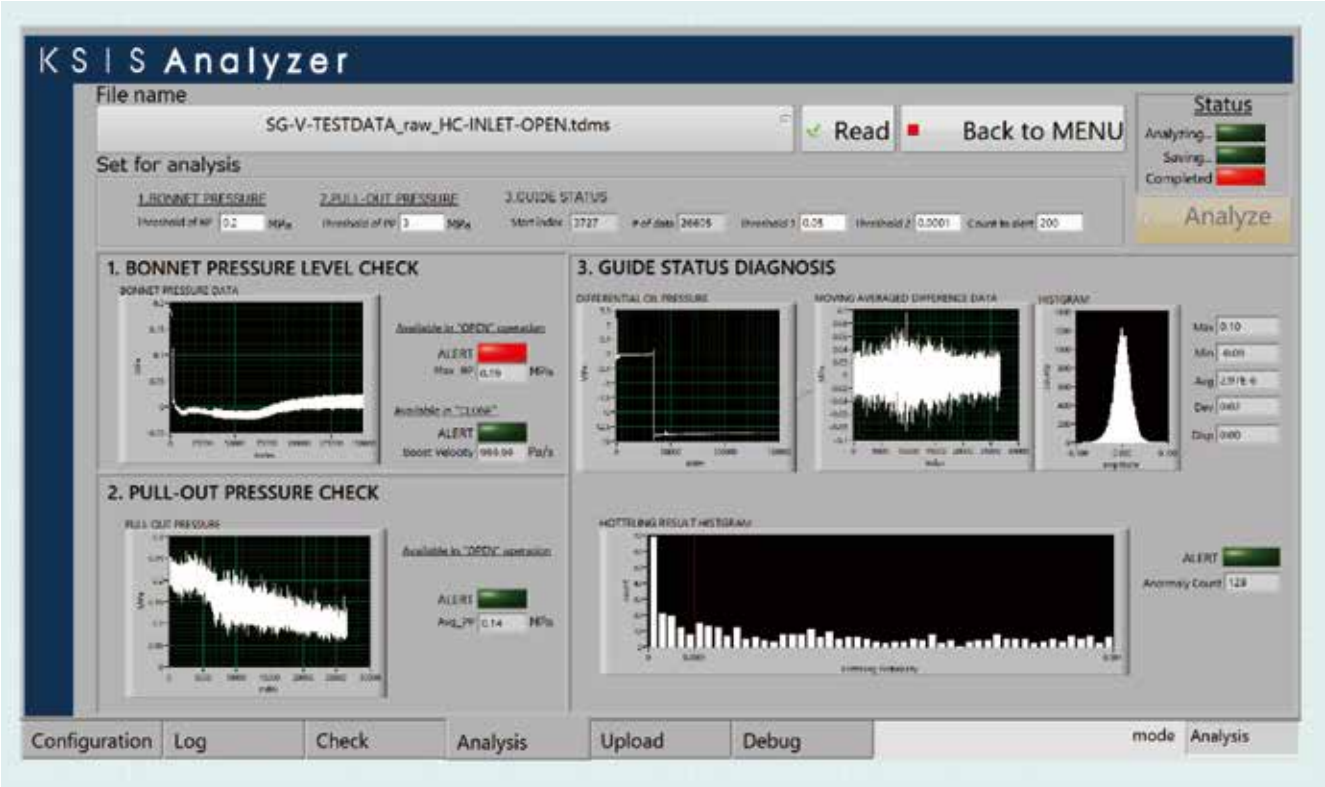



Fig. 10 Diagnostic Sample Screen of KSIS Tablet

## 5. Conclusion

This report has presented the diagnostic technology development that we are now working on. Diagnostic technology not only provides customers with preventive maintenance effects and minimizes the life cycle cost of their products, but also greatly contributes to enhancing the competitiveness of SG-V products by producing various side benefits including the following effects:

[1]. Optimization of valve operating power

[2]. Improvement of valve sealing performance under high temperature environment

[3]. Change of material properties to solve the longstanding valve damage issue

In the future, we will work to offer technological solutions through PR activities to licensors, and also will roll out our techniques to other models in the petrochemical market. In addition, since periodic data measurement, which is conducted every six months at present, cannot respond to rapid changes in the situation, we will promote activities to develop remote diagnosis techniques that achieve real-time data collection and monitoring.

## Contribution to SDG targets

9.1 Development of a high-quality, sustainable and resilient infrastructure
Contribution to stable plant operation through preventive maintenance activities using diagnostic technology

12.2 Sustainable management and efficient use of natural resources
Contribution to the efficient use of raw materials by extending product life

Reference

1) Hisham A. Maddah : A Comparative Study between Propane Dehydrogenation (PDH) Technologies, American Scientific Research Journal for Engineering, Technology, and Sciences (2018) Volume 45, No 1, pp 49 - 63

2) Yasutaro Yoshida, Daishi Fujiyama, Masashi Takahashi: "Valve Diagnosis by Kubota IOT Solution System KSIS", Valve Technique, No. 79, (2017), pp. 30-33

# Development of Combustion Analysis Technologies for Municipal Waste Incinerator

Water and Environment R&D Dept. Ⅰ / Water and Environment R&D Dept. Ⅲ
KUBOTA ENVIROMENTAL SERVICE CO.,LTD.Solid Waste Engineering Dept.

In order to develop a municipal waste incinerator which met the customer requirement for rapidly reducing the environmental burden and lifecycle cost (LCC), utilizing combustion analysis technologies has been imperative. However, there were two problems in conducting combustion analysis. First, it was impossible to take into account several hundred combustion reactions that take place inside an incinerator. Second, 3D numerical analysis, which was necessary to examine the performance of the actual incinerators, requires huge computational resources. To solve these problems, identifying the main combustion reactions and choosing an adequate numerical combustion model were conducted based on the results of a refuse-derived fuel (RDF) combustion test in the experimental reactor. As a result, it was found that 3D numerical analysis could be applied in incinerator design. The validation results for this combustion analysis method in an actual incinerator test are also described in this article.

【Key Word】
Municipal Waste Incinerator, Combustion Analysis, Combustion Reaction, Combustion Test, Three-dimensional Analysis



Related SDGs


## 1. Introduction

Municipal solid waste incinerators produce NOx (nitrogen oxides) as a result of combustion. For NOx, which are substances restricted in the Air Pollution Control Act, there are combustion techniques, such as exhaust gas recirculation (EGR), and NOx decomposition techniques, such as catalytic denitration (SCR) and non-catalytic denitration (SNCR). In recent years, other plant manufacturers have been developing high SNCR efficiency technology combined with combustion technology such as EGR in order to meet both of the two customer needs, which are environmental performance improvement and life-cycle cost (LCC) cutdown (Fig. 1). Now, to develop new technology that will be applied to municipal solid waste incinerators, the use of real incinerators is indispensable for tests and verifications. However, making a prototype of a real incinerator is not realistic. Even if an existing incinerator is used, a great deal of effort and cost will be required for facility modifications and experiments, and the number of and period of experiments available will be limited as well. To speed up the development of technology that matches the above mentioned customer needs, we needed to develop combustion analysis technology to solve these problems.

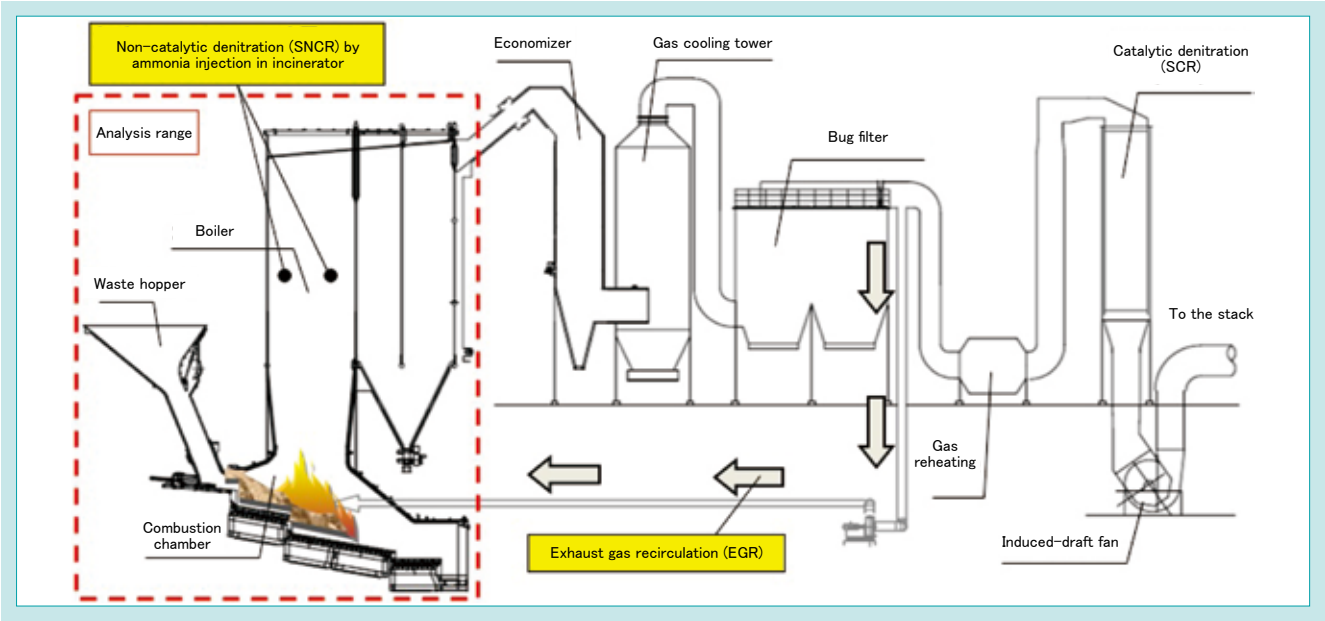



Fig. 1 Outlined Scheme of the Municipal Waste Incinerator

## 2. Development concept and goals

### 2-1 Development concept

We placed the following three requirements as the development concept to achieve the two customer needs - environmental performance improvement and LCC cutdown.

2.1.1 Reduction of calculation time in combustion analysis

(1) Perform a basic combustion test to narrow down the combustion reactions necessary for proper combustion analysis.

(2) Create calculation meshes that can stably carry out combustion analysis, which involves highly variable heats and flows, and can cover the whole incinerator as an analysis range.

2.1.2 Improvement of accuracy in in-incinerator temperature prediction

(1) Draw a combustion reaction formula from the earlier mentioned combustion test and determine the reaction rates to be reflected in this formula.

(2) Make the analysis model reflect the radiative heat transfers resulted from a combustion reaction and the heat losses through the incinerator's wall surfaces such as boiler heat absorption.

2.1.3 Development of combustion analysis technology that can predict and evaluate incinerator performance

Develop a combustion analysis technology that can predict and evaluate incinerator performance starting from the real incinerator's conceptual stage by enabling the prediction of exhaust gas flow and temperature on a real incinerator scale.

### 2-2 Development target value

Table 1 shows the target values for the development. From the viewpoint of achieving a combustion analysis that can be utilized in the design of real incinerators, we set up goals for the analysis range, calculation time, and in-incinerator temperature prediction for real incinerators.

(1) Analysis range
Analysis range with which results necessary for design verification can be provided for the design and testing of a real incinerator

(2) Calculation time
Calculation time which enables a quick response to design changes and additions

(3) In-incinerator predicted temperatures
Values qualified to be used for the temperature prediction of to-be-evaluated surfaces important as product performance based on the test data of the real incinerator

Table 1 Development Target (EGR Condition)

| Item | | Target values |
|---|---|---|
| Analysis range | | From the real incinerator's waste layer top to the boiler's pass 2 |
| Calculation time | | Within 1 day per condition (128 parallel cores) |
| In-incinerator predicted temperature*1 (Surface average) | Evaluation plane [1] | 950 – 1150°C |
| | Evaluation plane [2] | 800°C or more |
| | Evaluation plane [3] | 600°C or less |

*1 See Fig. 3 for the locations of evaluation planes [1] to [3].

## 3. Technical issues to be solved

In order to achieve the development concepts and target values, we proceeded with the development while specifying the following three points as technical issues to be solved.

[1] Narrowing down the combustion reactions and reflecting them in combustion analysis

Considering too many combustion reactions to place emphasis on enhanced prediction accuracy will take an enormous amount of calculation time (3 days or more per condition). To reduce the calculation time and improve prediction accuracy at the same time, we needed to perform a combustion test using samples that simulated municipal solid waste so that we were able to narrow down the combustion reactions to be reflected in combustion analysis.

[2] Creating a three-dimensional analysis model and optimizing calculation conditions

Calculation easily diverges with some operation conditions where the rate of gas injection reaches several tens of m/s. Another problem is that proper temperature prediction is not possible with conventional analysis methods, which handle the high temperature in the incinerator.

[3] Verification of the effectiveness by the real incinerator test

To apply a combustion analysis to the design of a real incinerator, its effectiveness must have been verified with a test that actually uses the real incinerator and real municipal solid waste. So, we verified, through solving our challenges in SNCR tests, the effectiveness of the combustion analysis that we developed.

## 4. Developed technology

### 4 - 1 Narrowing down the combustion reactions and reflecting them in combustion analysis

#### 4.1.1 Narrowing down the combustion reactions

The real incinerator has many combustion reactions that the combustion of municipal solid waste produces, but it is not realistic to consider all of them. So, we narrowed down the combustion reactions with a basic combustion test. Because the handling of the real municipal solid waste is difficult and so is not suitable for a combustion test, we selected refuse derived fuel (RDF) as the simulation sample. Fig. 2 shows the overview of the combustion test with RDF. We took measurements of the pyrolysis gas of RDF (φ16 to 17 mm) where the experiment device was kept under an internal temperature of 900°C. Table 2 shows the measurement results of pyrolysis gas. The amount of gas generated is the most with $H_2$, but $H_2$ burns fast to a great degree in comparison with CO and $CH_4$. Also, $CH_4$ is often modeled to be oxidized with $CO_2$ and $H_2O$ after going through CO and $H_2$. So, we turned our attention to the combustion reaction of CO as the representative of the reaction range and reaction rate.

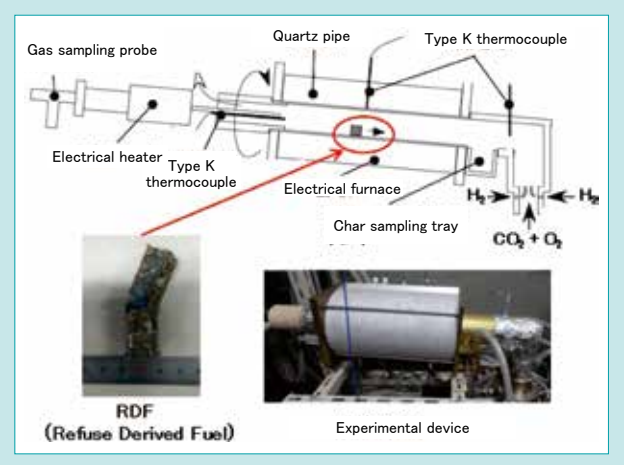



Fig. 2 RDF Combustion Test Device

Table 2 Result of Pyrolysis Analysis

| Item | Unit | $H_2$ | CO | $CH_4$ |
|---|---|---|---|---|
| Volume % of gas generated | % | 56 | 33 | 11 |

#### 4.1.2 Reflection in combustion analysis

From the above considerations, we modeled the combustion reaction of municipal solid waste based on the reaction mechanism of coal combustion[1]. Using the analysis result values of municipal solid waste shown in Tables 3 and 4 except ash, S and Cl, we derived the overall reactions in two steps shown in equations (1) and (2) and reflected them in the combustion analysis.

$$C_{1.09}H_{1.83}O_{0.73}N_{0.029} + 0.64O_2 \rightarrow 1.09CO + 0.92H_2O + 0.014N_2 \quad (1)$$

$$CO + 0.5O_2 \rightarrow CO_2 \quad (2)$$

Note that the combustible gas ($C_{1.09}H_{1.83}O_{0.73}N_{0.029}$) shown in equation (1) was provided with the enthalpy of formation corresponding to the lower heating value shown in Table 3. To simulate the combustible gas that arises from the waste layer, we used the combustible gas ($C_{1.09}H_{1.83}O_{0.73}N_{0.029}$) prepared for this analysis.

As the chemical reaction rate applied to equation (2), the Arrhenius reaction formula[2] shown in equation (3) was used.

$$-d[CO]/dt = 3.98 \times 10^{16} \cdot [CO]^{1.0} \cdot [H2] \cdot [O2]^{0.25} \cdot e^{-4000/RT} \quad (3)$$

Table 3 Result of Chemical Composition Analysis of Municipal Solid Waste

| Item | Unit | Data |
|---|---|---|
| Water | wt−% | 34.21 |
| Volatile | wt−% | 52.76 |
| Ash | wt−% | 13.03 |
| Lower heating value | kJ/kg | 9211 |

Table 4 Result of Element Analysis of Municipal Solid Waste

| Item | Unit | Data |
|---|---|---|
| C | wt−% | 25.36 |
| H | wt−% | 3.58 |
| O | wt−% | 22.64 |
| N | wt−% | 0.78 |
| S | wt−% | 0.03 |
| Cl | wt−% | 0.34 |

## 4 - 2 Creating a three-dimensional analysis model and optimizing calculation conditions

### 4.2.1 Creating a three-dimensional analysis model

Fig. 3 shows the schematic of the three-dimensional analysis model. It is modeled on a scale equivalent to that of the real municipal solid waste incinerator (26.6 m in height, 13.8 m in length, 3.5 m in width). The calculation domain starts from the waste layer top to the boiler's pass 2. To confine computational divergence, we used hexahedral meshing, which minimizes numerical divergence and reduces the number of meshes used, in all computational domains, and increased the number of meshes placed for the combustion chamber, into which the secondary air and EGR are injected. The first-time through quality of mesh is 0.59 or higher, and the number of meshes is approximately 6 million.

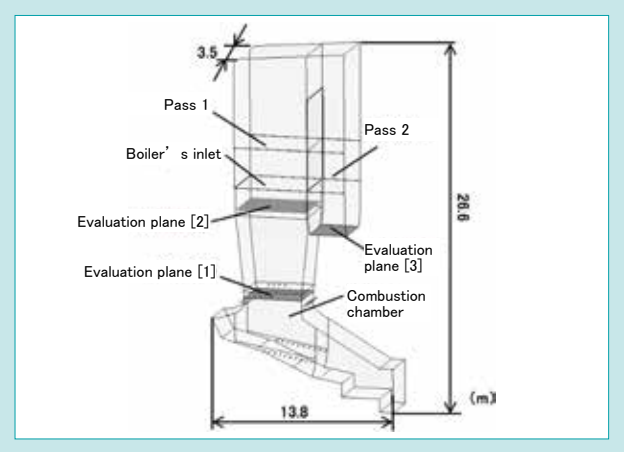



Fig. 3 Schematic of Three-dimensional Combustion Analysis Model

### 4.2.2 Optimization of calculation conditions

Fig. 4 shows the positions of the gas injection ports. The injection of primary air is distributed among the dry, combustion and post-combustion zones. The secondary air is injected through eight ports each on the front and rear wall sides (all used in the analysis) and four ports each on the right and left wall sides (the two ports each enclosed in red were used for the EGR conditions in the analysis), and the EGR gas is injected through ten ports each on the right and left wall sides (the four ports each enclosed in red were used for the EGR conditions in the analysis). The amount of combustible gas each in the dry zone, combustion zone and post-combustion zone was hypothesized from experimental data, and as the injection condition, we set up the gas mixture containing the primary air.

In this analysis, steady-state analysis with RANS (Reynolds Averaged Numerical Simulation) was carried out using Fluent19.2, which is general-purpose thermo-fluid analysis software. As the turbulence model, the Realizable k-ε model was used. In addition, for the turbulent combustion model, a finite-rate reaction model was applied in which the smaller of the chemical reaction rate or the turbulent mixing rate is given priority, and the reaction formula shown in equation (3) was incorporated.

In the incinerator, the radiative heat transfer incident to a combustion reaction of municipal solid waste occurs. Also, as the generated exhaust gas contains a lot of water vapor and carbon dioxide, we need to consider the absorption rates of these gases. In this analysis, a discrete ordinates model was used to model a radiative heat transfer, and a gray gas model was used for the absorption rates of water vapor and carbon dioxide, which affect radiation. In addition, the real incinerator has heat losses that occur through the incinerator's wall surfaces, such as the absorption of boiler heat. So, we set the wall surface conditions estimated from experimental data, etc. to consider the heat losses that occur through the incinerator's wall surfaces.

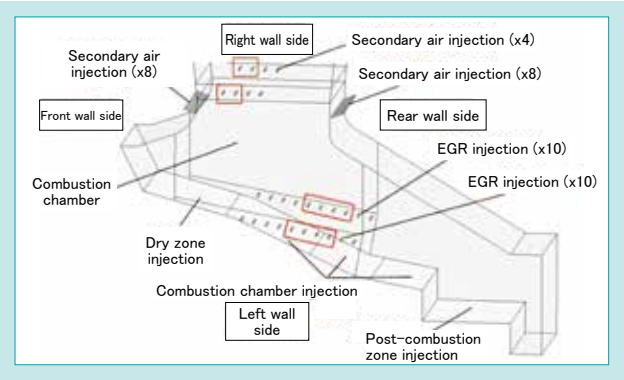



Fig. 4 Positions of Gas Injection Ports

4.2.3 Analysis results of the evaluation planes

Table 5 shows the analysis results of the evaluation planes. As shown in Table 5, the attainment of the development target values has been verified using the combustion analysis technology that we developed.

Fig. 5 shows the comparison of temperature distributions. Result (a) refers to the normal operation without EGR, and result (b) shows the results of a low excess air ratio run under EGR conditions. The area of in-furnace high temperature in (a) appears to be colder in (b), which shows us that the effectiveness of EGR conditions can be visualized.

Table 5 Combustion Analysis Summary and the Result (EGR Condition)

| Item | | Analysis result |
|---|---|---|
| Analysis range | | From the real incinerator's waste layer top to the boiler's pass 2 |
| Calculation time | | Within 1 day per condition (128 parallel cores) |
| In-incinerator predicted temperature (Surface average) | Evaluation plane [1] | 1060℃ |
| | Evaluation plane [2] | 850℃ |
| | Evaluation plane [3] | 580℃ |

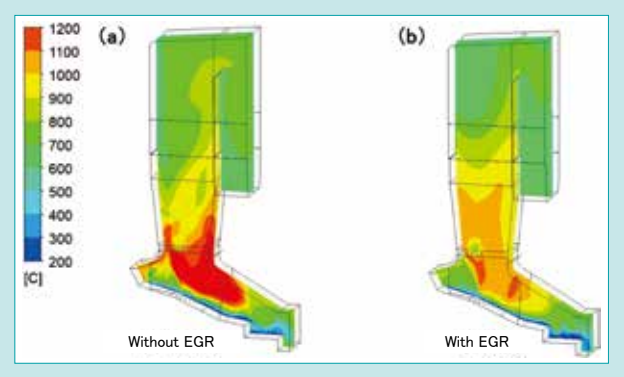



Fig. 5 Comparison of Temperature Distribution in Incinerator

## 4 - 3 Verification of the effectiveness by the real incinerator test

4.3.1 SNCR test and analysis result comparison

As an example of effectiveness verification of our developed combustion analysis during a test using a real incinerator and real municipal solid waste, this report presents the determination of SNCR test operation conditions. Fig. 6 shows the schematic of the SNCR test. In the SNCR test, through the $NH_3$ injection nozzles (4 places) that face each other, $NH_3$ is blown into toward the exhaust gas, which heads for the incinerator's outlet from the upper part of the combustion chamber. $NH_3$ reduces NOx with the denitration reaction shown in the following equation (4).

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O \quad (4)$$

The reaction shown in the above formula (4) requires a temperature of 800°C or more. On the other hand, if the temperature is 1,000°C or more, $NH_3$ is oxidized and discharged as NOx. So, the process is highly susceptible to temperature. In addition, if injected excessively, unreacted $NH_3$ is released and this causes white smoke. This is called leak $NH_3$. This SNCR test identified the issue that NOx was reduced but the concentration of leak $NH_3$ at the incinerator's outlet was high, exceeding the target value of 5 ppm. In addition, the NOx measurement at the incinerator's outlet identified the phenomenon that NOx is more reduced on the combustion chamber side than where $NH_3$ is injected. To elucidate the cause of this phenomenon, this analysis visualized the flow of exhaust gas in the incinerator. Fig. 7 shows the analysis results of exhaust gas flow in the upper part of the combustion chamber. As shown in Fig. 7, we found that the upper part of the combustion chamber had a vortex flow that extended to the boiler's pass 1. Fig. 7 is the plot of the earlier-mentioned NOx measurements. From the results of this analysis, we inferred that this phenomenon was possibly caused by unreacted $NH_3$ stagnant in the vortex, and this made the reaction of NOx and $NH_3$ in the exhaust gas insufficient and then let the unreacted $NH_3$ flow out from the incinerator's outlet.

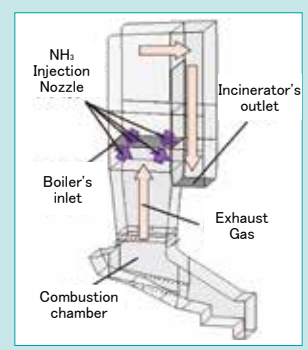



Fig. 6 Scheme of SNCR Test in Actual Incinerator

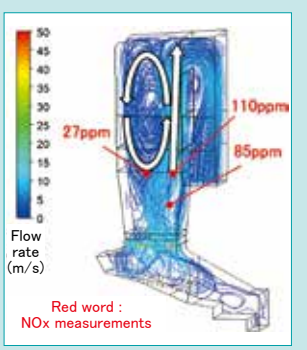



Fig. 7 Exhaust Gas Flow in the Upper Part of the Combustion Chamber

4.3.2 Study for vortex prevention measures

Fig. 8 depicts the velocity vector of the secondary air injection. In a real incinerator, the rate of secondary air injection reaches several tens of m/s with some operation conditions to accelerate the agitation mixing in the furnace (combustion chamber) and reduce the generation of carbon monoxide and NOx. Fig. 8 shows that the secondary air flows, which flow in opposite directions from the front wall and rear wall sides, collide with each other in the center of the combustion chamber. We formulated a hypothesis that the collision of the uniform flows of secondary air produces a sheet-like flow that passes close to the rear wall side, and because of this, a large vortex forms. Using this hypothesis to investigate into the measures for vortex prevention, we changed the method of secondary air injection for the following two purposes.

[1] Secondary air with variations in intensity of injection (Promotion of mixing)

As shown in Fig. 9, the colliding points of the secondary air flows that move in opposite directions were staggered by variations in intensity of injection in order to promote mixing. This arrangement dispersed the flows of the secondary air and thereby changed air movement so that fewer vortexes were formed.

[2] Air volume ratio control (Exhaust gas rectification)

We controlled the secondary air volume ratio of the front wall to rear wall sides so that the measurement temperatures (●) on the front wall (A) and rear wall (C) sides of the boiler's inlet shown in Fig. 10 were to be almost the same. With this, the rectification of exhaust gas was attempted.

Note that [Condition A] refers to the operation conditions before measures [1] and [2] were taken whereas [Condition B] refers to those after these measures.

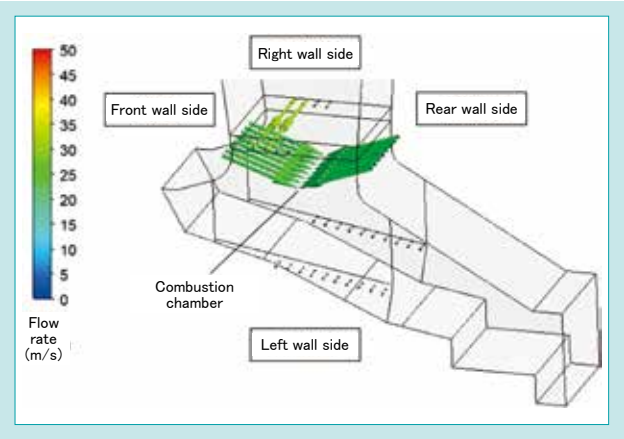



Fig. 8 Velocity Vectors Around Secondary Air-injection Ports

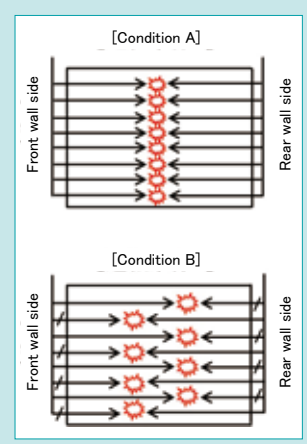



Fig. 9 Comparison of Two Secondary Air-injection Methods

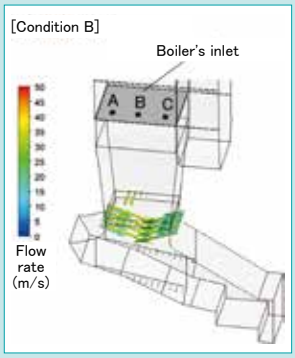



Fig. 10 Air volume ratio control

4.3.3 Analytical verification of effectiveness of vortex prevention measures

Fig. 11 shows the effectiveness of vortex prevention measures. The diagram shows the flow of exhaust gas in the combustion chamber's upper part (a) and also the temperature distribution at the boiler's inlet (b). The results show that the vortex prevention measures with [Condition B] have resolved the generation of exhaust gas vortexes. With these measures, exhaust gas can be expected to flow between the front and rear walls with no formation of vortex while the $NH_3$ injection nozzles shown in Fig. 6 are used. As for the temperature distribution at the boiler's inlet, [Condition A] forms an ununiform temperature distribution where the high-temperature zone is unbalanced to the rear wall side (C) and the low-temperature zone of below 800°C spreads from the center (B) to the front wall side (A). Contrarily, we see [Condition B] can form more uniform temperature distribution with a smaller low-temperature range of below 800°C. From this result, we estimated that the incinerator is capable of a wider distribution of the temperature range (800°C or more) suitable for the denitration reaction shown in equation (4).

4.3.4 Verification of leak $NH_3$ reduction effectiveness

Table 6 shows the SNCR test results of the temperature at the boiler's inlet and leak $NH_3$ concentration, which were measured for both cases where the vortex prevention measures were removed ([Condition A]) and used ([Condition B]). With [Operation A], the high-temperature zone is unbalanced to the rear wall side (C) as with Fig. 11, and on the front wall side (A), a low-temperature zone of below 800°C is formed. It can be surmised that the denitration reaction is insufficient due to this thermal flow condition and so the amount of leak $NH_3$ easily exceeds 5 ppm. As for [Condition B], the front wall side (A), the center (B) and the rear wall side (C) all exceed 800°C, and a uniform temperature distribution is formed as with the analysis results in Fig. 11, showing that the thermal flow condition suitable for the denitration reaction is produced. The concentration of leak $NH_3$ is 1 to 2 ppm and so we have achieved the target value of 5 ppm or below. In addition, using [Condition B], we conducted NOx measurement as in Fig. 7. As results, we confirmed that the phenomenon that NOx is more reduced on the combustion chamber side than where $NH_3$ is injected does not occur (Fig. 11).

Solving the leak $NH_3$ issue that arose in this SNCR test of a real incinerator has demonstrated that we have successfully verified the effectiveness of the combustion analysis technique that we developed.

Table 6 Verification of Reduction in Leaked $NH_3$

| Item | Boiler entrance temperature (° C) | | | Leak$NH_3$ (ppm–12%$O_2$) |
|---|---|---|---|---|
| | Front wall side (A) | Center (B) | Rear wall side (C) | |
| [Condition A] | 742～768 | 825～836 | 842～864 | 3～10 |
| [Condition B] | 803～827 | 873～882 | 844～856 | 1～2 |

*1 Results of three measurements

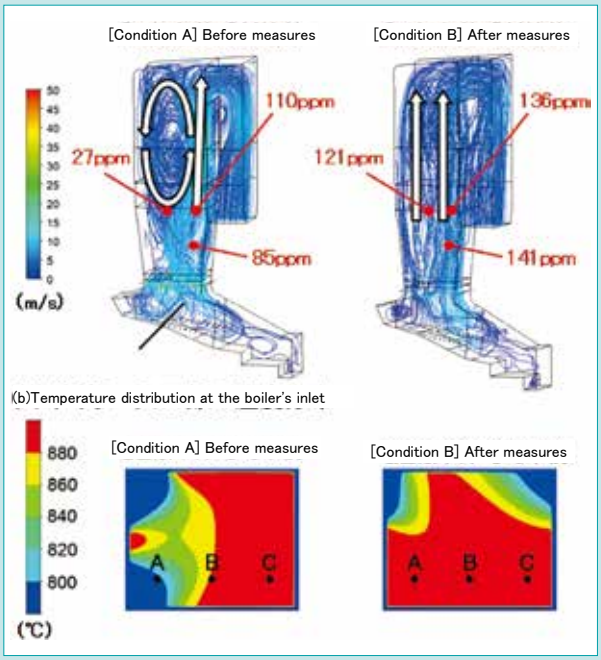



Fig. 11 Suppression Effect of Vortex Generation

## 5. Conclusion

In this project, we used a combustion test with samples that simulated municipal solid waste, then narrowed down the combustion reactions, and reflected the narrowed down results in a combustion analysis model, and thus our two technical challenges have been achieved - the reduction of calculation time and the improvement of temperature prediction accuracy. And, in the SNCR test using a real incinerator and real municipal solid waste, the effectiveness of the combustion analysis technique that we developed has been verified. At present, this combustion technique is being used to carry out design investigations for the designing and test planning of real incinerators. The verification of municipal solid waste incinerators is difficult to accommodate prototype analysis. To respond to a strong demand for the prediction of product performance by analysis, the analytical techniques that enable the determining of real phenomena need to progress further. Aiming more sophistication, we will draw issues about municipal solid waste incinerators from various viewpoints such as higher efficiency and energy-saving to solve them and thereby contribute to not only to social sustainability, but also the conservation of the global environment.

## Contribution to SDG targets

7.a Promoting investment in energy related infrastructures
Contribution to the reduction of greenhouse gases by efficiency improvement of waste-to-energy generation

12.4 Achieving waste management throughout the product life cycle
Contribution to the reduction of air contaminant emissions by advanced exhaust gas treatment

Reference
1) Ansys® Fluent, Release 2019 R2, Help System, 17.4.5. Modeling coal combustion using a diffusion combustion model, Fluent user's guide, ANSYS, Inc.
2) Masatoshi Hirokawa et al., Thermal flow analysis of municipal solid waste incinerators (Report No.2), Symposium on environmental engineering, Lecture papers, Vol.3 (1995)

# Development of the Full-speed, Any-water Level Operation Function and Diagnostic Function for Pump Gate System

Water and Environment R&D Dept. Ⅰ

In recent years, flood damage due to localized torrential rain has increased. As urgent action is required, integrating the pump gate that contains the drainage pumps with the water stop gate in an existing waterway is attracting attention because of the advantages of shortening the construction period and reducing costs. On the other hand, depending on the conditions, the pump gate has the following problems: the water level fluctuates over a wide range and the frequency of operation suspension becomes excessive, water cannot be stored in fine weather, and management operations cannot be performed. Kubota has contributed to the widespread use of pump gates, but has developed new functions to solve these problems and to provide more reliable equipment. In this paper, we introduce the details and effectiveness of the developed full-speed, any-water level operation function and the diagnostic function that can ascertain the soundness of the pump in idle operation.

【Key Word】
Localized Torrential Rain, Flood Prevention, Pump Gate System, Submergible Pump, Management Operation

Related SDGs


## 1. Introduction

According to figures released by the Japan Meteorological Agency, a precipitation of 80 mm or more per hour, which is classified as “severe rainfall”, increased about 1.7 times more during a recent 30-year period[1], With these localized torrential rainfalls on the increase, flood hazard risks are rising.

A pump gate is a rainwater drainage facility that has an underwater pump incorporated in the gate. It packages the functions of pumping, water stop, etc. into one-piece structure. Basically, a pump gate, debris remover and more equipment are installed as auxiliary systems on an existing waterway. Unlike conventional rainwater drainage facilities, pump gates do not require the building of bypass waterways and so do not need to secure a broad land. With shorter construction periods and cost advantages owing to them, pump gates are employed in small to medium rainwater drainage facilities (Figs. 1 and 2).

On the other hand, sine the pump is installed in a narrow waterway, the water level changes intensely on the pump’s inlet side and this may cause a chattering phenomenon, which shuts down pump operation extremely frequently.

As a typical remedy, the rotational speed of the pump is controlled with an inverter. However, inverters are expensive, and on top of that, relatively short-lived, and also have a high risk of trouble. To solve this problem, we needed to lower the frequency of operation shutdown with the use of full-speed, any-water level operation, which lets the pump continue operating at full speed even when the water level on the inlet side is reduced.

The appropriate upkeep of rainwater drainage pumps is important in order to maintain their functions because, if functionality is lost accidentally, the social and economic effects that would have on the surrounding area are enormous.

This facility is for emergency use and is not usually put into operation unless the water level of the river greatly

rises with heavy rain. Therefore, it is a fundamental principle that management operation be performed on a regular basis to confirm if it operates correctly. Pump gates, however, cannot store water due to the structure and so management operation is often difficult. Even where management operation is possible, determining the status of pumps was difficult because the conditions of pump operation changed greatly within a short period of time.

To solve these challenges, we developed the full-speed, any-water level Operation function and the diagnostic function.

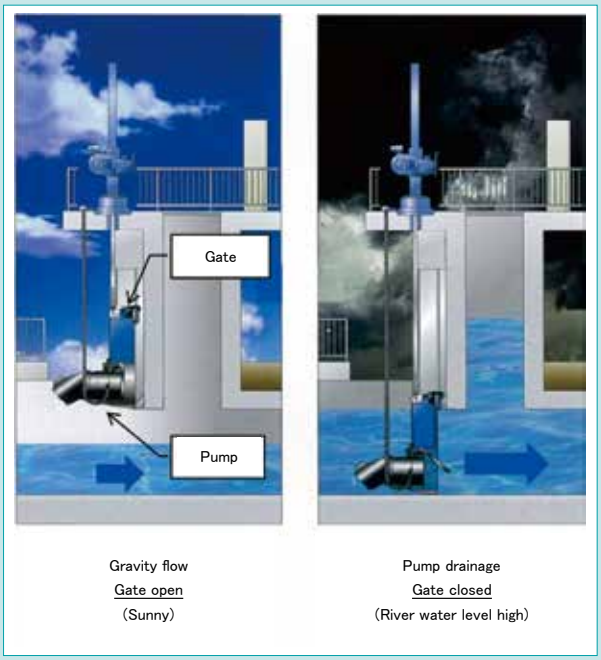



Fig. 1 Operation Method of Pump Gate

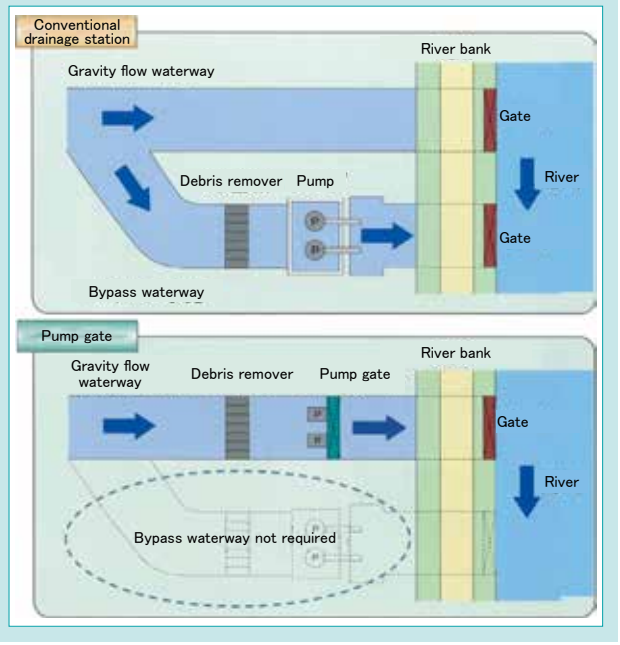



Fig. 2 Shape of Conventional Drainage Pump Station and Pump Gate

## 2. Development concept and goals

### 2-1 Development concept

2.1.1 Full-speed, any-water level Operation function

Even when the water level at the pump's inlet is reduced, the pump continues operating at full speed while changing operation conditions by taking in an appropriate amount of air depending on the water level. Drainage is resumed if the water level rises again.

[1] Solving the chattering phenomenon. No use of an inverter.
[2] Smooth shifting of operation conditions

2.1.2 Diagnostic function

In order to prevent serious malfunctions that may disable drainage, the soundness of the pump is diagnosed using the data taken from no-water management operation, which is performed under the condition that the gate is kept raised and the pump is kept idling.

[1] Realization of no-water management operation
[2] Pump soundness diagnosis from operation data
[3] Inexpensive and simple system

### 2 - 2 Development goals

2.2.1 Full-speed, any-water level Operation function

[1] The pump is kept operating at full speed, and at the same time, the operation modes are shifted continuously between drainage standby, air-water mixture drainage and full drainage operations in accordance with increases or decreases in the water level at the inlet. During this, no instability must result.
[2] Drainage standby operation can continue for 1 hour or more.

2.2.2 Diagnostic function

[1] Idling for the time required to carry out a diagnosis is possible.
[2] Soundness diagnosis is possible against major trouble risks through management operations without water.
[3] System configuration requiring no coordination with monitoring facilities.

## 3. Technical issues to be solved

3.1.1 Full-speed, any-water level Operation function

Kubota has an excellent track record for the full-speed, any-water level operation of vertical shaft on-land pumps since about 30 years ago but did not have any previous track record for underwater pumps. The technical challenges are listed below.

[1] Smooth shifting of operation conditions by air intake

[2] Solutions to abnormal vibration and heat

3.1.2 Diagnostic function

Kubota has been offering troubleshooting systems for vertical shaft on-land pumps for about 20 years but needed a diagnostic algorithm suitable for the idling of underwater pumps. The technical challenges are listed below.

[1] Trouble risk analysis

[2] Establishment of diagnostic methods

[3] Structure of a diagnostic system

## 4. Developed technology

### 4 - 1 Full-speed, any-water level Operation function

4.1.1 Smooth shifting of operation conditions

The achievement of full-speed, any-water level operation requires the control of the drainage amount while the pump keeps its operation at full speed. For this, the intake of air is the easiest method to adopt. The structure form we have adopted is shown in Fig. 3, where notches are added to the rear wall of the inlet cover to establish air-water mixture operation; the notches increase the amount of air intake gradually in accordance with decreases in the water level, and thereby lower the amount of drainage. The advantages of this method include that load changes are made smaller thanks to the gradual shifting of operation conditions and that the reduction in the amount of drainage in response to decreases in the water level can serve to avoid the generation of adverse vortexes, which are produced when the water level is low. After the water level is further lowered and this increases the amount of air intake, the pump shifts to drainage standby operation, during which no drainage takes place.

Fig. 4 shows the pump's operation conditions in a full-speed, any-water level test. The pump shifts to air-water mixture operation with decreases in the water level, and until drainage standby operation is reached, the amount of drainage and power consumption decrease smoothly.

During drainage standby operation, the water level of the waterway is kept low, and when again the water level is increased with an increase in the flow into the waterway, the pump again shifts to air-water mixture drainage operation.

4.1.2 Solutions to abnormal vibration and heat

The biggest concern about air intake is the increase of pump vibration. Since air and water differ in density by about 1,000 times, the mixing of air imbalances the fluid in the impeller. Therefore, how well vibration is controlled is the important point. We devised the configuration for air intake and achieved to suppress the increase of vibration caused by air-water mixture operation as shown in Fig. 4. We also adopted structural schemes such as the preventive measures for the loosening of fastening bolts, and in the end, achieved stable operation as a highly reliable pump.

Drainage standby operation can continue running more than 1 hour owing to the very small rise in temperature because during this operation the motor and mechanical seal are cooled by the impeller's rotary motion that agitates and substitutes the internal water of the pump.

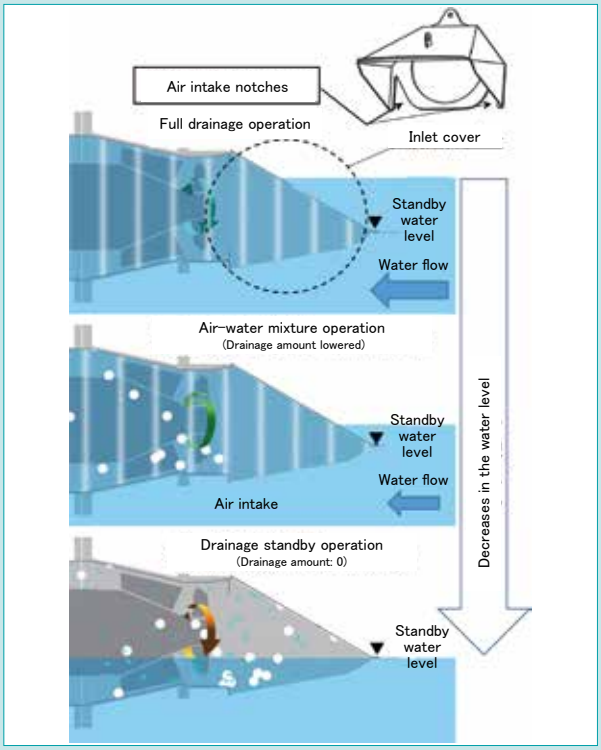



Fig. 3 Relationship Between Water Level and Operating Condition

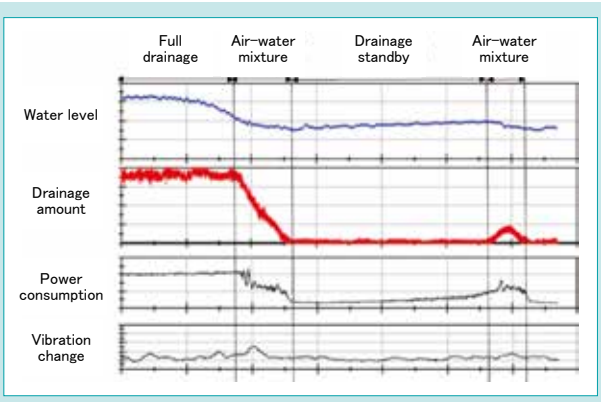



Fig. 4 Test Result of Full-speed Any-water Level Operation

## 4 - 2 Diagnostic function

### 4.2.1 Trouble risk analysis

Serious trouble in large underwater pumps, including pump gates, can prohibit the operation of drainage. Fig. 5 shows the parts that may cause such trouble and the causes.

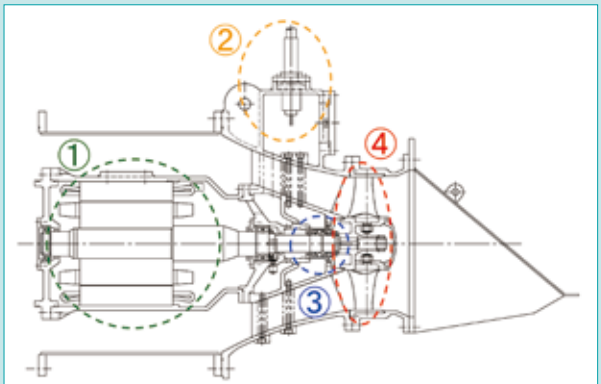
The major parts that may cause trouble are the motor, cable, mechanical seal and impeller.

(1) Motor and cable: Water intrusion, which due to underwater use may occur when sealed or protective areas are damaged, reduces insulation resistance and in the end may result in electric leakage.

(2) Mechanical seal: Seals lubricant to prevent water intrusion into the motor. However, the lubricant is reduced due to minute leakage or reduced sealing function over time. A significant reduction in lubricant damages the mechanical seal and may result in water intrusion into the motor.

(3) Impeller: Overcurrent occurs if operated where there is seizure caused by progressive corrosion, debris adhesion or foreign material inclusion.

In order to prevent serious malfunctions that may disable drainage, we looked for a diagnostic method that can detect these signs at an early stage, and with the analysis of test data with simulated malfunction conditions, we studied the development of the diagnostic method best suitable to performing a diagnosis with management operations without water. The diagnostic technologies that we developed are described below.




| Part | Trouble | Cause |
|---|---|---|
| [1] Motor | Electric leak Trouble | Water intrusion → Reduced insulation resistance |
| [2] Cable | | |
| [3] Mechanical seal | | Lubricant low → Mechanical seal damage → Water intrusion to motor |
| [4] Impeller | Electric leak | Seizure, foreign material inclusion |

Fig. 5 Major Pump Failure Parts and Causes

### 4.2.2 Starting current diagnosis

The three-phase induction motor incorporated in the underwater pump has a property of having a high current flow during the acceleration stage immediately after startup. The starting current is determined by the motor's characteristics, but on the other hand, the time it takes to flow varies depending on the load torque and moment of inertia of the rotator. When the pump is in idling operation, the load torque and moment of inertia are usually almost constant. At this time, the sliding torque, which is produced by the parts of the rotator when they each are slid, accounts for most of the load torque. This sliding torque increases if there is the sign of seizure or foreign material inclusion, and we took advantage of this fact to develop the starting current diagnosis, which estimates sliding torque from the current data obtained when the pump is started up.

As shown in Fig. 6, the cycle of startup and shutdown of the pump was repeated twice in succession, and from the current data obtained by this experiment, the startup time and interval time of each cycle were calculated. Then, from the startup time ratio, the rotational speed and sliding torque of the second startup were estimated.

Fig. 7 shows the estimated results of rotational speed with a varied interval time. Although the startup time and rotational speed of the second startup change depending on the interval time, the graph, which shows the relationship between the startup time ratio and the rotational speed at the time of startup, results in a straight line if the sliding torque is under the same conditions, and this indicates that we can estimate that an equivalent level of sliding torque is occurring. On the other hand, when the sliding torque is increased, a straight line does not result. This method can estimate sliding torque with a good accuracy and thus is able to diagnose the signs of seizure and foreign material inclusion.

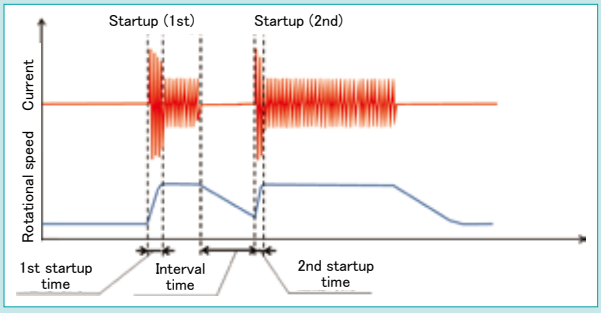



Fig. 6 Current and Rotational Speed at Pump Start-up

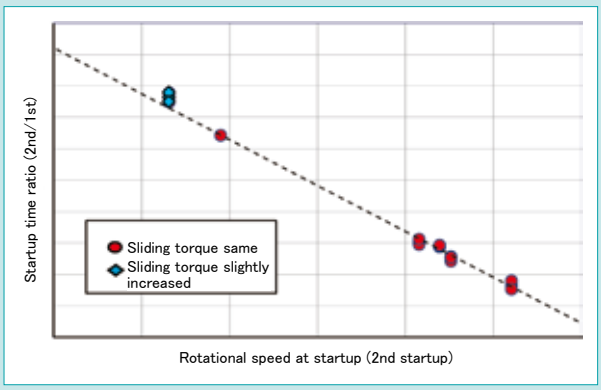



Fig. 7 Contour Diagram of Temperature Distribution

4.2.3 Current waveform diagnosis

The current waveform of the three-phase induction motor, which is sinusoidal with the frequency of power supply as the reference frequency, is slightly disturbed when the rotor of the motor is decentered with an abnormal load on the motor shaft. An abnormality in the pump disturbs the current waveform because the motor and the pump share the same shaft. Changes in the amount of characteristics are determined through the analysis of frequency in the current waveform, and we made use of this method to establish the current waveform diagnosis that detects pump abnormality.

Fig. 8 shows the results of the amounts of characteristics calculated through the amount of imbalance that was produced with various kinds of unbalance factors added to the pump's rotator and through the analysis of current waveform. Both of the two amounts of characteristics increase in proportion to the amount of imbalance. These amounts of characteristics increase when the impeller edge slides (interferes) in addition to when imbalance factors are added to the rotator. However, impeller interference can be isolated because when it increases the sliding torque, the increase can be detected by the starting current diagnosis.

With this, the increase of pump imbalance and the degree of foreign material inclusion in the impeller can be detected.

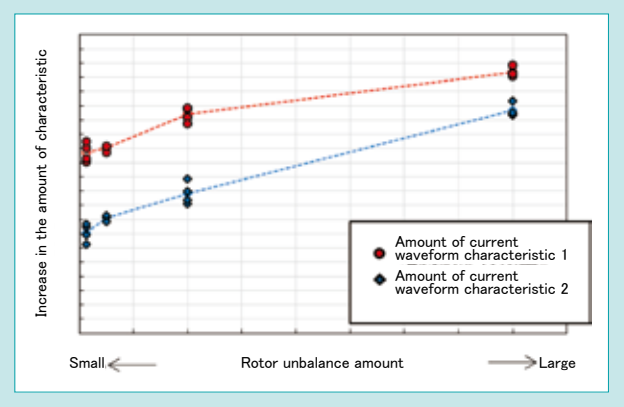



Fig. 8 Effect of Pump Rotor Unbalance

4.2.4 Lubricant temperature diagnosis

To prevent water intrusion into the motor's interior, the underwater pump utilizes a double-mechanical seal, which seals lubricant between its both sealing faces. Minute leakage occurs naturally at the seal faces, and so it is recommended that lubricant be inspected and replaced periodically. If accidentally the amount of lubricant is reduced and the seal faces dry out, abnormal heat is produced and it may damage the mechanical seal. This system has employed a system that detects the degree of lubricant reduction through the temperature of lubricant.

Fig. 9 shows the changes in temperature with different amounts of lubricant. As temperature is influenced by various ambient conditions such as solar radiation, we examined the trends in temperature changes under various ambient conditions. As results, the examinations confirmed that when there is sufficient lubricant, temperature changes very slightly even after the pump is shut down, but when the reduction in lubricant exceeds a certain level, the temperature decreases greatly.

This system is equipped with an alarm function for an abnormal temperature rise in the mechanical seal's lubricant, although the duration of no-water management operation is as short as several minutes and so there is no chance of abnormal heating.

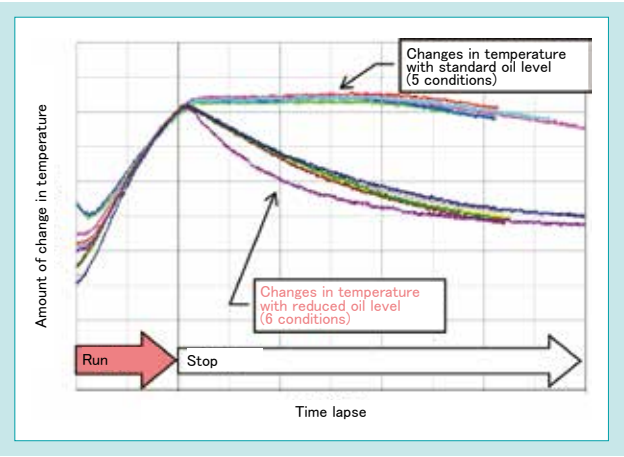



Fig. 9 Lubricating Oil Temperature of Mechanical Seal

4.2.5 Diagnostic system

This diagnostic system is configured with four diagnoses including those detailed above and the insulation resistance diagnosis. With several minutes of no-water management operation, the soundness of the pump can be evaluated by detecting its major trouble risks.

To make the diagnostic system take an inexpensive, simple configuration, the system is designed to be used in a tablet. When inspecting a facility, operating the tablet takes care of all the tasks from the data recording at the time of no-water management operation, then the preprocessing of the recorded data, and finally the transfer of the data to the KSIS (Kubota Smart Infrastructure System) cloud server for diagnosis. In this way, the system does not need to coordinate with the monitoring facility of the site. Monitoring facilities use different systems, such as central monitoring and cloud monitoring depending on the user. Incorporating the diagnostic system into them would require modifications according to each of the facilities. So, the system was configured not to require any coordination with monitoring facilities.

The KSIS cloud server carries out diagnosis by AI (Artificial Intelligence) implemented with the diagnostic algorithm in which our own unique know-how was input with the diagnostic technology

described above, and the diagnostic results are shown on an online page. The user does not need to pay the operating costs such as the usage fee of the diagnostic system because the user uses the tablet that they possess and no dedicated connection is used as shown in the system configuration in Fig. 10.

In addition to the diagnosis by no-water management operation, this system automatically records some data from drainage operation. Transferring it to the KSIS cloud server allows the user to check drainage operation time, current values, etc. at the time of drainage operation in a report form.

As another feature, the inspector can register inspection records to the KSIS cloud server to centrally manage them as an inspection record book in the cloud.

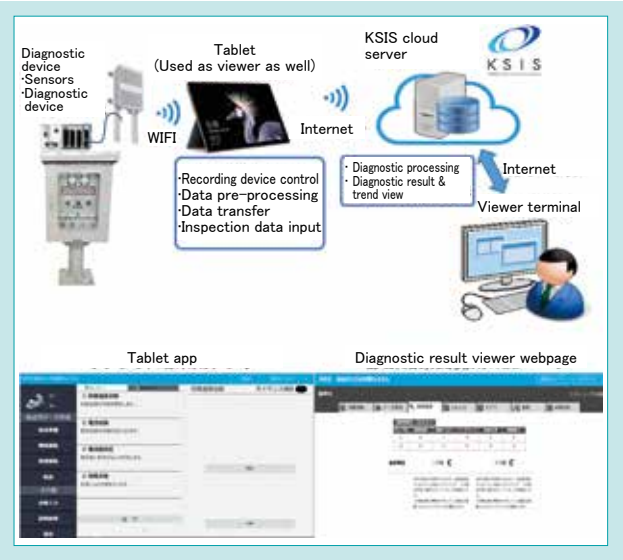



Fig. 10 Diagnostic System Configuration

## 5. Conclusion

A new series of pump gate with the addition of full-speed, any-water level Operation function and diagnostic function has been released to the lineup. Following the full-speed, any-water level Operation function, which has been already delivered in some pumps, we will include the diagnostic function into the upcoming pumps to be delivered.

What is required of future facility management is the stock management scheme that sets priorities in consideration of the deterioration progression of the entire facilities from a long-term perspective and then subsequently optimizes facility management with inspection, investigation, refurbishing and improvement. So, there is a growing need for Condition Based Maintenance, which evaluates the appropriate timing for maintenance and renewal through the evaluation of soundness. Although soundness evaluation used to rely on the knowledge of experienced engineers greatly, this diagnostic function makes it possible to perform soundness evaluation with quantitative indexes.

Kubota will continue contributing to securing the sustainability of infrastructures that support human life by working on further improved reliability of facilities, reduced life cycle costs, labor-saving and other challenges through software measures for various facilities with the use of ICT (Information and Communication Technology) and AI technology, as well as hardware measures.


Fig. 11 New Pump Gate, SG Series

## Contribution to SDG targets

9.1 Development of a high-quality, sustainable and resilient infrastructure
Contribution to the improved reliability of pump gate facilities

11.5 Decrease in disaster deaths and victims, and reduced economic loss
Achievement of reliable drainage function kept up by soundness evaluation of pumps

Reference

1) Japan Meteorological Agency: “Changes in torrential rainfalls and extreme hot days, etc. (extreme phenomena)” https://www.data.jma.go.jp/cpdinfo/extreme/extreme_p.html (reference on 2020-10-14)

# Development of FILCERA HD -Ceramic Membrane Filtration Equipment for Drinking Water Treatment Plants

Water and Environment R&D Dept. Ⅱ / Water and Environment R&D Dept. Ⅰ
Environmental Engineering Design and Procurement Dept. / Water and Environmental Solutions Developing and Sales Dept.

Water treatment plants using river surface water as raw water have found it necessary in recent years to cope with the rapid changes in the turbidity of raw water due to climate change. After the Great East Japan Earthquake, the importance of preparing for large-scale earthquakes has also been emphasized. At the same time, the declining population has led to a decline in water bill revenues and a shortage of technical staff. Against this backdrop, the Ministry of Health, Labour and Welfare has set "safety" "resilience" and "sustainability" as the ideal image of water supply in its new water supply vision. To achieve it, we have developed ceramic membrane filtration equipment (FILCERA HD) with dramatically improved responsiveness to changes in the turbidity of raw water. This equipment takes advantage of the characteristic of the membrane filtration method, which facilitates the automation of water treatment. This paper introduces the design concept, performance and durability evaluation.

【Key Word】
Water Purification, Ceramic Membrane, Membrane Filtration, High Turbidity, Stable Operation, Backwash, Durability, Earthquake Resistance

Related SDGs


## 1. Introduction

In recent years, water treatment plants withdrawing river surface water are demanded to cope with the sudden water turbidity changes which are caused by large typhoons and heavy downpours due to climate change. Moreover, after the Great East Japan Earthquake, the importance of water supply as an indispensable lifeline, and being prepared for large-scale earthquakes has also been emphasized. Meanwhile, the declining population has led to a decline in water bill revenues and a shortage of technical staff. Against this backdrop, the Ministry of Health, Labour and Welfare has set "safety" in water quality, "resilience" to natural disasters and "sustainability" of stable management, as the ideal image of water supply in its new water supply vision.

Membrane filtration is a water purification method that applies pressure to membrane, which has numerous micropores to physically separate to make raw water permeate so as to physically separate suspended solids (SS) and pathogenic microorganisms from water. By this method, stable effluent quality can be obtained regardless of various influent conditions. Also, since automatic operation can be easily realized, labor reduction can contribute to the "sustainability" of water supply.

On the other hand, membrane filtration needs to periodically remove the SS caught on the membrane surface by flushing in the reverse direction (backwash). At this point, if the influent turbidity rapidly rises, SS may not be completed removed by backwash and block the inner flow channel. This risk becomes higher especially when membrane has narrow flow channels, sometimes operation can even be forced to shut down depends on the specifications. Under this background, we took advantage of the membrane filtration characteristic such as labor reduction, and greatly improve the responsiveness to the influent turbidity, and developed original membrane filtration equipment (FILCERA HD) to achieve “safe” clean water delivery.This report covers not only the design principles, performance and durability evaluation methods of this equipment, but also the earthquake resistance evaluation from the viewpoint of “resilience”.

## 2. Development concept and goals

### 2-1 Development concept

Based on the "safety", "resilience" and "sustainability" viewpoints, development concept is set as a membrane filtration equipment that perform stably even with sudden rise of influent turbidity and can be easily operated by fewer people.

Exterior appearance and specifications of the developed membrane filtration equipment are shown in Fig. 1 and Table 1. In a stainless frame, 64 membrane modules is equipped, and 4 membrane elements is stored in each module. Since the frame material can be used as water pipe, it can also function as the header pipe of influent and filtrate water.

The membrane element is made of ceramic, which has strong chemical resistance and mechanical strength properties. Fig. 2 shows the cross-section surface of the flow channels in each membrane element.

Membrane element is designed as square shape, which is suitable for integrated configuration inside, pairs of influent flow channels are covered by membrane layer, and collecting slits are fabricated between them.

Fig. 3 shows the flow directions of the filtration and backwash processes in membrane modules. In the filtration process, filtrate water that permeated through the membrane layer is collected by the nearby membrane elements and flows through the slits. In the backwash process, backwash water is supplied from the outside of the membrane elements, and flows from the filtrate water side back to each influent channels through collecting slits. Meanwhile, separated SS are ejected with the backwash water to the downside by air purge.

Backwashing can drain most of the SS in the influent channels, but it can not prevent the increase of transmembrane pressure. When it reaches a specified value, the membrane needs to be recovered by chemical washing..

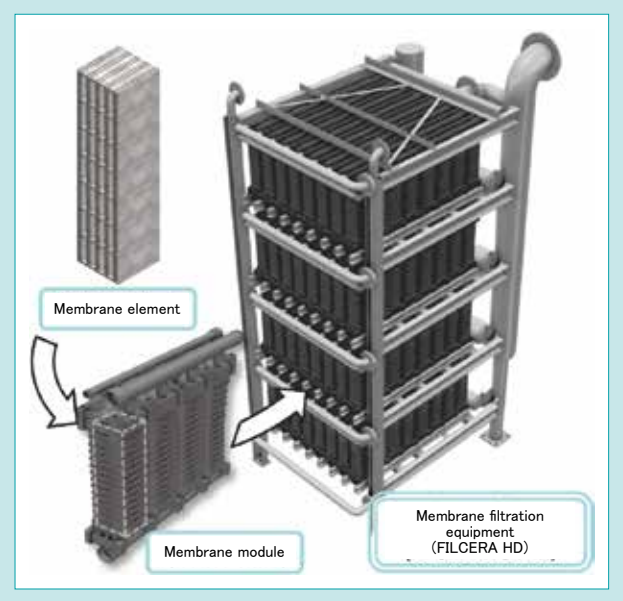



Fig. 1 Appearance of the Developed Membrane Filtration Equipment

Table 1 Specifications

| | |
|---|---|
| Water flow | Internal pressure type |
| Filtration | Full filtration |
| Cleaning | Backwash + Air purge |
| Type of membrane | MF (microfiltration) |
| Surface area of membrane | [Membrane filtration equipment] 128 $m^2$<br>[Membrane module] 2 $m^2$ |
| Dimensions | [Membrane filtration equipment]<br>Width 1,050 × Depth 1,450 × Height 2,800 mm<br>[Membrane module]<br>Width 120 × Depth 530 × Height 500 mm |
| Membrane module weight | 10 kg (empty) |

Water supply membrane module standard Certification No.507
Technical certification registration number Purification technical certification No.10027

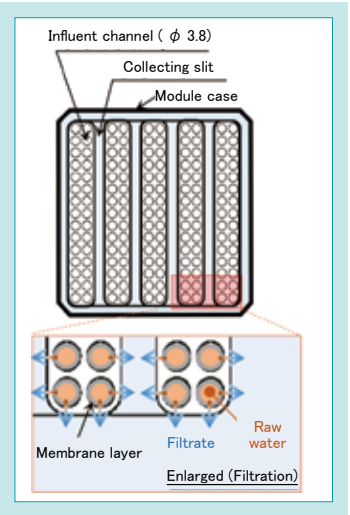



Fig. 2 Cross-section of the Flow Path

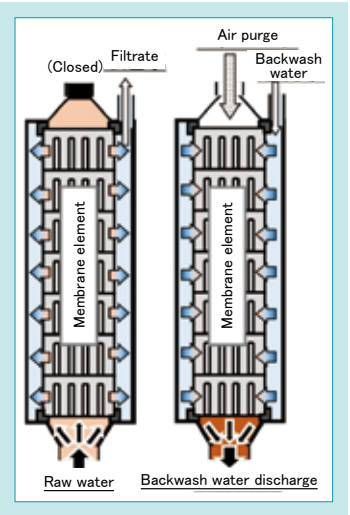



Fig. 3 Internal Flow of the Module

## 2-2 Goals

Development goals are set as below.

(1) Stable performance operation is possible even when the influent turbidity of raw water suddenly changes.
(2) Easy operation and maintenance.
(3) Minor damage and necessary repair caused by an intensity 2 earth quake*.

* Assumed maximum intensity of the installation site

Realizing goal (1) leads to easier automation of the equipment and consequent labor reduction. Moreover, if chemical washing frequent can be decreased, relative cost can be largely reduced, which is a great part of the entire operating cost.

Same with goal (1), reaching goal (2), also contributes to the labor reduction. For example, light and small membrane modules can be handled much more easily, and these are no need to use crane for replacement and maintenance. In addition, by raising the durability of gaskets, which usually are consumables, periodic replacement can be avoided.

For goal (3), since the membrane filtration equipment is an essential water supply facility, it is required to function even with minor damage due to possible earthquake. Unfortunately, very few reports can be found on the membrane filtration equipment earthquake resistance. Therefore, we set the goal in accordance with the guidelines for water supply facility anti-quake construction method, explanatory notes[2].

# 3. Technical issues to be solved

## 3-1 Appropriate flow path structure of the membrane element

To achieve the stable performance of the membrane filtration equipment even with high influent turbidity , the flow channel structure of the membrane element plays an important role. Equable filtration and drainage of the SS during backwash are required. As for the former, equable filtration on each influent channel can balance the membrane surface load even when turbidity suddenly changes. As for the latter, prevent residual SS in the influent channel can avoid the blockage of flow channels.

Generally, membrane element is designed with dense configuration of influent channels. However, very few of them have been evaluated on the suitability of filtration and backwash. Therefore, it is necessary to reflect the appropriate influent channels structure to the membrane element design, in order to achieve more adaptive to influent turbidity changes.

## 3-2 Durability of the module case

To realize membrane module replacement without crane, we intended to reduce the size and weight of the module case by application of resin material to the body storing membrane elements, and rubber material for sealing. The challenges of resin application were its durability to the pressure load during operation and the chemical resistance chemical cleaning. In particular, the rubber sealing material could be a weakness of the equipment, and frequent replacement can lead to increased maintenance cost

Therefore, durability evaluation by various resistance tests were necessary to choose and apply the most durable sealing material.

## 3-3 Quake resistance evaluation of the equipment

The quake resistance evaluation of water supply facilities includes dynamic and static methods. From the viewpoint of understanding the actual behavior, the dynamic evaluation through vibration tests using the real equipment is desirable. However, setting the entire equipment on a vibration tester was difficult due to size and weight. Therefore, it was necessary to conduct the vibration tests in a reasonable scale simulating the real earthquake based on the assumed possible largest vibration level and the identified vibration spots of the equipment.

## 4. Developed technology

### 4-1 Appropriate flow path structure of the membrane element

4.1.1 Designing the flow structure

The flow structure was designed under the following principles.

(1) The inner diameter of the influent flow channel is made greater to drain the SS during backwash, which are deposited and solidified on the membrane layer surface.

(2) The flow channel is designed to allow the influent in the filtration process and the backwash water in the backwash process to flow all across the channels as equable as possible.

More specifically, as shown in Fig. 2, the diameter of the influent flow channel was made as Φ3.8 mm, a relatively wider, and all influent flow channels were positioned adjacent to each collection slit so that the resistance occurred when water passes between the collecting slit and the influent channel can be dispersed.

The effectiveness of this improved flow channel structure was evaluated by simulation analysis and verification experiment. The results are shown below.

4.1.2 Evaluation by simulation analyses

Virtually applying a pressure to influent or backwash water, conditions of the improved flow channel mentioned above, and the initially designed flow channel (the previous structure) was compared by simulation analysis. Note that the only difference between the improved and the previous structures is the position of the collecting slit (collecting slit was located in the center of every 5 influent channel rows).

Fig. 4 shows is the contour views of the flow velocities in the flow channels on the upper and lower ends of the membrane element, as the analysis results of the influent and drained water in filtration and backwash processes. It was observed that the flow velocity in the flow channel of the previous structure was less equable than the improved structure, both in filtration and backwash. Especially in backwash process of the previous structure, the backwash water that should be quickly drained together with SS to the downside flowed to the upside in some of the flow channels of the membrane element.

These results showed that the improved flow channel structure is better in filtration equability and the drainage of SS than the previous structure, and therefore can lead to more stable performance.

4.1.3 Evaluation by verification experiment

To evaluate the membrane filtration performance of the model mounted with the improved flow channel structure membrane elements, a verification experiment fed with river surface water was conducted. Fig. 5 shows the process flow. Note that this process does not include any pretreatment system to remove SS.

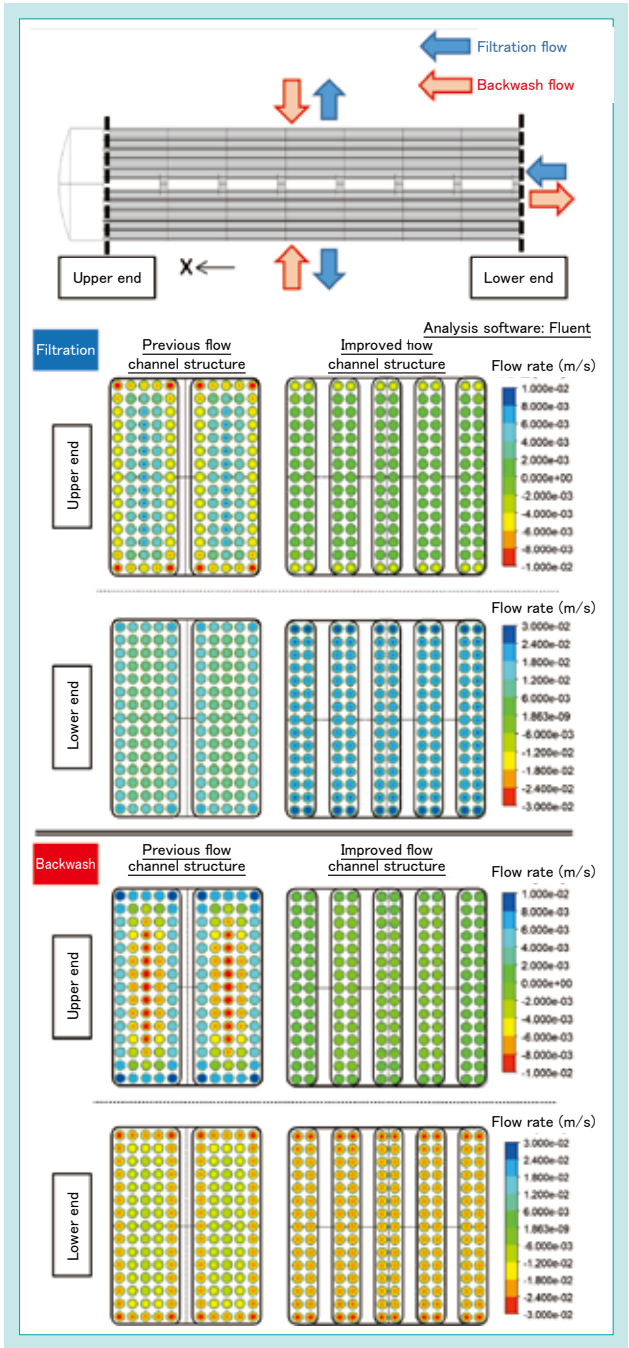



Fig. 4 Velocity Contour of Each Channel Section

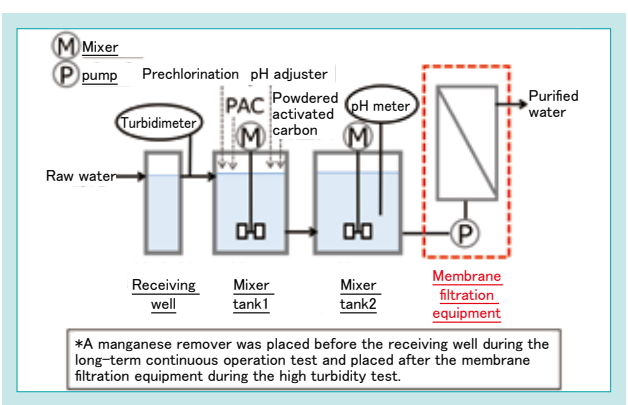



Fig. 5 Process Flow

1) Evaluation by long-term continuous operation test

The development model was operated continuously for approximately four months to verify the stability. The amount of water processed per membrane area (membrane filtrate flux) was 3.0 $m^3$/ ($m^2$ per day), and backwash was conducted every three hours.

Fig. 6 shows the transitions of raw water turbidity along with the average transmembrane pressure during filtration between periodic backwashes. There was almost no remarkable fluctuation in the rise trend of the average transmembrane pressure, including when raw water turbidity suddenly rose. This has confirmed that the development model has stable performance to cope with raw water turbidity changes.

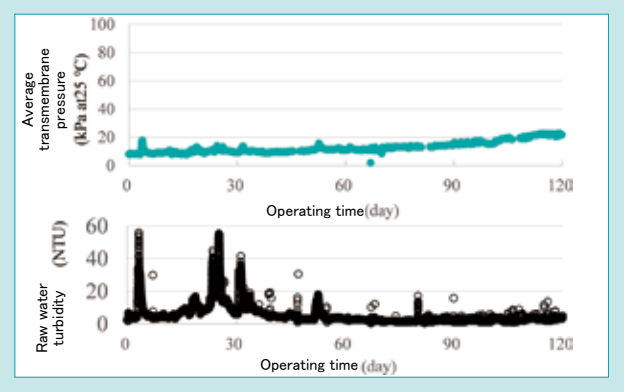



Fig. 6 Mean Transmembrane Pressure During Long Time Operation

2) Evaluation by high turbidity test

Furthermore, in order to verify the adaptability to high turbidity, a test fed with river surface water with addition of mud soil taken from water intake spot was conducted. After ten-hour feeding with prepared raw water which has a turbidity above 1,000, the equipment was continuously operated at 100 turbidity. The backwash was automatically conducted after every three-hour continuous operation or when the transmembrane pressure rose above 50 kPa.

Fig. 7 shows the transition of raw water turbidity and transmembrane pressure. It was observed that after the turbidity rise above 1,000, the transmembrane pressure temporarily increased as filtration continued. However, it was recovered at every backwash process, and the immediate pressure (base differential pressure) after backwash even reached the initial value of the start-up phase.

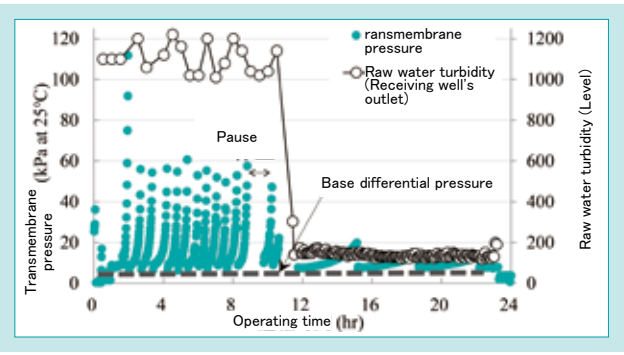



Fig. 7 Transmembrane Pressure During High Turbidity Test

3) Evaluation by the water quality test

Table 2 shows the water quality test results of raw water and filtrate. The membrane filtrate (purified water) met all the water quality standards. By adoption of a manganese removal unit, the manganese concentration was below the quantitation limit.

Table 2 Water Quality Test Results

| Item | Water quality Standard in Japan | Unit | Long-term continuous operation test | | High turbidity test | |
|---|---|---|---|---|---|---|
| | | | Raw | Purified | Raw | Purified |
| Turbidity | ≤ 2 | Level | 0.5 ～65 | ＜0.1 | 1100 | ＜0.1 |
| Color | ≤ 5 | Level | 1.5 ～8.4 | 0.5 ～0.9 | 2300 | ＜0.5 |
| Manganese (total) | ≤ 0.05 | mg/L | 0.006 ～0.15 | ＜0.005 | 1.57 | ＜0.005 |
| Iron (total) | ≤ 0.3 | mg/L | 0.06 ～2.2 | ＜0.03 | 72.4 | ＜0.03 |
| TOC | 3 or less | mg/L | 0.7 ～4.4 | 0.4 ～1.5 | 69 | 0.3 |
| Taste | No abnormality allowed | — | – | No abnormality | – | No abnormality |
| Odor | No abnormality allowed | — | No abnormality | No abnormality | Earthy odor | No abnormality |

The above results show that the development model, which employed the improved flow channel structure, has achieved stable performance with suppressed base differential pressure in both regular and high turbidity conditions..

## 4-2 Durability of the module case

To achieve longevity, the membrane module's components need to resist sulfuric acid and sodium hypochlorite corrosion, which are used for in chemical washing, as well as the internal pressure produced during filtration and backwash. This report presents how we selected the rubber sealing material, which is particularly susceptible to chemical and mechanical deterioration.

4.2.1 Chlorine resistance test

To examine the durability to sodium hypochlorite, which is expected to have a great impact on the component material, we conducted a chlorine resistance test on four types of sealing material candidates A to D, which are of the same shape but have different properties and were manufactured in different processes.

In the test, samples were immersed in chlorinated water controlled at 60°C, and after a predetermined time, the samples were examined to see the reduction in hardness and the amount of adherents that remained on the cotton swab after rubbed its surface[3]. Results showed that deterioration was detected in sealing materials A and B, so they were excluded from the candidates.

4.2.2 Thermal degradation test

Next, we conducted a thermal degradation test to evaluate its natural deterioration. First, assembling the sealing materials in the same way in the real application situation, they were exposed to high temperature to accelerate the deterioration, and the correlation between time elapsed from function to deterioration (lifetime) and the correspondent temperature (Arrhenius plot) was obtained. From the correlation, lifetimes were predicted. The results showed that, sealing material D is expected to have a fifteen-year lifetime while C only has 2.4 years. Therefore, we chose D as the appropriate material.

4.2.3 Repetitive endurance test

With application of sealing material D in membrane module, a repetitive pressure endurance test which repeatedly applies filtration and backwash was conducted. The results showed no damage in the membrane module including sealing material after fifteen-year equivalent load.

From the above test results, we have concluded that the employment of sealing material D secures the durability of the entire membrane module and has potentially reduced the replacement frequency owing to the enhanced longevity.

Table 3 Selection Method of Seal Material

| Seal material | A | B | C | D |
|---|---|---|---|---|
| Hardness | 68 | 73 | 60 | 61 |
| Chlorine resistance test | × | × | ○ | ○ |
| Thermal degradation test | – | – | Lifetime 2.4 years | Lifetime 15 years or more |
| Repetitive pressure endurance test | – | – | – | Lifetime 15 years or more |
| Evaluation | × Lack of chlorine resistance | × Lack of chlorine resistance | × Natural deterioration accelerates. | ○ Employed |

## 4-3 Earthquake resistance evaluation of the equipment

4.3.1 Overview of the evaluation method

To understand the maximum vibration level (acceleration and frequency range) and its location in the equipment that can be caused by earthquake, we conducted a frequency analysis with the earthquake vibration data as input. Then, we confirmed whether there are damages or components falling apart when the vibration was applied to the membrane module of the assumed actual operating equipment. The Next section reports the details and results of these evaluation steps.

4.3.2 Evaluation by frequency response analysis

We conducted a hammering test to confirm determine the characteristic values of the membrane filtration equipment, which was loaded with membrane modules full of water inside. Then, the vibration data observed in Ofunato City, Iwate, where the maximum vibration was recorded during the Great East Japan Earthquake, was virtually applied in X and Y directions as shown in Fig. 8. The results revealed that the biggest greatest vibration (acceleration of 16.6 m/s$^2$, frequency of 5 Hz) occurs in the location indicated in Fig. 8. Based on this result, we determined the vibration conditions to be input for the vibration test.

4.3.3 Evaluation by vibration test

Fig. 9 shows the image of the vibration test. The membrane module that simulated the real installation was subjected to vibration using a vibration tester (manufactured by IMV, J250/SA6M). Vibration with an acceleration of 20 m/s$^2$ and a frequency of 5 Hz was input in two directions of X and Y. The vibration duration was 10 seconds, which exceeds the peak duration of 3.7 seconds of the above-mentioned vibration data. The results show that the membrane module did not have any damage or component falling apart. Thus, we have confirmed that the membrane module can sufficiently tolerate a level 2 earthquake vibration as the goal set..

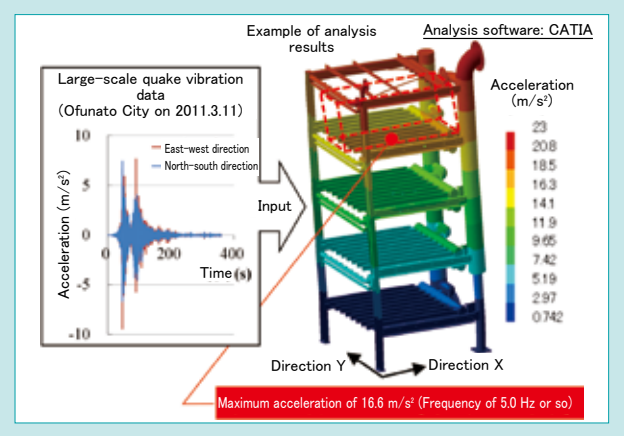



Fig. 8 Results of the Frequency Analysis

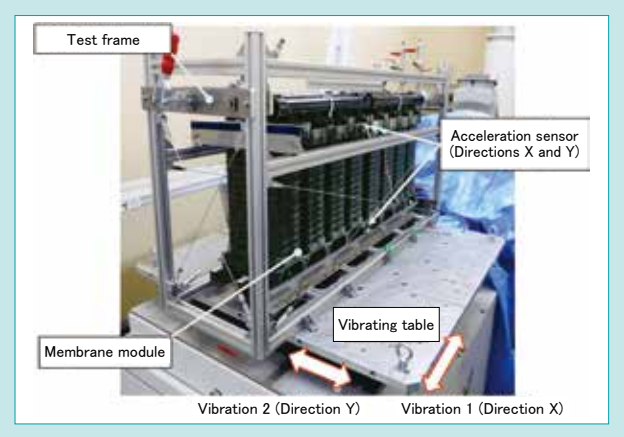



Fig. 9 Vibration Test

## 5. Conclusion

In this project, with the employment of an appropriate flow channel structure, the membrane filtration equipment has achieved stable performance even with a sudden rise in influent turbidity. In addition, durability has been secured as well as the reduction of size and weight. Thus, all of these improvements are contributory to the reduction of labor required for the maintenance of the equipment. Moreover, the membrane filtration equipment has been proven to be endurable with the maximum scale of possible earthquake as revealed by the earthquake resistance evaluation simulating the vibration that may apply to the equipment during a real possible earthquake.

From all these results, we are convinced that this membrane filtration equipment (FILCERA HD) will assist in the achievement of “safety”, “resilience” and “sustainability” that the water supply utilities assert as the ideal vision and will contribute to a sustainable society through the supply of safe water.



## Contribution to SDG targets

3.9 Reduction of deaths and diseases caused by hazardous chemical substances, and air, water and soil pollution
Contribution to the improvement of the sanitation environment through safe water production

6.1 Strengthening access to safe and affordable drinking water
Contribution to a stable water supply during disasters

6.5 Implementation of integrated water resource management
Contribution to the formation of management systems that also support wide-area lifeline administration through labor reduction technology with automation

Reference

1) Ministry of Health, Labour and Welfare: New water supply vision (2013)
2) Japan Water Works Association: 2009 Guidelines for water supply facility antiquake construction method, explanatory notes, pp. 104-111
3) Japan Water Works Association: JWWA B120 Water supply soft seal gate valve, attachment D (2017)
4) Japan Meteorological Agency website: Strong vibration waveforms (2011 Tohoku earthquake and tsunami)
http://www.data.jma.go.jp/svd/eqev/data/kyoshin/jishin/110311_tohokuchiho-taiheiyouoki/index.html (reference on 2020-10-12)

# Development of Plastic Single Stack Drain Fitting

Kubota ChemiX Co., Ltd. R&D Dept.

The construction industry faces many challenges such as soaring labor costs due to labor shortages, aging skilled workers, and reduction of construction costs. To solve these problems, the Group has been working on the development of cast iron single stack drain fitting and resin drainage vertical pipes with a fire spread prevention function. As a result, it has become possible to use inexpensive and easy-to-install PVC pipes for vertical and horizontal drainage pipes. In recent years, the needs of the market have further advanced, and there has been a demand for plasticization of all drainage pipes, including plasticization of cast iron single stack drain fittings penetrating the fire protection section. In this paper, we report on the development of a plastic single stack drain fitting with the aim of making the drainage pipes all-plastic.

【Key Word】
Drain Pipe, Fire Resistance, Fire Compartment, Sound Insulation



Related SDGs


## 1. Introduction

For the vertical drainage pipes of multi-dwelling unit buildings, single stack drain fittings are widely employed. They are often made of cast iron and installed through fireproof zones, and therefore the connected pipes need to be a fireproof double-layer or metal pipe under the law. To allow these pipes to use plastic pipes, which are inexpensive and have good workability, the Kubota Group developed the following pipes with fire spread prevention function: single stack drain fitting (cast iron)[1] in 2007; drainage vertical pipe (plastic) in 2012; leg part joint (cast iron)[2] in 2018. We have been promoting the plasticization of drainage pipes with the use of PVC to drainage vertical pipes, drainage horizontal branch pipes, and drainage horizontal main pipes under the grant of the MLIT Minister certified fire-fighting performance rating certificate through fire-resistance tests.

In recent years, the market needs have further advanced and are seeking plasticization for all drainage pipes including single stack drain fittings. A major developer, for example, is working on the prolongation of the interval of large-scale repair maintenance work by adopting highly durable materials and construction methods at the time of construction of newly-built buildings or facilities in order to reduce the work burdens of upcoming maintenance. Incidentally, plastic pipes, which are lightweight and excellent in corrosion and chemical resistance, are now employed and standardized for the drainage pipes used in private residential areas of multi-dwelling unit buildings, including their fittings as well.

To respond to these changes in the market, the Kubota Group is now actively working on converting all our drainage pipes to plastic models. In this report, we present the technology used for the plastic single stack drain fitting that we have developed.

## 2. Development concept

In the development of the plastic single stack drain fitting, we positioned fireproof and sound insulation performance as the important functional challenges.

Since single stack drain fittings are installed through fireproof zones, fire resistance performance is indispensable to prevent the spread of fire from the through-areas. In the development, with the rollout to hotels and for-rent housing units in view, we set up the goal of achieving fire-resistant performance that can support thin floors. To attain this goal, we adopted a blocking technique using a thermal expansion material to establish complete blockage in concrete slabs.

Since plastic has lower density than cast iron, the sound transmission loss tends to be lower when the thickness is the same. Therefore, sound insulation measures are important. In the development of the plastic single stack drain fitting, we identified three development points: [1] A swirl vane is installed to suppress the vibration of the lower tapered section buried in the floor slab (vibration control); [2] Vibration transmission to the concrete slab is suppressed (vibration isolation); and [3] Radiated sound is suppressed (sound insulation). We set these points as our goals in order to surpass the sound insulation performance of competitors.

## 3. Description of the technology

Fig. 1 shows the structure of the refractory material used for the plastic single stack drain fitting. Two types of thermal expansion materials having different expansion ratios are used to achieve both shape retention and a high expansion ratio. And, the fall of the thermal expansion materials is prevented by covering the outside with a rock wool sheet. Fig. 2, which are the photos taken after a fire-resistance test, shows the inside of the single stack drain fitting (complete blockage) and the heated side (single stack drain fitting's lower part). With the complete blockage in the concrete slab, the plastic single stack drain fitting can support a thin floor of up to 75 mm whereas those of competitors support a floor thickness of 100 mm or more.

Fig. 3 shows the structure of the sound insulation material. The material consists of three layers of sound insulation covering: From the inside, [1] a vibration control and sound insulation material for the vibration control and sound insulation of the body, [2] a rock wool sheet for sound absorption and vibration isolation, and [3] a rubber cover for sound insulation, vibration isolation and water shutoff. Fig. 4, which shows the measurement results of drainage noise, compares between the new plastic single stack drain fitting that we have developed and competitors' two products (plastic). In the test, the fittings, which were covered with each company's dedicated rear sound insulation cover, were buried in a concrete slab and measured. As results, our fitting has a noise level 5 dB lower than those of the competitors.

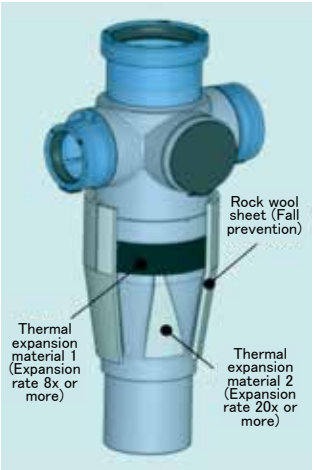



Fig. 1 Composition of Refractory Material


Fig. 2 Situation After Fire Resistance Test

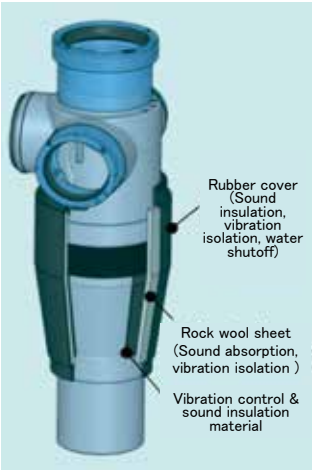



Fig. 3 Composition of Sound Insulation Material

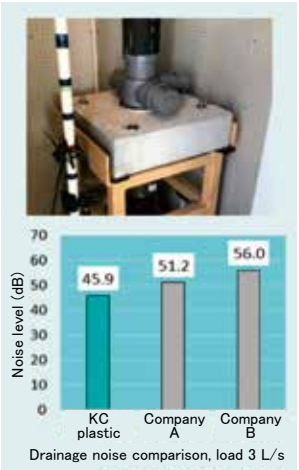



Fig. 4 Noise Measurement Result

## 4. Conclusion

In the construction industry, the use of plastic is advancing in various fields due to its lightness and low cost. The Kubota Group is currently planning the plasticization of leg part bend fittings, following this plastic single stack drain fitting. We will continue to reflect the architecture and construction sites' problems and needs in our products and techniques to offer technical solutions to our valued customers.

## Contribution to SDG targets

8.2 Improvement in productivity through innovation
Contribution to improved workability with a PVC pipe 40% or more lighter than fireproof double-layer pipes

12.5 Prevention and reuse of waste
Contribution to the reduction of cutting dust and waste materials through the elimination of the need of fireproof double-layer pipes

Reference
1) Takayuki Toyama, et al.: "Development of a single stack drain fitting with fire-spread prevention function", pp. 64-71, Kubota Technical Report, No. 42 (2008)
2) Hirofumi Yagi, et al.: "Development of a leg part joint with a fire-spread prevention function", pp. 92-93, Kubota Technical Report, No. 52 (2018)

# Introduction of Drainage Pump Vehicles to Assist Restoration Work Following Severe Flooding

Related SDGs


## 1. Introduction

In recent years throughout Japan, because of larger typhoons and localized heavy downpours (called guerrilla rainstorms in Japan), there are increasing cases of flood damage that seriously affects social and economic systems and also people's lives. According to the Ministry of Land, Infrastructure, Transport and Tourism, torrential rainfalls of 50 mm or more per hour increased by about 1.4 times during the 30 years between the 1975s and 2008s, where there were an average of 174 and 238 times of such rainfalls, respectively.

In response to this situation, systematic measures against floods have been promoted in accordance with the "comprehensive sewerage measures against floods" as national policy, but at the same time, large-scale flood damage occurred all across the country. In 2019, in order to further promote attentive flood measures, the provision of drainage pump vehicles was added to the support menu of the "comprehensive project for reducing flood damage in sewerage", and in addition, district requirements were relaxed.

In the same year, in the comprehensive disaster prevention project for drainage basins as well, the servicing of transportable drainage facilities was added in the scope of grants to achieve agile and flexible drainage actions because there are rivers managed by municipalities that are difficult to drain due to the influence of the rivers to which they merge.

Under these circumstances, drainage pump vehicles as merchandise are drawing attention and there is a growing need for them.

## 2. What is a drainage pump vehicle?

A drainage pump vehicle is a transportable drainage pump station where underwater pumps and motors (PTO, engine generator, etc.), control systems, hoses, etc. are loaded on the loading platform of a large truck.

To prevent damage or solve flood conditions at an early stage by arranging a drainage pump vehicle at the site and carrying out drainage work when a flood is expected or has occurred due to a rainfall that greatly exceeds the drainage capacity of the drainage pump station provided as a flood countermeasure.

In the case of large-scale flood damage, in particular, the early resolution of flood conditions leads to the early restoration of city functions.

Case examples of recent years' activities, which are presented in the website of the Ministry of Land, Infrastructure, Transport and Tourism, show that many pump vehicles were engaged in drainage work for early restoration in typhoon 19 in 2020 and the 2018 Japan floods.

At the time of the 2011 Tohoku earthquake, which is still fresh in our minds, drainage pump vehicles played an active role in restoring the functions of cities, the airport flooded by the tsunami, and various places. In this example, a mobile phone switching station was damaged by the tsunami. In a normal disaster, the mobile base station personnel would have rushed to the site to temporarily recover the station, but at this time, they were unable to go closer to the site. They finally arrived at the site owing to the good progress of drainage work by drainage pump vehicles, and mobile phone connection was restored in turn.

Fig. 1 Drainage Pump Vehicles Operating Photo

## 3. Development history and installation technology of drainage pump vehicle

### 3-1 Early stages of development

The development of Kubota's drainage pump vehicles started in the first half of 1990's in response to the demand for disaster prevention measures. A drainage pump vehicle consists of a large truck whose loading platform is mounted with underwater pumps, drainage hoses, generators, etc.

Later, the torrential rainfall at the end of August 1998 led to a reconsideration of the effectiveness of drainage pump vehicles with mobility as emergency measures in areas where there is high flood risk but any effective measures had not yet been taken. The current Ministry of Land, Infrastructure, Transport and Tourism (then Ministry of Construction) has increased the number of such vehicles, leading to their widespread use in Japan.

In the early times of development, various types of pump vehicles were introduced, such as those which operate an underwater drainage pump using the force of water pumped up by a land pump installed on the loading platform of the truck or those which have a pump with a crawler mechanism that allows it to travel to the site where it is to be installed.

Among them, those which use a crane, etc. to install large underwater pumps with a diameter of 400 mm were often adopted. They were equipped with a PTO mechanism that extracts power from the track's engine to operate large underwater pumps, which were not able to be powered by a generator alone.

Fig. 2 Early Drainage Pump Vehicle

### 3-2 Development of a drainage pump vehicle equipped with lightweight underwater pumps

Drainage pump vehicles have various problems and limitations particular to a vehicle equipped with large underwater pumps, such as difficulty in installing pumps by cranes in strong winds, difficulty in PTO operation, noise levels, and exhaust gas problems. Therefore, our development needs to pay attention for their performance to be more flexible and environmentally friendly.

In response, we have developed a drainage pump vehicle that uses a pump with a diameter of 200 mm, which is made of an aluminum alloy to reduce weight (approx. 35 kg) so that it and its hose can be installed by human power, and also developed an engine generator that is designed to be low in noise and easy in operation.

Fig. 3 Lightweight Pump

At present, the lightweight underwater pumps and engine generators, which are designed with these specification, are used in basically all the drainage pump vehicle modes of our lineup, which range from 30 to 60 $m^3$/min in drainage capacity and 8 to 22 t in total vehicle weight.

For your information, a drainage capacity of 30 $m^3$/min is equivalent to the capacity to empty an ordinary 25 m swimming pool in about 10 minutes.

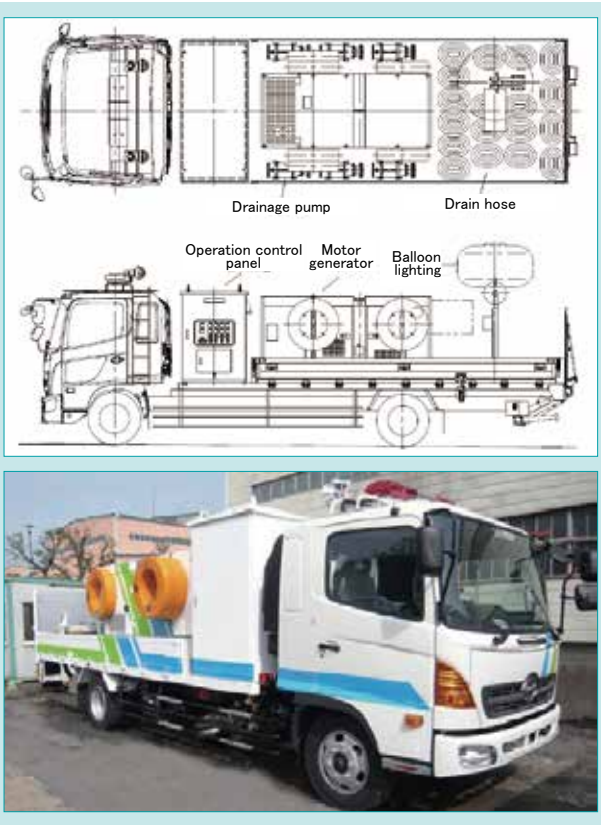



Fig. 4 Current Drainage Pump Vehicle

## 3 - 3 Improvement of the drainage pump vehicle, and development of additional technology

The following technologies, which have been highly requested in particular, have been developed and added to our lineup in response to the recent market's many improvement and development requests in line with the increased opportunities to dispatch drainage pump vehicles and the increase in the number of vehicles employed.

[1] Drainage up to low water level: Expanded drainage work application to roads, etc.

In the history of drainage pump vehicles having been introduced through the Ministry of Land, Infrastructure, Transport and Tourism, they have mainly been considered for use in rivers. However, in response to measures against flooding in underpasses and increased support by local governments for flooding in urban areas, we developed underwater pumps that are capable of draining water to the level where vehicles can pass (about 8 cm).

With the advent of lightweight underwater pumps capable of low water level drainage, the adoption of drainage pump vehicles have increased in local governments where the drainage in cities is needed.

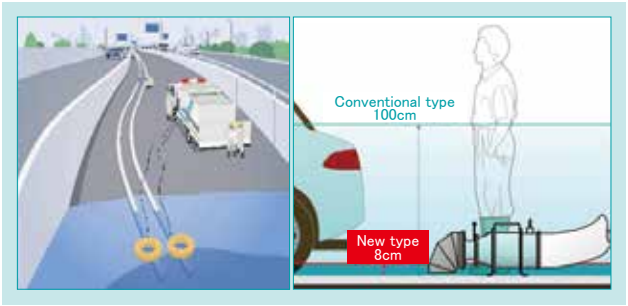



Fig. 5 Low Water Level Pump

[2] Pump-to-pump connection: Expanding opportunities of use

Due to the characteristic of "mobile", underwater pumps are used in a variety of situations. However, there are the cases where the pump's capacity (head) is insufficient because the pump, whose capacity is limited to a head of 10 m, is far away from where drainage is required. To solve this drawback, we made improvement so that two pumps can be connected in series to double the capacity (head).

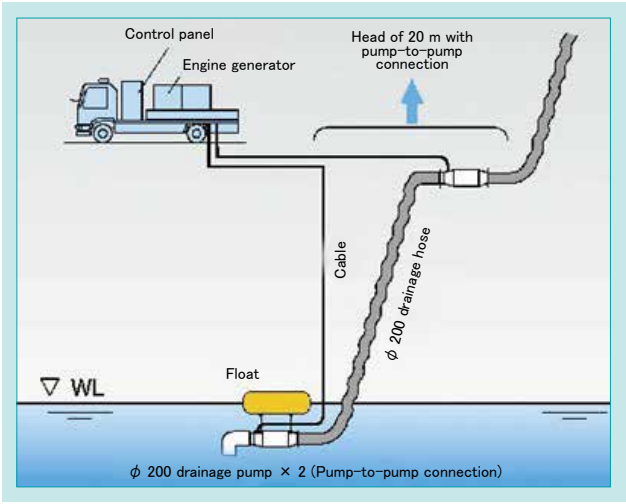



Fig. 6 Tandem Pump

[3] Drainage pump vehicle using an 8 t vehicle

With the increasing employment of drainage pump vehicles by local governments, there is a growing need for pump vehicles that use an 8 t vehicle that can be operated with a medium vehicle license (ordinary driver's license for those over a certain age) instead of conventional 22 t or 11 t pump vehicles that require a heavy vehicle license. So, we conducted development, and successfully, drainage function has been applied to 8 t vehicles with unchanged drainage capacity by further reducing weight, making the loaded equipment more compact, and by adopting a special inverter.

## 4. Introduction of related products

[1] Drainage pump package

As more and more local governments are employing the vehicles, the problem of vehicle maintenance costs became apparent. So, we have developed a drainage pump package, in which all the equipment items necessary to constitute a drainage pump vehicle except the generator are packaged. By renting any vehicle and generator in case of emergency case, the user can convert the vehicle into a temporary drainage pump vehicle if this package and the rented generator are attached.

Note that the drainage pump package has a maximum drainage capacity of 10 $m^3$/min, which is lower than that of a drainage pump vehicle.

Fig. 7 Drainage Pump Package

[2] Drainage pump unit

In order to support the cases where the rental of a vehicle is unavailable, we have developed a drainage pump unit with a drainage capacity of 5.0 $m^3$/min, which consists of subdivided drainage pump parts so that they can get on a compact van as separate pieces of parts.

The employment of this product is increasing especially in small and medium local governments.

Fig. 8 Drainage Pump Unit

## 5. Conclusion

Rainfall is increasingly becoming heavier as consequences of global warming and some research reports that flooding risks with class A rivers can grow to be four times more on average by the end of the century.

Although it is only the result of an estimation and it is difficult to make a quantitative judgment, many people feel that it is a major threat in their daily lives because there have been increasing cases of heavy downpours in recent years where flood damage is broadcast in the media or actually experienced.

However, the manufacturers in the disaster prevention industry are expected to take into consideration the financial constraints on flood control measures, which are more like public assistance. As another fact, the enhancement or new installation of drainage stations is a lengthy process and requires a large cost burden. Therefore, we believe drainage pump vehicles are effective for early and efficient rainwater management.

We actually see it from the recent increase in the use of drainage pump vehicles by local governments.

On another front, new market needs emerge with drainage pump vehicles since they have been now employed by various types of users and under a more diverse circumstances. The need for remote monitoring and control of drainage pump vehicles is an example.

This function, which utilizes the technology and product of drainage pump vehicles more safely and effectively by combining hardware and software, is discussed in the Ministry of Land, Infrastructure, Transport and Tourism as well. In line with this need, we need to aim for not only conventional hardware improvement and development (pump vehicles) but also software development. We need to integrate both of them to enhance the effect.

As an example, the simulation of flood risk has become more sophisticated due to the recent development of weather prediction technology. The Kubota Group is also accelerating its efforts to develop a system for predicting the basin rainfall index and rainfall intensity and is studying the possibility of offering services that can lead to the appropriate placement of drainage pump vehicles and their early dispatch to sites.

In the hardware aspect as well, we are considering the development of pumps that can support seawater as well as the reduction of space required for pump installation. We would like to further promote the reduction of flood damage through drainage pump vehicle products.

## Contribution to SDG Targets

11.b Formulation and implementation of disaster risk management
Contribution to prompt disaster recovery

13.1 Strengthening of disaster resilience and adaptive capacity
Contribution to recovery from disasters associated with climate change (floods)

# Introduction of Waste Treatment Operation at the Volume Reduction Facility of Futaba Town

Related SDGs

## 1. Introduction

The accident at the Fukushima Daiichi Nuclear Power Station, Tokyo Electric Power Company, as an effect of the 2011 Tohoku Earthquake, scattered its radioactivity into the air and polluted the environment. The goverment is promoting the incineration of waste that is produced by decontamination work with the designation of the areas shown in Fig. 1 to take measures based on the act on special measures concerning handling of contamination by radioactive materials.

The engineering joint venture including Kubota Environmental Service Co., Ltd (Constituent: Nippon Steel Engineering Co., Ltd., Kubota Environmental Service Co., Ltd, Obayashi Corporation, Tokyo Power Technology Ltd.) received an order of waste treatment to assume a project for the facility to reduce the volume of waste (nuclear waste repository) in Futaba town in March 2018. The earlier mentioned decontamination waste is disposed of at the temporary incineration facilities built in each municipality. The work Kubota Environment Service Co., Ltd received is the construction and management of the facility (temporary ash treatment) that minimize the volume of the bottom ash and the fly ash from incinerator that are carried to the nuclear waste repository from those incineration facilities and also the fly ash produced in the temporary incineration facilities in Futaba town.

Overcoming the short construction period of only two years from the receipt of the order, the facility started treatment from March 2020. This report presents the social significance of this project, the overview of the facility, Kubota rotary Surface Melting Furnace(KSMF), which is the core equipment, and the equipment automated for the handling of radioactive materials.


Fig. 1 Municipalities Within the Countermeasure Area[1)]

## 2. Development concept and goals

The facility was built for the purpose of reducing the burden of radioactive control, which will last a long time, by minimizing the volume of radioactively contaminated waste and thereby minimizing the volume of final disposal. They are located in the nuclear waste repositories, which were organized in Okuma town and Futaba town and are situated as if surrounding the Fukushima Daiichi Nuclear Power Station, Tokyo Electric Power Company (Fig. 2). The facility processes a total of 150 t/day with two units of KSMF, which has a treatment capacity of 75 t/day. The annual throughput is planned to be 37,500 t.

The bottom ash and the fly ash to be treated are subjected to pretreatment such as iron removal and crushing, and then melted in KSMF kept at 1,300°C. The radioactive materials contained in the waste become gaseous in the rotary surface melting furnace, then separated and transferred to exhaust gas treatment, and are collected as ash treatment soot by a filtration dust collector (Bug Filter). The product (slag) generated by the


Fig. 2 Overall View of Temporary Treatment Facility

melting process is recycled as civil engineering construction materials for waste water layers, etc. of the nuclear waste repository after confirming that it conforms to the environmental safety quality standards (Fig. 3).

By this process, the radioactive materials contained in the waste are concentrated into the fly ash from melting furnace. Decontamination waste, etc. is reduced in volume to about 1% by incineration and ash melting.

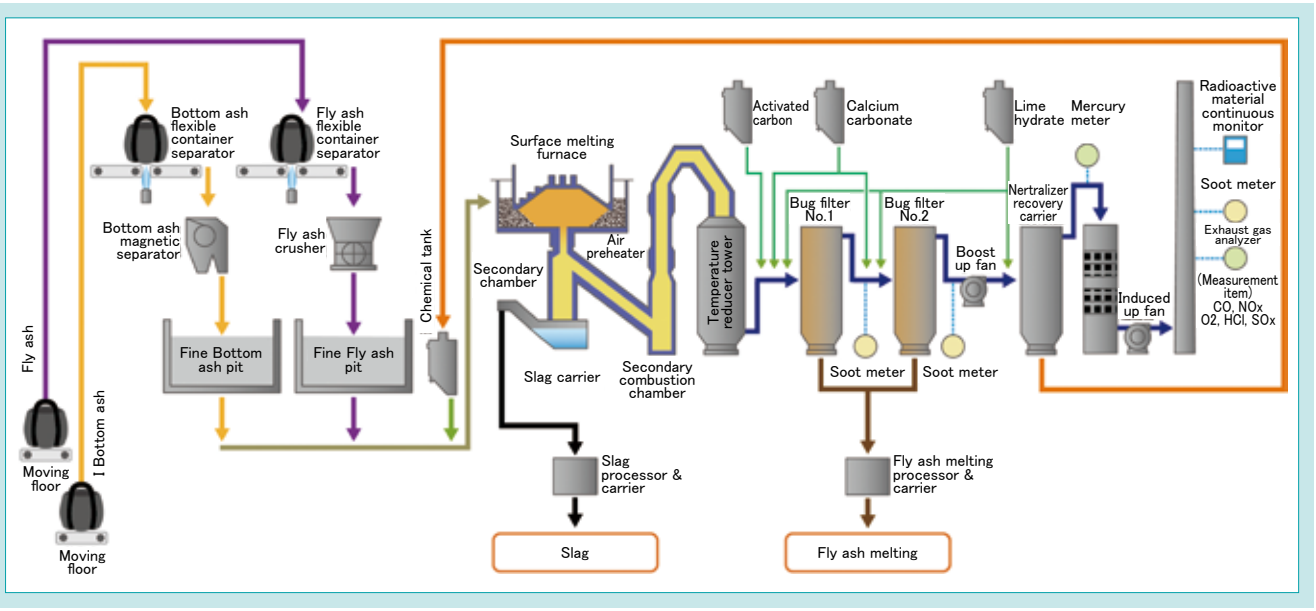



Fig. 3 Processing Flow of Temporary Ash Treatment Facility

## 3. Kubota rotary Surface Melting Furnace (KSMF)

KSMF performs melting treatment on the melting surface located at the main combustion chamber's bottom, which is shaped like an abacus bead with an inner diameter of 8.5 m. It is composed of a rotary outer barrel, a vertically movable inner barrel, and a slag port from which slag is discharged. The ash is uniformly and continuously supplied from the entire circumference to the melting surface of the main combustion chamber by the slow rotation of the outer cylinder. The waste fed to the main combustion chamber is uniformly heated and melted vertically in both directions by the burner flame and the melting surface, and becomes slag flowing to the slag port (Fig. 4). With these structural characteristics, slag can be produced with uniform properties and stable quality in environmental safety.

KSMF has been very positively evaluated in terms of technology and stable operation results, as represented by the illegal-dumping waste treatment in Teshima, Kagawa Prefecture.

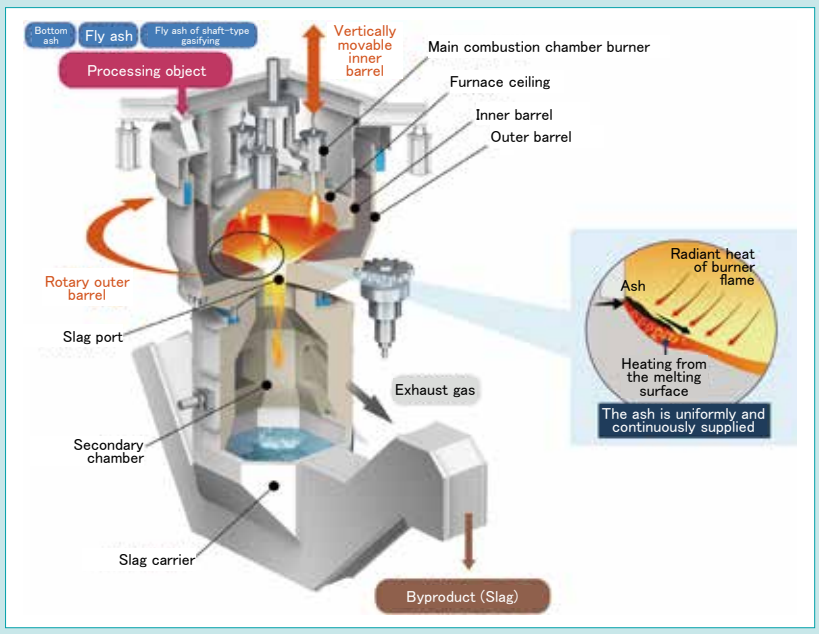



Fig. 4 KUBOTA Surface Melting Furnace

## 4. Introduction of automation technology

### 4-1 Automated and unmanned receiving yards

The bottom ash and fly ash, which are the waste to be treated and contain radioactive materials, are packed in a flexible container when arriving at the facility.

A forklift is normally used for unloading flexible containers, but in this project, a moving floor was adopted and it was also installed in the transporting vehicle, so that all the processes from unloading, storage, and to loading into the pretreatment facility are automated and unmanned, thus reducing the radiation exposure risk of workers. In addition, by attaching an RF tag to flexible containers in advance to establish the use of radio communication, automation is used for the check of container identity, such as the names of temporary incineration facilities as the source information of bottom ash and fly ash (Fig. 5).

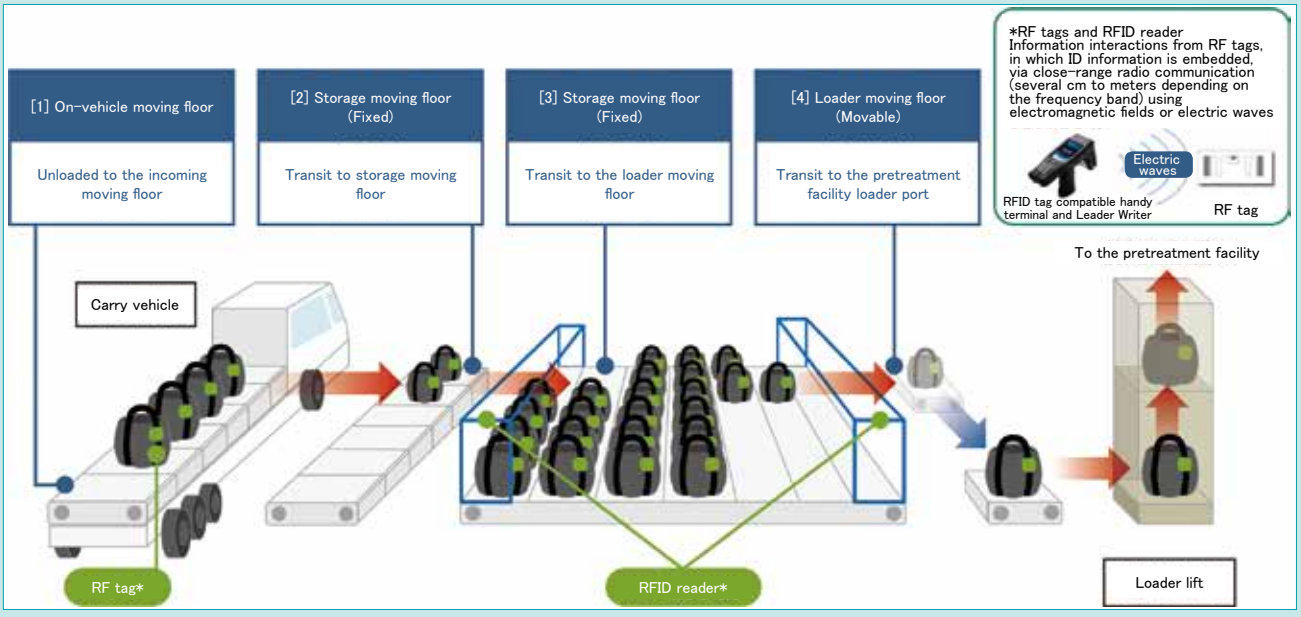



Fig. 5 Receiving Yard Automation

### 4-2 Automated or unmanned operation of fly ash melting container filling equipment

The fly ash melting, which is generated as the byproduct of treatment, has a high concentration of radioactive materials. It is sealed in steel square containers with inner bags and stored in waste storage facilities in the nuclear waste repository.

This storage work has been automated and unmanned: By placing an empty inner bag and a steel square container, the machine does the work of removing the upper lid of the steel square container, setting the inner bag and the steel square container, filling and sealing fly ash melting, and reattaching the upper lid. In this way, the radiation exposure risk of workers is reduced (Figs. 6, 7). In addition, lead glass for radiation shielding is installed on the front of the forklifts used for transportation to reduce exposure dose to workers.

Fig. 6 Filling a Steel Square Container

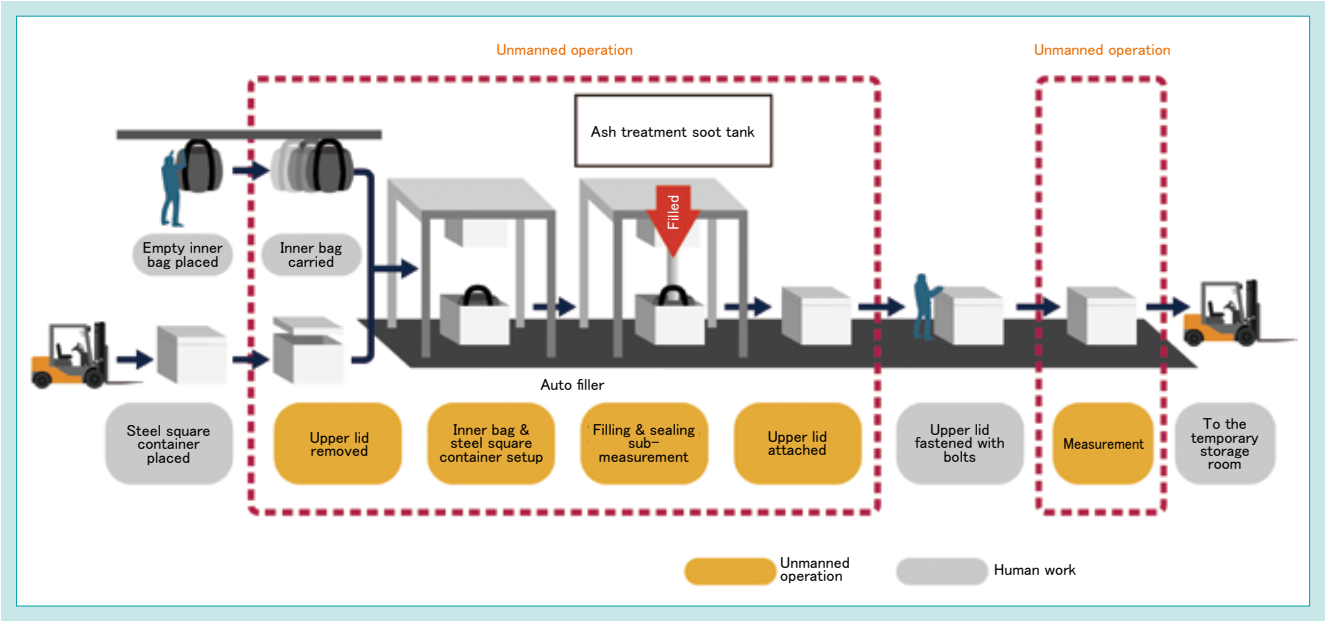



Fig. 7 Automation of Soot and Dust Filling Equipment

## 5. Conclusion

The entire JR Joban Line was restored in March 2020, and the 2011 Tohoku Earthquake and Nuclear Disaster Hall was opened in the Nakano area of Futaba town in September to provide information on disasters and reconstruction. Although the recovery is proceeding steadily, it is also true that houses that were destroyed in the disaster still remain. This project accelerates the reconstruction of the affected areas by reducing the volume of waste produced by this disaster and will grow to serve as one of the projects to get the residents back to the town soon.

From now on, we will achieve the safe and secure operation of our facilities with the awareness and sense of responsibility of playing a part in national projects. By completing this project, as Kubota Environmental Services Co., Ltd., we would like to further enhance our technological capabilities to contribute to the development of local communities and the preservation of the global environment.

## Contribution to SDG targets

11.6 Environmental improvement through waste management strengthening, etc.
Contribution to environmental improvement by reducing the volume of waste

11.b Formulation and implementation of disaster risk management
Contribution to prompt disaster recovery

12.5 Prevention and reuse of waste
Contribution to waste volume reduction by reuse of byproduct (slag)

Reference

1) Radioactive pollutant waste management information site, Ministry of the Environment Waste in the designated areas http://shiteihaiki.env.go.jp/radiological_contaminated_waste/regional_measures/ (reference on 2020-12-07)

# Highly Packed KUBOTA Submerged Membrane Unit SP900-A

## 1. Introduction

KUBOTA Submerged Membrane Unit is a membrane filtration system used for the membrane bioreactor process, which is an advanced wastewater treatment method. The use of KUBOTA Submerged Membrane Unit delivers secure and safe treated water and also saves space in wastewater treatment facilities.

In recent years, the needs for boosting the treatment capacity by modifying existing facilities are growing in the wastewater treatment market. The introduction of KUBOTA Submerged Membrane Unit under these circumstances can increase treatment volume with minimal facility modification. Aiming at increased volumes of water treatment by making full use of existing biological treatment tanks to reduce retrofit cost, we have developed the Highly Packed Submerged Membrane Unit "SP900-A", which has enhanced the membrane packing density (surface area of membrane per area of membrane unit installation) compared to conventional products.

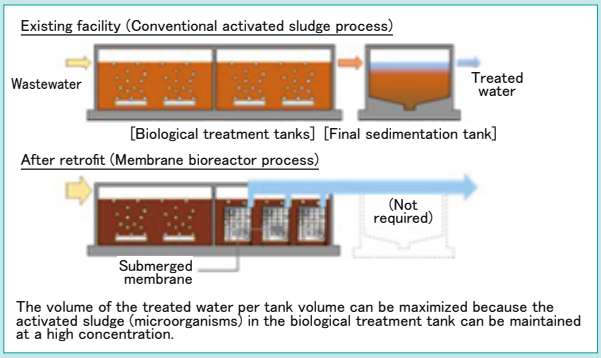



Fig. 1 Image of KUBOTA Submerged Membrane Unit Application to Retrofit of Existing Facilities

## 2. Product overview

In KUBOTA Submerged Membrane Unit SP Series, the membrane modules, in which membrane elements are bound, are mounted in a multi-stack and multi-row combination (Fig. 2).

With the following two improvements, the SP900-A has realized the membrane packing density 50% greater than with the SP600, which is the previous largest model.

1) Structure of the membrane module

The membrane element has been reduced 25% in thickness while keeping the filtration performance and durability at the same level as that of conventional products.

With this, the number of membrane elements per membrane module was increased and thereby has achieved an increase of 12.5% in membrane packing density.

2) Structure of the unit

By improving the frame strength of the membrane unit, the number of membrane modules that can be mounted has been successfully increased to up to 12 to 16 stacks. This increased the membrane packing density by 33.3% in comparison with SP600.

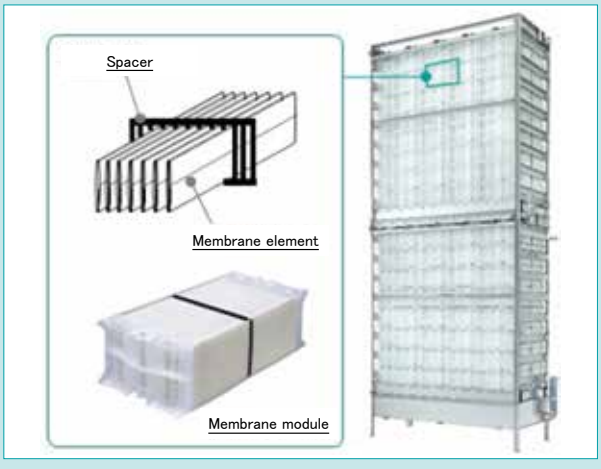
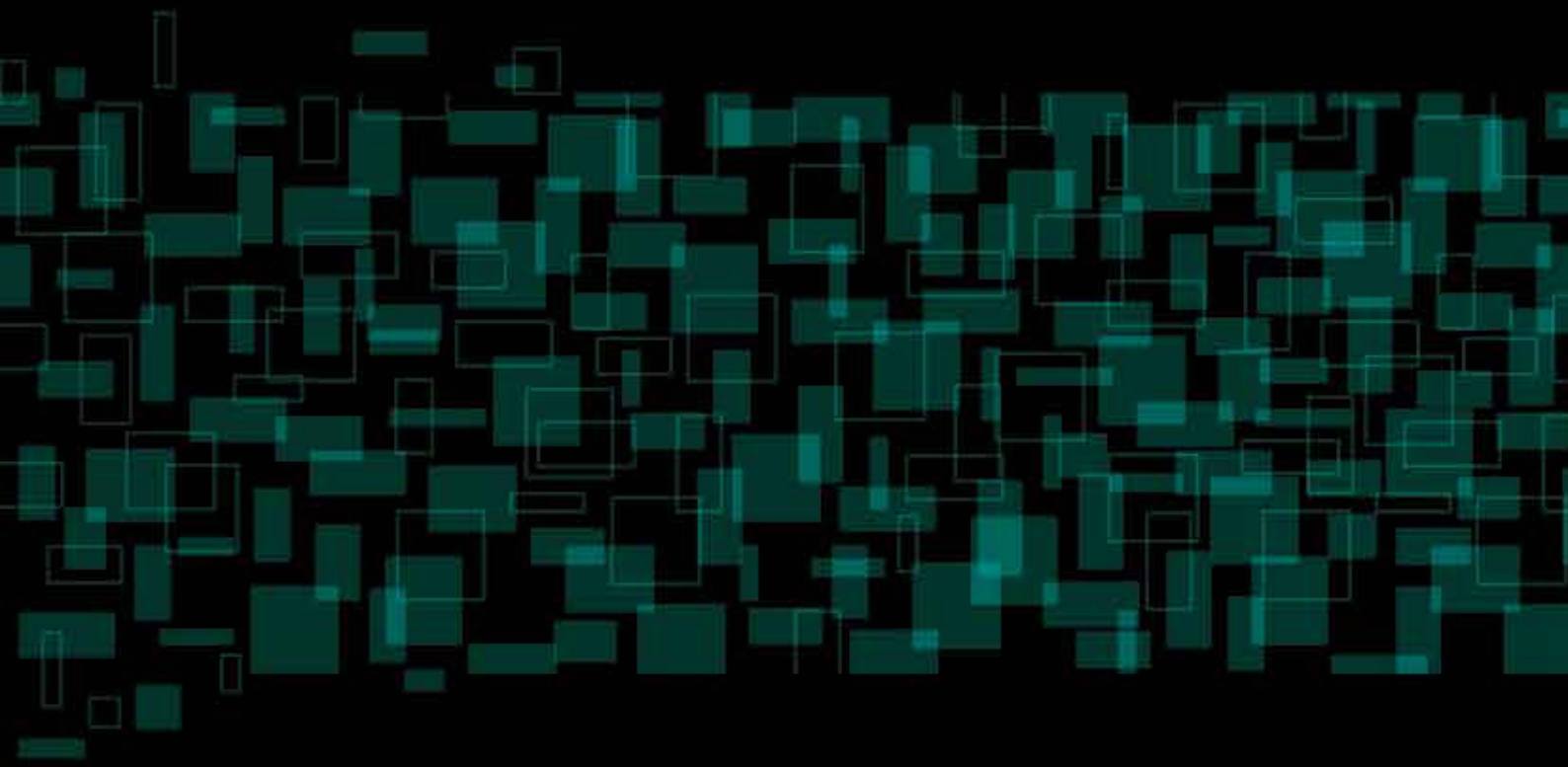



Fig. 2 Highly Packed KUBOTA Submerged Membrane Unit SP900-A

## 3. Conclusion

Kubota will continue improving KUBOTA Submerged Membrane Unit and work on improving its energy-saving performance when in use as well. We continue our taking on the challenge of achieving high performance and low cost wastewater treatment technology to attain the SDGs that the world has set as its goals.

Contact: 〒661-8567
Company: Membrane Systems Engineering Dept., Kubota Corporation
Address: 1-1-1, Hama, Amagasaki City, Hyogo 661-8567, Japan
TEL: +81-6-6470-5840



株式会社クボタ

www.kubota.co.jp