For Earth, For Life
Kubota

KUBOTA TECHNICAL REPORT

DECEMBER 2025

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No.58 DECEMBER 2025

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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 High-clearance Tractor “NR Series” for the Domestic Market
■		Development of the RTV-X1130 Long-bed Utility Vehicle
■		Development of the Evaluation Technology for the 5-axis Powertrain Testbed Following the MBD
■	■	Development of Technology to Improve the Comfort of Cabin Air Conditioning
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	■	Introduction of the KSIS BLUE FRONT Equipment Monitoring System “KEMOS”

For more information on SDGs (Sustainable Development Goals),
please visit the website of the United Nations Information Center.
https://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
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Research and Development Sustaining the Future of the Earth and Humanity

President and
Representative Director
Yuichi Kitao

Kubota was founded in 1890 and marked its 135th anniversary in 2025. The conviction of our founder, Gonshiro Kubota—that our products should not only be technically excellent, but also useful for the good of society—continues to be passed down in Kubota's DNA. Through our businesses in the fields of food, water, and the environment, we have remained committed to addressing social issues. As a "platform provider supporting life" dedicated to realizing a sustainable Earth, society, and prosperous livelihoods, Kubota will continue its research and development efforts with the aim of being an indispensable presence for all.

Climate change continues to intensify. Populations are rapidly surging in Asia and Africa, and developed countries in particular are facing declining birthrates and aging populations. Against this backdrop, society's challenges are becoming steadily more complex. Kubota shared a part of its approaches to these issues at the "Future City" Pavilion during the Osaka-Kansai Expo 2025, which successfully concluded in October of this year, by presenting concept models of agricultural machinery for the future and interactive games that encouraged visitors to envision the future of agriculture. The company exhibited two types of versatile platform robots and a concept model of autonomous fuel cell tractor. However, these are not simply visionary concepts. At the 1970 World Expo, Kubota showcased the Dream Tractor, equipped with an enclosed cabin and air conditioning unit. Now, 55 years later, the company has realized autonomous agricultural machinery and data-driven precision farming that far surpass the "dream" envisioned at that time. This vision forged by Kubota was brought to life through collaboration with a wide range of partners. Likewise, we are also confident that the concepts for the future exhibited at this year's Expo will––within the next several to a dozen years––take shape as products and services that make an even greater contribution to the futures of communities around the world.

Japan and the rest of the world are all striving toward a new form of society to address the increasingly complex challenges of the future. This new form––known as Society 5.0––is defined as achieving both economic development and the resolution of social issues, following the stages of industrialization and transformation into an information-oriented society, through the advanced integration of cyberspace and physical space. To aid in achieving this, Kubota is drawing on the expertise it has cultivated in the fields of castings, farm and industrial machinery, and electronic control technologies, while also embracing new technologies such as ICT, AI, and electric motors. In addition, conditions relating to climate, water, soil, crops, roads, and pipeline infrastructure vary by region and country, as do the social issues they face. We will work to accurately understand these characteristics in order to continue delivering products, services, and solutions that help address these issues in a sustainable way.

I believe that the challenges are always at the frontlines. That is why I consider it essential to stay close to the frontline operations, gain a deep understanding of the challenges faced from the customer's perspective, formulate a compelling vision, share this vision with our stakeholders, and move forward together to bring it to life. By leveraging the advantages of industry-government-academia collaboration and open co-creation projects with external partners from both inside and outside of the industry, we aim to realize a vision that far surpasses the concepts we presented at this year's Expo.

Kubota Technical Report No. 58 features articles on high-clearance tractor, utility vehicles, and rice transplanters that improve work efficiency for customers (users); new earthquake-resistant ductile iron pipes with enhanced workability; cabin air-conditioning comfort-improvement technologies developed using analytical methods; and an infection-trend monitoring system developed through industry–government–academia collaboration. We hope this report provides a better understanding of Kubota's initiatives.

Development of High-clearance Tractor "NR Series" for the Domestic Market

Tractor Enginieering Dept. Ⅰ／Farm and Industrial Machinery R&D Dept. Ⅲ

In Japanese agriculture, as consumers' awareness of 'food safety and security' increases, there is a growing demand for reduced use of pesticides. Intermediate management tasks are crucial for reducing pesticide use, but these tasks require significant manpower and effort, making the efficiency and labor-saving of intermediate management tasks a challenge. To address this issue, Kubota has developed a high-clearance machine on a tractor base and introduced it to the market to improve work efficiency. This paper introduces the development technology of this high-clearance Tractor.

【Key Word】
High-clearance Tractor, 4-wheel Steering, Operability, Electric Control, Safety Features

Related SDGs

1. Introduction

The Ministry of Agriculture, Forestry and Fisheries is implementing plans to increase vegetable cultivation and production by 2030, driven by recent efforts to boost domestic self-sufficiency and the growing interest in domestically produced, safe vegetables. Additionally, increased consumer awareness of food safety and security is leading to greater demand for reduced pesticide use. Careful management practices, such as intertillage and mechanical weeding, are required to reduce pesticide use, and walk-behind tractors (Fig. 1), which can maneuver between growing crops and perform detailed work, are often used for such labor-intensive tasks. Meanwhile, a shortage of agricultural workers has become a serious problem for Japanese farms in recent years. In vegetable farming, there is market demand to streamline and reduce the labor required for management tasks, which are particularly labor-intensive. Consequently, there is a growing trend toward introducing riding tractors instead of walk-behind tractors for these tasks (Fig. 2).

In 1999, Kubota launched the GR16 high-clearance tractor for upland crops, primarily soybeans and wheat grown on converted paddy fields, in the domestic market. However, declining demand for crop conversion led to falling sales, prompting the company to discontinue its production in 2009. Meanwhile, after the discontinuation of the GR16, high-clearance tractors with changeable steering modes, including a four-wheel steering mode, were recognized as having suitable vehicle specifications for managing not only wheat and soybeans but also vegetables. Consequently, the demand for riding tractors increased alongside the aforementioned trend of using them for vegetable management tasks. However, since the GR16 had already been discontinued and Kubota lacked a lineup of high-clearance tractors to meet the market demand, the company developed the NR series, which incorporates the GR16's functions, based on the NB tractor. This paper introduces the new features of the NR series.

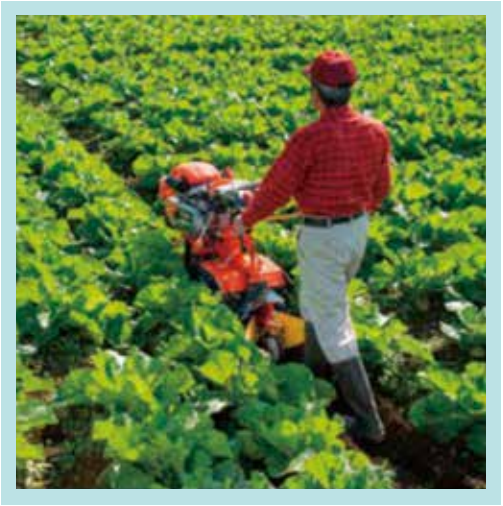


Fig. 1 Walk-behind Tractor in Operation

Fig. 2 High-clearance Tractor in Operation

2.Development concept and target values

To develop high-clearance tractors tailored to market demands, it was necessary to meet vehicle specifications suitable for vegetable management tasks and incorporate features that enhance usability and reliability. It was also necessary to bring the product to market early to meet the rising demand. Therefore, the NR series (Fig. 3) was developed as a tractor-based product. The concept was to "enable anyone to work easily and confidently in various fields" by providing outstanding durability and operability while minimizing new investments, development efforts, and costs. To achieve this concept, the following three goals were kept in mind during the development process:

(1) As a high-clearance tractor designed for vegetable management tasks, its body dimensions should be capable of handling various field conditions.

(2) The tractor should have a steering mode switching function that enables smooth transition to the steering method best suited for a given task.

(3) The tractor should incorporate safeguards against carelessness and operational errors, allowing anyone to use it with confidence.

Fig. 3 High-clearance Tractor "NR Series"

3.Technical issues to be solved

3-1 Achieving vehicle dimensions suitable for various fields

Operating a high-clearance tractor for upland crops requires driving over ridges and crops, making minimum ground clearance (Fig. 4) and tread (Fig. 5) critical vehicle dimensions. Cultivation systems for upland crops vary by region and crop type. Therefore, a wide range of tread adjustment is necessary to adapt the single tractor model to diverse cultivation systems. The challenge, therefore, was to develop a mechanism that would allow the operator to easily adjust the tread to match the spacing of crop rows.

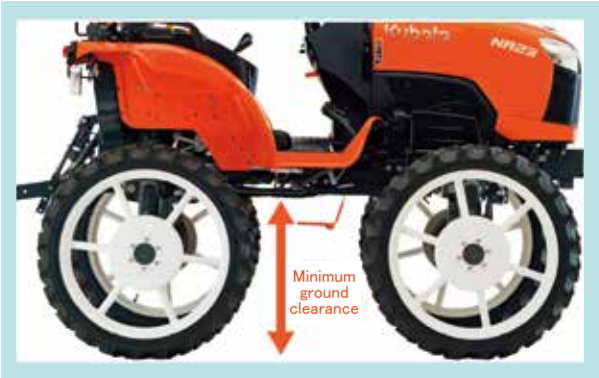


Fig. 4 Min Clearance

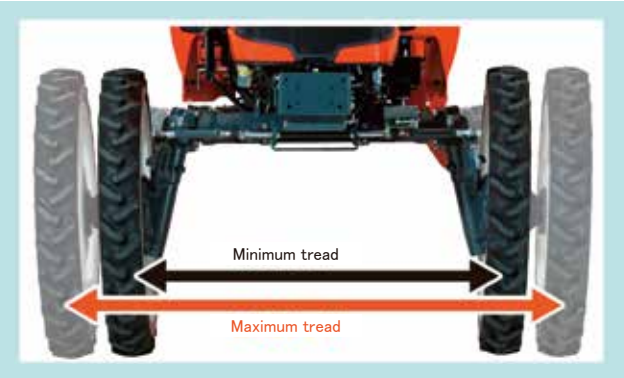


Fig. 5 Tread

3-2 Achieving a steering mode switching function suitable for the given task

In upland crop management operations, since vehicles must travel and work within the limited space where crops are planted, the required movements differ depending on the specific task. For example, stable straight-line travel is required when working across crops to avoid trampling crops or ridges. On the other hand, tight turns are required for minimizing the space needed for turning to prioritize crop planting space, thereby maximizing yield. After turning, it is necessary to adjust the vehicle's position smoothly so that the tires align between the ridges. Therefore, a challenge was to develop a steering mode switching function that enables appropriate maneuvers in various work situations. Another challenge was installing a steering mode switch that is easy to use and allows for smooth switching between modes.

3-3 Achieving features anyone can use with confidence

Due to their specifications, high-clearance tractors have a higher center of gravity than standard tractors of the same horsepower range. Therefore, braking suddenly while traveling at high speeds or operator negligence, such as forgetting to engage the right and left brakes, can cause the tires to lift or the vehicle body to sway, potentially making the operator feel more uneasy than they would in a conventional tractor. Therefore, preventing carelessness and operational errors was a challenge.

4.Developed technology

4-1 Development of a variable tread mechanism

To change the tread, you can generally offset the tires using methods such as: (1) inserting spacers between the axle and the tire, (2) swapping the right and left tires, or (3) using tires that allow the rim and disc to be reassembled. However, while these methods can adjust the position of the tires outward, the gear cases remain inward. This poses a problem when substantially widening the tread because the gear cases interfere with crops (Fig. 6). To prevent this interference, a structure was needed that would allow the gear cases to move simultaneously with changes to the tread. Therefore, the NR adopted a zoom tread structure (Fig. 7), which changes the tread by relocating the entire gear case. In this structure, turning the tread adjustment bolt with a tool causes the rack to slide, which moves the entire gear case and allows for tread adjustment. Combining the zoom tread structure with swapping the right and left tires achieved an eight-stage variable tread mechanism ranging from 1,145 to 1,505 mm in approximately 50 mm increments.

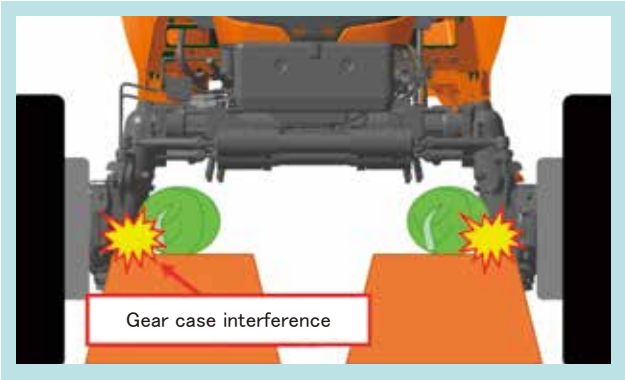


Fig. 6 Interference Between the Gear Case and the Crop

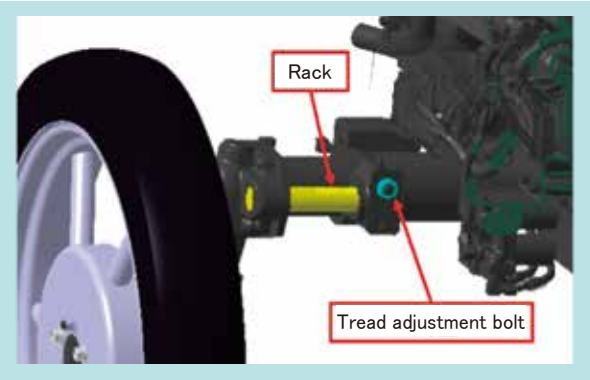


Fig. 7 Zoom Tread Structure

4-2 Development of the steering mode switching function

The NR features a steering system that allows the steering of not only the front wheels but also the rear wheels, enabling various vehicle maneuvers. It incorporates the following steering modes: front-wheel steering (FWS), rear-wheel steering (RWS), four-wheel steering (4WS), and crab walk steering (CWS). The characteristics of each mode are as follows.

Front-wheel steering (FWS):

This mode facilitates steering during forward movement and uses the same controls as a standard tractor, allowing for quick familiarization. It is used for straight-line operations and driving on public roads.

Rear-wheel steering (RWS):

This mode improves steering performance during upland crop management tasks that involve long-distance reversing along ridges.

Four-wheel steering (4WS):

The front and rear wheels steer in opposite phases, enabling tight turns. This mode is used for headland turns. The NR ensures that the front and rear wheels have the same opposite steering angle, so they follow the same track and minimize trampling (Fig. 8).

Crab walk steering (CWS):

The front and rear wheels steer in phase with each other to enable parallel movement. This mode is used for fine adjustments such as aligning with rows or pulling the vehicle over to the side (Fig. 8).

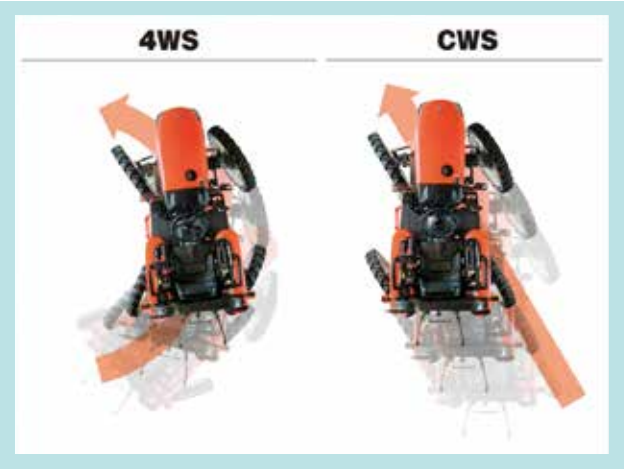


Fig. 8 4WS and CWS Running Trajectories

4.2.1 Steering mode switch location

In order to smoothly switch between steering modes as conditions change during operation, it is important to position the steering mode switch where it is easily visible and simple to operate. To ensure visibility and operability without obstruction from the steering wheel or other components when the operator is seated, the panel cover was placed on the left side in the NR. An illustrated label and text indicating the status of the steering mode were placed on the right side of the switch, with the selected mode being illuminated. This significantly improves visibility and operability compared to competing models (Fig. 9).

Furthermore, since the planned production volume was lower than that of conventional tractors, it was necessary to minimize mold investment. Therefore, the switch mounting bracket was designed to use sheet metal instead of molds. By incorporating angles and bending structures that harmonize with the panel cover, we achieved an aesthetically pleasing bracket.

Fig. 9 NR Series Steering Mode Switch Layout

4.2.2 Development of a customizable auto mode

In addition to manually switching between steering modes as mentioned above, the NR is equipped with an automatic switching function that selects the appropriate steering mode based on the product's status during operation (Fig. 10). This feature aims to eliminate the need for manual switching between steering modes by detecting the product's forward/reverse direction and the position of the implement. Some products on the market automatically switch steering modes in the following manner: When the tractor moves forward with its implement lowered, the system recognizes that the tractor is in operation and selects the front-wheel steering mode; when the tractor moves forward with its implement raised, the system recognizes that the tractor is turning and selects the four-wheel steering mode; and when the tractor moves backward with its implement raised, the system recognizes that the tractor is turning around and selects the rear-wheel steering mode. However, some users reported that the turnaround maneuver in the rear-wheel steering mode felt different from usual reversing in the front-wheel steering mode, which made the maneuver difficult. Therefore, the NR has incorporated a customization feature allowing the operator to freely select the steering mode (front-wheel steering, rear-wheel steering, or four-wheel steering) when the tractor is in turnaround mode, i.e., moving backward with its implement raised. The customization feature allows the operator to configure settings simply by pressing and holding the auto mode switch while operating the switch according to the procedure. The operating procedure can be instantly confirmed by scanning the QR label on the switch bracket, so that anyone can easily make customizations.

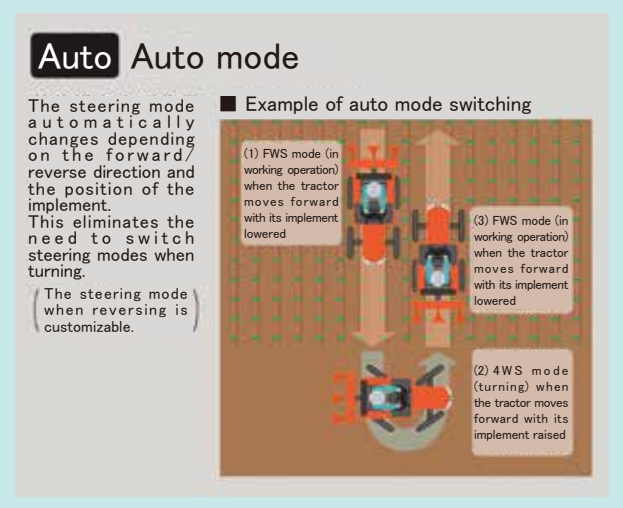


Fig. 10 Example of Steering Mode Switching in Auto Mode

4-3 Implementation of safety features

4.3.1 4WD notification function

Because of its high center of gravity, a high-clearance tractor's rear wheels may lift off the ground during an emergency stop in four-wheel steering (4WD) mode at high speeds. Other manufacturers' countermeasures have been limited to reducing the maximum speed of their vehicles and issuing warnings in their manuals and on labels, advising users to switch to two-wheel drive (2WD) except during working operation. However, reducing the maximum speed could slow travel between fields and on public roads, which could lead to user dissatisfaction. On the other hand, relying solely on warnings in instruction manuals and on labels raises concerns about the risk of forgetting to switch to 2WD. Since high-clearance tractors are relatively inexpensive, they currently have few sensors to monitor their condition. Therefore, the NR aimed to implement features that would provide users with a sense of security while using a minimal number of sensors.

First, a switch sensor was installed on the 4WD on/off lever to detect the 4WD status, and a 4WD indicator was added to the meter panel lamp display (Fig. 11). It was also necessary to detect high vehicle speeds, but adding a vehicle speed sensor was difficult due to space limitations and cost. We therefore

utilized the detection switch for the auxiliary gear "high," which was already installed in the base NB tractor. We regarded the auxiliary gears "low" and "medium" as working operation mode gears and "high" as a travel mode gear and considered that the auxiliary gear "high" indicates high-speed driving. This enabled us to use the detection switch effectively. However, the vehicle speeds that were set using the existing gear combinations were suitable for plowing operations in paddy fields, where typical tractors are used. Specifically, the auxiliary gears "low" and "medium" correspond to 1.5 km/h and 5.2 km/h, respectively. On the other hand, the typical working speeds for vegetable management tasks are 2–3 km/h and 7 km/h for "low" and "medium," respectively. Therefore, the auxiliary gear was redesigned to fit within the limited machine space, achieving 3.2 km/h and 7.0 km/h for the auxiliary gears "low" and "medium," respectively. This allowed the auxiliary gears "low" and "medium" to cover the working speed range, and the detection of the auxiliary gear "high" to indicate that the vehicle is in high-speed driving mode rather than working operation mode.

These changes allowed the buzzer to sound when the auxiliary gear "high" state is detected while the vehicle is in 4WD mode. Furthermore, to help the operator understand why the buzzer sounds, we implemented a 4WD notification feature that flashes the 4WD lamp on the meter panel, thereby preventing operator errors.

4.3.2 Brake disengagement notification feature

High-clearance tractors have been equipped with a single-side braking mechanism since previous models. The single-side braking function features independent brake pedals on the right and left sides, enabling braking on only one side. This allows for tight turns and fine adjustments to the vehicle's direction during working operation, making it useful for work. On the other hand, caution is required when using single-side braking. Especially when driving at high speeds, such as on public roads, unintentionally applying only one brake may cause the vehicle to skid sideways. Therefore, except during working operation, the right and left brakes should be mutually engaged, and care must be taken not to apply only one brake. Previous models and competing products addressed this issue through warnings in instruction manuals and on warning labels.

On the other hand, tractors feature a disengagement pedal. This allows the use of a single brake only while the pedal is depressed and automatically re-engages the brakes when the pedal is released, thereby preventing operator error. However, this method has drawbacks. Notably, it is impossible to operate the clutch and disengagement pedals simultaneously because they both require the use of the left foot, and this has led to complaints from users.

Therefore, rather than using a disengagement pedal to prevent accidental operation, the NR uses a method that alerts the operator with a buzzer and flashing lamp (Fig. 11) when a situation requiring attention arises, i.e., when single-side braking is a possibility while running at high speed. For detecting high-speed running, the same auxiliary gear "high" detection switch used in the 4WD notification function was employed. For detecting the brake pedal engagement status, a switch and structure similar to those in comparable models were employed. This enabled the implementation of a brake disengagement notification function that prevents operator errors without incurring additional costs, which was achieved by combining the existing base unit's functions instead of adopting new sensors.

Fig. 11 NR Series Meter Panel Layout

5.Conclusion

The developed machine, launched in 2023, is a high-clearance tractor for upland farming based on a tractor platform. This model type has not been offered by other manufacturers. In light of the changing environment surrounding domestic agriculture and the need for efficiency amid the declining number of agricultural workers, we believe the NR series can contribute to greater agricultural efficiency as a product that can adapt to various fields and that anyone can use with confidence.

The development of the riding tractor for intermediate management tasks has also enabled the creation of products with autonomous driving technology, allowing for greater efficiency.

Moving forward, we will develop more user-friendly, high-clearance tractors based on customer feedback and requests. At the same time, we will advance technological development to achieve automation through the relentless pursuit of efficiency and labor savings.

Contribution to SDG targets

2.4 Realization of sustainable and robust agriculture
Reducing the workload for intermediate management tasks by streamlining the steering mode switchover process

9.4 Improvement of industries by introducing environmentally friendly technologies and industrial processes
Contributing to the introduction of environmentally conscious technologies through reduced pesticide use

12.2 Sustainable management and efficient use of natural resources
Reducing fuel consumption by improving work efficiency

Development of the RTV-X1130 Long-bed Utility Vehicle

Kubota Research & Development North America Corporation

RTV-X1130 is a derivative model introduced to expand the lineup of the RTV series. This model is directed towards the work-focused customer who wants the larger capacity of a long-bed model. The development concurrently provided several accessories to expand the model's functionality. This model has been well received, and the work-focused customer appreciates the option to purchase a model which caters to their needs. In the first full year of sales RTV-X1130 shipments exceeded original target by more than 30 %.

【Key Word】
Long-bed Utility Vehicle, Folding Side Gate, Cargo Winch

Related SDGs

1. Introduction

At the time of the RTV-X1130 concept investigation, the North American Pure Utility Vehicle market volume was basically static, and the Kubota RTV series held a dominant position in the diesel segment. The RTV-X series was introduced several years prior and the interest in the model line had been decreasing. To reinvigorate the RTV-X series sales RTV-X1130 will be developed to capture customer interest ahead of the next major diesel model change and expand the market offering of the RTV series.

Market surveys prior to RTV-X1130 development indicated some customers were purchasing the current RTV-X1140 to utilize the larger cargo bed configuration only. It was evident that there was an unrealized market for a single-row long-bed RTV. It was determined that a model could be developed to meet the needs of the customer while providing a boost in profitability over the RTV-X1140.

Once the basic strategy was set, it must be decided how to capitalize on the needs of the target market. This was accomplished by adding useful features and functions, while concurrently developing accessories tailored to the usage cases of the customer. This technical report will describe challenges encountered in this development and the solutions that were created to meet them.

Fig. 1 RTV-X1130

2. R&D Concept and Target Value

2-1 R&D Concept

RTV products are used for a wide variety of tasks by customers in various industries. Customers range from small hobby farmers or landowners to large institutions in commercial settings. Kubota RTVs are well known for their durability and capability when used for carrying or pulling heavy loads. The target of the RTV-X1130 development was to introduce a work-focused RTV to revitalize the pure utility vehicle market and expand the RTV business. This model should offer more working capabilities to the user while maintaining the reputation for durability. The development should also control the investment of manpower and capital to facilitate rapid introduction to the market.

2-2 Target Value

The primary targets of the RTV-X1130 development were:

(1) Introduce a new model to the RTV line-up with enhanced capabilities.

This will attract new customers to the RTV line and generate interest until the next generation of RTV models is introduced. It will expand the capabilities of the RTV platform to capture more market share.

(2) Improve the work capability of the model.

Increasing cargo volume and weight capacity will make it more attractive to users performing heavy work. Adding folding side gates will make it more user friendly and attractive to a larger market. Accessories that leverage the work focus and larger bed will provide additional opportunities to increase profitability.

(3) Respond to the customer who desires additional work functions of a diesel utility vehicle.

The existing diesel RTV provides the customer with a versatile platform, however there are requests for configurations focused on heavy work. The development should provide a solution that does not compromise work capacity while remaining within the performance limits of the existing platforms.

(4) Maintain current platform (RTV-X1140) as much as possible.

The established RTV-X1140 platform has already been developed and passed required durability testing. To reduce development investment of manpower and capital it will be used as the basis for the development. Efforts will be made to maintain the basic parameters of the chassis to prevent issues in development.

3. Technical Challenge to be Solved

3-1 Cargo Bed Sizing, Structure and Integration

Developing a cargo bed large enough to satisfy customer demand was the most important challenge to meet the development values. The current RTV one-row model cargo bed is fairly short, or folds into the passenger area on the two-row model. This compromise leaves a niche to be filled by a large non-folding cargo bed. The existing RTV platform places some limits on the overall size of the cargo bed to be implemented and there are competitor vehicles in the market which can offer some guidance to the development.

The designed structure of the cargo base plate also bears consideration due to the restriction on investment for the project. Without significant tooling investment part forms must be limited and welding configurations require careful consideration. The overall size of welded parts must be controlled as well due to limitations in the manufacturing facility material handling equipment.

Working with a long cargo bed requires consideration of human interaction during loading and unloading. This leads to the requirement of accessing cargo from the side of the bed which can be facilitated by folding side gates that were not yet developed for the RTV series.

The base vehicle platform for the development was selected to be the RTV-X1140. This platform required the removal of parts related to the cargo bed, rear seat, ROPS, and several rear covers. In addition to integrating the new cargo bed the development had to account for the related parts removed from the chassis. Additionally, the chassis load limits had to be respected to prevent durability issues in the released model.

3-2 Accessory Integration

The larger cargo area and work focus of the project led to consideration of accessory development as well. Accessories that would allow the user to get more work done faster could be key to increasing the value of the machine. The accessory packages must integrate into the base platform and aid in tasks that the work focused customer would be expected to perform.

4. Developed Technology

4-1 Cargo Base and Structure

4.1.1 Technical Challenge

The most significant consideration for the development was the cargo bed size and configuration. The project could not invest significant capital into tooling or fixtures so the part forms and weld process must respect the capabilities of the current manufacturing processes. The larger cargo bed also required the project to confront the base vehicle tendency to allow the cargo bed to rise unintentionally when loaded on the rear side.

4.1.2 Solution of Challenge

Utilizing the maximum space available in the RTV-X1140 chassis footprint after removal of the rear seating would yield a cargo bed just over 5-feet-long (1.5 m). While this is an improvement over the existing models, many longer tools and parts would not be able to lay flat in the cargo bed. Therefore a 6-foot-long (1.8 m) cargo box was realized allowing long or bulky items to fit inside the cargo volume. The progression of the cargo bed size consideration is shown in Fig. 2. The resulting cargo bed volume is 37 % larger than the RTV-X1140 and 72 % larger than the other single-row RTV models. The cargo bed was developed to take advantage of the mass reduction due to the removal of components related to the seat and cargo transformation functions resulting in a 10 % increase in cargo load capacity to 1212 lbs. (550 kg).

Realizing the larger cargo bed required the structure to adopt a ladder-style frame with interlocking joints between the lateral and longitudinal members shown in Fig. 3. Welding was limited to the GMAW (Gas Metal Arc Welding) process due to manufacturing facility capacity and fixturing. The project also decided to keep all of the welding on one side of the cargo component parts to facilitate torch access.

The RTV-X series cargo beds are known to rise without user input if weight is placed on the rear side of the cargo bed due to internal leakage in the lift cylinder control valve. The additional length and capacity of the RTV-X1130 make this tendency more pronounced and requires an additional countermeasure. A mechanical lock underneath the cargo bed (Fig. 4) was added to secure the cargo base to the vehicle frame preventing unintended rising of the cargo bed due to the valve leakage. Analysis and testing of the lock system showed it would withstand repeated abuse while maintaining the ability to perform its intended function without damaging the base vehicle or cargo base.

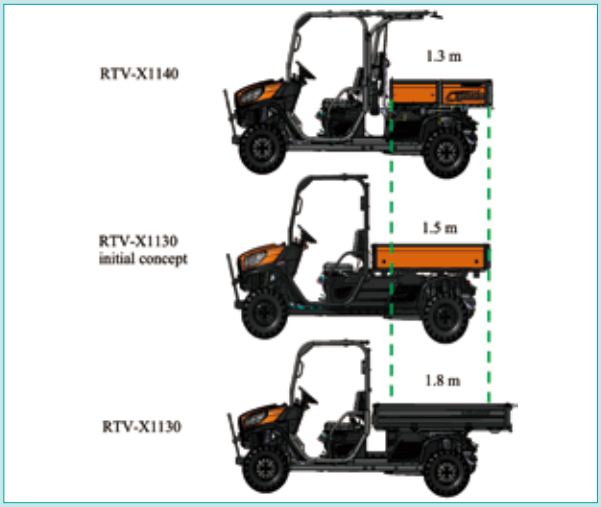


Fig. 2 Cargo Bed Length Development Progression

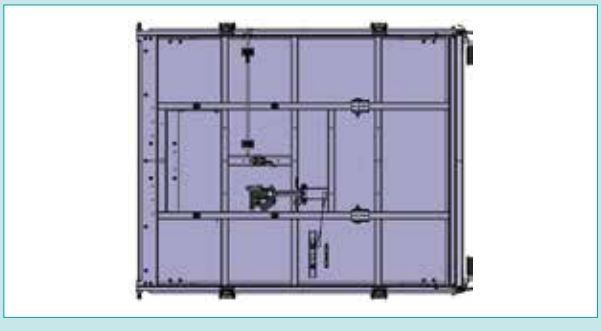


Fig. 3 Cargo Base Frame Ladder Structure

Fig. 4 Cargo Bed Lock

4-2 Three-way Folding Cargo System

4.2.1 Technical Challenge

The large size of the cargo bed prevents customers from reaching items loaded in the center of the bed easily. Even with the larger cargo bed some customers may still want to load oversize items that exceed the cargo bed footprint or side wall height so features should be provided to allow this.

4.2.2 Solution of Challenge

The side gates were designed to fold down as shown in Fig. 5 so customers can easily load/unload items from the larger cargo bed. The current model cargo beds feature a base plate with corrugations to prevent cargo sliding during operation. The side loading option planned for this model required the base plate to be flat so items could be slid easily. Cargo base traction would be provided by a rubberized coating (Line-X) on the base plate.

In order to provide customers additional flexibility in configuring their cargo area, divider slots were integrated to allow division of the cargo space using standard dimensional lumber, as shown in Fig. 6.

There are also stake pockets integrated into the side gates which allow the customer to raise the height of the side gates, Fig. 7, to increase the enclosed volume of the cargo bed using standard dimensional lumber.

The folding side gates and tailgate were developed to be easily removed without the use of tools. The resulting flat-bed configuration (Fig. 8) allows oversized cargo to be placed on the bed and secured with the attached cargo rings.

Fig. 5 Cargo Side Gate Open

Fig. 6 Cargo Bed Dividers

Fig. 7 Cargo Raised Stake Sides

Fig. 8 Flat Bed Configuration

4-3 Base Vehicle Integration

4.3.1 Technical Challenge

The RTV-X1130 was developed with the RTV-X1140 as a base model. The RTV-X1140 is a two-row model with a cargo bed that converts from a short configuration to a long one by utilizing the rear seat space to expand forward. The rear seat is covered by the ROPS and serves as a cover for powertrain components located under the seat. With the removal of the rear seat the ROPS and cover functions need to be replaced and integrated into the RTV-X1130.

4.3.2 Solution of Challenge

Throughout the development base chassis modifications were kept to a minimum, so that the development did not impact the durability of the powertrain and chassis components. Fig. 9 shows a high-level distribution of parts used in the development. The removal of the rear seat and step required that the area be covered for aesthetic and user protection purposes. Adding difficulty to this were several competitor patents restricting the layout of the area.

The RTV-X1140 ROPS that covered the area of the back seat and needed to be removed to allow overhead access to the longer cargo bed of RTV-X1130. However, the existing ROPS for single-row models is not strong enough to protect occupants on RTV-X1130, due to the higher curb weight of its long chassis. A new ROPS was developed using main tubing from the RTV-X1140. Additionally, a method was developed to prevent incorrect welding of the lighter single-row model tubing onto an RTV-X1140 or RTV-X1130 ROPS since outwardly the tubing for both types appear identical. The pin shown in Fig. 10 will reject a ROPS that is not intended for the RTV-X1130.

Fig. 9 Development Parts Distribution

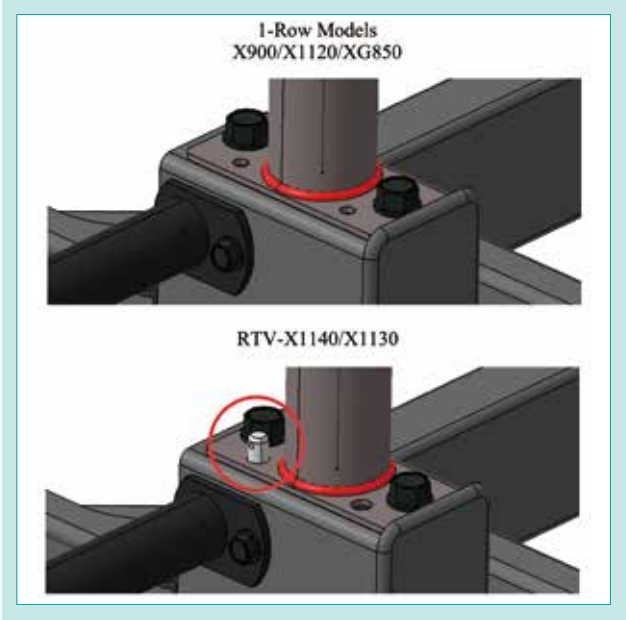


Fig. 10 ROPS Poke-yoke Pin

4-4 Concurrent Accessory Development

4.4.1 Technical Challenge

Accessory development is a key profit driver for utility vehicles like the RTV series so it was essential to consider what could be developed to provide the target customer with more value in a work-focused unit. The accessories should leverage the large cargo bed and available space on the unit to maximize value. They should also maintain the integrity of the base vehicle platform to prevent market issues or increase the development investment.

4.4.2 Solution of Challenge

4.4.2.1 Cargo winch - Fixing an electric winch inside the cargo bed reduces the effort required by a customer to load heavy items into the cargo bed. Fig. 11 shows the cargo winch in operation with a large tractor tire. The selected winch uses a wireless remote to allow the user to manipulate the item being loaded or stand clear of the vehicle as the situation requires. When adding the cargo winch capability protecting the integrity of the cargo bed and frame was a significant consideration. Readily available winches are rated to pull thousands of pounds which could cause significant damage to the vehicle without some protection. An electronic limiting system was developed to prevent the cargo winch from overloading the vehicle structure by cutting power to the winch when cable tension, determined by winch amperage, exceeds a set threshold.

Fig. 11 Cargo bed winch

4.4.2.2 Extended tailgate - The capability to pull items into the cargo bed with the cargo winch accessory led to the development of an extended tailgate accessory. This bridges the gap between the standard open tailgate and the ground when the cargo bed is raised. The resulting ramp lets the customer pull items directly into the cargo bed without requiring them to lift the item onto the tailgate as shown in Fig. 12. The extended gate can be folded down when not in use as a ramp or extended to increase the cargo volume in concert with user installed side panels.

Fig. 12 Cargo Extended Gate

4.4.2.3 Cargo panel and lamp - When working behind the vehicle in low-light conditions it is helpful to have a rear-facing work light attached to the unit. The existing rear work lights for RTVs attach to the ROPS and will fit the RTV-X1130 but are blocked when the cargo bed is raised. The addition of a panel with lights attached (Fig. 13) to the front of the cargo bed alleviated these shortcomings by illuminating the cargo bed and the area behind it when the cargo bed is raised or lowered. The panel also complements side panels installed by the user to increase cargo volume.

Fig. 13 Cargo Panel Lamp

4.4.2.4 Storage box - With the removal of the RTV-X1140 rear seat, unused space was provided under the front of the cargo bed. Lockable storage boxes (Fig. 14) were provided to exploit these spaces giving the user additional locations to store small items and tools.

Fig. 14 Under-bed Storage Box

5. Conclusion

The RTV-X1130 created a Kubota offering into a new market segment for the RTV series. The capabilities and features have been well received by dealers and customers who appreciate the work-focused nature of the machine. Customers who would have purchased the RTV-X1140 solely for the longer cargo bed now have an option that offers more of the capabilities they are looking for.

The development was completed while retaining much of the durability tested and market proven vehicle architecture. This significantly reduced the development time and investment as compared to a full new model development.

In 2024 sales of the RTV-X1130 made a significant contribution to the overall RTV model sales. The sales volume exceeded the original target volume by over 30 %.

After a year in the market the RTV-X1130 cargo system will be updated and applied to a new base vehicle platform. This will incorporate incremental improvements to usability and respond to manufacturing and market request.

Contribution to SDG Targets

2.3 Increasing agricultural productivity and income — Increase in production through improvement in work efficiency

8.2 Improvement in productivity through innovation — Provide product to the customer by development in market

Development of the Evaluation Technology for the 5-axis Powertrain Testbed Following the MBD

Farm and Industrial Machinery R&D Dept. Ⅲ／ Farm and Industrial Machinery R&D Dept. Ⅴ

In recent years, in the tractor market, there has been a demand for higher functions, higher speeds, and lower fuel consumption, including the introduction of CVT. In order to cope with the increasing sophistication and complexity of transmissions (T/M), it has become necessary to accelerate the development of T/M performance. In this study, introducing a 5-axis powertrain testbed (four wheel dynamometer axes and one PTO dynamometer axis), the vehicle dynamics simulation was coupled with the four wheel dynamometer axes to enable bench testing of vehicle driving conditions. A method to reproduce the DLG PowerMix test (a tractor fuel consumption test) was established through integration with a PTO dynamometer and a hydraulic load unit and by recreating the load caused by PTO power and hydraulic power supply to the implement. This is expected to enhance development efficiency, reduce costs, and improve Kubota's tractor performance and market competitiveness.

【Key Word】
Tractor, Powertrain, Drivability, Fuel Consumption, Bench Test, MBD

Related SDGs

1. Introduction

In recent years, the tractor market has demanded greater functionality, higher speeds, and improved fuel efficiency, including the adoption of continuously variable transmissions (CVTs). In particular, performance requirements for drivability have increased significantly. Kubota offers CVT models in its tractor lineup for developed countries. The company must respond to market demands for increasingly sophisticated and complex transmissions, as exemplified by CVTs (Fig. 1).

The conventional development process follows the following sequence: (1) functional verification through bench testing that simulates steady-state loads, (2) performance development including electronic control via actual vehicle testing, and (3) fuel consumption testing at external facilities (e.g., the DLG PowerMix test). Therefore, performance development relies heavily on actual vehicle testing. Actual vehicle testing has limitations in terms of reproducibility due to variations in region, season, road surface conditions, and human operation. Furthermore, conducting extreme operating condition tests, such as harshly towing a trailer on long, steep slopes, are difficult for safety reasons and securing test sites also poses a challenge. Kubota products have traditionally been developed using established testing methods and locations based on years of experience.

However, for CVT tractors demanded by the market, past development experience is limited, and conventional development approaches have resulted in prolonged performance development cycles. Therefore, a new development process is necessary to improve development efficiency. Therefore, we introduced a five-axis powertrain testbed and developed bench test technology to evaluate tractor driving conditions and fuel efficiency.

Fig. 1 Example of Advanced T/M

2. Development concept and target values

2-1 Development concept

We adopted the following points as our development concept:

(1) Enable bench testing at each development stage of the transmission unit and prototypes to reproduce the tractor's dynamic operational load.

(2) Automate bench testing to improve efficiency and enhance test reproducibility.

(3) Enable DLG PowerMix test reproduction (a representative tractor fuel consumption test simulating field operations conducted by DLG; hereinafter the "DLG PowerMix test").

2-2 Target values

(1) Improving the accuracy of reproducing driving conditions in bench testing

Reproduce the dynamic loads acting on the four wheels while the tractor is running. Introduce a method for quantitatively scoring the performance of drivability based on response times and acceleration waveforms to achieve a comprehensive error margin of 10% or less in acceleration waveforms compared to actual vehicle testing.

(2) Improving the efficiency and reproducibility of repeated testing

Implement test automation to enable 24-hour operation and repetition of the same test patterns.

(3) DLG PowerMix test (pre-verification)

Using the aforementioned powertrain testbed, subject the tractor to loads simulating field operations defined by the DLG PowerMix test cycles to enable preliminary in-house verification of the DLG PowerMix test.

3. Technical issues to be solved

To address increasingly sophisticated and complex transmissions, it is necessary to start developing transmission performance earlier and secure a longer development period. In transmission development, functional verification is performed through bench testing of the transmission unit, and performance validation is conducted through vehicle testing. However, the following challenges are encountered.

(1) Reproducing driving conditions in bench testing

Conventional transmission test equipment (Fig. 2, left), designed to apply steady-state loads, cannot reproduce dynamic driving conditions. Consequently, performance development involving electronic control inevitably relies on actual vehicle testing, and any required mechanical countermeasures can result in increased rework hours. Furthermore, conducting dangerous extreme operating condition tests on special terrain, such as long, steep slopes (Fig. 2, right), is difficult for safety reasons, and securing test sites also poses a challenge. One example of such a test involves a tractor towing a 30-ton trailer down a steep slope and controlling the tractor by applying the emergency brake to come to a safe stop when it enters a state of over-acceleration.

(2) Improving the reproducibility of repeated testing

Field tests subject to regional or seasonal characteristics (Fig. 2, right) carry the risk of postponement due to temporal constraints or adverse weather conditions. Additionally, it may be difficult to reproduce malfunctions due to limitations in reproducing road surface conditions and human operation.

Fig. 2 Development by Conventional Technology

(3) Preliminary verification of fuel efficiency

Although the DLG PowerMix test (Fig. 3) is a representative tractor fuel consumption test, it has to be conducted at a European public institution since preliminary verification cannot be done in-house. Conducting repeated testing until target performance is achieved is inefficient in terms of time and cost. Therefore, it is difficult to conduct prototype testing during development in keeping with the development schedule. Since fuel efficiency testing occurs later in the schedule, significant rework is required if improvements to fuel efficiency are necessary, which poses a challenge.

Fig. 3 European Fuel Consumption Test (DLG-PowerMix Cycles) [1) 2)]

4. Developed technology

4-1 Bench test evaluation technology for driving conditions

4.1.1 Challenges in bench test evaluation technology for driving conditions

Since conventional powertrain testbeds for transmission testing cannot reproduce dynamic driving conditions, development of driving performance, including electronic control systems, can only be achieved through actual vehicle testing. Meanwhile, the automotive industry uses powertrain testbeds that reproduce actual road driving conditions for test vehicles (passenger cars) in conjunction with vehicle dynamics simulation.[3) 4)] However, tractors differ from passenger cars in terms of their horsepower and working speed ranges. Furthermore, tractors bear loads on the power take-off (PTO) shaft and hydraulic system in addition to the four wheels. Therefore, equipment designed for passenger cars cannot be directly applied to tractors. It is necessary to establish equipment and equipment control systems suitable for tractors.

4.1.2 Solutions for bench test evaluation technology for driving conditions

To enable workload reproduction, the setup incorporates five dynamometer axes (for four wheels and one PTO shaft) featuring extremely fast torque control response, sized to match Kubota tractors in the primary horsepower range of 60 to 200 horsepower. It also includes a hydraulic load device that reproduces the load applied to implements via hydraulic supply (Fig. 4).

For control and evaluation purposes, we used a vehicle dynamics simulation for model-based development (MBD), which is comprised of the vehicle, tires, implement, and driving course (Fig. 5), to calculate the axle torque resulting from operating loads and road inclination, and then applied this torque to the axles via dynamometers to reproduce driving conditions.

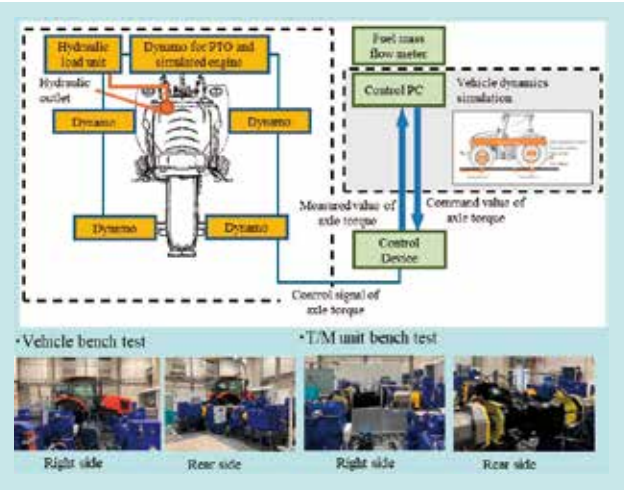


Fig. 4 Structure of the 5-axis Powertrain Testbed

MBD is a development methodology that uses models to describe control software and vehicles (e.g., hydraulic equipment and tires), simulates vehicle behavior, and enables the verification and tuning of control software prior to actual vehicle testing. Figure 6 illustrates an MBD environment with PC-based simulation. In the 5-axis powertrain testbed, the vehicle dynamics simulation is executed on a control PC. The vehicle dynamics simulation uses a vehicle model to calculate the forces between the vehicle and the ground and then computes the vehicle's equations of motion (ma = F) to simulate the vehicle's behavior.

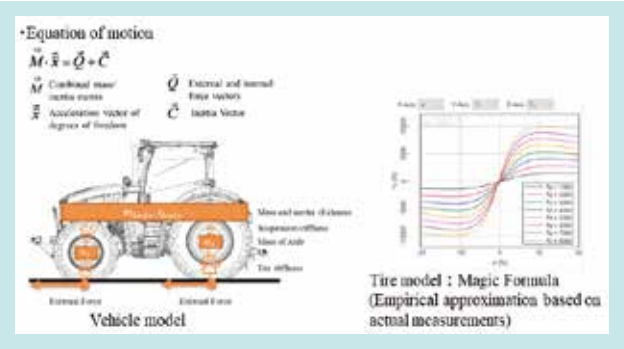


Fig. 5 Vehicle Dynamics Simulation

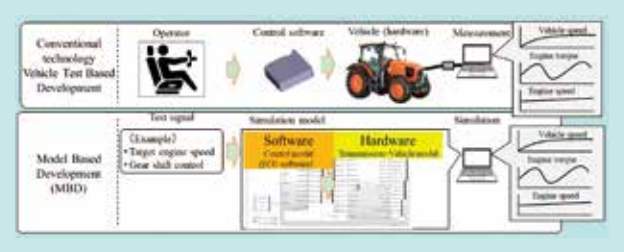


Fig. 6 Model-based Development

Since human operation is difficult to reproduce, the accelerator and gear shifting can be controlled remotely from the equipment's side (Fig. 7, left). Improved efficiency and test reproducibility have been achieved by creating an automated test sequence that simulates operator control actions (Fig. 7, right) and by implementing automated bench test sequences.

Since bench testing cannot evaluate drivability sensorially, we introduced a proven automotive industry method that quantitatively scores drivability based on response times and vehicle acceleration waveforms. The methods (tests and algorithms) used to evaluate the drivability performance of automobiles cannot be directly applied to tractors due to differences in their mechanisms and operations. Therefore, we developed a methodology for relatively evaluating drivability by formulating actual vehicle test items for tractor drivability assessment based on our in-house development expertise and a comparison of current and bench-tested models.

Finally, we conducted driving tests on the M6-142 tractor with and without a towed trailer (Fig. 8, top left) by both actual vehicle and bench testing (Fig. 8, top right). We verified that actual vehicle driving behavior could be accurately reproduced in the bench testing. For example, the lower part of Fig. 8 shows the results of switching from forward to reverse movement. With regard to vehicle acceleration changes, internal vehicle conditions (vehicle speed, engine RPM, and engine load factor), and drivability evaluation, highly accurate results were obtained by the vehicle dynamics simulation integrated with the powertrain testbed.

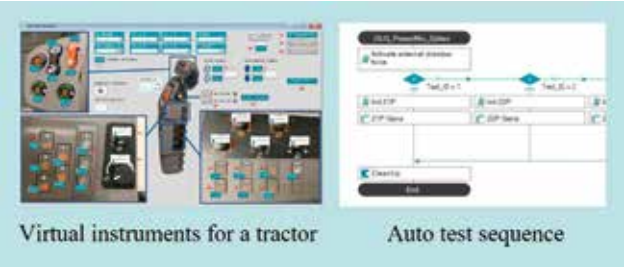


Fig. 7 Remote Control Function and Test Automation

■ Test Items

Type	Operation	Vehicle Condition	
		Without a Trailer	With a Trailer
Drivability Test	Coast Down	Tested	Tested
	Shuttling Forward and Reverse	Tested	Not Tested *1
	Drive Away	Tested	Tested
	Vehicle Stop	Tested	Tested
	Manual Shift	Tested	Tested
	Auto Shift	Tested	Tested
Extreme Test	Drive Away on the Uphill	Tested	Tested
	Drive Away on the Downhill	Tested	Tested
	Shuttling Forward and Reverse on the Uphill	Tested	Not Tested *1
	Flat into the Uphill	Tested	Tested
	Flat into the Downhill	Tested	Tested
Fuel Consumption Test	DLG-PowerMix cycles	Not Tested *2	Not Tested *2

■ Test Tack

■ Test Vehicle

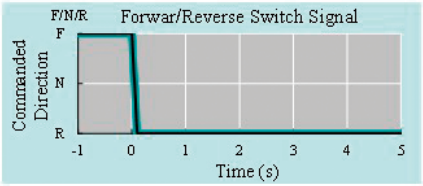
・Vehicle with a Trailer

・Vehicle without a Trailer

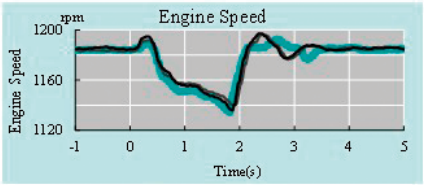
*1 This operation is not performed in practical use and is therefore not included in the test.
*2 This is a bench test conducted based on a test pattern established by the certification body, so no actual vehicl measurements were taken.

■ Example of Comparison Between the Actual Vehicle and the Bench Test: Shuttling Between Forward and Backwarderaiton

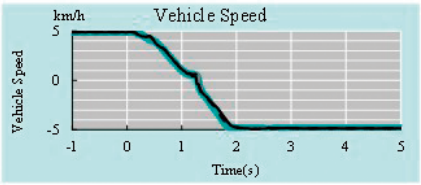
・Operaiton



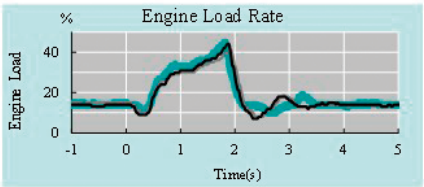
・Engine State

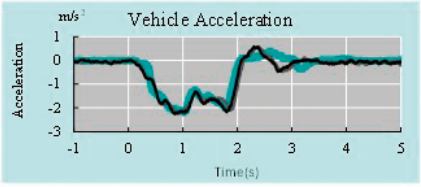


・Vehicel Behavior



■ Black Solid Line : 1st Result of Vehicle Test
■ Drak Gray Solid Line : 2nd Result of Vehicle Test
■ Blue-green Solid Lne : 1st Result of Bench Test
■ Light Blue-green Solid Line : 2nd Result of Benc Test





・Rating of Drivability

	Vehicle	Bench	Difference
Rating	8.4	8.3	-0.1

Fig. 8 Comparison Between the Actual Vehicle and the Bench Test [5]

4-2 Bench test evaluation technology for fuel consumption

4.2.1 Challenges in bench test evaluation technology for fuel consumption

In the DLG PowerMix test, the load patterns of implements such as plows (tilling) and balers (grass collection and baling) are defined as time-series waveforms combining traction, PTO, and hydraulic loads. Therefore, it is necessary to accurately reproduce the DLG PowerMix test load patterns using the five-axis powertrain testbed.

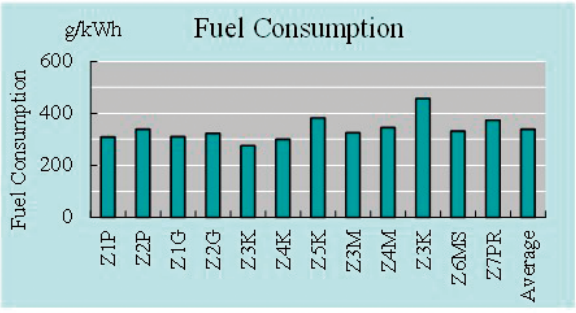
4.2.2 Solutions for bench test evaluation technology for fuel consumption

Using the aforementioned method to reproduce driving conditions, the load waveform for the DLG PowerMix test was accurately reproduced through vehicle dynamics simulation with the dynamometers of the four wheels, the PTO shaft dynamometer, and the hydraulic load device, while measuring fuel consumption using a fuel mass flow meter. This enabled in-house reproduction of the DLG PowerMix test. And this enabled in-house pre-verification testing equivalent to the DLG PowerMix test. For example, Fig. 9 shows the results of a test pattern equivalent to manure spreader operations, including towing, PTO, and hydraulic loads, as in the DLG PowerMix test. It is now possible to reproduce load waveforms specified in the DLG PowerMix test and apply operational loads to the tractor in bench testing.

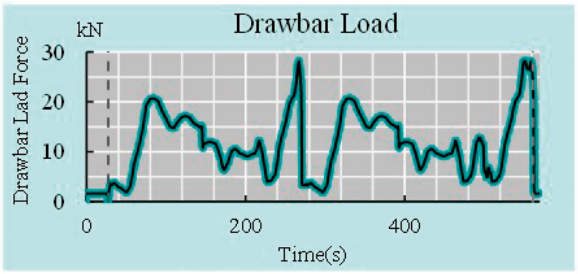
■ DLG-PowerMix Cycles

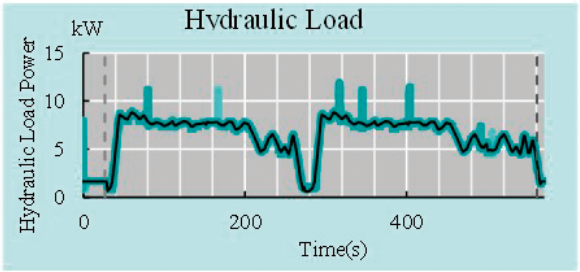
Load Type	Assumed work	Load	Cycle Name
Drawbar work	Ploughing	100%	Z1P
		60%	Z2P
	Cultivator	100%	Z1G
		60%	Z2G
Drawbar work +PTO work	Power harrow	100%	Z3K
		70%	Z4K
		40%	Z5K
	Mowing	100%	Z3M
		70%	Z4M
		40%	Z3K
Drawbar work +PTO work +Hydraulic work	Manure Spreading	100%	Z6MS
	Balling	100%	Z7PR

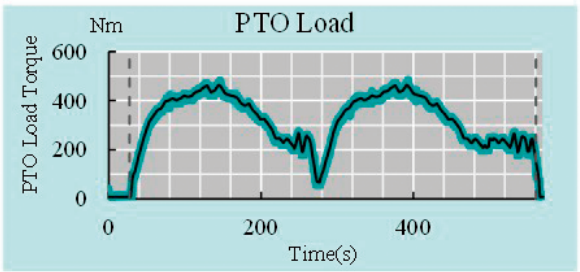
■Test Result: 12 cycles



■Load Reproduction Example: Z6MS
→Equivalent ot manure spreader (fertilizer application) works







■ Black solid line : Target Load
■ Blue-Green solid line : 1st Result
■ Light Blue-Green solid line : 2nd Result
--- Dark Gray vertical dotted line: Scope of DLG-PowerMix Cycle

Fig. 9 Example of the DLG-PowerMix Cycles of the Z6MS
(The Test Cycle Assumed Manure Spreading with Drawbar + PTO + Hydraulic Work) [1)]

5.Conclusion

For the first time in Japan (according to Kubota's survey), we have introduced a five-axis powertrain testbed consisting of five dynamometers (four for the wheels and one for the PTO) and a hydraulic load device to simulate tractor operating conditions. By integrating this testbed with vehicle dynamics simulation, we have established bench test evaluation technology that accurately reproduces the driving conditions of Kubota tractors, enabling simulation of actual tractor operations. This enables comprehensive performance verification, including safety and gear shift performance evaluations incorporating electronic control, starting from the stand-alone transmission test phase (Fig. 10). Virtual terrain simulation of steep slopes, for example, reduces dependence on field testing and enables extreme testing that would otherwise be difficult to perform with actual vehicles for safety reasons. Additionally, preliminary in-house verification of the DLG PowerMix test is now possible, enabling the simultaneous development of driving performance and fuel efficiency. This enables us to meet market demands for increasingly sophisticated and complex transmissions.

Moving forward, we will expand the application of this technology to hardware-compatible tractor products in the 60 to 200 horsepower range, thereby implementing it in Kubota's core products.

Fig. 10 Front Loading of Development of T/M [2)]

Contribution to SDG targets

2.4 Realization of sustainable and robust agriculture
Improving the development efficiency of high-performance agricultural machinery, thereby contributing to streamlining farm work.

7.3 Improvement of energy efficiency
Promoting improved fuel efficiency in agricultural machinery

9.5 Promotion of scientific research and innovation
Promoting the advancement and high functionality of agricultural machinery transmissions

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Development of Technology to Improve the Comfort of Cabin Air Conditioning

Analysis Center

In this study, we developed a technology to improve thermal comfort within the cabins of agricultural machinery. Given the current situation where the number of agricultural workers is decreasing and the burden on operators is increasing, enhancing cabin comfort is essential. Therefore, we aimed to identify and predict comfort levels and improve them efficiently. Specifically, we used the SET* index to determine the comfort range and employed analytical techniques to calculate the thermal balance within the cabin and predict comfort levels. Additionally, we proposed ergonomically designed air conditioning ducts to achieve a balance between comfort and energy efficiency. These efforts are is expected to contribute to increased productivity in agricultural work and a reduction in CO_2 emissions, thereby lessening the environmental burden.

【Key Word】
Fluid Analysis, Thermal Comfort, Carbon Neutrality, Tractor, Combine

Related SDGs

1.Introduction

As the number of agricultural workers declines and farmland becomes more integrated, the cultivated area of "capable farmers" is increasing (Fig. 1[1]). This has also increased the working hours per person. As the number of workers is expected to continue declining, concerns have been raised that maintaining agricultural production will place an increasing burden on workers.

Given the progress of global warming, high-temperature working conditions in agriculture are becoming an increasingly serious problem. The agricultural machinery cabin is enclosed by large glass panels to ensure visibility (Fig. 2), making the interior susceptible to high temperatures caused by sunlight. Because high-temperature environments can reduce work efficiency and pose health risks, improving thermal comfort inside the cabin is essential to reducing worker strain. As temperatures are expected to rise further due to global warming, maintaining a comfortable working environment is becoming an increasingly important challenge. On the other hand, from a carbon neutrality perspective, excessive cooling consumes fuel, so optimal cooling is required.

The Kubota Group aims to solve the societal challenges of enhancing agricultural productivity and realizing a carbon-neutral and resilient society. The Analysis Center aims to mitigate the effects of global warming on agricultural work and reduce worker strain by improving the thermal comfort of cabin air conditioners. This effort is important for improving the sustainability of agriculture and for effectively combating global warming.

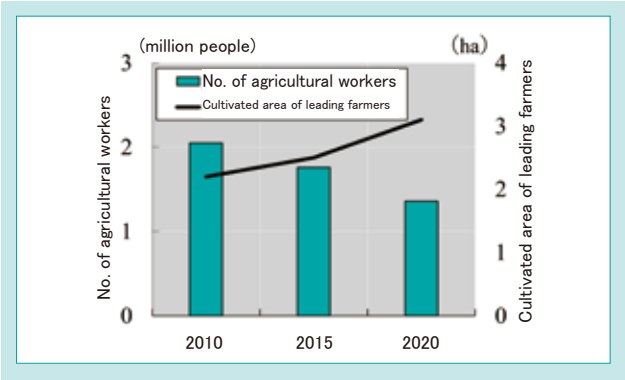

Fig. 1 Number of Agricultural Workers and Cultivated Area per Core Farmer in Japan

Fig. 2 Sunlight Passing Through Large Glass

2.Development concept and target

Until now, the level of comfort provided by cabin air conditioners was determined by operating prototype units and verifying that the wind speed and temperature met the specified standards. However, during user interviews for products developed using this approach, some users said they felt hot. Two issues were behind this outcome.

First, evaluation tools were traditionally limited to physical indicators such as wind speed and temperature, failing to assess the human sensation of comfort.

Second, evaluations using prototypes were conducted later in the development process, making it difficult to fundamentally improve comfort while balancing other performance requirements and design constraints.

This research aims to develop technology that enables the design and evaluation of cabin air conditioners prior to prototyping, when design flexibility remains high. This will allow for the market introduction of cabins equipped with comfortable, energy-efficient air conditioners.

3.Technical issues to be solved

The technical challenges that must be addressed to resolve the aforementioned issues and achieve the objectives are as follows.

(1) Technology for identifying human comfort

To evaluate human comfort, it is necessary to accurately measure the cabin environment and determine what conditions people perceive as comfortable.

(2) Technology for predicting human comfort

Because there is no prototype at the design stage, evaluation by testing is impossible. Therefore, it is necessary to accurately predict the in-cabin environment during operation, as well as the level of comfort experienced by a person in it.

(3) Technology for efficiently enhancing human comfort

Increasing cooling capacity to enhance comfort leads to higher fuel consumption. Therefore, technology is needed to enhance comfort while maintaining or reducing cooling capacity.

4.Developed technology

4-1 Technology for identifying human comfort

4.1.1 Definition and evaluation indicator for comfort

In the field of ergonomics, a state that is not too hot or too cold is defined as comfortable. The human perception of warmth and coldness is evaluated using a seven-point temperature scale, where extremely cold is -3 and extremely hot is +3. The range of thermal comfort is from -1 to +1. To evaluate comfort, it was necessary to determine what kind of environment users find comfortable.

An individual's thermal sensation is influenced not only by the ambient temperature and wind speed, but also by radiant heat and humidity. In the construction and automotive industries, a unified metric called SET*[2] is used to define the range of SET* values that people perceive as comfortable. However, the structure and usage conditions of agricultural machinery differ from those of buildings and automobiles. For example, agricultural machinery has large glass areas to ensure visibility, which makes it susceptible to the effects of sunlight. Additionally, since riding agricultural machinery involves long hours of operation, users may require a different level of comfort. For these reasons, the comfort range for agricultural machinery is believed to be different, but until now, there has been no metric to evaluate that comfort.

4.1.2 Determination of comfort evaluation indicators for tractors

We therefore decided to measure (1) the thermal sensation experienced while riding a tractor and (2) the SET* of the environment at that time and to link the two to identify the comfortable SET* range for agricultural machinery. Specifically, we attempted to create an equation that correlates the tractor's thermal sensation with the measured environmental values by plotting the acquired values on a map, with the vertical axis representing thermal sensation and the horizontal axis representing SET* as shown in Fig. 3, and then performing a linear approximation. This relational expression can be used to estimate a SET* range of -1 to +1 for thermal sensation, which allows one to evaluate whether the environment is comfortable.

(1) Method for acquiring thermal sensation data

Thermal sensation data was obtained through a questionnaire in which respondents quantified their sensation on a thermal scale.[3] In addition to individual differences in thermal sensation, concerns arose about variations based on personal attributes, such as age and physique. This study focused on male subjects aged 50 to 60 with average BMI values, representing 50% of Japan's agricultural workforce, to identify the comfort range for farm work. To obtain statistical significance in any difference, measurements were conducted on eight or more subjects.

(2) Measurement method for SET*

The upper part of the cabin cools due to airflow from the air conditioner ducts, while the lower part heats up due to the transmission and other heat sources. Consequently, the SET* values around the operator vary spatially. To measure this distribution precisely, sensors had to be placed at multiple points according to the subject's working posture. Therefore, measurements were conducted using a sensor manikin equipped with 128 sensors to measure air temperature, wind speed, radiant heat, and humidity, enabling simultaneous multi-point measurements (Fig. 4). Both thermal sensation acquisition and SET* measurement were conducted in a constant-temperature test chamber with high environmental reproducibility to standardize the test environment.

The relational expression obtained allowed for the identification of the SET* range that users find comfortable in a tractor cabin. As expected, the resulting SET* range differs from those of automobiles and buildings.

Through these efforts, we have clarified the type of environment in which users feel comfortable and made it possible to evaluate the level of comfort.

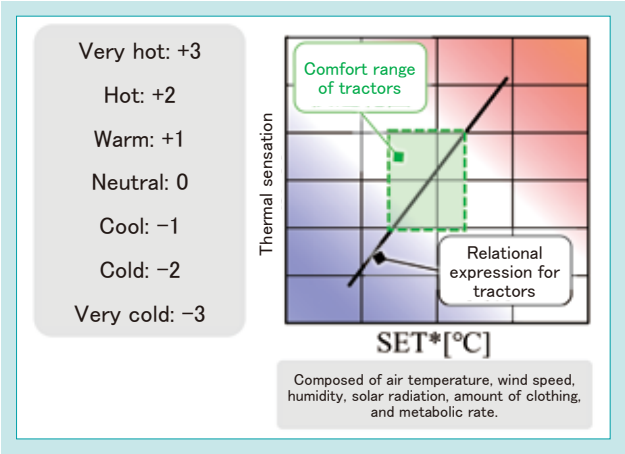

Fig. 3 Thermal Sensation-SET* Map

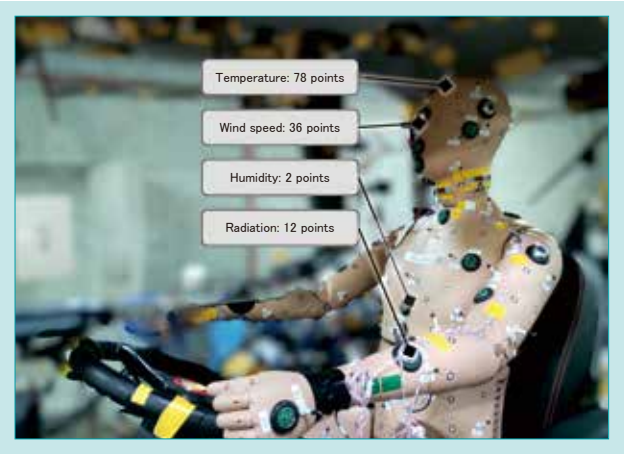

Fig. 4 Sensor Mannequin

4-2 Technology for predicting human comfort

4.2.1 Development of comfort analysis methods for use in design purposes

Using the relationship between thermal sensation and SET*, as described in Section 4-1, it has become possible to evaluate the level of comfort. An actual machine is needed for SET* measurements. However, once a prototype is actually built, it becomes difficult to implement fundamental improvements due to limited flexibility for design changes. Therefore, we opted to develop a method for obtaining SET* through analysis.

4.2.2 In-cabin thermal balance analysis

To evaluate comfort, SET* must be derived analytically. Here, temperature and wind speed, which are components of SET*, are determined based on the cabin's heat balance. Therefore, this must be accurately represented in the analysis. The cabin air is heated by solar radiation and engine exhaust heat and cooled by cold air from the air conditioner unit (Fig. 5). To solve the cabin's heat balance problem, it is necessary to accurately represent all these heat sources. We must also account for the heat dissipation from the human body, which had not been considered in previous analyses. Therefore, we attempted to develop technology that calculates the cabin's thermal balance by combining (1) in-cabin thermal fluid analysis and (2) human body heat dissipation analysis, derives SET* from this calculation, and predicts whether the obtained SET* falls within the comfort range.

(1) In-cabin thermal fluid analysis

Three methods are used to analyze the thermal sources that warm or cool the cabin air. The first method, solar radiation analysis, represents how heat is transferred when solar radiation hits the roof or enters through glass. The second method, hood heat dissipation analysis, depicts how the engine and other components generate heat inside the hood and warm the inside air. Additionally, a fan is operated to simulate exhaust airflow. The exhaust air that hits the cabin causes the inside air temperature to rise. The third method, air conditioner cooling analysis, reproduces the airflow within the air conditioner unit and depicts how the air blows around the operator after passing through the ducts.

(2) Human body heat dissipation analysis

Heat generated within the human body is transferred throughout the body via blood vessel circulation and released through the bones, muscles, fat, and skin. To analyze this dissipated heat, we introduced a new human thermal model[4] capable of predicting heat transfer within the human body. This model now enables calculation of whole-body thermoregulation by setting the basal metabolic rate and the amount of clothing. In particular, measuring the amount of clothing actually worn has made it possible to reproduce heat dissipation more closely aligned with real conditions. This allows for a more accurate representation of how human body heat warms up the cabin.

We were able to represent the thermal balance of the entire cabin by combining the above analysis methods (1) and (2). To verify analytical accuracy, we conducted analyses in hot and cool environments that were known to produce different thermal sensations based on subject tests. The results are shown in Fig. 6. The very small difference between the actual measurements and the analysis results demonstrates that thermal sensation can be precisely predicted through analysis.

Accordingly, we have developed a way to evaluate human comfort through analysis during the design phase, even without a prototype.

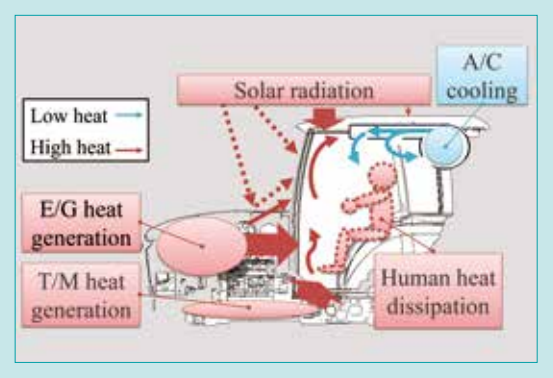

Fig. 5 Heat Balance of the Human Body and Cabin

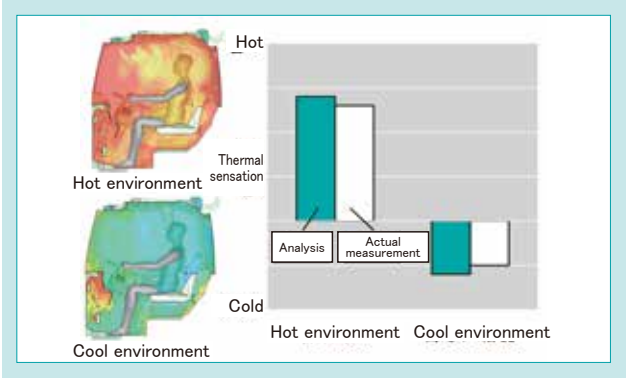

Fig. 6 Prediction Accuracy of Comfort

4-3 Technology for efficiently enhancing human comfort

4.3.1 Need for comfort enhancement measures considering energy efficiency performance

Enhancing comfort by increasing cooling capacity reduces fuel efficiency. From a carbon neutrality perspective, we examined ways to improve comfort without increasing cooling capacity.

4.3.2 Contribution analysis of improvement measures

There are two approaches to improving comfort when the cabin is hot: (1) cooling the operator directly and (2) cooling the operator indirectly by reducing the heat transferred through the cabin. However, no case studies have verified which approach is most effective.

Therefore, we analyzed how these approaches contribute to comfort. The contribution was evaluated using the map of thermal sensation and SET* shown in Fig. 3.

(1) Directly cooling the operator

Ergonomic studies have demonstrated that lowering the temperature of human blood flow achieves a cooling effect throughout the body.[5] Given this finding, we reasoned that it would be easier to lower the temperature of blood flowing through areas with thin skin and large arteries. Based on this, we conducted a subject test using air conditioner ducts to cool the neck, face, and armpits. The number of respondents who reported feeling cool and comfortable was highest when cooling the neck, followed by the armpits, and then the face. This confirms that cooling the neck is the most effective method.

(2) Reducing heat transfer to the operator through the cabin

There are two approaches to reducing heat transfer through the cabin: insulation and heat shielding.

Insulation is a measure that prevents heat transfer using insulating materials and maintains internal temperature. Thermal shielding is a measure that primarily uses heat-shielding materials that reflect infrared radiation to prevent external heat intrusion and keep the interior cool. To confirm the effects of each measure, subject tests were conducted in cabins with each measure applied, while keeping the air-conditioning capacity the same.

The results are shown in Fig. 7. The map indicates that cooling effectiveness increases toward the lower left, and it was confirmed that direct human cooling is the most effective, followed by heat shielding and thermal insulation.

Accordingly, we have developed a way to enhance comfort while maintaining the same cooling capacity.

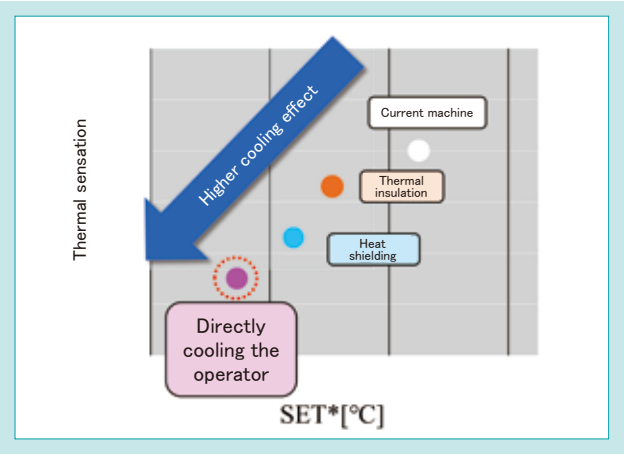

Fig. 7 Measures to Improve Comfort Sensory Tests

4-4 Achievements of developed technology

4.4.1 Application to products

The following case study illustrates the application of the three new technologies described in Sections 4-1 through 4-3 to develop a highly comfortable tractor cabin.

4.4.2 Study of air conditioner duct shapes for neck cooling

The current model has air vents embedded in the inner roof. This design allows the air conditioner to cool the entire cabin. As mentioned earlier, however, it has been found that people tend to feel cooler when their neck is cooled locally rather than when their entire body is cooled evenly. Therefore, we investigated air conditioner duct shapes that could cool the user's neck directly. First, we rerouted the ducts and positioned an air vent so that air would flow toward the neck (Fig. 8). However, because the air conditioner has multiple vents, positioning one near the neck might not provide enough airflow for adequate cooling. Therefore, we modified the shape inside the duct to ensure sufficient airflow from the vent to the neck. An analysis predicted that the pre-improvement ducts would cause discomfort in extreme heat, whereas the improved ducts would provide comfort.

The comfort level of the air conditioning ducts is evaluated using the thermal sensation versus SET* map shown in Fig. 3. However, it is impractical to prepare a map for each product because doing so requires months of subject testing. To solve this problem, we used a self-heating thermal manikin to simulate human heat dissipation and quantify thermal sensation. This allowed us to create product-specific maps within days. Based on duct evaluations conducted prior to subject testing, we predicted that using the improved ducts would increase comfort levels from “uncomfortable” to “comfortable.”

4.4.3 Evaluation of energy efficiency performance

By cooling the neck area, where people most readily perceive coolness, it may be possible to achieve the same level of comfort as cooling the entire body, even with a lower air conditioner airflow or higher air temperature. Therefore, we measured the amount of fuel injection while changing the airflow and temperature of the tractor's air conditioner. Field test results showed that reducing the air conditioner's airflow by 40% reduced fuel injection by 2.8% (Table 1).

This suggests that using air conditioner ducts that can cool the neck locally could maintain or improve comfort while consuming less fuel.

4.4.4 Effectiveness verification of the developed ducts in an extreme heat environment

To verify the effectiveness of the developed ducts, subject testing was conducted in an extreme heat environment. Figure 9 shows the test results. The pre-improvement ducts were tested at their maximum airflow capacity. On the other hand, the developed ducts were tested at 40% less than the maximum airflow, and the results were within the comfort range of the tractor.

This shows that the developed ducts can enhance user comfort while decreasing airflow by 40% and fuel injection by 2.8%.

Based on the above, applying the developed technology made it possible to study ways to enhance comfort during the design phase, leading to the development of a comfortable, energy-efficient product.

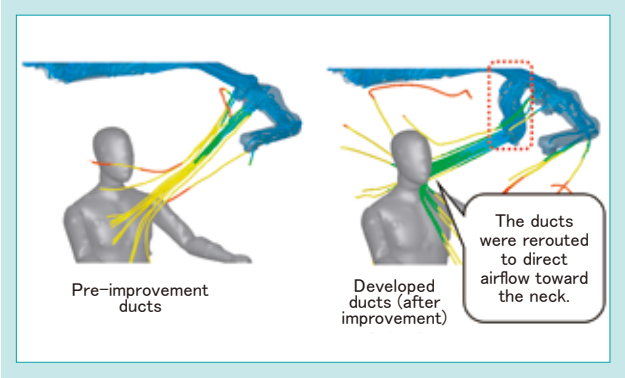

Fig. 8 Predicted Comfort from Analysis

Table. 1 Reduction Rate of Fuel Injection Amount Due to Differences in A/C Airflow

	Airflow volume 5	Airflow volume 3
Airflow volume (%)	100 (maximum)	60
Fuel injection reduction rate (%)	— (Control)	−2.8

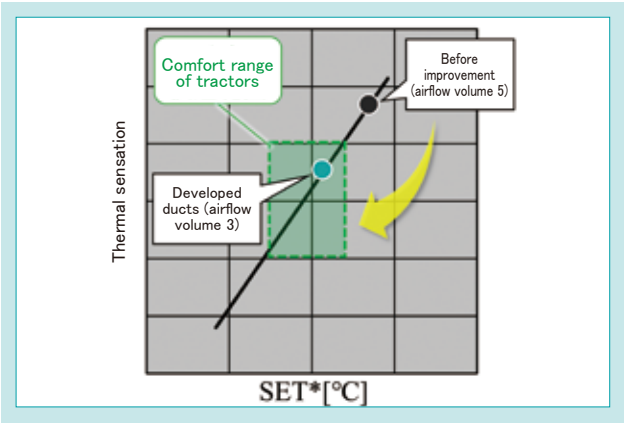

Fig. 9 Examination of Practical Application of the Developed Duct

5. Conclusion

Our technology has made it possible to predict human comfort levels during the early stages of product development and improve them. This allows for the development of cabins that save energy while providing high thermal comfort. This technology can be applied to the cabins of all agricultural and construction machinery. Starting in 2026, it will be implemented sequentially in combine harvesters, tractors, and compact track loaders used in construction. Using this technology to reduce air conditioner output and cut fuel injection by at least 2.8% has the potential to reduce CO_2 emissions by approximately 240,000 tons by 2030.

Moving forward, we will develop energy-efficient cabins that offer a high level of comfort by identifying optimal comfort conditions suited to factors such as race, personal attributes, location, and specific tasks. Furthermore, Kubota aims to create a cabin environment that is both comfortable and fatigue-reducing. By minimizing the burden on workers as much as possible, we will contribute to enhancing agricultural productivity and realizing a carbon-neutral and resilient society.

Contribution to SDG targets

2.4 Realization of sustainable and robust agriculture
Providing a comfortable working environment and contributing to increased agricultural productivity

7.3 Improvement of energy efficiency
Reducing CO_2 emissions and contributing to lowering the environmental impact

8.8 Safe and secure work environment
Improving the working environment in extreme heat conditions and reducing the physical burden on workers

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Development of the Riding-type Rice Transplanter NW60S / 80S for the Japan Market

Transplanter Engineering Dept.

The decline and aging of agricultural workers in Japan is continuing, leading to a further consolidation of farming into capable hands. To meet the needs of these farmers, the current series has focused on improving the basic performance of rice transplanters. As a further initiative, based on market demands, we are introducing the development of a successor model to the NW series with a focus on enhancing “ease of use” and “work efficiency.” Specifically, we are concentrating on improving the usability of the “keeping straight function” and enhancing the work efficiency of the seedling replenishment process.

【Key Word】
Rice Transplanter, Keeping Straight Function, Seedling Replenishment Process, Ease of Use, Work Efficiency

Related SDGs

1. Introduction

In Japan, the aging of the agricultural workforce and the increasing number of abandoned farms are leading to the consolidation of land under the control of full-time and capable farmers. Both capable and mid-scale farmers are seeking larger, more efficient machinery to help them scale up their operations. The current series of transplanters are focusing on improving their basic performance in terms of driving, transplanting, and fertilizing. Their go-straight function, which uses the Global Navigation Satellite System (GNSS), has been well-received. Based on the basic performance of the current series, this development project aimed to create a rice transplanter that would improve operability, including ancillary tasks beyond the planting operation itself (Fig. [1)].

Fig. 1 Riding-type Rice Transplanter NW80S for Japan

2. Development concept and target values

2-1 Development concept

The primary goal of the development project was to enhance user satisfaction and improve the product's appeal by improving the operability of the current model. Based on our market research findings, we adopted ease of use and improved work efficiency as our key concepts. In the development process, our focus was on two aspects: improving the usability of the go-straight function to enhance user-friendliness and improving seedling replenishment operations to increase efficiency.

2-2 Development goals

(1) Improvement of the usability of the go-straight function
  (i) Simplifying the startup operation of the go-straight function
  (ii) Improving the accuracy of the go-straight function, which can be impaired by poor satellite reception, and reducing downtime (functional outage time)

(2) Improvement of seedling replenishment operations
  (i) Developing a reserve seedling platform that can be switched out according to field conditions
  (ii) Developing an empty tray recovery system

3. Technical issues to be solved

3-1 Improvement of the usability of the go-straight function

3.1.1 Simplified operation (development of the easy start feature)

The go-straight function automatically steers the vehicle along a preset heading during straight-line travel. In the current series, this function can be initiated at any time by pressing the go-straight switch. The challenge was to eliminate operator complexity since simultaneous operations were required, such as adjusting the vehicle to the spacing of adjacent seedling rows after turning or manually pressing the go-straight switch.

Additionally, it took time to meet the conditions for starting the go-straight function in the current series. Therefore, the challenge was to meet the market demand for faster activation of the go-straight function after turning.

3.1.2 Improvement of the go-straight function accuracy

The go-straight function is highly regarded for its accuracy, but GNSS satellite reception may be poor depending on the environment, such as when fewer satellites are available for reception in certain regions or during specific hours. These factors reduce the accuracy of go-straight travel during operation and cause instances when the go-straight function is unavailable, diminishing its usability. Until now, the only option when reception became unstable was to wait for it to stabilize. The current series' GNSS settings utilize two GNSS systems for positioning: GPS (U.S.) and GLONASS (Russia). A key challenge was the inability to change these settings from the rice transplanter.

3.1.3 Reducing the go-straight function downtime

One factor contributing to downtime is temporary service suspensions due to maintenance or other operational activities of the Satellite-Based Augmentation System (SBAS). The current series uses SBAS satellite correction data, as well as Differential GNSS (D-GNSS) satellite signals. The system is designed to restrict the go-straight function when SBAS correction data is unavailable, making it impossible to use the go-straight function while SBAS is unavailable.

3-2 Improvement of the efficiency of seedling replenishment operations

3.2.1 Developing reserve seedling platform systems that can be switched according to field conditions

In general, the process of seedling replenishment involves placing seedling trays on the spare seedling platform and sending them to the seedling loading platform located at the rear of the machine. The spare seedling platform is a platform on the machine for temporarily holding seedling trays before they are sent to the seedling loading platform at the rear of the machine. There are two main systems, rail type and stackable type, and the user chooses one at the time of purchase. The respective advantages and disadvantages are described below.

[Rail type (Fig. 2)]

Advantage: The easy replenishment of seedling trays by sliding them leads to superb operability.

Disadvantage: The forward protrusion of the rails from the machine makes turning difficult when there are obstacles on the field ridge.

[Stackable type (Fig. 3)]

Advantage: The compact layout of the machine allows it to turn easily even in fields with high ridges or obstacles where rail-type machines have difficulty maneuvering.

Disadvantage: The seedling trays are positioned far from both the ridge and the seedling loading platform, making it difficult to load trays and supply seedlings.

The challenge was to develop a mechanism that leverages the advantages of the aforementioned types, i.e., a highly workable, rail-type system that can easily be switched to a stackable type when needed.

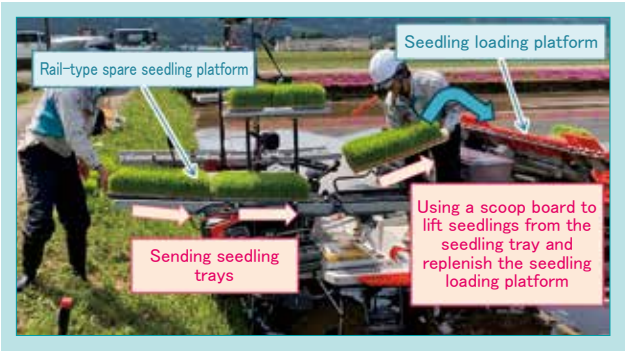

Fig. 2 Replenishing the Rail-type Spare Seedling Platform

Fig. 3 Replenishing the Stackable-type Spare Seedling Platform

3.2.2 Developing an empty tray recovery system

The method for collecting empty seedling trays after sending out seedlings is not clearly defined with the current machine. As a result, the operator has to temporarily place empty trays in locations that hinder work, such as on a step or on the fertilizer applicator. Additionally, the operator had to lean out from the machine to have an assistant retrieve the empty trays that had been temporarily placed. Sometimes, empty trays were thrown onto the ridges, and the assistant picked them up. The challenge was to create a work system that would enable easy and effortless handoffs between the operator on the machine and the assistant on the ground.

4. Developed technology

4-1 Development of the easy start feature

To reduce complexity in work, we considered automating the start of the go-straight function (easy start feature). The automatic start should occur at a time as close as possible to when the operator can begin using the function without feeling stressed. The conditions for starting in the current series are determined by the vehicle's heading and speed, among other factors.

The go-straight function uses a GNSS antenna and an inertial measurement unit (IMU) to perform control based on the target heading and machine heading. In the current series, we regarded the heading calculated from the IMU during turns as unreliable due to drift error. Therefore, rather than using the IMU heading during turns, we used the GNSS heading during straight-line travel after a turn. Therefore, a certain straight-line distance was required for the GNSS heading to stabilize after a turn. That means a certain amount of time was required before the conditions were right for the go-straight function to begin. In this development project, we reviewed the controls and confirmed that the straight-line maintenance function is usable even when accounting for the drift error of the IMU heading. In addition, we implemented a control system that prevents sudden changes in heading when switching from the IMU heading to the GNSS heading.

These measures, along with using the IMU heading to calculate the machine heading during turns, have reduced startup time by eliminating the straight-line distance needed in the current series. In addition, a setting screen for adjusting the start timing of the go-straight function has been added to the meter panel mounted on the rice transplanter, enabling the function to start automatically at the operator's desired time (Fig. 4).

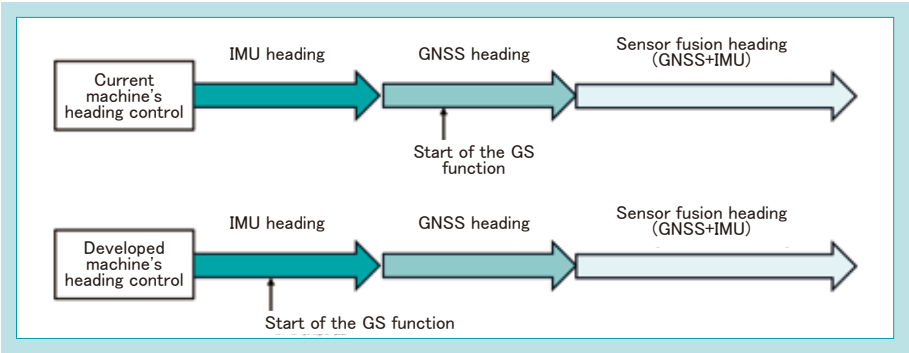

Fig. 4 Overview of the Differences in Orientation Control Between the Current and Developed Model

4-2 Development of the GNSS switching function

We studied the possibility of continuing to use the go-straight function when the reception of the combined GPS + GLONASS system is poor, which is the setting for the current series, by changing the GNSS setting to another system. The combinations studied were GPS + BEIDOU (China) and GPS + GALILEO (Europe), besides GPS + GLONASS. Under domestic field conditions, the above combinations of antenna units were mounted on the product (Fig. 5), and the number of receiving satellites and the positioning data during straight-line travel were compared among the target GNSS systems. The evaluation method was to compare the positioning performance of each satellite system by using the positioning results of the dual-frequency RTK unit as true values. Results from different areas in Japan confirmed that the number of positioning satellites was up to 40% higher for GPS + BEIDOU than for other settings, and this

number was similar for GPS + GLONASS and GPS + GALILEO. Straight-line travel with GPS + BEIDOU tended to be more accurate and stable, and the final positional deviation was smaller. As shown in Fig. 6, this satellite combination had less deviation than the others and was superior in performance.

In light of these results, the new model was set to GPS + BEIDOU by default, rather than GPS + GLONASS as in the current series, and allowed users to select satellites based on their usage environment via the meter panel.

Fig. 5 Test Scene of GNSS Comparison

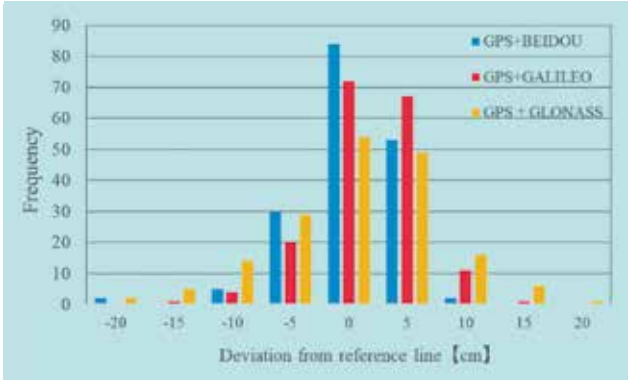

Fig. 6 Comparison Results of Positioning Accuracy for Each GNSS

4-3 Reducing the go-straight function downtime

The SBAS correction data is used for control to calculate the timing of the warning indicating that the machine is approaching a field ridge, as well as the position at which the machine will be forced to stop. The accuracy of the stop position will be reduced if SBAS correction data is not available. For safety reasons, the entire go-straight function will be disabled in the current series, resulting in downtime. By contrast, the new model only uses SBAS correction data to enhance the safety feature's accuracy when approaching a ridge and does not affect straight-line travel control. Therefore, by reviewing the specifications for the stop position when approaching a ridge, we thought it would be possible to continue driving with the go-straight function while ensuring safety and precision. Specifically, a new control was added to stop the machine to be on the safe side if SBAS correction data cannot be received, taking into account the amount of absolute positional deviation when SBAS correction is not available, as confirmed by testing. Furthermore, we enabled go-straight travel that ensures safety even when SBAS correction data is not received. This was accomplished by adding a feature that detects ridges and causes the vehicle to stop farther ahead than the current model, in proportion to its speed (Fig. 7).

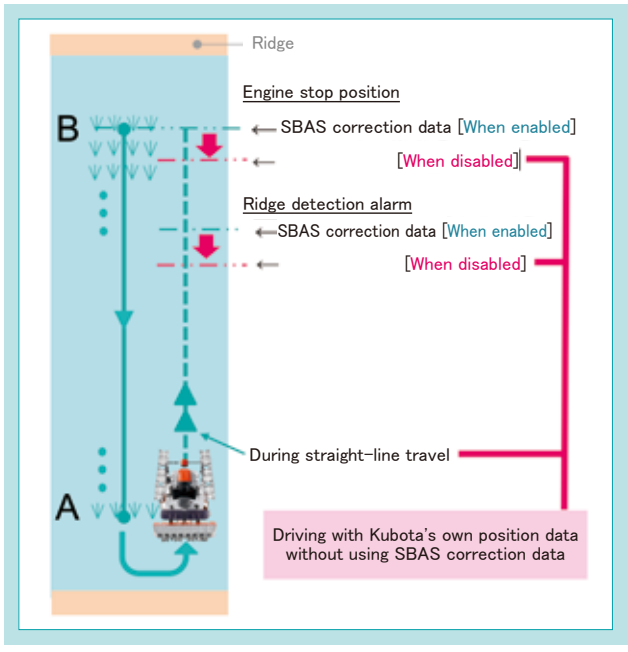

Fig. 7 Image of Using SBAS Correction Information in Rice Transplanting Machines

4-4 New spare seedling platform mechanism

Our policy was to develop an improved spare seedling platform based on the current rail-type platform, taking into account its operational advantages. The spare seedling platform can be switched to a stackable type by retracting the front tray, which allows for adaptation to different fields. A new mechanism with the following specifications was developed (Fig. 8):

(1) Provide a mechanism that prevents workers from getting caught in moving parts.

(2) Secure the platform to prevent movement due to vibration or impact after switching between types and ensure safety with automatic locking.

(3) Improve ride comfort compared to the conventional rail type.

Mechanism (1): To prevent the operator's hand from getting caught during the switching process, this mechanism is designed to be operated with both hands. The layout ensures that the switching lever will not interfere with operation.

Mechanism (2): When switching from the rail type to the stackable type (Fig. 9), a piston-type locking pin is incorporated to automatically lock the platform as the link rotates, preventing the user from forgetting to lock the platform when switching.

Mechanism (3): In the conventional rail-type system, it was necessary to hold the rear tray by hand when boarding or disembarking from the side of the vehicle during operation. A new locking mechanism has been added to the rear tray area to enable one-touch opening and closing, improving ease of boarding from the side of the vehicle.

By achieving the above specifications, we have completed a new spare seedling platform that allows for easy switching between the rail and stackable types.

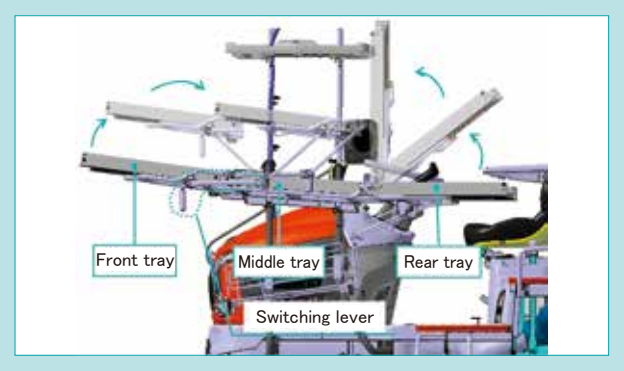

Fig. 8 Side View of Rail Mode

Fig. 9 Side View of Stacking Mode

4-5 Empty tray recovery system

The operation of the current machine when collecting empty trays is shown in Fig. 10.

The operation can be divided into the following four main motions.

Motion 1: Pick up an empty tray from the spare seedling platform.

Motion 2: Place the empty tray on the fertilizer hopper or a step.

Repeat motions 1 and 2 four times.

Motion 3: Stack the empty trays into one.

Motion 4: Hand the trays off to the assistant.

The operator and assistant must lean forward and coordinate the hand-off timing, resulting in waiting time for the assistant. Additionally, while supplying seedlings, the assistant must receive empty trays whenever they are returned, which is a heavy burden.

Therefore, for this development, we considered an arrangement that satisfies the following two conditions so that both the operator and the assistant can efficiently collect empty trays without generating inefficient work.

(1) Set aside an area for depositing empty trays within the work area where the operator supplies seedlings.

(2) The above area should be where the assistant can collect all the empty trays together within the work area while supplying seedlings to the rice transplanter from the ridge.

Based on the above, regarding point (1), a new opening large enough for seedling trays to pass through was added to the bottom of the spare seedling platform rail section. This allows the operator to easily collect empty trays after scooping up seedlings and feeding them into the machine and then lifting the edge of the empty trays.

Regarding point (2), a holder for collecting empty trays was installed on the front section of the vehicle in a position not protruding beyond the front hood (see Fig. 11). This position facilitates the assistant on the ridge collecting empty trays without obstructing the operator's work and movement on the machine or the machine's turning. As shown in Fig. 12, the new mechanism enables the operator to insert and the assistant to collect empty trays at any time, thereby increasing efficiency. The new operation is as follows.

Motion 1: The operator inserts an empty tray into the opening with a slight movement added to the seedling supply movement.

Motion 2: The assistant collects the accumulated empty trays from the empty tray holder after supplying seedlings.

Furthermore, since the shape of the ridges and stopping positions vary by field, two retrieval openings were provided to allow empty trays to be removed from the front and the side of the vehicle, which made it easier for the assistant to work.

A comparison of the man-hours required for empty tray collection shows that the current series of machines requires four motions, whereas the new mechanism requires only two, reducing the collection time by approximately 20% under Kubota's test conditions.

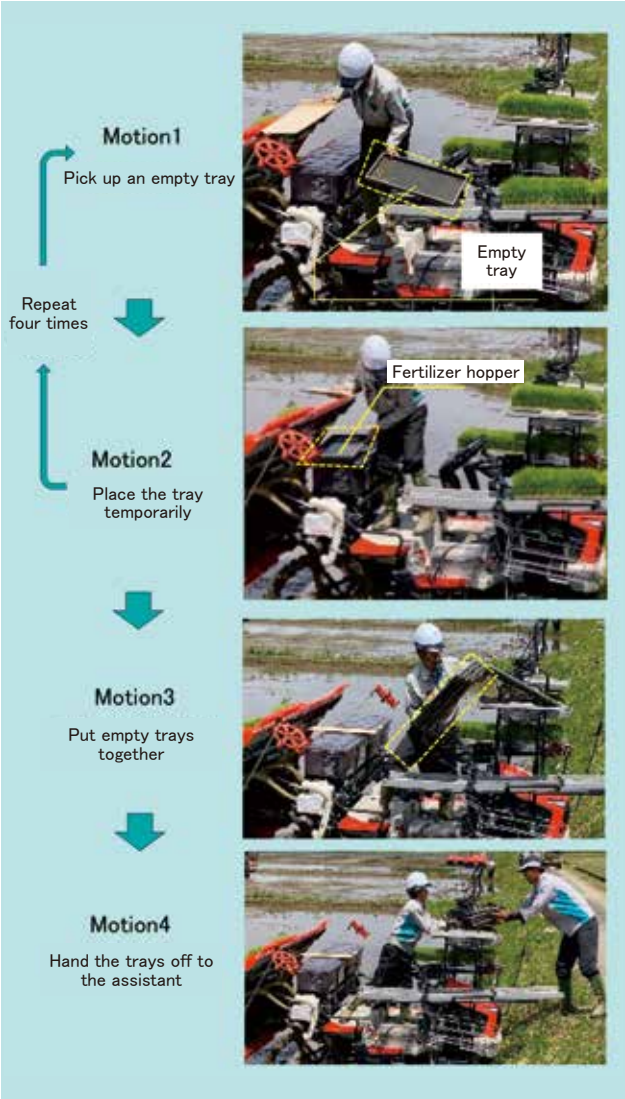

Fig. 10 Collection of Current Seedling Boxes

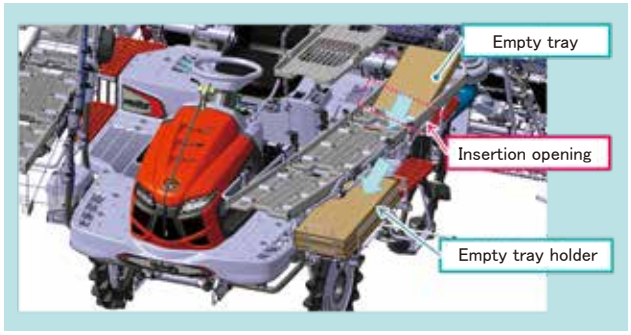

Fig. 11 Flow of the Empty Box Retrieval Operation

Fig. 12 Operational Actions Using the New Mechanism

5. Conclusion

We have developed an easy-to-use, adaptable, and always-ready go-straight function.

To improve seedling replenishment operations, we developed a new spare seedling platform that can switch between rail-type and stackable-type configurations. We also developed a new empty tray collection mechanism that allows the operator and the assistant to easily collect empty trays collaboratively, reducing labor hours and minimizing inefficient movement during teamwork.

As a result of this development, product monitors gave high evaluations to the improved go-straight function, the new spare seedling platform, and the empty tray collection mechanism. In the future, we will contribute to the development of Japanese agriculture by applying this approach to other models.

Contribution to SDG targets

2.3 Increase in agricultural productivity and income
Improving the efficiency of seedling feeding operations

8.2 Increase in productivity through innovation
Reducing downtime due to poor satellite reception

Development of the Diesel Engine Z482-K for European Quadricycle in Compliance with the EURO5+ Standard

Engine Engineering Dept. Ⅰ

In Europe, there is a market for Quadricycle that can be driven on public roads without a license. Kubota supplies the mechanically controlled Z482 diesel engine to manufacturers producing quadricycles, having shipped 17,000 engines in 2024. The EURO5+ vehicle emissions regulation for European quadricycles came into effect in January 2025. The EURO 5+ regulations impose stringent requirements, mandating an 84% reduction in NOx and a 94% reduction in PM emissions. To meet the EURO 5+ regulations, the mechanical Z482 engine adopted an electronically controlled fuel injection system, aiming to achieve compliance through the integration of only essential emission-reduction devices, while considering vehicle packaging constraints and cost competitiveness. We aim to achieve compliance without the use of SCR and DPF, focusing instead on utilizing DOC and EGR systems as exhaust emission reduction devices. This paper will discuss approaches for optimizing the electronic-controlled engine for compliance with EURO 5+ regulations, improvements in combustion through the optimization of the combustion chamber shape, and the development of a compact EGR design that balances EGR distribution performance and installation feasibility.

【Key Word】
Z482-K, TVCR, Electronic Control, Vehicle Emissions, EURO5+ Emission Regulation

Related SDGs

1.Introduction

The Super Mini (SM) series of engines, which have a displacement of less than 1 L, comply with emission regulations in the United States, Europe, China, and other regions around the world, thanks to their improved E-TVCS combustion system. The SM series is widely installed in agricultural, construction, and industrial machinery, and is used as a power source in a wide variety of applications. Among these, the mechanical Z482, which is in the smallest displacement class, is installed and used in quadricycles (hereinafter referred to as “minicars”), which are four-wheeled vehicles permitted for public road use in Europe without requiring a driver's license.

The European minicar market includes battery electric vehicles and internal combustion engine vehicles, each with different applications. Among them, the market for internal combustion engine vehicles is approximately 25,000 units per year, and Kubota supplies Company A, the top market share holder, with the mechanical Z482.

As shown in Table 1, the EURO 4 emission regulations for minicars were introduced in 2017, and the test cycle was revised in 2020 as EURO 5 (Fig. 1). Then, in 2025, EURO 5+ came into effect with significantly stricter regulatory values for each emission component. The EURO 5+ regulations are very strict, requiring an 84% reduction in NOx and a 94% reduction in particulate matter compared to EURO 4. The transient test cycle WMTC, which simulates actual vehicle driving, is continuing to be employed. As a result, the EURO 5+ regulations demand precise combustion control tailored to each vehicle speed and load, strengthening requirements to a level unattainable with the previously installed mechanical Z482.

Company A's vehicles are required to comply with the EURO 5+ regulations for the L6e-B category, which is defined as vehicles with a weight of 425 kg or less and an engine displacement of 500 cc or less. Since the EURO 5+ regulations are a vehicle certification, it is necessary to improve the performance of the engine alone in the first half of the development process and ultimately to comply with the L6e-B category regulation with the engine installed in a vehicle. Therefore, to achieve regulatory compliance, it is necessary to closely coordinate our engine development with Company A's vehicle development. This paper describes the development of Z482-K, which was installed in Company A's EURO 5+ compliant vehicles, as well as the technology and approach used to ensure the compliance.

Table. 1 Vehicle Emission Standard Comparison

Regulation	Timing	CO	THC	NMHC	NOx	PM	Test Cycle
		mg/km	mg/km	mg/km	mg/km	mg/km	
EURO4	Jan. 2017	1000	100	–	550	80	ECE R47
EURO5	Jan. 2020	1000	100	–	550	80	WMTC Stage3
EURO5+	Jan. 2025	500	100	68	90	4.5	WMTC Stage3

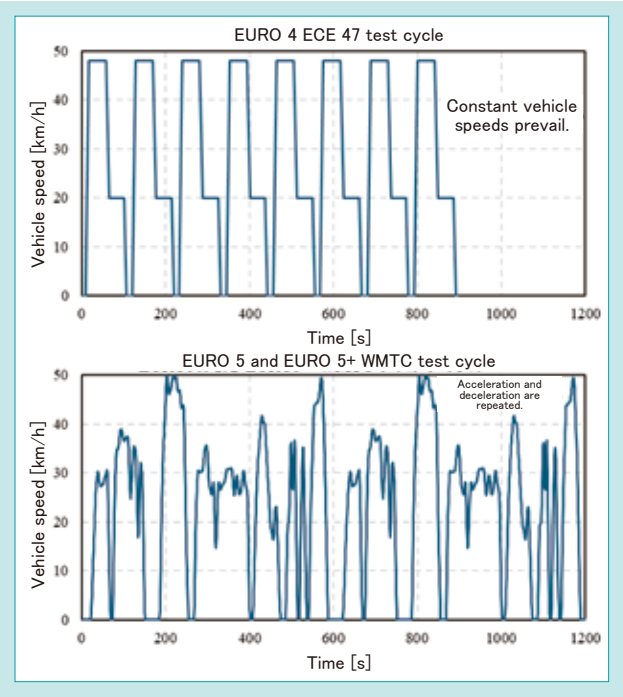

Fig. 1 Test Cycle

2. Development concept and target values

2-1 Development concept

To ensure that Company A's vehicles comply with the EURO 5+ regulations, we developed the following concept for the engine to be installed in them.

(1) Complying with the EURO 5+ regulations by adopting the minimum necessary emission reduction devices

Rather than using large and expensive emission reduction devices such as diesel particulate filter (DPF) and selective catalytic reduction (SCR) systems, which are commonly used in engines with a displacement of 3 L or more, we use the minimum devices necessary to comply with the EURO 5+ regulations, such as diesel oxidation catalyst (DOC) and exhaust gas recirculation (EGR) systems. We developed a simple, compact, cost-effective engine that offers a higher level of combustion control than conventional models.

(2) Making the engine package compact

Even with the addition of emission reduction devices, we allow the engine package to be installed in the engine compartment of existing vehicles, which helps reduce Company A's development burden.

2-2 Target values

Table 2 shows the specifications of the EURO 5+ compliant Z482-K engine, and Fig. 2 shows an external view of the engine. Given the displacement regulations of the L6e-B classification, the new Z482-K is designed to repurpose the core components of the mechanical Z482 model and features a new TVCR combustion system with two cylinders. Figure 3 illustrates the system configuration of the EURO 5+ compliant engine. The electronic control unit (ECU) that controls the injector's injection and the EGR system use the KCX unit manufactured in-house by Kubota.

To estimate emission performance under vehicle operating conditions, operating patterns simulating the WMTC were created on an engine bench. This created an environment in which performance could be improved solely through engine development. The development targets for the new Z482-K model were set as follows:

(1) Complying with the EURO 5+ regulations by adopting the minimum necessary emission reduction devices, such as DOC and EGR systems
(2) Achieving an engine weight that does not exceed the stipulated 425 kg weight limit for the vehicle body and engine combined
(3) Allowing the engine package to be installed in the engine compartment of existing vehicles

Fig. 2 Z482-K

Table. 2 Engine Specifications

Item	Mechanical Z482 (current model)	Z482-K (new model)
No. of cylinders	2	
Displacement [L]	0.479	
Combustion method	E-TVCS	TVCR
Fuel injection method	Mechanical control	Electronic control
Length/Width/Height [mm]	366/384/507	424/477/601
Engine mass [kg]	54	64
Net output [kW/rpm]	6.0 kW at 3200 rpm	
ECU	None	KCX (in-house)
Conforming emission regulations	EURO4, EURO5	EURO5+

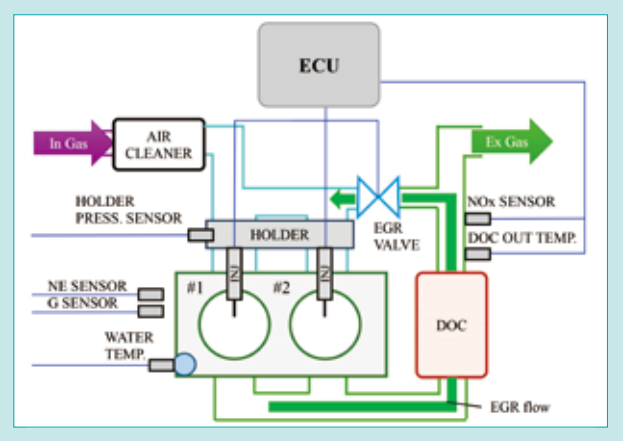

Fig. 3 Engine System Configuration

3. Technical issues to be solved

3-1 Combustion improvement for compliance with the EURO 5+ regulations

The mechanical Z482 has been made compliant with the EURO 4 and EURO 5 regulations by optimizing the mechanical fuel injection system and E-TVCS. In the mechanical fuel injection system, the injection amount and timing are determined mechanically at the design stage, making it impossible to optimize the injection amount and timing for different rotations and loads. Therefore, electronic control, which can dramatically increase the degree of freedom of fuel injection control, is essential to achieving the significant reduction of NOx and particulate matter required by the EURO 5+ regulations. Kubota has developed a new TVCR combustion system, which combines the indirect

injection (IDI) combustion system shown in Fig. 4 with an electronically controlled fuel injection system, and has implemented it commercially in the D902-K engine. While Fig. 4 shows a three-cylinder system, an injection system and injection logic optimized for the two-cylinder Z482-K must be developed.

In the IDI combustion system with two combustion chambers (a swirl chamber and a main combustion chamber), the gas jet form the swirl chamber into the main chamber is controlled by the shape of the main combustion chamber at the piston top (see Fig. 5). Therefore, the key technology to minimize particulate matter through combustion improvement lies in effectively utilizing the air in the main combustion chamber by optimizing the shape of the piston top.

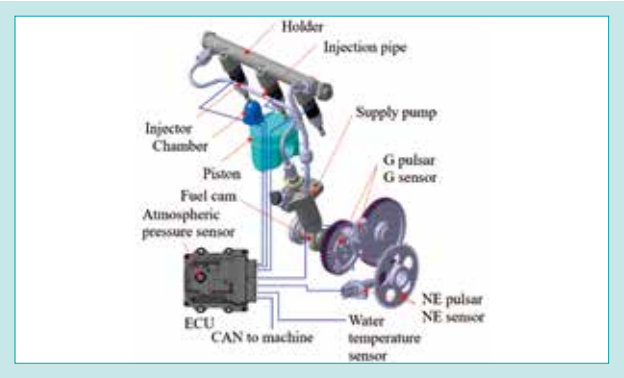

Fig. 4 Overview Diagram of the Electronic Control Engine in the D902-K

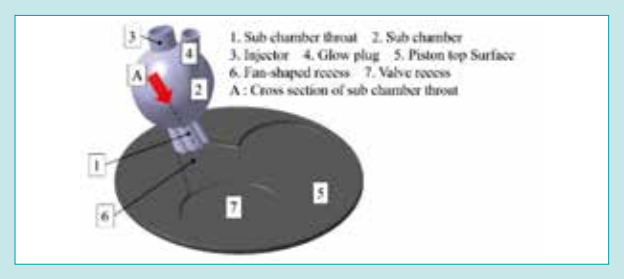

Fig. 5 Schematic Diagram of the Combustion Chamber Shape

3-2 Compact engine with reduced inter-cylinder EGR rate variation

Since the EURO5+ regulations require an 84% NOx reduction compared to EURO 4, an EGR system was adopted aiming at achieving a high EGR rate. Because the Z482-K is a naturally aspirated engine with a 180° crank combustion interval, the difference in the amount of EGR between the cylinders is a concern. Specifically, the intake timing of the first cylinder overlaps with the exhaust timing of the second cylinder. Exhaust back pressure is applied during the intake stroke of the first cylinder, but not during the intake or exhaust of the second cylinder. Therefore, the amount of EGR of the first cylinder is higher than that of the second cylinder (Table 3 and Fig. 6).

The EGR rate of each cylinder was measured, and a significant difference of 7.6 percentage points was confirmed between the first and second cylinders (Fig. 7). If the cylinder-to-cylinder variation in EGR rate increases, the EGR rate becomes non-uniform between the first and second cylinders, increasing the risk of misfiring in the first cylinder, which has a higher EGR rate, thereby limiting the application of a high EGR rate. Therefore, the EGR gas and fresh air must be mixed and homogenized effectively in the intake manifold. Achieving uniformity in EGR usually requires more space, with the downside that it necessitates a larger intake manifold. Therefore, in order to reduce NOx emissions as desired, it is necessary to establish an EGR system that is compact enough to be installed on the vehicle and provides highly uniform EGR rate distribution.

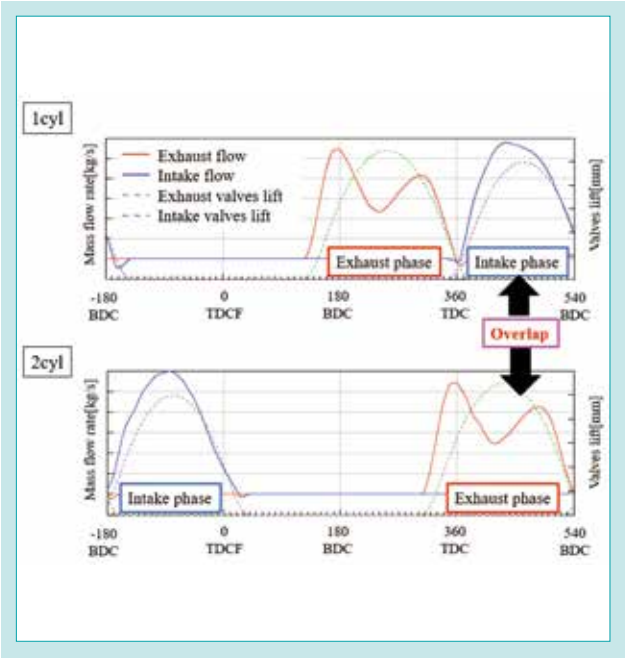

Fig. 6 Relation of the Mass Flow Rates in the Intake and Exhaust Phases

Table. 3 Combustion Interval of the Z482-K

Crank angle	0°	180°	360°	540°	720°
First cylinder	Expansion	Exhaust	Intake	Compression	Expansion
Second cylinder	Compression	Expansion	Exhaust	Intake	Compression

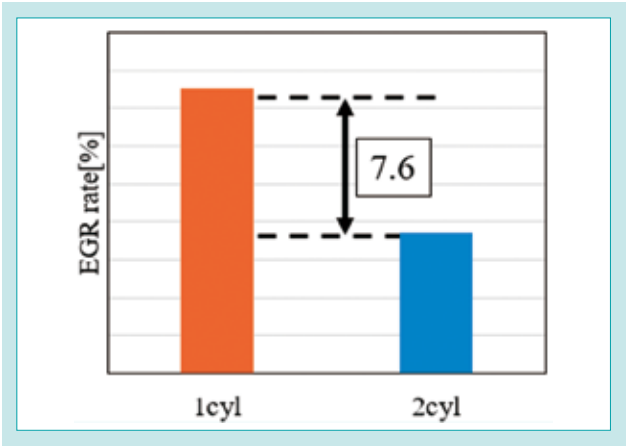

Fig. 7 Cylinder-to-cylinder variation in EGR rate

4. Developed technology

4-1 Improvement of combustion by optimizing the TVCR system

4.1.1 Electronically controlled fuel injection system with two cylinders

An electronically controlled fuel injection system with an injection system and injection logic optimized for the two-cylinder Z482-K was developed to enable fine combustion control over the entire operating range, which was not possible with the mechanical Z482. A holder pressure sensor that monitors the internal pressure of the holder was newly added to the holder assembly, which accumulates fuel pressure. Achieving the same combustion conditions in the first and second cylinders by optimizing the injection timing for each cylinder individually according to the internal pressure of the holder enables more precise combustion control. Furthermore, the implementation of multiple injections and optimized injection timing allows for precise control of combustion throughout the entire operating range. Emission performance was verified using specifications combining an electronically controlled fuel injection system with an early prototype EGR system. The results showed that NOx was reduced to about one-quarter and particulate matter was reduced to about one-half compared to the mechanical Z482 (Fig. 8).

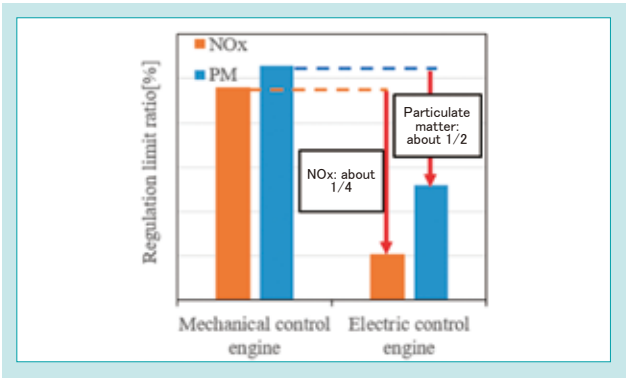

Fig. 8 Improvements Through Electronic Fuel Injection Control

4.1.2 Improved combustion by optimizing the combustion chamber shape

We also performed a fluid analysis to optimize the shape of the piston top (Figs. 9 and 10), which serves as the primary combustion chamber, to promote air-fuel mixing at the piston top and reduce particulate matter. The analysis revealed that, with the conventional fan guide recess shape, combustion gas ejected from the swirl chamber stagnates at the center of the piston top and does not promote mixing of the combustion gas and air, resulting in a large area of rich mixture combustion. We worked on improving the shape of the piston top to enable smooth combustion gas flow and prevent stagnation at the center of the piston top and to make effective use of the air in the main combustion chamber. We changed the guide recess shape at the piston top to a linear type and then confirmed that the combustion gas flows smoothly and does not stagnate at the center of the piston top and that the area of rich mixture combustion at the center is reduced. This resulted in a 20 percentage point decrease in particulate matter and improve combustion robustness (Fig. 11).

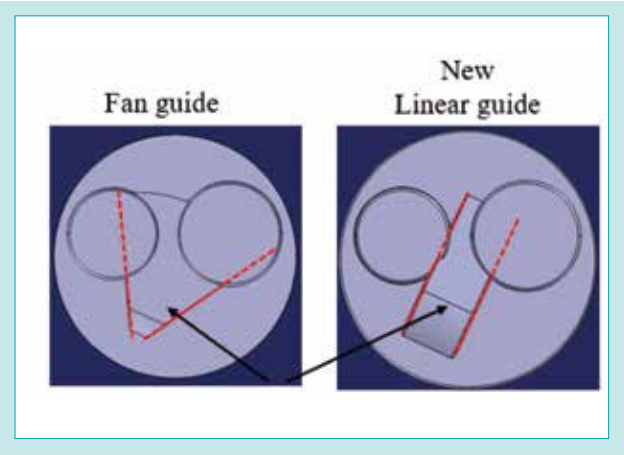

Fig. 9 Gas Guide Recess Shape of the Piston Top

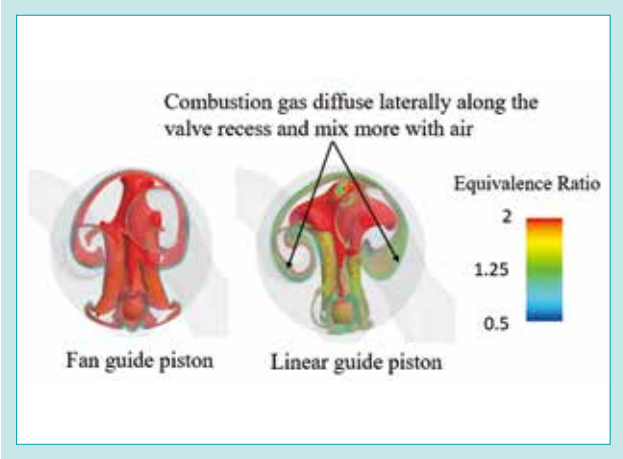

Fig. 10 Analysis Results of the Gas Guide Recess Shape of the Piston Top

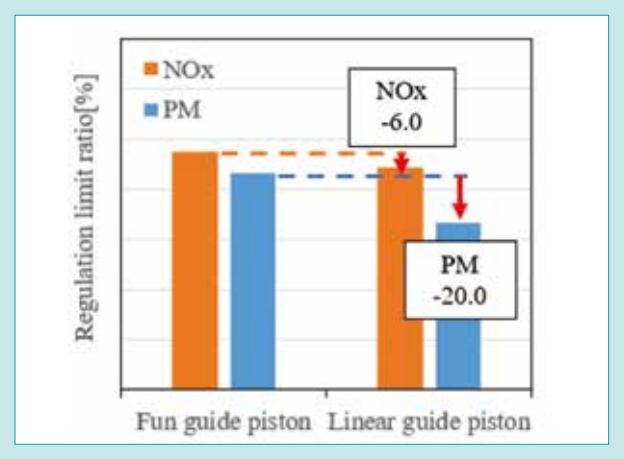

Fig. 11 Improvement of the Combustion Chamber

4-2 Compact engine with reduced inter-cylinder EGR rate variation

In order to reduce NOx by 84% compared to the EURO 4 level, we studied an EGR system that can achieve both compactness and EGR uniformity in the intake manifold at a high level.

Accordingly, we designed a new surge tank capable of effectively mixing EGR gas and fresh air and optimized it through analysis. As a result, a compact surge tank was achieved (Fig. 12) by providing a space for mixing fresh air and EGR gas upstream of the intake manifold and by determining the directions in which the EGR gas and fresh air are introduced. As shown in Fig. 13, this improved the difference in the EGR rates between the cylinders by 5.6 percentage points. As a result, the application of a high EGR rate became possible, achieving a reduction of NOx emissions by 19.9 percentage points.

Additionally, particulate matter decreased by 54.2 percentage points due to the uniform combustion achieved between the cylinders.

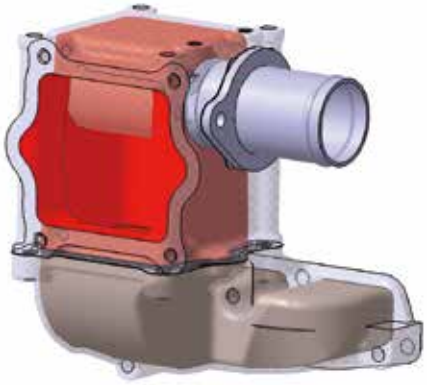

Fig. 12 Intake Manifold with Surge Tank

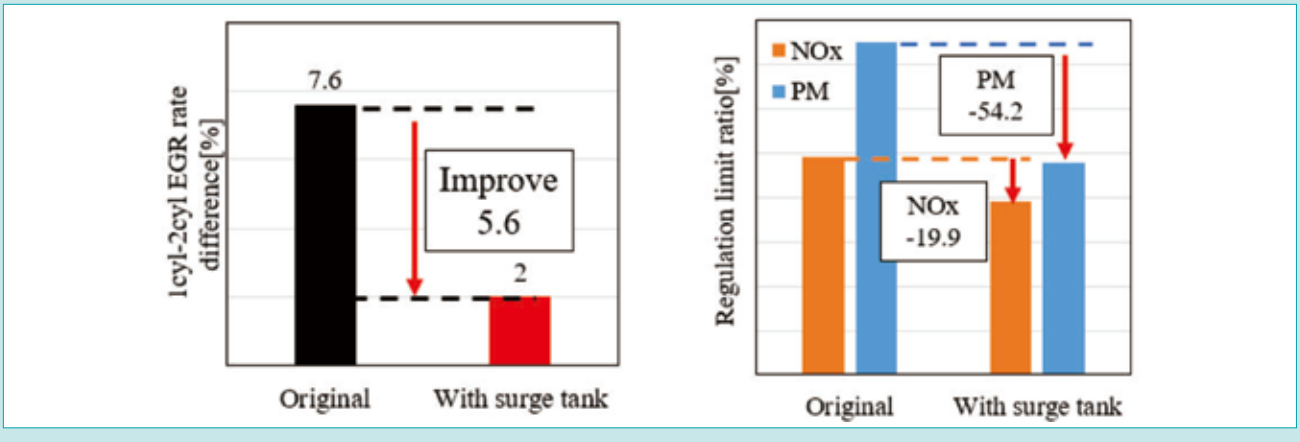

Fig. 13 Reduction in the cylinder-to-cylinder variation in EGR rate and the resulting emission improvement

4-3 Verification of exhaust gas performance when mounted on a vehicle

The Z482-K with a DOC system compatible with the main regulation-compliant technologies described in Sections 4-1 and 4-2 was installed in a vehicle, and its emission performance was verified. As shown in Fig. 14, the emission performance fell within the EURO 5+ framework. Additionally, the EGR system was made more compact, which allowed the engine to fit in the existing vehicle's engine compartment. In addition, using the minimum required emission reduction devices to comply with the EURO 5+ regulations contributed to keeping the vehicle weight within specifications.

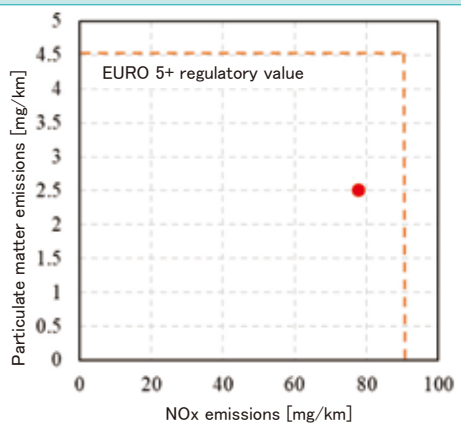

Fig. 14 Vehicle Exhaust Gas Results

5. Conclusion

To comply with EURO 5+ regulations, we worked on an electronic control system based on the mechanical Z482 and were able to comply with regulations by adding the minimum necessary emission reduction devices, namely, the DOC and EGR systems. These improvements not only helped comply with the EURO 5+ regulations, but also contributed to better vehicle performance, such as reduced combustion noise, improved starting performance, and increased maximum torque.

With the development of the Z482-K, we demonstrated that electronically controlled fuel injection systems and emission reduction devices can be used even in small engines to comply with strict emission regulations, such as EURO 5+.

The outcome of this development is a fundamental technology that can be used to ensure compliance with future emission regulations for small engines. We will continue to contribute to a sustainable society by developing engines with high environmental performance, thereby promoting the growth of our engine business.

Contribution to SDG targets

7.1 Ensuring universal access to modern energy services
Providing clean engines compliant with the EURO 5+ regulations

9.4 Improvement of infrastructure by introducing environmentally friendly technologies
Improving sustainability by developing low-emission engines

11.2 Provision of safe, affordable, and sustainable transportation systems
Contributing to transportation systems by providing engines for minicars

Development of Emissions Prediction Technology Using 1D-CAE and AI

Engine Engineering Dept. Ⅲ

Emissions regulations for off-road diesel engines are becoming stricter worldwide, and the California Air Resources Board's (CARB) next Tier 5 rulemaking under consideration will require significant reductions in nitrogen oxides (NOx) and particulate matter. Furthermore, the importance of evaluating emissions under actual-use conditions is growing worldwide, creating even more complex development requirements. In this context, it is crucial for the extension of Kubota's engine business to bring regulation-compliant engines to market quickly. However, the conventional development method of repeated prototyping and testing requires a vast number of man-hours, so Kubota is working to improve efficiency through model-based development (MBD). As part of this effort, this paper proposes and validates analytical methods for predicting emissions during transient test cycles, such as the non-road transient cycle (NRTC) and the low-load cycle (LLC).

【Key Word】
1D-CAE, Emissions Regulations, Diesel Engine, Machine Learning, Simulation

Related SDGs

1.Introduction

Emission regulations for off-road diesel engines are being tightened worldwide, and the California Air Resources Board's (CARB) next Tier 5 rulemaking under consideration will require significant reductions in nitrogen oxides (NOx) and particulate matter. Furthermore, the importance of evaluating emissions under actual use is growing worldwide, creating even more complex development requirements. In this context, it is crucial for the extension of Kubota's engine business to bring engines that comply with regulations to market quickly. However, since the conventional development method of repeated prototyping and testing requires a vast number of man-hours, Kubota is working to improve efficiency through model based development (MBD). As part of this effort, this paper proposes and validates analytical methods for predicting emissions during transient test cycles, such as the non-road transient cycle (NRTC) and the low-load cycle (LLC).

2.Development concept and target

We employed a one-dimensional computer aided engineering (1D-CAE) model to reproduce emission test cycles lasting several tens of minutes. In 1D-CAE, the behavior of the entire engine can be quickly calculated by combining a fluid analysis that performs one-dimensional spatial discretization in the flow direction with sub-models that represent each device that makes up the engine system.

The concept of this development is to construct a 1D-CAE model integrating the engine model, engine control unit (ECU) model, and emissions model. Given engine specifications such as the compression ratio and displacement, as well as the operating conditions, the integrated model should be able to predict emission performance for any test cycle (Fig. 1). The engine model consists of an intake/exhaust system (including intake and exhaust pipes, exhaust gas recirculation (EGR) system, and a turbocharger), as well as a fuel injection system, while reproducing changes in control quantities, such as RPM, load, fuel injection timing, fuel injection pressure, and EGR rate.

The emission components subject to prediction are NOx and soot, which are particularly important for complying with diesel engine regulations. Among them, soot is a major constituent of particulate matter (PM). The target accuracy is a relative error of less than 5% against the integrated test cycle value in g/kWh.

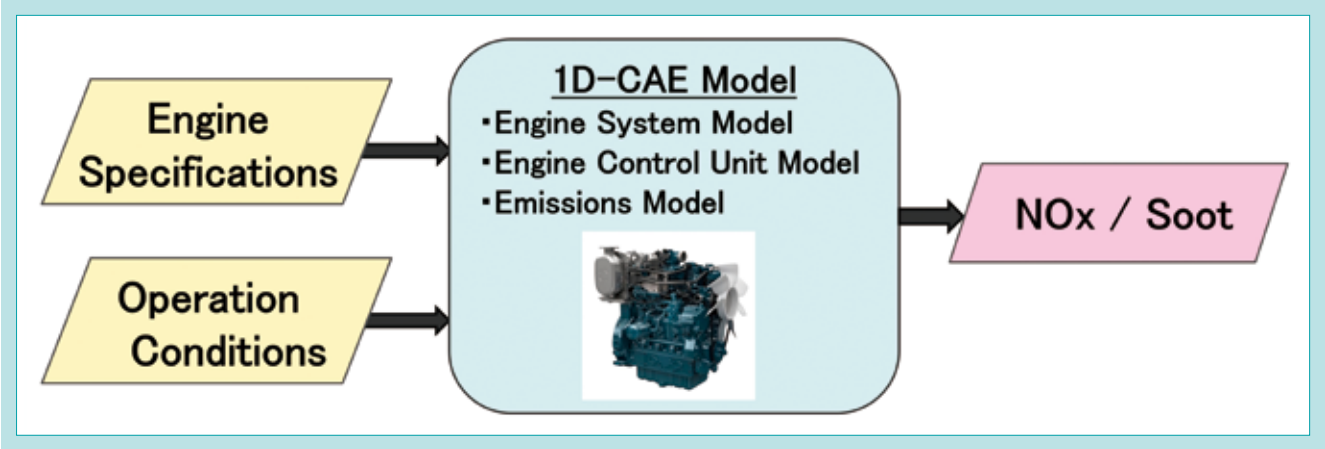

Fig. 1 Concept of the Emissions Prediction Method

3. Technical issues to be solved

This development project addresses the following three issues in predicting emissions in transient test cycles using 1D-CAE.

(1) Engine modeling

To accurately predict emissions, it is essential to have the basic technology to reasonably estimate physical quantities in cylinders, such as the temperature, pressure, and equivalence ratio, during transient operation. The challenge here is to develop a high-precision 1D-CAE model that includes an intake/exhaust system and a diesel combustion model, and to reproduce transient in-cylinder conditions while following changes in the ECU control inputs.

(2) NOx modeling

The majority of NOx emitted from diesel engines is known to be thermal NO, which is generated by the oxidation of nitrogen in air that has become hot due to combustion. The challenge of this development project is to create a method that can predict thermal NO with high accuracy.

(3) Soot modeling

As shown in Fig. 2, soot forms through a complex interplay of processes, including nucleation, surface growth, aggregation, and oxidation. Currently, there is no established model that can accurately predict the amount of soot produced, and the challenge lies in developing a prediction method.

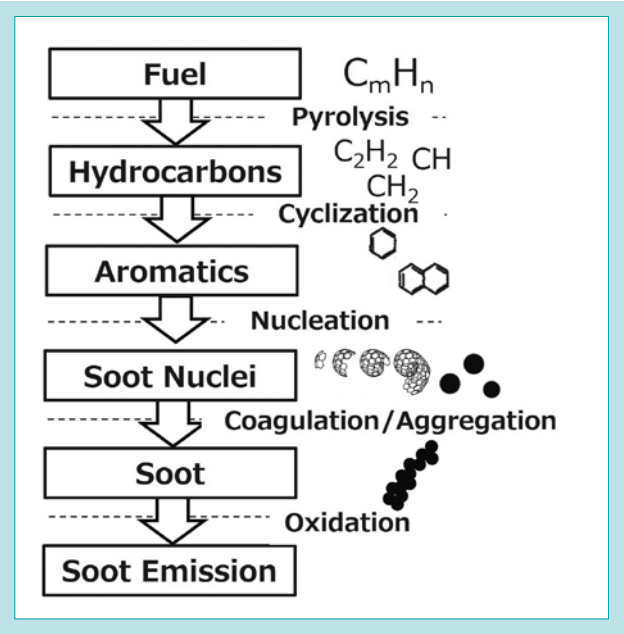

Fig. 2 Soot Formation Process

4. Developed technology

4-1 Engine analysis technology using 1D-CAE

4.1.1 Engine intake/exhaust system modeling

For this development project, we constructed a 1D-CAE model that accurately reproduces the behavior of the entire system for a common rail diesel engine equipped with turbocharging and an EGR system. To achieve this, the fluid and heat transfer phenomena occurring in components such as the intake/exhaust pipes, turbocharger, and EGR system must be modeled accurately, and the temperature, pressure, and flow rate of each component must be predicted precisely.

To construct a highly accurate turbocharger model, we modeled the aerodynamic loss, heat loss, and bearing friction loss generated in the turbocharger on a separate basis. For heat loss, we used the thermal network method (Fig. 3) to describe the heat capacity, heat transfer, and radiation of each turbocharger component. In modeling the turbocharger, we measured each loss through turbocharger stand-alone rig testing. To improve the reproducibility of the transient response, we measured the moment of inertia of the turbocharger.

To predict physical quantities in the cylinder with high accuracy, we modeled the temperature of the combustion chamber wall. We constructed a solid-state heat transfer model of the engine components, including cylinder heads, crankcases, and pistons, based on their dimensions and physical properties,

and then calculated the wall temperatures of the combustion chamber and the intake/exhaust ports. The model calculates the wall temperature of engine components by taking into account the heat transfer, conduction, and radiation between fluids (such as cylinder gases, engine oil, cooling water, and surrounding air) and solid components. To construct this model and reproduce combustion chamber wall temperatures over a wide range of engine speeds and loads, we measured the wall temperatures of the cylinder head and liner.

Thanks to these efforts, we have succeeded in accurately predicting physical quantities such as the engine air intake and gas temperature (Fig. 4).

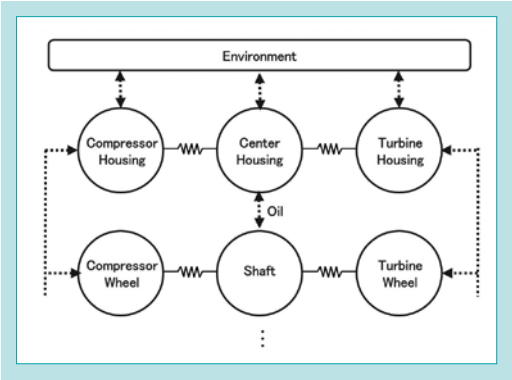

Fig. 3 Overview of the Thermal Network Model

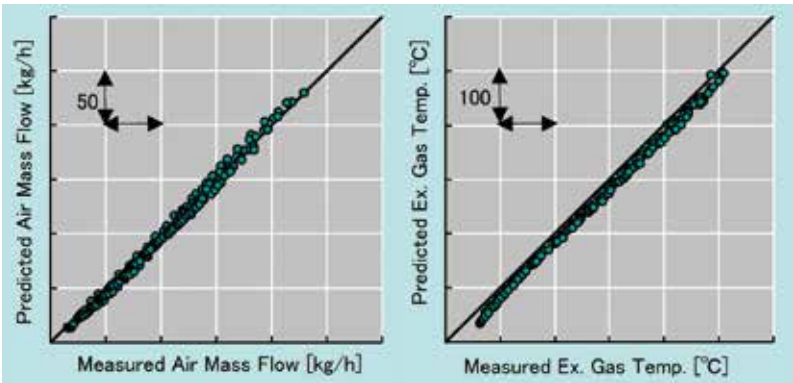

Fig. 4 Comparison of Calculated Results from the 1D-CAE Model and Measured Values (Left: Airflow;Right: Exhaust Gas Temperature)

4.1.2 Diesel combustion modeling

To reproduce actually measured combustion processes, we calibrated four model parameters that represent combustion in a common rail diesel engine. They respectively control the amount of ambient gas entrainment in the fuel spray, ignition delay, premixed combustion, and diffusion combustion. We used a genetic algorithm to tune the parameters and build a model that reproduces combustion over a wide operating range. Figure 5 shows the measured and predicted heat release rates (HRRs), and Fig. 6 shows the measured and predicted values of 50% mass fraction burned (MFB 50%). Both figures confirm that the predictions were made with high accuracy.

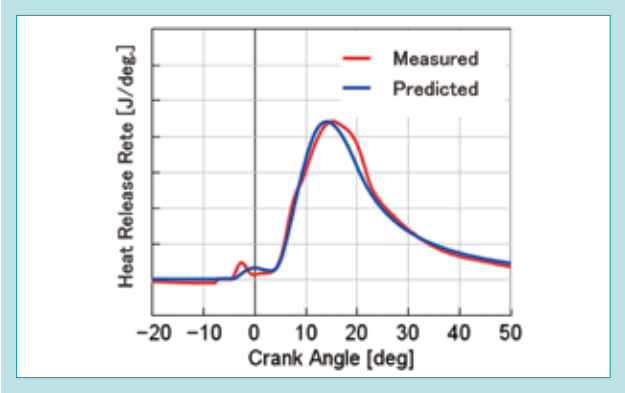

Fig. 5 Comparison of the Measured and Predicted Heat Release Rate

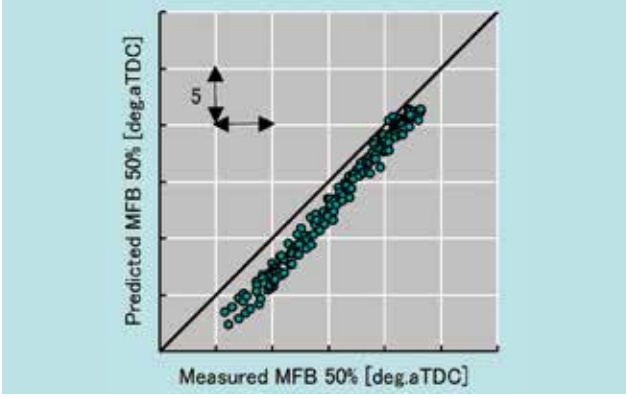

Fig. 6 Comparison of the Measured and Predicted MFB 50%

4-2 NOx prediction technology

Equations (1) to (3) in Fig. 7 show the expanded Zeldovich mechanism for the formation of thermal NO. To predict the progress of the reaction, the forward and reverse reactions in Equations (1) through (3) are calculated using the reaction rate expressed by the Arrhenius equation, which requires a large number of model parameters. However, in the fuel-lean, high-temperature region, NO emissions can be expressed by Equation (4), assuming partial equilibrium is established for the $O_2 \leftrightarrow O$ reaction.[1] For this development project, two model parameters in Equation (4), i.e., frequency factor A and activation energy E, were calibrated to reproduce the measured NOx emission results over a wide operating range.

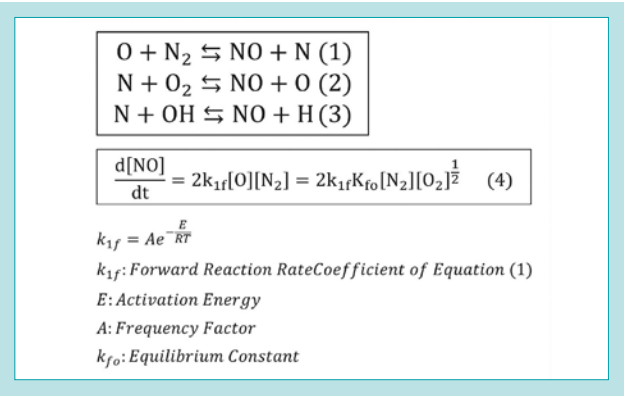

Fig. 7 Formation Mechanism of Thermal NO

4-3 Soot prediction technology

Because soot is formed in a complex process, there is currently no theoretical model that can accurately predict its emissions. However, it is known that machine learning, an AI technique, can be used to build predictive models for objects that are difficult to model theoretically. In this development, we constructed a soot prediction model that combines 1D-CAE and machine learning.

As described below, there are two important requirements for building highly accurate machine learning models.[2]

(1) Selection of appropriate features

Because the saying "garbage in, garbage out" applies to machine learning, it is crucial to feed high-quality information into the learning process to obtain highly accurate prediction results. Therefore, it is essential to prepare high-quality input information (explanatory variables) having a physical relationship with the prediction target.

(2) Selection of appropriate learning algorithms

Different machine learning algorithms result in different model prediction accuracies. As the no-free-lunch theorem indicates, there is no universally optimal algorithm for all prediction problems. Therefore, to select an appropriate algorithm, data must be trained on multiple candidate algorithms and the accuracy of each must be evaluated. The mechanism of soot formation (Fig. 2) suggests that soot emissions are correlated with in-cylinder temperature, soot components, and the progress of combustion. As indicated in item (1), this information should be entered as explanatory variables into the machine learning model. However, these parameters are difficult to measure, and moreover, since the objective of this method is to predict emission performance before prototyping and testing, explanatory variables must be prepared for conditions for which there is no actual measurement data. Therefore, we used 1D-CAE to estimate detailed information in the cylinder under arbitrary conditions and used this information as explanatory variables. The explanatory variables used for learning were selected based on the generative mechanism of soot and an importance analysis using a decision tree-based algorithm. Figure 8 illustrates the process of building a machine learning model with this method.

In selecting the machine learning algorithms described in item (2), we selected several models as candidates that are expected to have high accuracy when learning several hundred data sets. We constructed machine learning models by training candidate models

with data and then compared their prediction accuracy using validation data not used for learning. This allowed us to select the machine learning model best suited for predicting soot emissions. Here, Bayesian optimization[3] was used for the hyperparameter tuning of the model. By training the machine learning model with approximately 400 data sets under steady-state operating conditions (constant speed and torque), we constructed a prediction model for soot emissions.

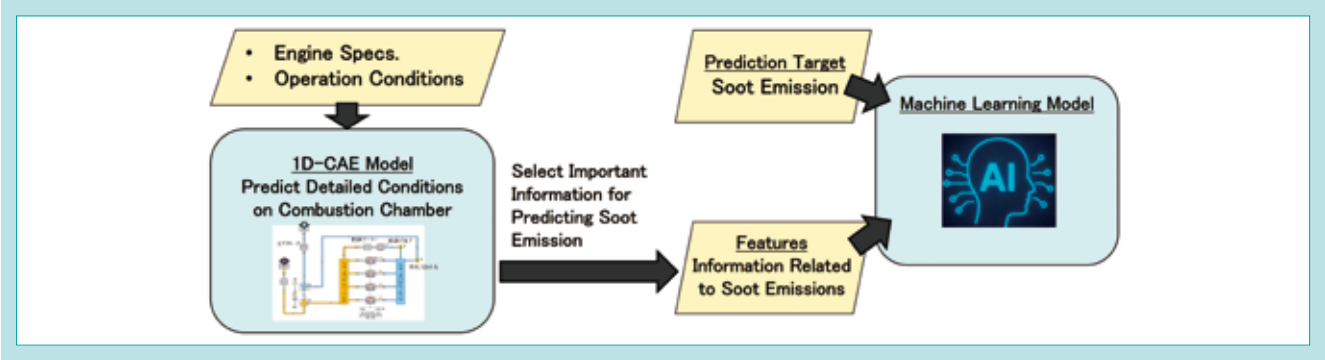

Fig. 8 Training Process of the Machine Learning Model for Predicting Soot Emission

4-4 Overview of the developed emission prediction method and confirmation of its effectiveness

4.4.1 Overview of the developed emission prediction method

Figure 9 shows an overview of the developed emission prediction method. NOx emissions are predicted using the thermal NO model incorporated into 1D-CAE, and soot emissions are predicted using a combination of 1D-CAE and the machine learning model.

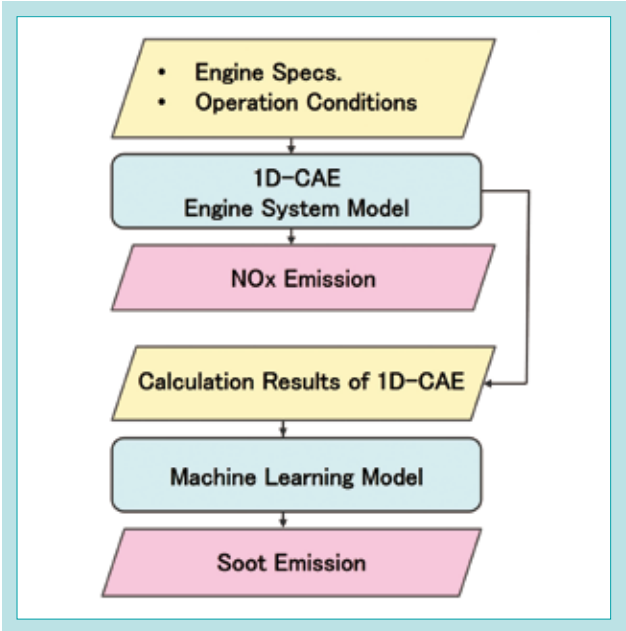

Fig. 9 Overview of the Developed Emissions Prediction Method

4.4.2 Effectiveness evaluation

We used the developed method to predict NOx and soot emissions in NRTC and LLC operations, which are transient operation patterns used to measure off-road engine regulatory values. We then compared the predictions with the measured results (Figs. 10 and 11). It was confirmed that NOx and soot emissions in NRTC, as well as soot emissions in LLC, could be predicted with high accuracy, with relative errors of less than 5% against the time-integrated value in g/kWh. The relative error for NOx emissions in LLC operation was relatively high at 18%. This is presumably due to relatively low NOx prediction accuracy at low loads, corresponding to the main operating region for LLC. Further improvements to the methodology will be implemented in the future.

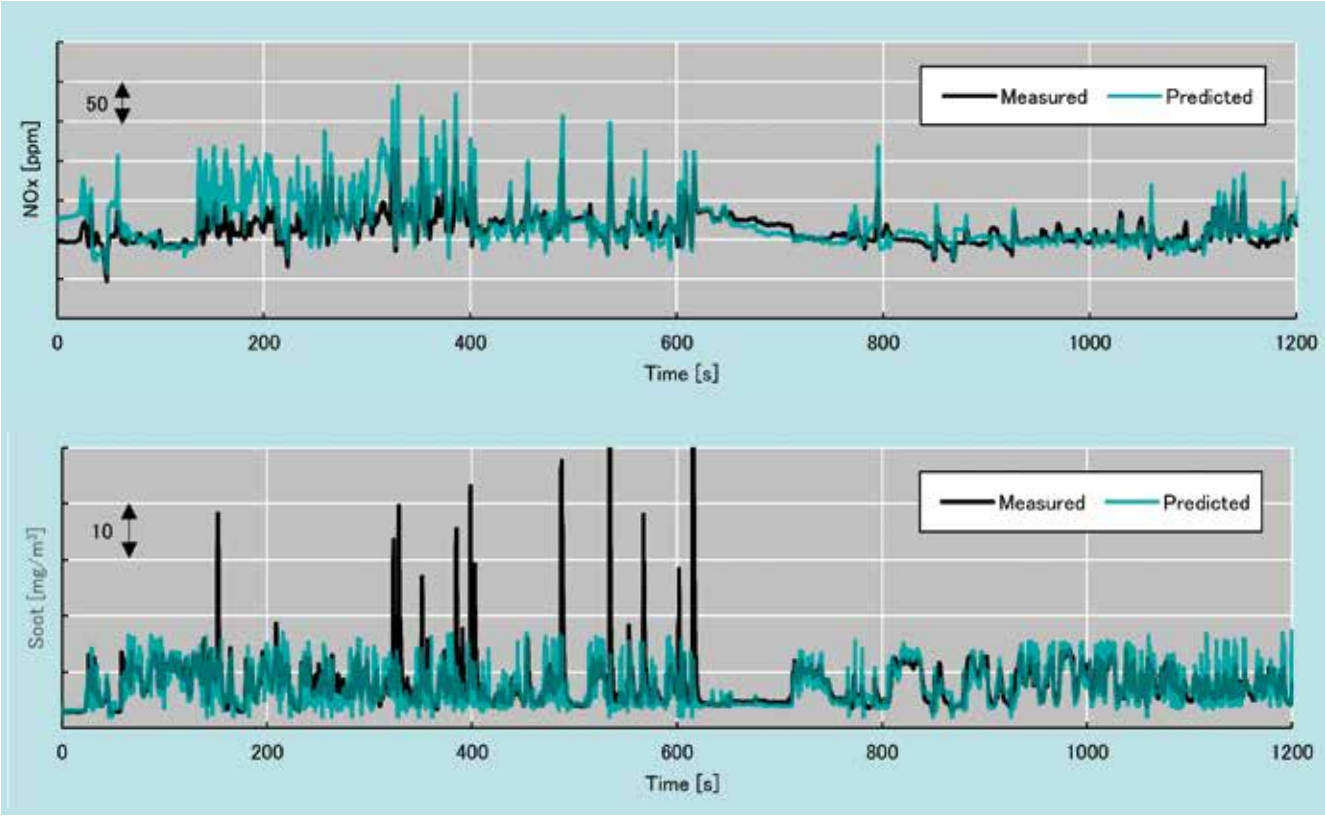

Fig. 10 Comparison of Measured and Predicted Emissions During NRTC Operation (Top: NOx, Bottom: Soot)

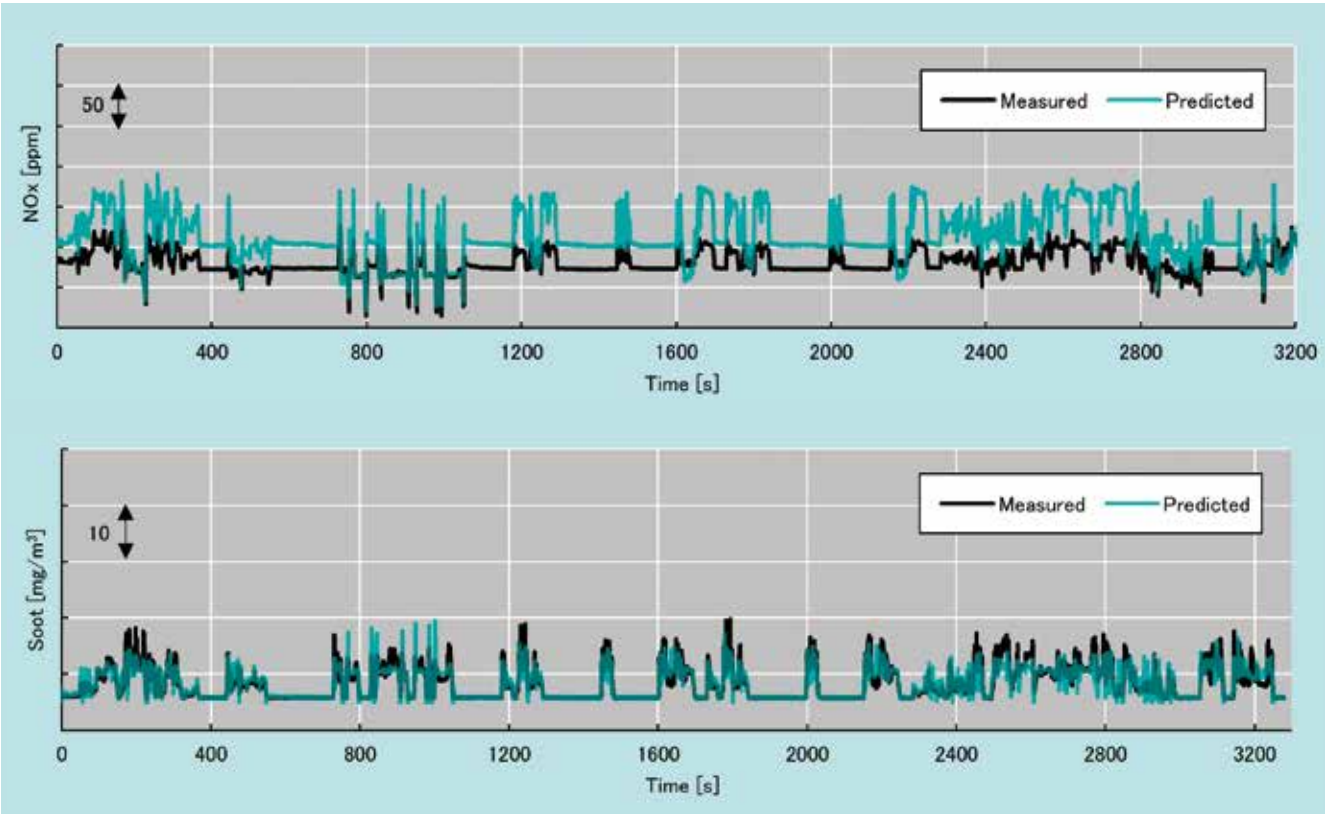

Fig. 11 Comparison of Measured and Predicted Emissions During LLC Operation (Top: NOx, Bottom: Soot)

5.Conclusion

The presented approach enables the identification of design proposals with significant emission-reduction effects from the early stages of development and allows desktop evaluation of emission performance for any test cycle, thereby improving development efficiency and emission performance. Deploying this technology across multiple engine models will help us develop cleaner engines and further expand our engine business.

Contribution to SDG targets

7.3 Improvement of energy efficiency: Improving engine efficiency by designing for emission reduction and high thermal efficiency in the early stages

9.4 Improvement of infrastructure and industries by introducing environmentally friendly industrial processes: Reducing energy consumption through increased development efficiency

Reference

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Development of the Next Generation of the Monitoring and Control System “CraftPat”

Measurement System Dept.

The in-house developed monitoring and control system, “CraftPat” provides a solution for centralized management and visualization of on-site data, such as the operational status and process data of facilities. This has contributed to solving various on-site challenges, including reducing operator burden, cutting costs, improving operational efficiency, managing energy, and ensuring quality control. This time, to respond to the diversification and sophistication of customer needs, we aimed for the next generation of CraftPat. While maintaining conventional high-speed monitoring performance, we achieved enhanced scalability while looking ahead to AI control and data analysis, multi-platform compatibility for clients, improvements of reporting functions, and strengthened security.

【Key Word】
Monitoring and Control System, Remote Monitoring, SCADA, Visualization, Web, Software Development

Related SDGs

1.Introduction

The CraftPat monitoring and control system is Kubota's supervisory control and data acquisition (SCADA) system, which collects and visualizes data from equipment. To date, the company has provided solutions based on CraftPat to centrally manage and visualize on-site data such as facility operating conditions and process data, mainly for water incineration plants, water treatment plants, draining pump stations, and in-house and external manufacturing plants. This has helped solve various on-site issues, such as reducing the operator's workload, cutting costs, improving operational efficiency, managing energy usage, and ensuring quality control.

Figure 1 shows the system configuration of CraftPat. CraftPat consists mainly of a server and a client. Signals from field devices under monitoring are collected by the server via a programmable logic controller (PLC) or similar control device connected to equipment and other devices. The collected signals are sent to the client and can be displayed as monitoring views, graphs, and reports on a web browser, which is software required to view the Internet. It is also possible to send operation signals from the web browser screen to field devices.

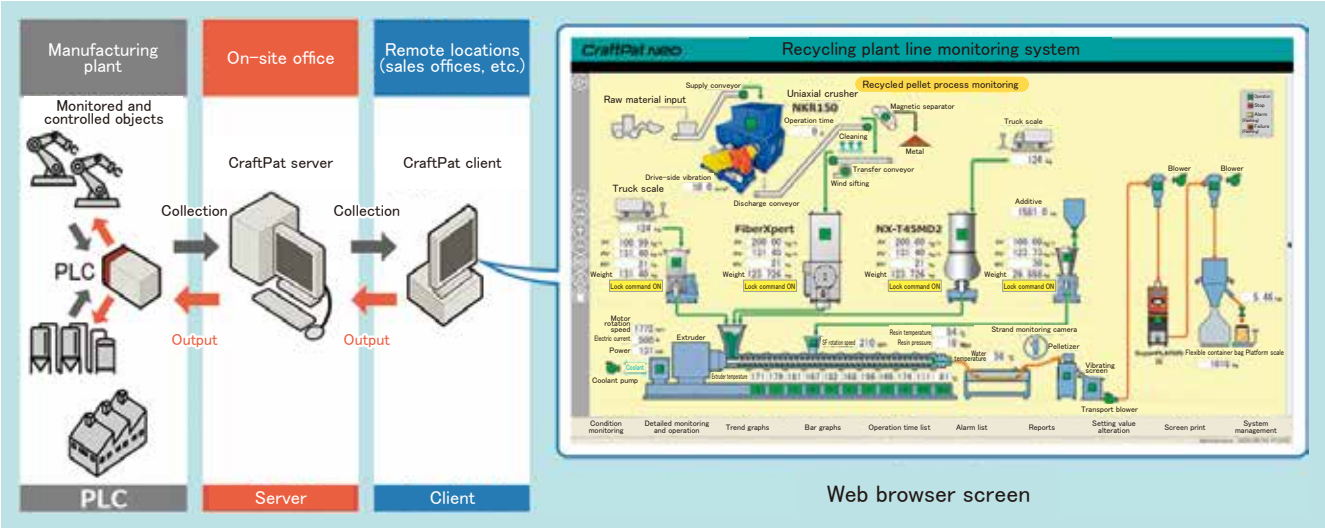

Fig. 1 System Configuration and Monitoring Screen Sample of CraftPat

2. Development concept and target

2-1 Development concept

To continue creating added value by resolving customer issues based on CraftPat, we must respond quickly to diverse, changing customer needs. With the advancement of technologies for digital transformation (DX: transformation using digital technology) and the Internet of Things (IoT: various devices communicating via the Internet), among others, it is becoming important to provide added value in line with the times, going beyond mere data visualization. This includes the use of artificial intelligence (AI) for automatic control and predictive maintenance, as well as remote monitoring via smartphones and tablets. In order to achieve this, it was crucial to implement new technologies and update CraftPat's operating and development environments. Therefore, we developed a next-generation system called CraftPat Neo. There were two development concepts as follows.

(1) Inherit the basic specifications of CraftPat while updating the operating and development environments with technology appropriate for the times. Maintaining high-speed communication performance is particularly important for real-time monitoring, one of the features of SCADA.

(2) Make the product flexible enough to meet a wider range of customer needs. More specifically, the product should excel at adding and extending functions, as well as developing new functions, in response to market and customer needs. Additionally, the product should be multi-platform, operating similarly on different devices, and be capable of providing solutions tailored to the customer's operating environment.

2-2 Development goals

To achieve the development concepts, the following target values were set for three themes: high-speed monitoring, enhanced scalability, and enhanced web client versatility.

(1) High-speed monitoring

(i) The time from when the PLC receives a signal status change at the site to when the monitoring screen display is updated should be 100 ms at the fastest speed, which is equivalent to CraftPat. This target value was determined to be a requirement for high-speed communication in real-time monitoring, based on the SCADA performance of other companies and past results.

(ii) The report function for automatically recorded field data in tabular form should display a report within 3 seconds after switching screens. Compared to about 10 seconds required in CraftPat, responding to the request for a higher speed will improve the system's convenience.

(2) Enhanced scalability

(i) The product should offer high functionality and system scalability to meet market and customer needs. In particular, adopt technologies suited for AI control and data analysis, which are now indispensable

(ii) In line with the next-generation product, develop new features that surpass competing SCADA systems

(3) Enhanced web client versatility

(i) In order to provide proposals tailored to the customer's usage environments, support multiple operating systems (OSs), which are software programs that control computer operations. These include Windows, macOS, iOS, Android, and Linux, enabling monitoring even on smartphones and tablets.

(ii) Support multiple browsers, including Chrome, Edge, Safari, and Firefox, which are the top browsers in terms of domestic market share.[1)]

3.Technical issues to be solved

3-1 Next-generation operating and development environments

The key to developing CraftPat Neo was choosing the right technologies to meet the development goals and determining the best combination of those technologies. CraftPat Neo consists of three main technologies: a web server with software that provides the information necessary for displaying web pages, a web client with software that uses this information, and a communication protocol that defines the communication procedure (Fig. 2).

(1) Web server selection

CraftPat's web server uses the C++ Builder ver. 5 development environment, which runs on 32-bit Windows but not on the current mainstream 64-bit system. This has posed challenges in terms of extending functionality, developing new functions, and integrating with external programs to meet customer needs. Therefore, a new web server needs to be selected. The web server's performance must be carefully evaluated because it directly affects the monitoring function's response and data processing capabilities. In particular, the combination of the web client with the communication protocol and the server's compatibility with the development environment should be considered, and the impact on development speed and maintainability should be evaluated.

(2) Web client selection

The ActiveX control (Microsoft's software technology) that has been used in CraftPat's web client works only with Internet Explorer, which is a web browser on the Windows OS. Therefore, Internet Explorer has been the only browser that can be used with CraftPat. In order to improve versatility, it is necessary to review web client development technology and achieve multi-browser support. Additionally, changes in the collected data must be reflected instantly in the monitoring view displayed on the web browser. Therefore, efficient, real-time graphics display technology is required. Furthermore, if data processing can be done on the client side, communication with the server can be minimized, and response time can be sped up.

(3) Communication protocol selection

A communication protocol is required that enables constant, bidirectional communication between the server and client, as well as high-speed, real-time data transmission and reception. Therefore, it is important to select a protocol that is highly efficient at real-time data processing and that can update data quickly. It must also be compatible with multiple browsers.

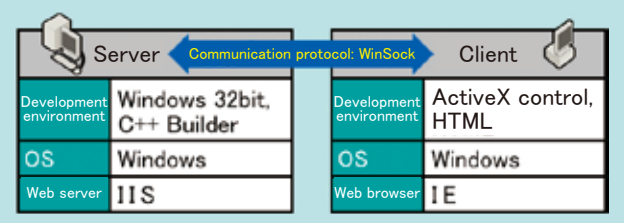

Fig. 2 Server and Client Configuration of Conventional CraftPat

3-2 Next-generation functions

To meet the diverse and ever-changing needs of customers, it is necessary to develop next-generation functions.

(1) Scalability

In CraftPat, COM (Component Object Model: a specification defined by Microsoft that enables software components to be modularized and used externally) and VBScript (a programming language developed by Microsoft) have been used to implement processing such as calculations and the execution of external programs that are not supported by the basic functions. However, the demand has shifted from simple monitoring to meeting advanced requirements, such as automatic control and predictive maintenance using AI, and prediction and optimization using collected data. These needs are difficult to meet with COM or VBScript. Accordingly, it was necessary to establish a framework that enables easy functional expansion, including integration with external libraries (collections of program components) and cloud services (systems that store data on Internet-based servers), as well as the utilization of AI.

(2) Report function

To display reports in CraftPat, Excel is installed on the client and embedded in a browser using an ActiveX control. As a result, it is necessary to install Excel on the client, and the only available web browser is Internet Explorer. This resulted in additional effort when adding clients and imposed restrictions on the client-side usage environment. In addition, recent versions of Excel have become more advanced in functionality, so it takes more time to start up. The CraftPat report function opens Excel in a web browser to display reports, which takes time to start up, resulting in delays in the initial display and decreased usability. These issues called for the creation of a new mechanism that would achieve multi-browser compatibility without relying on ActiveX controls and speed up report display.

(3) Security

SCADA systems are typically configured to operate independently and are not connected to the Internet. Since CraftPat was also intended for use in a closed network, security functions were not implemented. However, networking for remote monitoring and data utilization has increased in recent years. Security has become a critical issue, as plant control systems have increasingly become targets of unauthorized access and data theft. Therefore, it was necessary to have security features that would lead to proposing a customer-tailored usage environment and system expansion.

4. Developed technology

4-1 Next-generation operating and development environments

4.1.1 Selection of component technologies

(1) Web server selection

NginX, IIS, and Apache were selected and compared as candidates due to their popularity and high market share among web servers (Table 1). After the comparison, the candidates were narrowed down to IIS and Apache due to their superior processing of the dynamic content handled by CraftPat Neo. IIS, a standard Windows web server, is already used in CraftPat. Apache is used on a wide range of operating systems.

(2) Web client selection

HyperText Markup Language Living Standard (HTML LS) and WebAssembly, which are web browser specifications, were selected as candidates. Because WebAssembly was a very new technology at the time of development, we chose HTML LS for its reliability in terms of the development environment. HTML LS uses the Canvas element and JavaScript to render graphics in web browsers, and this enables fast screen rendering without requiring complex processing. Here, the Canvas element is a technology used for rendering graphics, and JavaScript is a programming language used in web development. These technologies are also widely supported by major web browsers, enabling multi-browser compatibility.

Table 1 Comparison of Web Servers

NginX	IIS	Apache
– Top domestic market share – Not good at handling dynamic content	– Windows standard – Good at handling dynamic content – Also used in CraftPat	– Used on a wide range of operating systems – Good at handling dynamic content

(3) Communication protocol selection

We selected WebSocket and Server-Sent Events (SSE) as candidates. These technologies are supported by major web browsers, enabling multi-browser compatibility. While WebSocket always allows bidirectional communication between the server and the client, SSE only allows one-way communication from the server to the client and is therefore not suitable for CraftPat's specifications. We therefore selected WebSocket. WebSocket is suitable for high-speed monitoring because it enables high-speed, real-time, bidirectional communication and is more efficient than other communication technologies for processing real-time transmission and reception.

Based on the above considerations (1) through (3), we configured demonstration systems with basic monitoring functions and trend graphs, as shown in Table 2, to compare and evaluate the performance of each configuration. We chose Windows 10 as the operating system for the server since many customers prefer Windows for its ease of maintenance and management.

Table 2 Experimental Conditions for the Server Test

	Server	Client	Communication protocol
Configuration 1	Web server: IIS OS: Windows 10 Pro 64 bit Development environment: ASP.Net, C#	Web client: HTML LS, Java Script Web browser: Chrome, Edge, Safari, Firefox	WebSocket
Configuration 2	Web server: Apache OS: Windows 10 Pro 64 bit Development environment: Spring, Java		

4.1.2 Comparative evaluation results

We measured the communication processing and speed between the server and client to evaluate the performance required for high-speed monitoring. We also measured the display performance on web browsers to evaluate compatibility between the web server and web client. The results are shown in Table 3.

As a result, Configuration 1 (IIS) outperformed in data transmission time (Item 3). The reason is thought to be that, compared to the Apache development environment, ASP.Net, as used in combination with IIS, is a Microsoft product and therefore runs more efficiently on Windows. Regarding the web browser screen (Item 4), verification of the web client screen display and the refresh time of specified screens revealed no differences between Configurations 1 (IIS) and 2 (Apache), and the display performance was found to be the same as with CraftPat. From the above results, IIS was determined to be appropriate as a high-speed web server. Based on this, we established the configuration of CraftPat Neo as shown in Fig. 3.

Table 3 Comparison of Evaluation Results

	(1)Received data sets per sec	(2)Transmitted data sets per sec	(3)Data transmission time	(4)Web browser screen
Configuration 1	999	1,000	1,471 ns	Similar to CraftPat
Configuration 2	924	1,000	344,435 ns	Similar to CraftPat

(1) Number of data sets sent from the client and received by the server
(2) Number of data sets that can be sent from the server to the client
(3) Time required from the acquisition of data from the server's signal generator until the completion of transmission to the socket
(4) Screen rendering, graph display, and button operation on the client's web browser

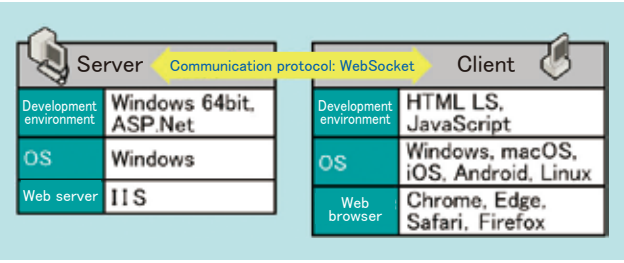

Fig. 3 Server and Client Configuration of CraftPat Neo

4-2 Next-generation functions

4.2.1 Enhanced scalability

In anticipation of the realization of AI control and data analysis, shared dynamic link libraries (DLLs) were developed for CraftPat Neo to access internal data and acquire and use values. This allows the system to be used with multiple programming languages such as C# and Python, enabling development in a flexible environment to meet diverse needs. Python is particularly important for the future because of its extensive libraries for AI control and data analysis. Therefore, we developed a standard feature that facilitates integration with Python programs. This enabled us to develop an infrastructure for AI control and data analysis. Python is an interpreted language, which translates code into machine language and executes it line by line. While it has the advantages of not requiring a development environment and being highly readable, it has the disadvantage of slow processing speed. Therefore, using Python for processes that require real-time performance, such as capturing sensor values and responding to alarms, may cause instability. Accordingly, we adopted a hybrid configuration: using C# for real-time processing due to its high responsiveness and using Python for accessing and retrieving values from internally stored data and performing data processing, integration, and analysis. This prevents delays in processing that requires real-time performance, while enhancing system scalability.

4.2.2 Report function improvement

CraftPat Neo uses a new method for displaying reports. Specifically, a mechanism was introduced that uses Excel on the server side to generate data for reporting, which is then saved as PDF files and displayed in a web browser. By changing to a method of outputting and displaying reports in PDF format, we can now display reports in the four major browsers listed in the development goals without using a mechanism that relies on ActiveX controls to display Excel views embedded in a browser. This eliminates dependence on ActiveX controls and provides support for multiple browsers. Additionally, eliminating the need to install Excel on client PCs has made it easier to add clients, thus making the system more scalable. Furthermore, the client does not need to call Excel every time a report is displayed, which speeds up the process.

4.2.3 Enhanced security

SSL/TLS was made available as a security technology that encrypts and protects communications over the internet. In recent years, security has been required to be strengthened even within closed networks, such as in-house networks. Therefore, we established a mechanism to allow the use of certificates issued by private certification authorities, which manage digital certificates only within organizations such as companies. By supporting SSL/TLS, the system can securely handle remote monitoring and other internet-based operations, making it easier to respond to customer needs and expand the system.

4.2.4 Development of new market-specific features

(1) Development of features for the compound market

At compound plants that produce raw resin materials for plastic products, the settings for devices such as feeders are managed separately for each grade, or type of compound product. Each time grades were switched, it was necessary to change the settings of each device, which was time-consuming and laborious. Therefore, we developed a grade management function to improve efficiency.

The grade management function allows pre-registration of each device's settings by grade, which ensures that the settings are applied as a batch process when switching grades. Previously, updates such as scale changes to management data and alarm thresholds were handled by a separate application. With CraftPat Neo, however, these updates are now performed by a web server. We enabled immediate application of setting updates without requiring a system restart by implementing the function of data change detection in Data Access

Objects (DAOs: design patterns in programming). Additionally, we have developed a grade report function that efficiently retrieves data from grade names by using the grade name and production period as keys for data management. This has reduced the burden on operators and improved convenience.

(2) Development of functions for test laboratories

The Feeder Technical Center is a facility for testing Kubota feeders. It conducts sampling tests on various raw materials and proposes optimal feeders to customers. We developed a feature for test laboratories that allows users to retrieve and analyze trend graphs linked with camera recording data for any period from the start to the finish of a test (Fig. 4). The Hypertext Transfer Protocol (HTTP), a communication protocol, is used to send start and stop commands for camera recording data. This reduces the amount of data by only recording during necessary periods. This function allows for the quick identification of the cause of any abnormality and the precise communication of information. Additionally, the database of powder and granular material properties is linked to CraftPat Neo, enabling advanced analysis of test results, such as the simultaneous analysis of feeder operating conditions and material properties. We have demonstrated that these digitalization and automation efforts improve work efficiency, and that CraftPat Neo can also be used for test laboratory purposes.

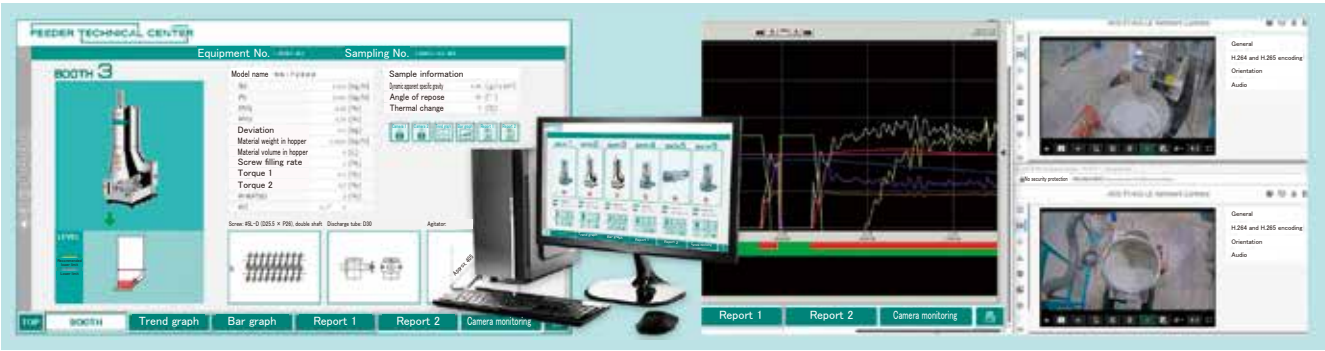

Fig. 4 Trend Graph and Camera Recording Data for the Feeder Technical Center

4-3 Verification of results

(1) High-speed monitoring

(i) We measured the shortest time from when the monitoring PLC received a signal status change to when the CraftPat Neo's monitoring screen was updated. Figure 5 shows the time required for PLC-to-server communication, server processing, and server-to-client communication. The resulting shortest time was less than 100 ms, equivalent to CraftPat. Using a cache function in the server processing to improve data acquisition efficiency also increased speeds.

(ii) As for the report function, we measured the time required from switching to the report screen in CraftPat Neo to the display of a report. As a result, the time to display was confirmed to be within three seconds.

(2) Enhanced scalability

(i) The development of functions that facilitate integration with DLLs and Python programs has facilitated functional expansion. It particularly expands AI control and data analysis capabilities using Python. In-house, we have incorporated an arithmetic processing function using open-source Python libraries and confirmed that the AI control works correctly. Additionally, the system's scalability has improved thanks to the enhanced report function and increased security.

(ii) New functions were developed for the compound market and test laboratories. We were able to demonstrate our market superiority by implementing features specific to each market ahead of competitors' SCADA systems.

(3) Enhanced web client versatility

(i) We verified system operation on the following devices within the company and confirmed multi-OS compatibility: Windows PC, Windows tablet, Mac PC, iPad, iPhone, Android tablet, Android smartphone, and Linux PC.

(ii) We conducted compatibility testing on Chrome, Edge, Safari, and Firefox to achieve our development goal of providing support for multiple browsers.

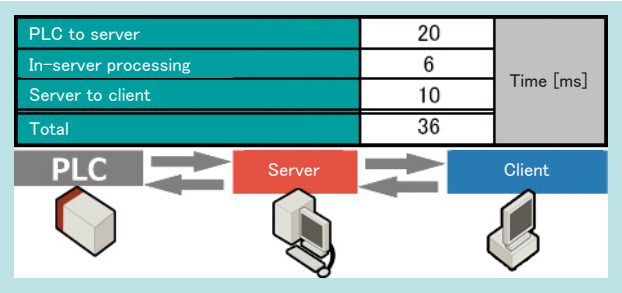

Fig. 5 Measurement Result

5. Conclusion

This development has increased CraftPat's scalability and versatility, allowing it to respond flexibly to market and customer needs. Planned future developments include cloud support, AI-based predictive maintenance capability, and support for multiple languages and standards for overseas deployment. As we continue to deliver CraftPat Neo, we will respond to customer needs and add new features. We will continue to help solve various on-site issues, such as reducing operator workload, improving operational efficiency, managing energy usage, and ensuring quality control.

Contribution to SDG targets

7.3 Improvement of energy efficiency
Monitoring energy usage to improve efficiency

9.2 Strengthening of inclusive and sustainable industrial infrastructure
Promoting industrialization by improving the efficiency of work in plants and manufacturing facilities

12.4 Achieving waste management throughout the product life cycle
Monitoring waste treatment processes to reduce negative environmental impacts

Reference

1) Statcounter GlobalStats: “Browser Market Share in Japan - August 2025”
https://gs.statcounter.com/browser-market-share/all/japan (referenced on September 23, 2025)

Development of the New Earthquake-Resistant Ductile Iron Pipe GENEX (DN500–1000)

Pipe Systems Networks R&D Dept.
Pipe Systems Quality Assurance Dept.

As part of national policy, high targets have been set for enhancing the seismic resistance of trunk pipelines. NS-type ductile iron pipes, known for their excellent toughness and seismic performance, have long been widely used for critical trunk pipelines of DN500–1000. With their widespread adoption, there have been growing requests for easier installation and lower-cost seismic pipelines.

To meet these needs, we developed "GENEX," a new DN500–1000 seismic ductile iron pipe that provides the same seismic performance as NS-type pipes, while reducing installation costs and simplifying jointing.

【Key Word】
Earthquake-resistant Ductile Iron Pipe, Improved Jointing, Reduction of Pipeline Laying Cost, Reduction of Environmental Impact, Metal Touch, Boltless Gland at the Pipe Invert

Related SDGs

1.Introduction

In the Noto Peninsula Earthquake in 2024, water supply and sewage systems were seriously damaged, and restoration work is still taking time. This disruption has reminded us of the importance of earthquake-resistant water pipelines. The Ministry of Land, Infrastructure and Transport (MLIT), which has undertaken the administration of water supply services since April 2024, has been rapidly launching various initiatives to strongly promote the construction of earthquake-resistant water supply and sewage systems.

Conventionally, our NS-type ductile iron pipes (hereinafter referred to as the "NS type") for pipelines with DN500 to 1000 have been used by many water utilities for critical trunk pipelines, demonstrating excellent toughness and seismic resistance against numerous earthquakes and natural disasters. Meanwhile, we have received many requests for simplifying installation work and further improving the workability of joints as an aging workforce, labor shortages, and unsuccessful bidding processes are continuing.

To meet the demands from water utilities and contractors and to address the above issues, we have developed a new DN500 to 1000 earthquake-resistant ductile iron pipe GENEX (hereinafter referred to as the "GX type").

2.Development concept

In order to contribute to the earthquake resistance of trunk pipelines with a product that can address the NS type's issues while maintaining high toughness and seismic resistance, the development concepts of the GX type are: (1) improvement in workability, (2) reduction in pipeline installation costs, and (3) same joint performance as that of the proven NS type.

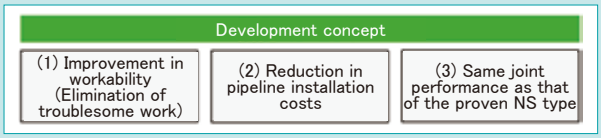

Fig. 1 Development Concept of the GX Type

3. Technical issues to be solved

The technical issues to be solved in developing the GX type are as follows:

(1) Quick jointing without dependence on the operator's skill level

As shown in Fig. 2, bolt tightening with a torque wrench and construction management of the NS type are time-consuming. Furthermore, many processes in jointing work require high-level skill, and work such as pipe centering and dimensional measurement imposes great burdens on the operator.

We decided to develop a joint allowing operators to simply and quickly perform jointing regardless of their skills.

(2) Elimination of work beneath the pipe

As shown in Fig. 3, jointing work under the pipe is difficult due to insufficient space, and construction management is also troublesome. In addition, the trench needs to be dug deeper at each joint area (hereinafter referred to as "digging for jointing") to ensure working space under the pipe, which requires much time and effort.

Therefore, we aimed to develop a joint capable of eliminating work beneath the pipe to improve workability, as well as to shorten work time and reduce pipeline installation costs by minimizing digging for jointing.

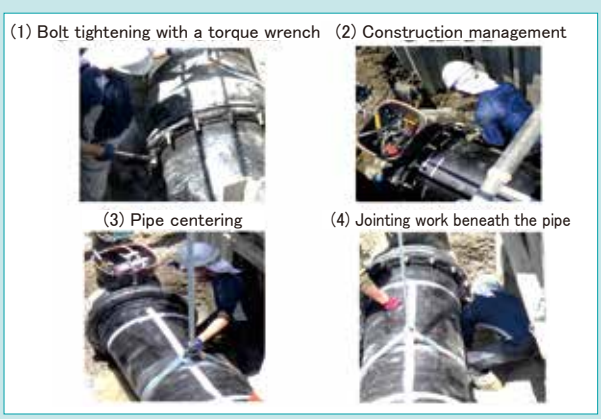

Fig. 2 Construction Challenges of the NS Type

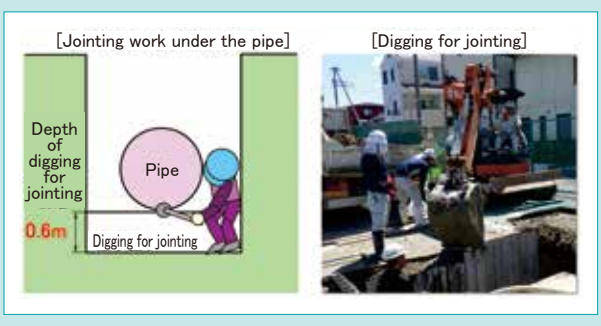

Fig. 3 Pipe Jointing Beneath the Pipe and Joint Excavation

4. Developed technology

4-1 Joint structure of the GX type

Fig. 4 shows the joint structure of the GX type. The major features of the GX type are a metal touch structure and a boltless gland at the pipe invert.

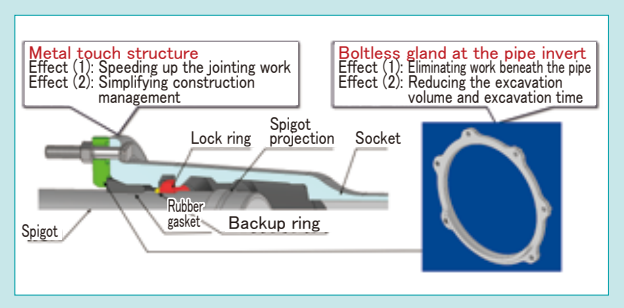

Fig. 4 Joint Structure and Features of the GX Type

4-2 Development of the metal touch structure

4.2.1 Metal touch structure

In order to improve workability, we adopted a metal touch structure for the joints of the DN500 to 1000 GX type, as well as the joints of the DN75 to 450 GX-type fittings. The metal touch structure is a joint structure for ensuring watertightness in which the bolts and nuts are tightened until the projection on the gland (projection for management) is in contact with the socket surface, as shown in Fig. 5, so that the rubber gasket is fully pushed to the position where it can retain watertight performance.

In the NS type, as shown in Fig. 6, three management items, (1) tightening torque, (2) distance between the socket and the gland, and (3) rubber gasket compression status, need to be checked during jointing, and there is the issue that the processes require a longer time as well as a certain high level of skill.

On the other hand, in the GX type with the metal touch structure, it is possible to perform bolt tightening with a power tool, achieving quick jointing without dependence on the operator's skill level. Management after jointing only involves checking if the projection of the gland is in contact with the socket surface, as shown in Fig. 7, eliminating measurement work.

The DN500 to 1000 GX type uses the metal touch structure for both straight pipes and fittings, unlike the small- and mid-diameter (DN75 to 450) series. Since straight pipes need to ensure watertightness even when the joints are greatly deflected, the sealing performance is designed to be higher than that of the small- and mid-diameter fittings while considering a good balance with workability. In addition, since the use of the power tool makes it more likely that the bolt tightening becomes uneven, the structure has been developed considering this risk.

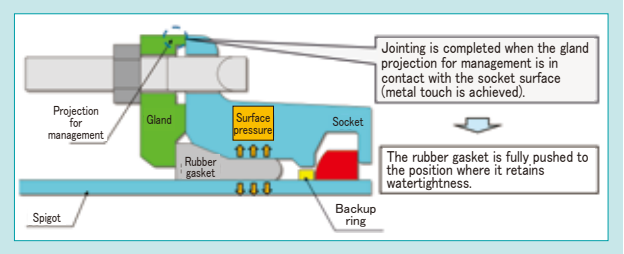

Fig. 5 Metal Touch Structure

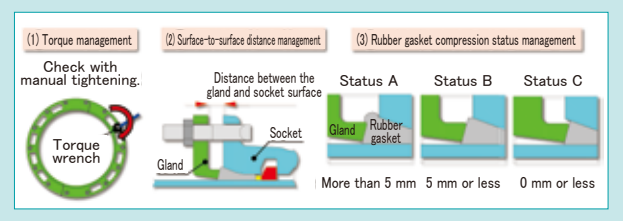

Fig. 6 Construction Management for the NS Type

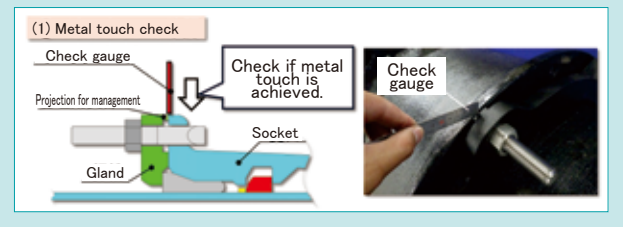

Fig. 7 Construction Management for the GX Type

4.2.2 Ensuring watertightness

Earthquake-resistant pipes need to secure watertight performance not only in normal times but also during an earthquake or other events that cause significant displacement of the joint. In the metal touch structure, the push-in amount of the rubber gasket is kept constant regardless of the dimensional relationship between the iron pipes. Therefore, in order to allow the joint to constantly maintain watertight performance, the shape of the rubber gasket, the inner surface of the socket, and the contact surface of the gland were designed to achieve both workability and sealability through repeated FEM analysis and testing so that the rubber gasket could be accommodated in the stuffing box (the gap between the socket and the spigot) under any condition, taking into consideration joint dimensions and even behavior during an earthquake.

(1) Investigation results of rubber gasket behavior by FEM analysis

By investigating the behavior of the rubber gasket during jointing through FEM analysis, we identified the optimum design conditions under which the target surface pressure value can be achieved when the round portion of the rubber gasket properly seats in the designated position of the stuffing box by compressing the gasket by a specific amount (Fig. 8).

(2) Measurement results of the surface pressure of the rubber gasket

The results of measuring the surface pressure generated on the rubber gasket by joining actual pipes, as shown in Fig. 9, confirmed that the surface pressure is equivalent to or higher than the FEM analysis value (Table 1).

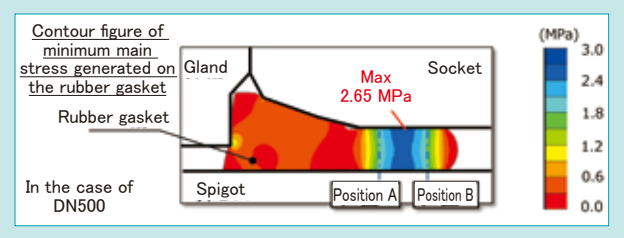

Fig. 8 FEM Analysis Results of Rubber Gasket Behavior

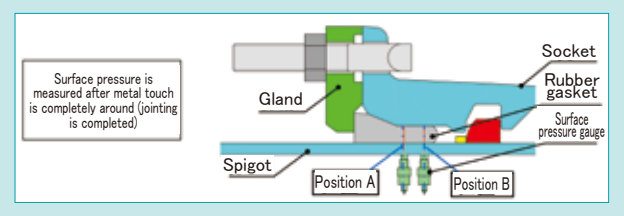

Fig. 9 Surface Pressure Measurement Method of the Rubber Gasket

Table. 1 Surface Pressure Measurement Results of the Rubber Gasket

Test item	Result: Surface pressure		Watertightness evaluation
	Position A	Position B	
Investigation results using actual pipes	1.82MPa	2.02MPa	○
FEM analysis results	1.79MPa	1.95MPa	○

4.2.3 Reduction in the number of bolts

In order to achieve quick installation with the metal touch structure, we considered reducing the number of bolts of the NS type by half through FEM analysis and testing.

(1) Determination of analysis conditions

The force applied to the gland during jointing (reaction force received from the rubber gasket) was determined through FEM analysis. The results showed that a maximum force of 53 kN was applied on the gland when the rubber gasket was pushed; for example, in the DN500 pipe (Fig. 10).

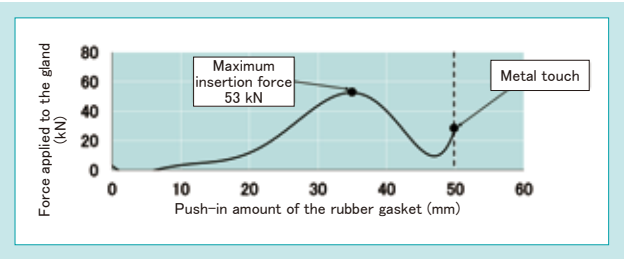

Fig. 10 Forces on the Gland (FEM Analysis Results)

(2) Stress evaluation of the gland by FEM analysis

By applying the above reaction force to the gland during jointing, the shape of the gland was determined such that the stress generated on the gland was within the elastic range. Since the use of the power tool could cause uneven tightening during jointing with the metal touch structure, this severe condition was incorporated into the analysis conditions (Fig. 11).

(3) Test results of the strength check of the gland with uneven tightening

As a result of uneven tightening of actual joints, we confirmed that jointing is possible, and the gland does not deform after jointing (Fig. 12).

Based on the FEM analysis and test results above, we have concluded that the number of bolts of the NS type can be reduced by half in the GX type.

4.2.4 Jointing work regardless of the operator's skill level

The jointing work of the NS type involves many processes dependent on the operator's skill level, such as: (1) centering between the socket and the spigot, (2) temporary tightening while aligning the socket and the spigot to be nearly straight, and (3) tightening the bolts evenly on the circumference (Fig. 13, left).

On the other hand, the GX type was developed to enable jointing under rough conditions with (1) decentering, (2) deflection, and (3) uneven tightening, to simplify the installation (Fig. 13, right).

We checked the behavior of the rubber gasket by FEM analysis under the above conditions as shown in Fig. 14. The results confirmed that the gasket is naturally fit between the socket and the spigot.

Furthermore, to verify that jointing under the rough conditions simulated in the analysis was feasible in practice, we performed a jointing test using actual pipes under the most severe conditions. The results confirmed that jointing is possible under all conditions and that jointing work regardless of the operator's skill level can be achieved (Table 2).

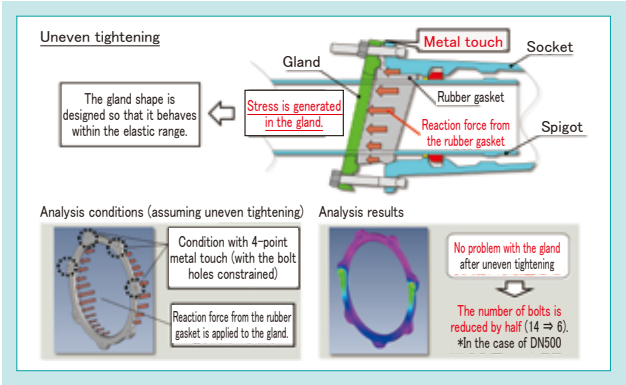

Fig. 11 FEM Analysis Conditions and Results for the Gland

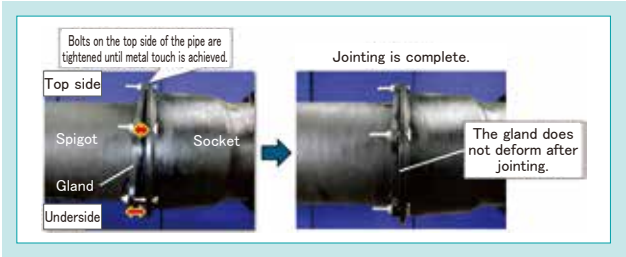

Fig. 12 Results of the Strength Verification Test of the Gland

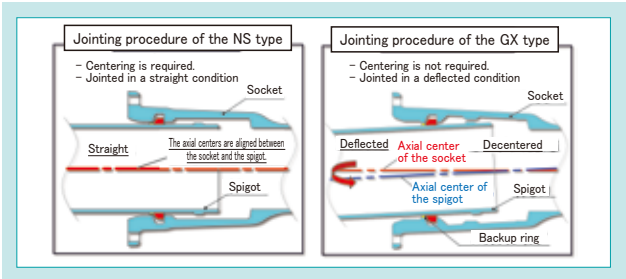

Fig. 13 Assembly Procedure for the NS and GX type

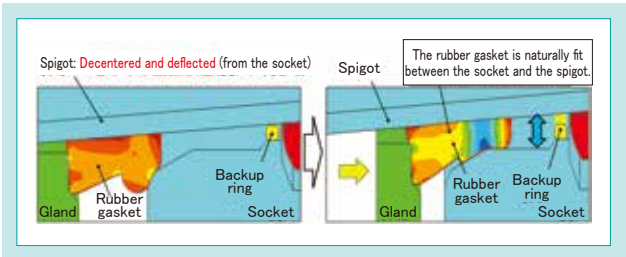

Fig. 14 FEM Analysis Results Reproducing a Rough Fit

Table. 2 Jointing Test Results Under Severe Conditions

DN	Target	Jointing conditions		Test results
		Deflection angle	Bolt tightening method	Jointing feasibility
500	Straight pipe	0.0°	Even tightening	○
			Uneven tightening	○
		3.5°	Even tightening	○
			Uneven tightening	○

4-3 Development of a boltless gland at the pipe invert

4.3.1 Boltless gland at the pipe invert

To reduce bolt tightening work and construction management under the pipe, we have developed a gland without bolt holes on the underside, as shown in Fig. 15.

As shown in Fig. 16, the bolt holes are evenly arranged on the circumference of the conventional gland, and work in a narrow space is unavoidable. In the GX type, no bolt holes are provided in positions where work is painstaking, such as beneath the pipe, thereby eliminating work in a narrow space and improving workability.

Furthermore, as shown in Fig. 17, the depth of digging for jointing can be reduced from 0.6 m to 0.2 m due to the elimination of jointing work beneath the pipe. Thus, we have confirmed that the excavation volume and the excavation time can be reduced, and that the civil construction cost can be reduced by approximately 2 to 3% compared with the NS type, through calculations using a pipeline model (Table 3).

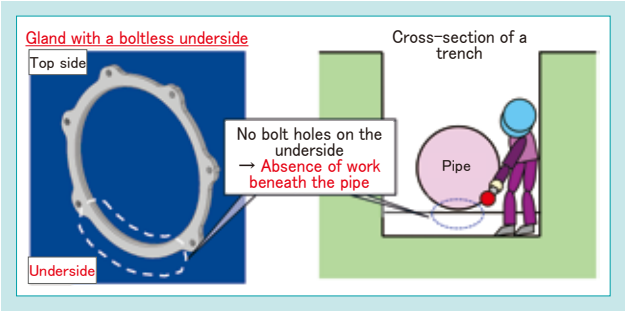

Fig. 15 Boltless gland at the pipe invert

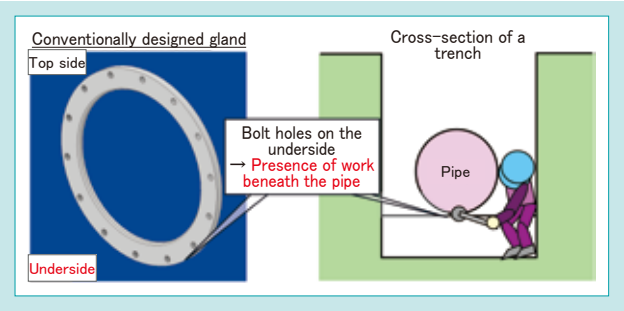

Fig. 16 Conventional Gland

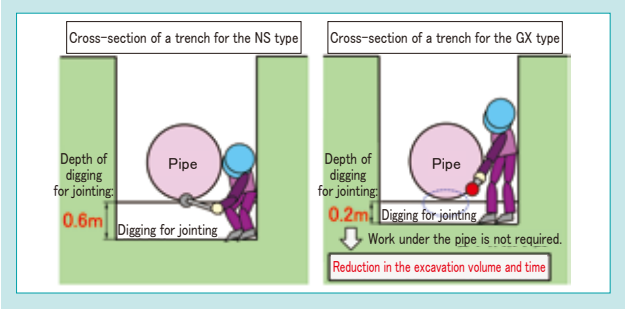

Fig. 17 Excavation Cross-Section of the NS and GX Type

Table. 3 Civil Construction Costs for the NS and GX Type

DN	Civil construction cost (unit: thousand yen)		Reduction rate from the NS type
	NS type	GX type	
500	98,236	96,997	▲2.9%
800	154,697	152,946	▲2.5%
1000	229,537	227,306	▲2.3%

4.3.2 Design of the boltless gland at the pipe invert

Since the boltless gland at the pipe invert has a long distance between the bolt holes on the underside, as shown in Fig. 18, there was a concern that the gland would be deflected due to the reaction force received from the rubber gasket during jointing or under water pressure.

We then identified the area where deflection is significant under reaction pressure from the rubber gasket through FEM analysis and thickened the relevant area to improve the stiffness, as shown in Fig. 19.

In both FEM analysis and testing using this gland, no significant deformation was observed in the relevant area, and it was also confirmed that watertightness is sufficiently ensured.

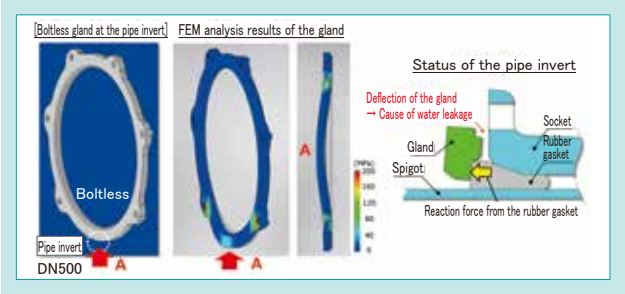

Fig. 18 Concerns About the Boltless Gland at the Pipe Invert

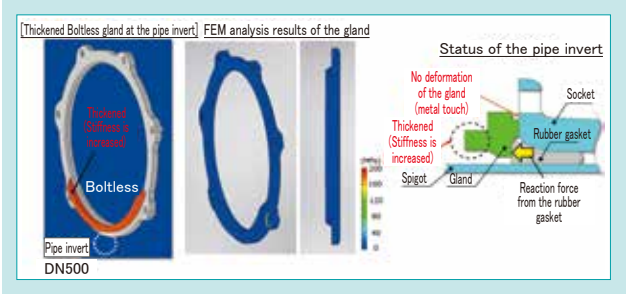

Fig. 19 Thickened Boltless Gland at the Pipe Invert

4-4 Performance evaluation (DN500 and 1000)

For the performance evaluation of the GX type, we conducted jointing tests, pull-out resistance tests, and watertightness tests on the DN500 and 1000 straight pipes. We confirmed the following results:

(1) Jointing test results

Due to the reduction in the number of bolts by half and the elimination of torque management, the time taken for bolt tightening and construction management has been significantly reduced, resulting in the total work time being shortened by 42 to 47% compared with the NS type (Fig. 20).

(2) Pull-out resistance test results

When a pulling force was applied to the joint, the joint did not separate and showed no abnormalities, such as deformation, withstanding a pulling force of 3 DkN (D: mm in DN), after the joint was expanded up to 1% or more of the pipe length (Fig. 21).

(3) Watertightness test results

No water leakage was observed when a water pressure of 2.0 MPa was applied under the condition where the joint was in a straight or a deflected condition (7°) (Table 4).

Based on the above results, we concluded that the workability was significantly improved compared with the NS type, and the pull-out resistance and watertightness were maintained at levels equivalent to those of the NS type.

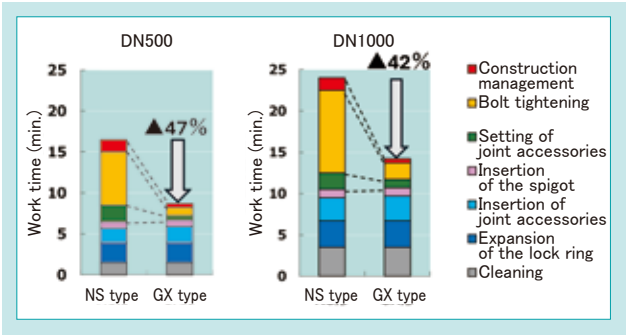

Fig. 20 Comparison of the Jointing Time

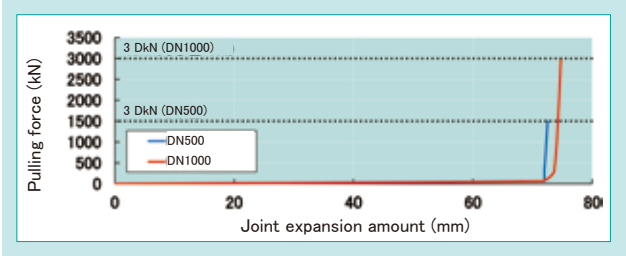

Fig. 21 Pull-Out Resistance Performance of the Joint

Table. 4 Result of the Watertightness Test

DN	Target	Test conditions			試験結果
		Deflection angle	Applied water pressure	Retention time	Presence/absence of water leakage
500	Straight pipe	0°, 7°	2.0 MPa	5 minutes	Absent
1000		0°, 7°	2.0 MPa	5 minutes	Absent

5. Conclusion

As described above, we have developed and commercialized the GX-type DN500 to 1000 earthquake-resistant ductile iron pipe. The features of the GX type are summarized below.

(1) Metal touch structure

The development of the metal touch structure, reducing the number of bolts and allowing jointing under rough conditions, has enabled quick construction regardless of the operator's skill level.

(2) Boltless Gland Underside of the Pipe

The development of the gland without bolt holes has eliminated work beneath the pipe and improved workability. In addition, the excavation volume and time have been reduced, which can cut pipeline installation costs.

(3) Joint performance

The workability was significantly improved compared with the NS type, and the pull-out resistance and watertightness were maintained at levels equivalent to those of the NS type.

So far, we have demonstrated the GX type's jointing and lifting performance to water utilities and received a high evaluation of its workability, toughness, and earthquake resistance.

Furthermore, full-scale adoption of the DN500 and 600 GX type started in 2025, and construction investigations have been conducted at several sites nationwide. As a result of investigations of a total of 37 joints, we have confirmed at all the sites that the jointing time can be shortened compared with the NS type, and in particular, a comparison with the NS type under the same work conditions (with the same DN and construction company) have shown a 46.1% time reduction, demonstrating a result similar to the test result. Going forward, we will continue to sequentially replace the NS type with the GX type. By bringing the GX type to the market, we are aiming to significantly contribute to renovating trunk pipes and improving their earthquake resistance to help the government tackle this urgent task.

Contribution to SDG targets

6.1 Increased availability of safe and affordable drinking water
Contributing to building water supply and sewage infrastructures by providing water supply materials and equipment, reducing pipelining costs

9.1 Development of high quality, sustainable, and resilient infrastructures
Contributing to developing sustainable and resilient infrastructures by providing earthquake-resistant pipes

Development of Drinking Water Coagulation Control System

Water and Environment R&D Dept. Ⅱ

For labor saving and manpower reduction in drinking water treatment plant operation, an automatic coagulation control system was developed. With a renewed machine learning approach built on previous operation data, human-level performance in coagulant dosage decisions was achieved. Meanwhile, based on images obtained by a floating monitoring device, coagulation status evaluation was conducted constantly to ensure effluent water quality. Furthermore, pre-information application of operation details based on predicted influent turbidity was also developed to gain a more rational and efficient operation plan. Field verification was conducted at the Inagawa Water Treatment Plant. The results confirmed that the system functioned effectively, demonstrating its potential for reliable practical operation.

【Key Word】
Drinking Water Treatment, Coagulant, Injection Control System, Influent Turbidity Prediction, Machine Learning

Related SDGs

1.Introduction

In Japan, drinking water treatment plants that adopt rapid sand filtration (coagulation and sedimentation + sand filtration) account for approximately 80% of all the plants in terms of water volume[1]. To ensure good quality of clean water by this method, it is essential to appropriately manage the operation of the coagulation-flocculation process.

In the coagulation-flocculation process in rapid sand filtration plants, it is necessary to determine an appropriate coagulant dosage according to the influent quality, which varies depending on rainfall and other conditions. Therefore, manual operations by an experienced operator is indispensable, such as a daily jar test (a manual test for checking the coagulation status and the supernatant turbidity of influent collected into several beakers by adding coagulant with different dosages for each beaker, agitating the solution, and leaving it to stand for a predetermined period of time), and on-site visual check of the coagulation status. Meanwhile, due to recent climate change, local heavy rains and landslides in the water source area often cause a deterioration in the influent quality (particularly, a rapid rise in influent turbidity). Fig. 1 shows time-series influent turbidity data provided to the authors by each drinking water treatment plant.

Under these circumstances, a decline in the number of water supply engineers has also been continuing due to the retirement of experienced staff and other factors (Fig. 2)[2]. Thus, the operation management of the coagulation-flocculation process in response to fluctuations in the influent turbidity is becoming a great burden. In particular, when the influent turbidity rapidly rises during nighttime, it is necessary to deploy personnel and give work instructions appropriately and efficiently to make a quick response in such a situation.

Against this background, a variety of automatic control technologies related to coagulant dosing have been proposed by various companies[3]. However, since there are some issues, such as concern over worsening of the quality of treated water due to inappropriate settings of the coagulant dosage and a need for maintenance of the control device, these technologies have not been widely adopted.

Thus, we have developed a coagulation-flocculation control technology capable of solving these issues.

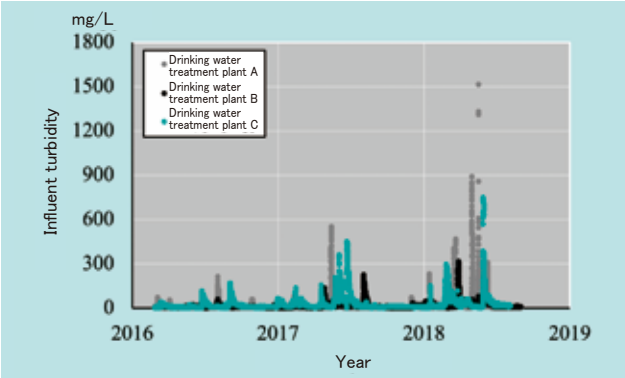

Fig. 1 Influent Turbidities of Three Drinking Water Treatment Plants

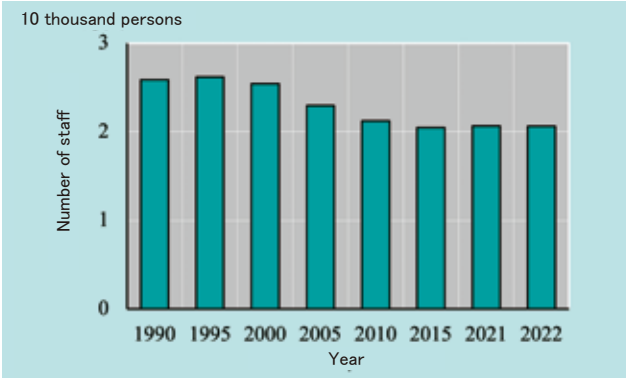

Fig. 2 Number of Nationwide Water Supply Engineers

2. Development concept and target values

2-1 Development concept

We aimed to develop a coagulation-flocculation control system capable of ensuring stable and good quality treated water so that water suppliers can promote reliable labor-saving operation with reduced manpower. To this end, a coagulant dosage predictive calculation function was combined with a coagulation status judgement function (Fig. 3).

For the coagulant dosage predictive calculation, machine learning regression including model updating was adopted to inherit technical expertise while maintaining calculation accuracy by collecting operational know-how. For coagulation status judgement, an interlock function capable of detecting abnormalities was installed to prevent worsening of the quality of treated water, thereby providing a mechanism allowing reliable operation. In addition, to achieve labor saving and manpower reduction, we aimed to significantly remove manual work, such as the jar test and visual check of the coagulation status. Furthermore, an optional high-turbidity prediction function was implemented, assuming a situation where irregular operation management is required due to a rise in influent turbidity. This allows us to recognize the situation well in advance to change the work shift and prepare for the work.

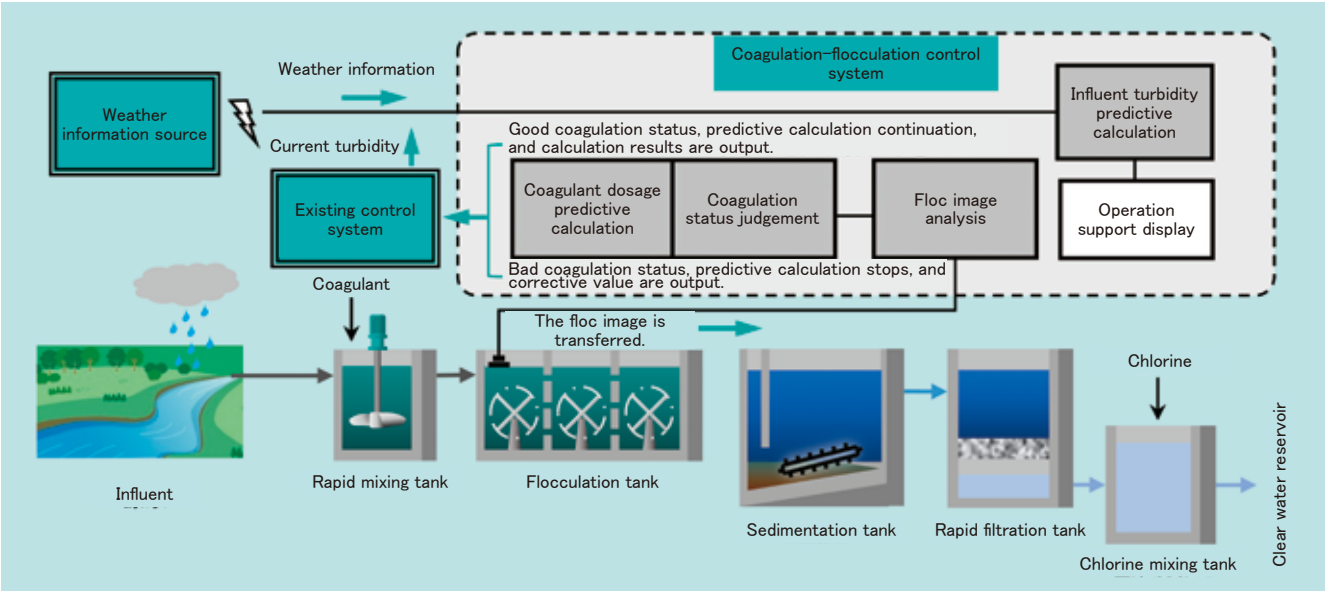

Fig. 3 Image Diagram of the Coagulation Control System

2-2 Target values

The target of the coagulant dosage predictive calculation was set such that the error between the calculated value and the set value, which was considered to be in fact appropriate, would be smaller than the minimum set dosage range based on jar test results at the drinking water treatment plant. In other words, the setting was such that the acceptable error range of the automatic calculation results was equivalent to that of the jar test results. In addition, the target for the accuracy rate of coagulation status judgement was set to 95% or more. The target for the influent turbidity prediction was to make the prediction six hours before the influent turbidity reaches the value requiring a change in operation management details at the drinking water treatment plant, so that the manager can give work instructions with appropriate timing to respond to fluctuations in turbidity.

3. Technical issues to be solved

Technical issues to be solved are described below in comparison with conventional technologies.

1) Among the conventional coagulant dosage calculation techniques, fixed calculation methods such as multiple regression and random forest regression, as well as a calculation with parameter setting, are mainstream[4)5)]. However, such techniques have the problem that a predetermined calculation method cannot derive appropriate results if the water source environment or the water treatment process changes (deterioration of the calculation method). Therefore, we aimed to establish a highly accurate calculation method that minimizes the deterioration even if an environmental change occurs.

2) Among the conventional techniques related to coagulation status evaluation, the general methodology is to install an underwater camera or similar device in a flocculation tank (where added coagulant aggregates suspended matter in water to form a clump (floc) that tends to precipitate) to observe the coagulated floc[6)7)]. However, this method has the problem that, since the camera is immersed in water, dirt is likely to adhere to optical measuring devices, such as the lens, requiring frequent cleaning and other maintenance work. Therefore, we aimed to develop a device structure capable of observing the floc state while preventing the adhesion of dirt.

3) As a previous example of the influent turbidity prediction technique, there is a study on predicting the influent turbidity based on aggregated data on precipitation and the river flow rate in the water source area. However, the method has the problem that it targets a specific river and lacks versatility. In addition, output information is limited to the predicted turbidity value, and information on specific action to support the operation management of the drinking water treatment plant is not output. Therefore, we aimed to complete an operation management support technology featuring versatility in addition to influent turbidity prediction accuracy, allowing it to be highly practical for the operation management of various drinking water treatment plants.

4. Developed technology

4-1 Establishment of a highly accurate calculation method of coagulant dosage

4.1.1 Technical overview

For the coagulant dosage predictive calculation, to produce calculation results approximate to actual operations by experienced water supply engineers, we adopted a methodology that fragments past operation data using a clustering process and determines the most accurate results for each cluster through multiple regression procedures. Moreover, a regression calculation considering the similarity between current and past events was adopted. In addition, different calculation methods suitable for usual turbidity and high-turbidity states were selectively used to improve the overall calculation accuracy. Furthermore, we built an algorithm for preventing the deterioration of the calculation method by importing the latest learning data regularly to update the model[8].

4.1.2 Technical verification

We conducted technical verification at the Inagawa Drinking Water Treatment Plant, the main advanced drinking water treatment plant operated by the Hanshin Water Supply Authority, with a treatment capacity of 916,900 m^3/day of water from the Lake Biwa and Yodogawa River system. The drinking water treatment plant uses aluminum sulfate as a coagulant and conducts a five-beaker jar test (with a 3.0 mg/L range) every day to determine the dosage.

In this verification, we built a regression model using past data at the drinking water treatment plant and continuously output the calculated values of coagulant dosage based on data input in real time, such as the water volume and water quality. Then, based on the calculated coagulant dosage values output and the actual set values at the plant, the mean absolute error (MAE) was calculated to evaluate the calculation accuracy. The specific verification method is shown in Table 1.

The verification results found that there were generally no large deviations between the calculated values of coagulant dosage and the actual set values, and that the calculated values approached the actual values without delay when the required coagulant dosage increased as the influent turbidity rose (Fig. 4). In addition, the mean absolute error MAE value between the calculated and actual values was 2.3 mg/L, falling below the set dosage range of 3.0 mg/L for the jar test at the drinking water treatment plant. Thus, we succeeded in obtaining calculation results comparable to experienced water supply engineers' operations.

Table. 1 Test Method of Coagulant Dosage Prediction

Item	Detail
Target variable	Aluminum sulfate dosage
Explanatory variable	10 items related to chemical dosing such as water volume and water quality
Usual turbidity	Selected from neural network regression, etc.
High turbidity	Selected from partial least squares regression, etc.
Learning data	Apr. 1, 2016 to Jan. 31, 2021
Verification data	Feb. 1, 2021 to Feb. 28, 2023

However, there was a deviation between the calculated and actual values of coagulant dosage during Jan. 6 to Jan. 31, 2022 (Fig. 5). After checking the operational situation during this period, we found that the coagulant dosage had been intentionally increased from the usual value to deal with odor caused by algal growth. Although the ideal response to such an operation management change is to add a related explanatory variable (the biovolume of algae, etc.) to perform learning before calculation, it was difficult to acquire continuous data like the biovolume of algae at that moment. Thus, we incorporated these operation results into the calculation procedure as additional learning data before updating the model (Feb. 1, 2022). As a result, the calculated values became close to the actual values, allowing us to confirm the effect of improving accuracy with the updated calculation procedure.

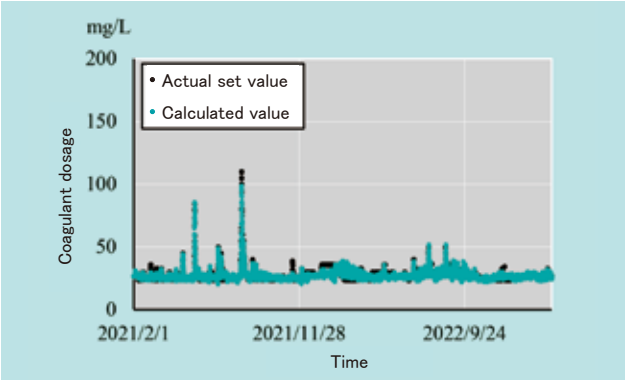

Fig. 4 Test Result of the Coagulant Dosage Prediction

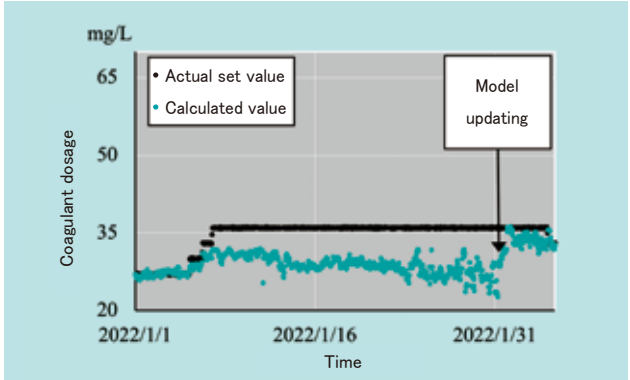

Fig. 5 Deviation Between Actual Dosage and the Prediction

4-2 Development of a coagulation status monitoring device excelling in maintainability and judgement technique

4.2.1 Technical overview

The coagulation status judgement was performed based on captured floc images. To acquire these floc images, we developed a coagulation status monitoring device. This device has a sensor composed of a laser light source and a camera (Fig. 6), which are arranged along an optical path not in contact with the liquid phase. The device is mounted on a floating frame that can move up and down in response to fluctuations in the water level of the flocculation tank, allowing it to be installed above water. Images of coagulated floc captured continuously by the coagulation status monitoring device are analyzed, and if abnormal coagulation is detected, the interlock function is activated by issuing an alarm to prompt inspection and stopping the calculation of the coagulant dosage (while outputting the corrective value simultaneously). This can prevent worsening of water quality in the event of an emergency, resulting in reliable use of the coagulation control system.

For the calculation of coagulation status judgement,

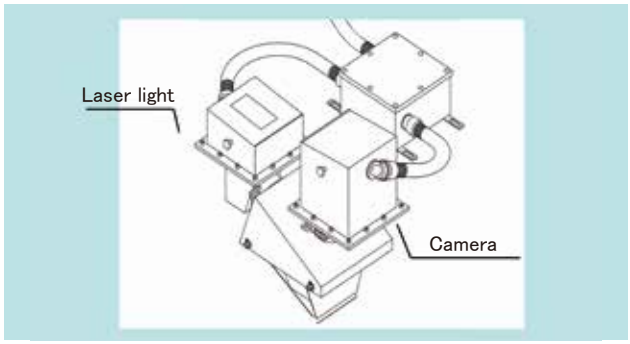

Fig. 6 Coagulation Status Evaluation Sensor

analysis results of coagulated floc images labeled as “normal” or “abnormal” were combined in advance with data on coagulant dosage and water quality. Then, multiple classifiers were built through machine learning using the combined data. Finally, to improve judgement accuracy, the judgement results by the multiple classifiers were further narrowed down by majority voting, and the final judgement results were output.

4.2.2 Technical verification

A coagulation status monitoring device was installed in the upstream area of flocculation tanks of up-and-down flow type and mixer type at the Inagawa Drinking Water Treatment Plant (Fig. 7) to continuously acquire floc images in the initial stage (Fig. 8). Since these two types of flocculation tanks had different mixing methods, floating frames suitable for each tank structure were designed.

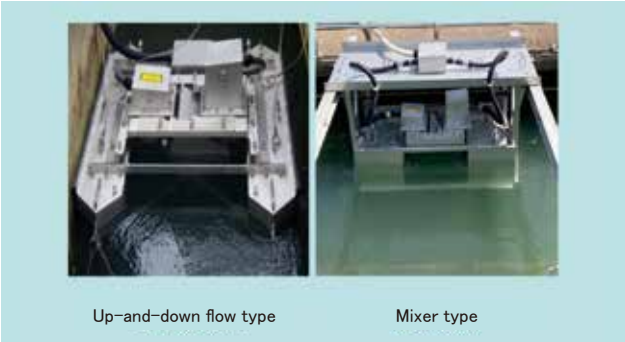

Fig. 7 Floating Coagulation Status Monitoring Devices

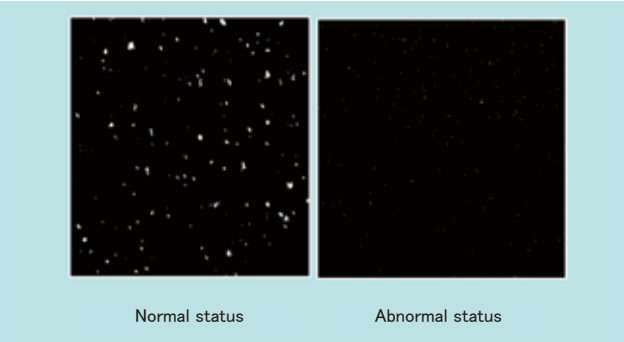

Fig. 8 Coagulation Floc Image Samples

Based on the method shown in Table 2, we performed quantification processing on the images and then data labeling according to the influent quality and operational situation to accumulate learning data. Then, the accuracy rate of coagulation status judgement was verified by utilizing the classification method of machine learning. Based on the judgement results of the normal/abnormal status of verification floc images, we obtained an accuracy rate of 99% or more over the entire period. In addition, we verified the accuracy rate with a confusion matrix of the judgement results (Table 3), and found that the appearance rate of false-negative results (judged to be normal although the status was actually abnormal), which must be definitely avoided from the viewpoint of operation management, was 0.3% or less, allowing us to conclude that the calculation method enables operation with high judgement accuracy.

Furthermore, we inspected the coagulation status monitoring device after nine months of continuous operation and found that the device remained in good condition and did not require maintenance for further use. During this period, the device did not require cleaning or other maintenance work and retained the imaging, monitoring, and evaluation functions necessary for coagulation status judgement, demonstrating excellent maintainability.

Table. 2 Test Method of Coagulation Status Evaluation

Item	Detail
Variable	Distributed values related to the number of floc particles, area, and perimeter
Number of sheets of learning data	5000
Number of sheets of verification data	1000
Classification methodology	Support vector machine classifier, etc. type 4

Table. 3 Confusion Matrix of the Coagulation Status Evaluation

Confusion matrix		Judgement result	
		Normal	Abnormal
Actual state	Normal	750	10
	Abnormal	3 (0.3%)	237

4-3 Development of operation management support technology based on a versatile turbidity prediction technique

4.3.1 Technical overview

In the influent turbidity prediction technique, focusing on the relationship between influent turbidity and geographical information on the weather and river in the upstream area of the intake point of a drinking water treatment plant, we adopted a methodology that selects the geographic grid of an area with high contribution to the prediction and makes a predictive calculation based on weather data in the relevant area. This allowed us to build a versatile prediction model by utilizing the turbidity data and past weather information of the grid selected for each drinking water treatment plant as learning data. For the prediction model, long short-term memory (LSTM) regression suitable for time-series data prediction was adopted. In addition, the influent turbidity was associated in advance with operation management details (or the response level) at the drinking water treatment plant, so that the predicted turbidity value and the corresponding operation management details could be presented simultaneously to the monitoring terminal[9].

4.3.2 Technical verification

We prepared past weather data (precipitation and the river basin rainfall index) at the third geographic grid (Basic Grid Square, 1 km x 1 km) of the water source area of the Inagawa Drinking Water Treatment Plant[10], compared it with the influent turbidity behavior during the same period, and then extracted geographic grids with approximate behaviors and the corresponding weather data to create a verification data set linked with the turbidity data. We then conducted cross-validation on the data set and built a prediction model using the parameters with which the most accurate prediction results were obtained. Next, we input the current weather data and influent turbidity data in the same geographic grid into the prediction model, performed a predictive calculation of turbidity six hours in advance, and obtained the accuracy rate of the prediction of turbidity requiring a change in the preset management response level. The verification results found that the prediction could be made six hours in advance, with an accuracy rate of 89%, of the necessity to change the management response level due to a turbidity rise (an example is shown in Fig. 9). Predicting the timing when the turbidity begins to rapidly rise enables effective implementation of work required at high turbidity, thus allowing us to believe that this technique can be utilized in operation management. Fig. 10 shows an example of the screen presenting the turbidity prediction results and operation management details.

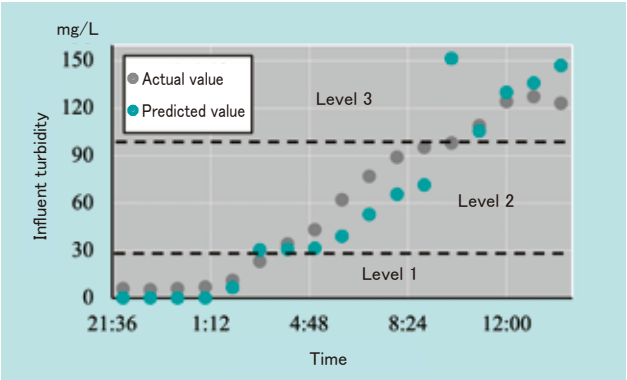

Fig. 9 Prediction of the Operation and Response Level

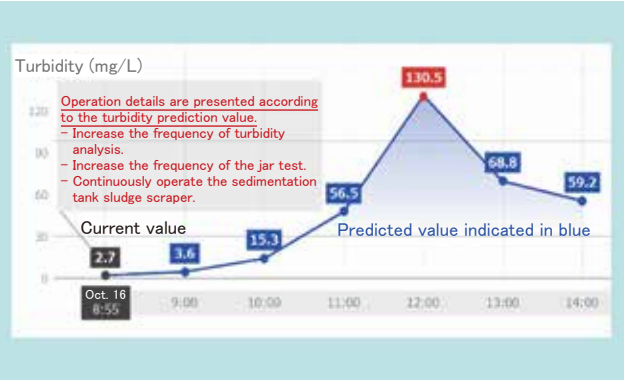

Fig. 10 Predicted Influent Turbidity and Operation Details

5.Conclusion

We have developed a control system that combines the coagulant dosage predictive calculation technique with the coagulation status judgement technique, together with the influent turbidity prediction technique, aiming for labor saving and manpower reduction in operation management at drinking water treatment plants. We have also conducted long-term verification at the Inagawa Drinking Water Treatment Plant to check the system performance. The results demonstrated good performance for all the techniques, proving that reliable labor-saving operation with reduced manpower is possible.

Acknowledgement:

This research was carried out as part of the joint research program "Construction of a coagulation-flocculation control and support model utilizing big data and tacit knowledge" in collaboration with the Hanshin Water Supply Authority and Nihon Suido Consultants Co., Ltd. I would like to express my deepest gratitude for their particular cooperation in providing the verification field and the research data.

Contribution to SDG targets

6.1 Increased availability of safe and affordable drinking water
Contribution to drinking water treatment operation ensuring stable and good water quality

9.1 Development of high quality, sustainable, and resilient infrastructures
Development of a new technology allowing water suppliers to achieve reliable labor-saving operation with reduced manpower

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Development of Infection Trend Monitoring Using Wastewater Surveillance

Water and Environment R&D Dept. Ⅱ／Technology Innovation R&D Dept. Ⅲ

Wastewater surveillance is a method for monitoring infectious disease outbreaks by measuring the concentration of pathogenic microorganisms in wastewater. To achieve the societal goal of building resilience to infectious diseases, we report on a real-world implementation of wastewater surveillance that employed transdisciplinary research. In this research, local governments, interdisciplinary researchers/experts, and Kubota Corporation collaborated to develop the concept and technology while collecting input from citizens and medical associations. As a result, a system is being implemented to enable effective public disclosure of wastewater surveillance information.

【Key Word】
Wastewater Surveillance, Transdisciplinary Research (TDR), Sewerage, Infectious Disease Prevention

Related SDGs

1.Introduction

Wastewater contains information discharged from residents' bodies in a catchment area, and therefore the effective utilization of this information can lead to the creation of new value from wastewater. Wastewater surveillance, an approach to monitoring the epidemic situation of infectious diseases by measuring pathogenic microorganisms excreted from people in a river basin, has been attracting attention since the spread of COVID-19. The advantages of this method include its ability to promptly detect the infection status of the entire local population, including asymptomatic infected individuals, as well as its non-invasive and anonymous process. Thus, the effective utilization of wastewater surveillance has potential for the realization of a society resilient to infectious diseases.

During the COVID-19 pandemic, local governments without public health centers had difficulty monitoring the epidemic situation at the municipal level, which highlighted problems such as the inability to alert citizens to the spread of infection and insufficient preparations for accepting patients at medical institutions.

To help solve the societal issue of achieving a society resilient to infectious diseases, Kubota Corporation has been studying the social implementation of wastewater surveillance. For this activity, transdisciplinary research with experts in a variety of science fields and diverse stakeholders representing citizens works well[1]. This paper describes a case example of transdisciplinary research on the social implementation of wastewater surveillance technologies.

2. Development concept and target

2-1 Development concept

In this development, in order to achieve the societal goal of building a society resilient to infectious diseases, we aimed to involve not only experts in science fields but also all related stakeholders, from the initial process of research. First, we shared technical seeds with academic experts, obtained approval from the Komatsu City government about the seeds, and concluded the Komatsu City Consortium Partnership Agreement to organize the joint team and launch the research (Fig. 1). We then initiated a trial for disclosing wastewater surveillance data obtained from the research to citizens and got feedback from the Health and Welfare Department of the Komatsu City government, citizens, and members of the Komatsu City Medical Association.

In this process, the development concept was established as follows: "To quickly disseminate information necessary for citizens while ensuring reliability."

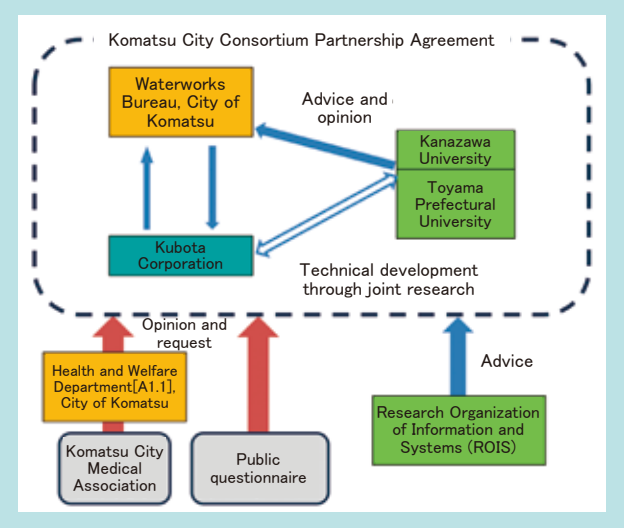

Fig. 1 The Organizational Structure of the Komatsu City Community

2-2 Target

In order to achieve the above-described development concept, we set the following targets to work on technical development:

[Information dissemination] To establish a system that enables quick information dissemination by analyzing wastewater on the day following sampling.

[Reliability] To ensure reliability with a high correlation coefficient between wastewater surveillance data and case counts.

[Versatility] To expand the range of viruses subject to wastewater surveillance and quantitatively evaluate the effectiveness.

3. Technical issues to be solved

3-1 [Information dissemination] Establishment of an effective system for information dissemination through wastewater analysis on the day following sampling

In the analysis method using conventional polyethylene glycol (PEG) precipitation[2], a two-day lead time is required because the analysis is only started after the sample is transported to the laboratory. For this reason, if information is distributed on the day following the analysis, a three-day lead time is required after water sampling. In order to promptly inform citizens of infection trends, it is necessary to establish a method for shortening the analysis lead time. In addition, it is necessary to study a method for effectively disseminating the obtained information to arouse and maintain continuous public concern.

3-2 [Reliability] Ensuring the reliability of wastewater surveillance data

Quantification of viruses in wastewater involves various error factors. Such errors include, for example, a difference in the amount of virus excreted by individuals, a variation in the behavior of viruses in wastewater, a variation in the amount of wastewater inflow, and errors in measuring instruments. It is necessary to develop a data processing method that reduces these errors and demonstrate how accurately the concentration of a virus in wastewater reflects the local epidemic situation.

3-3 [Versatility] Expansion of the range of viruses subject to wastewater surveillance

In the initial stage of this development, wastewater surveillance was initiated to detect COVID-19. However, opinions collected from the related stakeholders revealed, in addition to a high reputation for COVID-19 surveillance, a need for wastewater surveillance of the influenza virus as the next target. We then aimed to establish a technology for analyzing the influenza virus. In expanding the range of target viruses, it was necessary to evaluate the validity of information dissemination for the influenza virus as well.

4. Developed technology

4-1 [Information dissemination] Establishment of an effective system for information dissemination through wastewater analysis on the day following sampling

4.1.1 Establishment of a quick analysis method

What is needed to achieve quick information dissemination is to reduce the lead time for wastewater analysis. With conventional wastewater analysis technology, the supernatant of sampled water is used and mixed with PEG before virus concentration (Fig. 2). The following two are bottlenecks in reducing the analysis lead time. It is essential to maintain analysis sensitivity while reducing the lead time.

(1) If the supernatant is obtained through low-speed centrifugation of wastewater, the wastewater needs to be transported to the laboratory, where centrifugation is performed before mixing with PEG.

(2) Since the wastewater is mixed with PEG after being transported to the laboratory, a two-day lead time is required to complete PEG mixing after water sampling.

As a result of the study among the consortium partners, we discovered that the low-speed centrifugation process can be omitted and both the supernatant and the sediment can be used for more sensitive analysis. It was also demonstrated that early PEG addition and the resulting prompt ribonucleic acid (RNA) extraction can lead to sensitive analysis.

As shown in Fig. 2, instead of mixing with PEG after low-speed centrifugation at the laboratory, as in the conventional method, PEG was added at the sewage treatment plant, and the mixture was shaken during transportation. As a result, the analysis lead time was shortened. Thus, we developed a method and system for quick analysis with higher sensitivity than that of the conventional method.

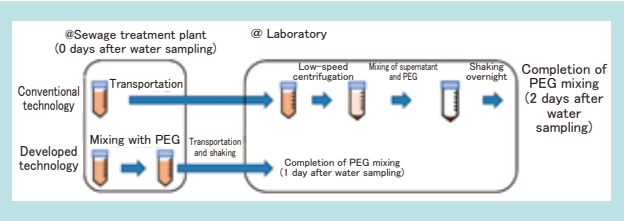

Fig. 2 Comparison Between the Developed Wastewater Analysis Process and the Conventional Analysis Process

4.1.2 Establishment of effective information dissemination

To tackle the challenge of information dissemination, we sought a method for effectively disseminating the information and promoting continuous interest among citizens in cooperation with personnel in charge of public relations in the Komatsu City government. As a result, we decided to construct a push type information distribution system to increase awareness and provide alerts.

Specifically, we introduced a mechanism to provide graphs and numerical information through the LINE message distributed by the city government every Friday, as shown in Fig. 3. Approximately 27,000 people have added the Komatsu City government's official LINE account as a friend (city population: approximately 103,000), and the government's official website is constantly ranked fourth or higher in the number of views. Furthermore, the alert and warning levels were set according to the virus concentration and the amount of change from the previous week for easy-to-understand information sharing. Thus, we developed a system capable of effectively disseminating information.

We further proceeded to the new technical development described in Section 4-3 based on opinions collected from questionnaires and an opinion exchange meeting. We believe that these information dissemination efforts incorporating the viewpoints of transdisciplinary co-creation arouse the citizens' interest and help promote behavioral changes.

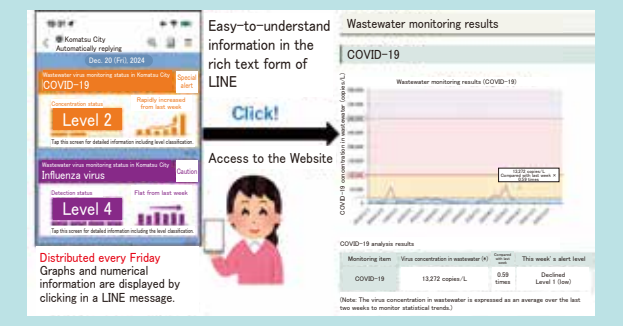

Fig. 3 Wastewater Surveillance Information Released by Komatsu City

4-2 [Reliability] Ensuring the reliability of wastewater surveillance data

4.2.1 Verification of the data processing method

Since the raw data of wastewater surveillance cannot be sufficiently utilized due to its large variation, we have developed an appropriate data processing method to ensure the reliability of the information. As a simple data processing method, we employed a moving average and then studied the moving average period and the average calculation method.

First, we determined an appropriate moving average period as described below. COVID-19 is detected in feces several days before infected patients notice symptoms, and the amount of virus excretion reaches a peak several days after infection[3]. For this reason, it is thought that it requires time until the patient who has noticed symptoms takes a test and then the infection is reported as one case count. On the other hand, wastewater surveillance can monitor the infection status from viruses excreted before symptoms appear. Furthermore, using data disclosed in the "Demonstrative Project on the Utilization of Wastewater Surveillance" conducted by the Cabinet Secretariat in FY 2022[4], we evaluated the number of days with a mismatch between case count data and wastewater surveillance data based on a correlation coefficient. The results indicated that the wastewater surveillance data was approximately three days ahead of the case counts during the notifiable disease surveillance period. When the moving average period of the wastewater surveillance data was set to two weeks by using as a reference the one-week moving average of case counts, taking into account the periodicity of human society, the centroid of the wastewater surveillance data coincided with that of the case counts, revealing that this set period was the most appropriate for representing the infection status.

In addition, we surveyed the distribution of the released wastewater surveillance data and found that the distribution was similar to a logarithmic normal distribution. Since the mean of data that

follows a logarithmic normal distribution is generally represented by a geometric mean, we can conclude that a data processing method using a two-week moving geometric mean is the most appropriate, considering the above-described two-week moving average.

Fig. 4 shows the relationship between the wastewater surveillance data and case count data for COVID-19 in Komatsu City for April to September 2022, when the virus was subject to notifiable disease surveillance in Japan. It can be found that large variations in the raw data are smoothened out by applying the two-week moving geometric mean and thus the processed data accurately reflects the infection status in regard to the case counts from notifiable disease surveillance. Fig. 5 shows plotted data to check the relationship between the wastewater surveillance data and the case count data. The Pearson correlation coefficient between the two pieces of data, each of which has been log-transformed, is 0.83. The value exceeds the average of the Pearson correlation coefficients (0.66) among all the local governments which is found in a report by the Cabinet Secretariat[4], allowing us to conclude that a more accurate means for monitoring the epidemic situation in Komatsu City has been established through the above-described analysis method and data processing method.

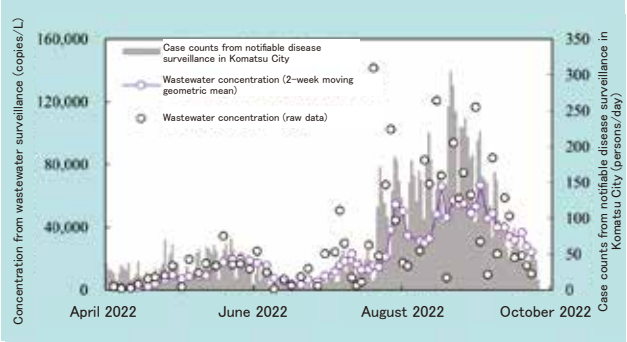

Fig. 4 Temporal Trends in Wastewater Surveillance Concentrations and Case Counts During the Period of Notifiable Disease Surveillance

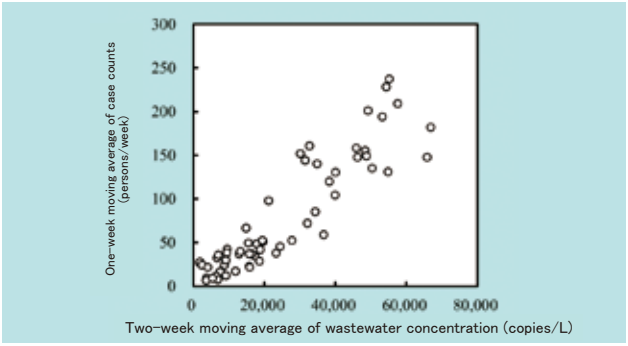

Fig. 5 Relationship Between Wastewater Surveillance Concentrations and Case Counts During the Period of Notifiable Disease Surveillance

4.2.2 Verification of the validity of wastewater surveillance data

We examined the validity of case count evaluation in the area according to wastewater surveillance data. In the earlier period of the COVID-19 pandemic, notifiable disease surveillance was conducted. However, the government later transitioned to sentinel surveillance in response to changes in the situation.

Komatsu City belonged to the sentinel surveillance area of the Minamikaga Public Health Center (Komatsu City, Kaga City, Nomi City, and Kawakita Town), where individual surveillance data was not disclosed. Since the transition to sentinel surveillance was made in May 2023, we examined the relationship between case counts in sentinel surveillance and wastewater surveillance data using data from May 2023 to September 2025. Fig. 6 shows time-series trends in wastewater surveillance data and case counts in sentinel surveillance, and Fig. 7 shows the relationship between wastewater surveillance data and case counts reported from sentinel surveillance in the Minamikaga area.

The correlation coefficient between the wastewater surveillance data and the case counts in sentinel surveillance was 0.71 (Fig. 7), in contrast to the correlation coefficient with the case counts in notifiable disease surveillance of 0.83 (Fig. 5). This reduction was presumably because the case counts in sentinel surveillance were based on patients at specific medical institutions within the area of the Minamikaga Public Health Center, unlike the case counts in notifiable disease surveillance. However, the correlation was statistically significant, indicating that the wastewater surveillance data is useful in monitoring the actual local case counts. For practical use, it is probably desirable that data obtained by both methods be utilized in a complementary manner.

By applying the developed data processing method, we have demonstrated a significant correlation with case counts even after the transition to sentinel surveillance, as well as with case counts during the notifiable disease surveillance period.

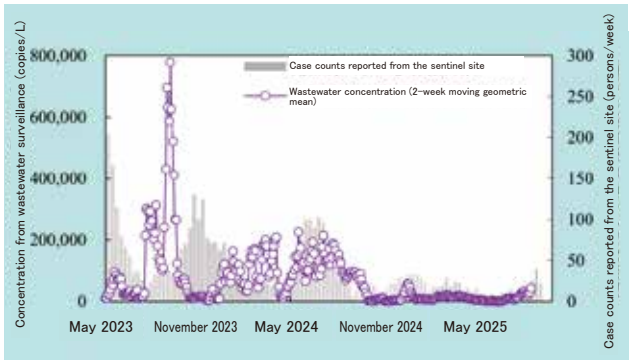

Fig. 6 Temporal Trends in Wastewater Surveillance Concentrations and Case Counts During Sentinel Surveillance

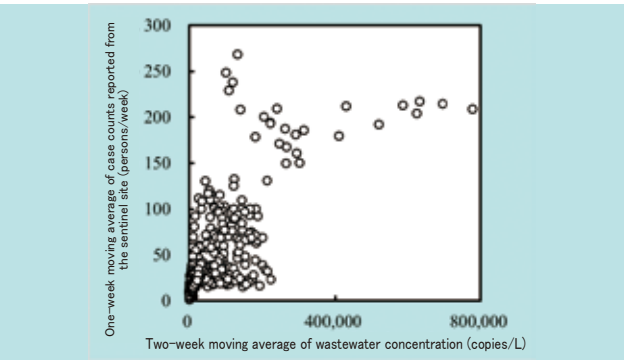

Fig. 7 Relationship Between Wastewater Surveillance Concentrations and Case Counts During Sentinel Surveillance

4-3 [Versatility] Expansion of the range of viruses targeted by wastewater surveillance technology

4.3.1 Results of a survey of Komatsu citizens

In order to hear the opinion of citizens on the wastewater surveillance data and find out information they needed, we conducted a survey of users of "Disaster Prevention with LINE," a service provided by the Komatsu City government's official LINE account, twice, in January (#1) and October (#2) of 2023. Fig. 8 shows the results of the survey of Komatsu citizens[5].

When asked if "the wastewater monitoring information is useful for your infection prevention and other behaviors," approximately 83% and 90% of the respondents answered "useful" or "relatively useful" in the first and second surveys, respectively. In addition, in response to the results of the first survey showing that approximately 35% answered "useful," we revised the information content by utilizing the survey results. As a result, the respondents who answered "useful" increased to approximately 52% in the second survey, a growth of around 17% compared with the first survey.

To the question, "Do you want information other than the COVID-19 concentration to be distributed?" approximately 35% replied "yes" both in the first and second surveys. Of them, approximately 90% requested "information on other infectious diseases such as influenza," revealing the need for influenza virus information from wastewater surveillance.

By establishing this information dissemination system for citizens, we have increased awareness of our activities and collected opinions and requests regarding this development. We also believe that we can effectively utilize this feedback to revise the information content and determine the direction of the development.

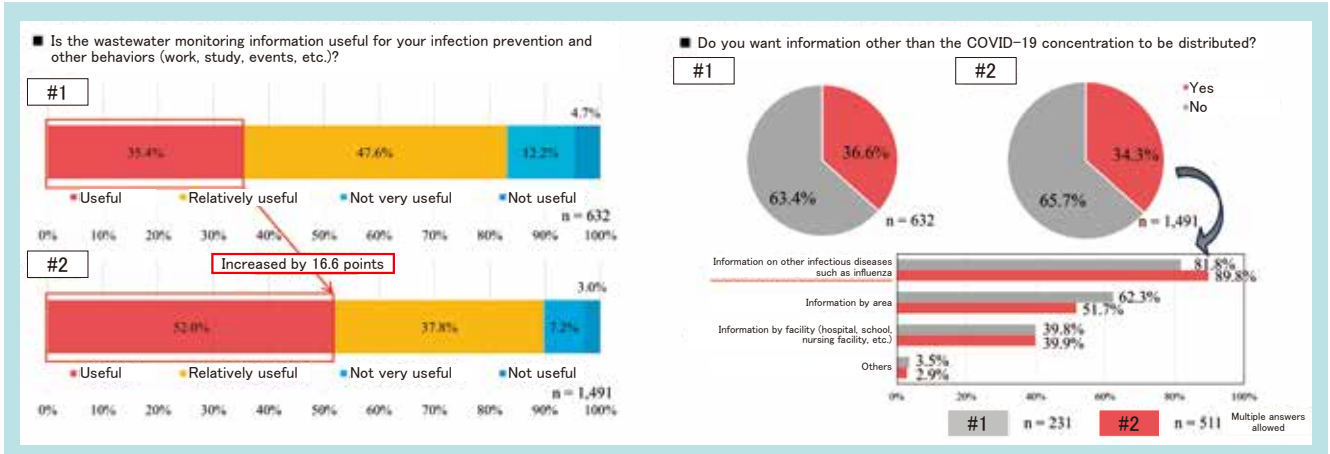

Fig. 8 Survey Results for Residents of Komatsu City

4.3.2 Opinion exchange with the Komatsu City Medical Association

To research the needs of medical experts, we conducted an opinion exchange meeting with representatives of the Komatsu City Medical Association. Along with the meeting, we also conducted a survey on all the members of the association.

At the opinion exchange meeting, we discussed the utilization status of wastewater surveillance, a method for improving information to be distributed, the next target to be added, and other topics. By reflecting the opinions from medical settings in the wastewater surveillance, we revised the information content and determined the direction of the development.

Fig. 9 shows the results of the survey of the Komatsu City Medical Association on wastewater surveillance utilization. Here, the respondents' answers to each item of one question, "How do you evaluate the information content of wastewater surveillance?" are shown. By collecting various opinions on the information content from the members of the association, we explored an information dissemination approach contributing to local medical care.

In addition, the need for wastewater surveillance of the influenza virus as an additional target was revealed at the opinion exchange meeting.

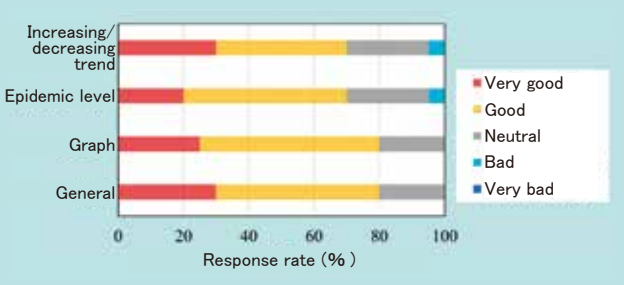

Fig. 9 Survey Results for the Komatsu Medical Association

4.3.3 Verification of the effectiveness of wastewater monitoring of the influenza virus

Based on the survey results of Komatsu citizens and the Komatsu City Medical Association, we shared the need for influenza virus monitoring among the consortium partners and initiated the technical development for wastewater surveillance of the virus. Then, we conducted influenza virus wastewater surveillance in Komatsu City from October 2024 to March 2025. Fig. 10 shows the results of influenza virus wastewater surveillance. The alert levels were set based on the opinions of the Komatsu City Medical Association, and an information distribution trial with LINE was conducted.

As verification data on the effectiveness of the influenza virus wastewater surveillance, Fig. 11 shows the case counts and morbidity of National Health Insurance subscribers in Komatsu City. (For the case counts, the number of medical receipts (outpatient) including ICD-10 code J10.1 and J11.1 was counted. Data may be duplicated for the same person.) As a result of wastewater surveillance information dissemination, the morbidity rate of influenza was 4.8% in 2024, the smallest since 2016 except for 2019 to 2022 when influenza was not relatively prevalent due to the COVID-19 pandemic.

The disclosure of information on influenza virus wastewater surveillance likely contributed to reduced case counts due to the citizens' behavioral and other changes. As described above, we have established wastewater surveillance technology targeting viruses other than COVID-19.

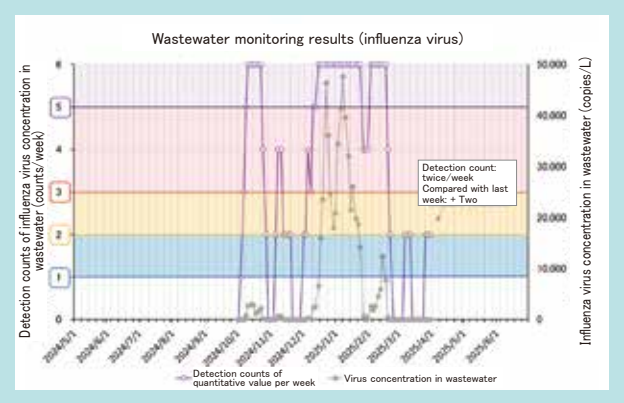

Fig. 10 Published Wastewater Surveillance Information of Influenza

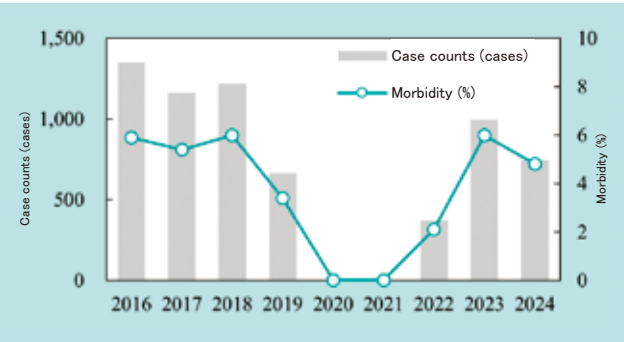

Fig. 11 Trends in Influenza Cases Among National Health Insurance Subscribers in Komatsu City

5.Conclusion

A case example of transdisciplinary research toward the social implementation of wastewater surveillance in order to help solve the societal goal of achieving a society resilient to infectious diseases has been presented above. The achieved results are described below.

- We have worked on the social implementation of wastewater surveillance to monitor the local infection status and established a system for effective information dissemination.
- We have achieved valuable technical development and information dissemination through transdisciplinary research by spreading awareness of the usefulness of the information among citizens and medical experts through push-type distribution on SNS and collecting opinions from the related stakeholders.
- Going forward, we will contribute to creating safe and secure communities that can respond to various types of infectious diseases by introducing a proactive information dissemination and utilization method nationwide as the "Komatsu City Model."

The project presented in this paper has been awarded the "STI for SDGs Award 2025" Excellence Prize by the Japan Science and Technology Agency (JST). We would like to express our appreciation to the Waterworks Bureau of the Komatsu City government, Kanazawa University, and Toyama Prefectural University for their dedicated participation in the research consortium and to the Research Organization of Information and Systems (ROIS) for its advisory support.

Contribution to SDG targets

3.3 Eradication of infectious disease and response to infection
Contribution to building a society resilient to infectious disease through utilization of wastewater surveillance

16.10 Ensuring public access to information and promising fundamental freedom
Implementation of infection control involving all citizens through information dissemination

Reference

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5) Komatsu City government: "Survey Results of Users of Wastewater Monitoring" https://www.city.komatsu.lg.jp/soshiki/1042/surveillance/14588.html, Date of reference: Sep. 24, 2025)

Research and Development of Polypropylene Pipes and Fittings for High-Temperature Wastewater (Mainly for Commercial Kitchens)

Kubota ChemiX Co., Ltd.

In the core market in the building equipment sector, there are potable water and hot water piping, air conditioning piping, and drainage piping, with metal piping currently being the mainstream. Through user needs assessments, it has become clear that there are many requests for the development of lightweight and easy-to-install resin piping instead of heavy metal piping. Especially in the commercial kitchen drainage piping market, there are high demands for heat resistance, chemical resistance, and low thermal expansion; however, there were no products made by Kubota Chemix that met all of these demands. This report describes the development of resin pipes and fittings that meet these performance demands.

【Key Word】
Pipes, Fiberglass, Polypropylene, Heat Resistance, Chemical Resistance

Related SDGs

1.Introduction

Major piping products for the building equipment market are water and hot water piping, air conditioning piping, and drainage piping, most of which are made of metal at present. However, users at construction sites often request the development and proposal of lightweight and easy-to-install resin piping to replace heavy metal piping. In particular, commercial kitchen drainage piping is subject to severe conditions due to the discharge of high-temperature water, detergents, fat, and oil from commercial kitchen equipment. Polyvinyl chloride piping and polyethylene piping of Kubota ChemiX's existing product lineup are difficult to use because they are strongly susceptible to softening due to high-temperature drainage and deformation due to thermal expansion and contraction. In addition, both materials have heat resistance grades, but their chemical resistance is insufficient against oils, detergents, chemical wastes, and other fluids flowing down the piping. To accommodate such a usage environment, we have developed pipes and fittings for commercial kitchen drainage using polypropylene resin (hereinafter referred to as "PP resin"), which has excellent chemical and heat resistance, and glass fiber with low thermal expansion/contraction.

2. Development concept and target values

2-1 Development concept

To meet the performance requirements for commercial kitchen drainage pipes, we used two types of resins as pipe materials. One was PP resin for chemical-, oil- and heat-resistance and another was a PP glass fiber compound for low thermal expansion/contraction. We used a two-layer pipe that has glass-fiber-reinforced PP resin for the outer layer and PP resin for the inner layer to prevent drainage from leaking out through the glass fibers (hereinafter referred to as "HTPP") (Fig. 1).

For fittings, the development concept was to be "lightweight" and "does not require skilled workers and special tools." The bodies of various types of fittings such as elbows and tees were designed to deal with a variety of shapes by processing HTPP and attaching sockets to their ends using PP resin welding. They were also designed so as to absorb thermal expansion/contraction even when HTPP was inserted all the way inside (Fig. 2).

Fig. 1 HTPP for Commercial Kitchen Drainage

Fig. 2 HTPP Fittings for Commercial Kitchen Drainage

2-2 Target values

(1) Chemical resistance

The target was to ensure sufficient chemical resistance against neutral detergents which are typically used in commercial kitchens, alkali detergents used for commercial kitchen equipment, and chlorine detergents used for sterilization.

(2) Oil resistance

Since animal fats and oils such as lard, which are solid at room temperature, are more likely to stay in the piping than other edible oils, the target was to ensure sufficient oil resistance against animal fats and oils even among edible oils.

(3) Linear expansion coefficient

To suppress the thermal expansion/contraction of HTPP, the target for the linear expansion coefficient was set to 2.4×10^{-5} (1/℃).

(4) Thermal expansion/contraction of the fittings

Regarding the fittings, the target was set such that there would be no damage or water leakage within the thermal expansion/contraction (±6mm) that occurs under standard construction.

(5) Bending and flattening of the fittings

The target was to ensure water tightness of the jointing area under expected bent or flattened conditions, because there is a risk of pipe bending and flattening at the jointing area during construction.

3. Technical issues to be solved

3-1 Improvement in the unevenness of the HTPP surface

The addition of glass fibers to PP resin causes the formation of fine unevenness on the HTPP surface, and as a result, water leaks at the joint with the fitting through the uneven HTPP surface. In addition, the uneven HTPP surface may cause rubber to wear due to repeated thermal expansion/contraction during long-term use, and as a result, water leaks. Therefore, smoothing the HTPP surface to prevent water leakage was a technical challenge.

3-2 Improvement in impact resistance

In glass-fiber-containing PP resin, an adhesive, such as a silane coupling agent, is applied to the surfaces of the glass fibers to provide adhesion between the glass fibers and PP resin[1)], but the adhesive interface is less strong and more brittle. In fact, when a drop test was conducted, simulating HTPP falling from a truck tailgate height of 1.5 m, the HTPP cracked, starting from the glass fibers. Therefore, improving the impact resistance of HTPP to prevent cracking due to a drop impact was a technical challenge.

3-3 Improvement in the smoothness of the HTPP inner surface

In the process of extrusion molding of HTPP, the glass fibers in the outer layer of HTPP are pushed into the inner layer, and as a result, it generates unevenness on the HTPP inner surface. This may cause an inability to achieve the target value of drainage performance, and thus improvement in the smoothness of the HTPP inner surface was a technical challenge.

3-4 Implementation of a new evaluation

Despite the need for judgement on the resistance against various chemicals, fats, and oils used and discharged in commercial kitchens, there are no general industrial standards on evaluation methods.

In addition, although fittings are often embedded in concrete, making it necessary to determine whether it is possible to embed fittings or not, there are no general standards for this determination. Therefore, the technical challenge was how to evaluate chemical and oil resistance with concrete embedding.

4. Developed technology

4-1 Improvement in the unevenness of the HTPP surface

Unevenness on the HTPP surface is formed when glass fibers protrude from PP resin as foreign matter and glass fibers which are foreign matter are coated by PP resin. Therefore, it is estimated that controlling the protrusion of glass fibers can improve the smoothness of the HTPP surface.

Molding of HTPP is performed by bringing a cylindrical resin coming out from the extruder into contact with the cooling tube in a cooling tank. Here, we considered improving the unevenness of the HTPP surface by pressing the resin against the cooling tube at a high temperature, just like ironing. As a result, we found that the unevenness of the HTPP surface was reduced through high-temperature resin contacting a cooling tube having fine unevenness on its inner surface (Figs. 3 and 4).

This improved the uneven HTPP surface and solved issues such as water leaks at joints and rubber wear.

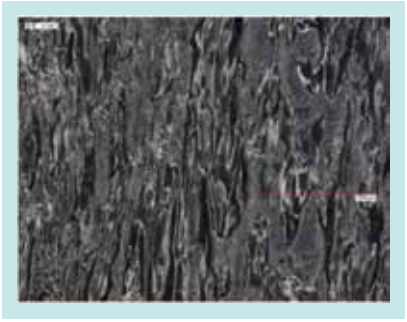

Fig. 3 Surface of Leaking HTPP

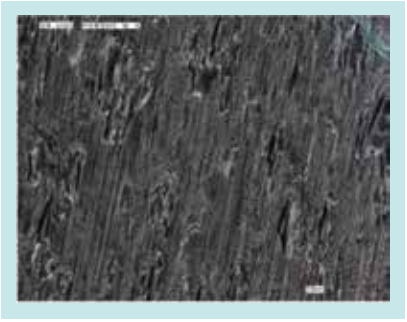

Fig. 4 Surface of HTPP with Improved Unevenness

4-2 Improvement in impact resistance

In fact, when a drop test was performed on HTPP, a crack formed in its longitudinal direction (Fig. 5). Initially, we tried to solve this issue by adjusting the resin flow. However, since it became clear that the impact resistance of the PP resin itself was insufficient, we changed the PP resin to one with superior impact resistance (block polymer). Thus, the impact resistance of HTPP improved and the problem of cracking was solved (Fig. 6).

Fig. 5 Inner Surface of Cracked HTPP

Fig. 6 Inner Surface of Improved Impact-Resistant HTPP

4-3 Improvement in the smoothness of the pipe inner surface

HTPP consists of glass-fiber-containing PP resin outer layer and a PP resin inner layer, such that the inner layer covers the unevenness due to the addition of glass fibers. To improve the unevenness of the inner surface, we conducted prototype moldings by changing the ratio of the inner and outer layers. As a result, we found that the unevenness tends to become smaller as the inner layer thickness increases. This improved the unevenness of the inner surface, and the target value for drainage performance was achieved (Figs. 7 and 8).

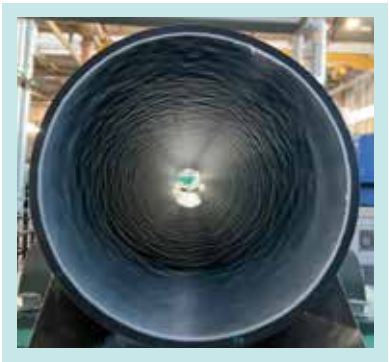

Fig. 7 Inner Surface of HTPP Before the Improvement of Unevenness

Fig. 8 Inner Surface of HTPP After the Improvement of Unevenness

4-4 Implementation of a new evaluation

For the evaluation of the chemical and oil resistance of HTPP, we decided to evaluate simultaneously HTPP, fittings, and joints in their connected condition. As chemicals for the evaluation, we selected the following three types: "a cleaning agent for commercial kitchen equipment," "a chlorine cleaning agent" as representative of a cleaning agent, and "a mixture of lard, neutral detergent, and water" as representative of oils. We conducted an accelerated test by sealing these chemicals in the jointing area. As a result, we judged there were no problems with chemical resistance or oil resistance because there were no problems with the water stop performance of the jointing area after the accelerated test. Next, regarding concrete embedding, we actually conducted concrete embedding tests for HTPP and fittings to evaluate whether heat generation occurred during concrete hardening, whether flattening or cracking occurred due to the embedding load, or if there were any problems with watertightness. Furthermore, since it was expected that concrete slurry would enter the jointing area during concrete pouring, we newly added a rubber plate at the jointing area for preventing the entry of concrete slurry (Fig. 9). Based on these evaluation results and the addition of the rubber plate, we judged there were no problems with cracking, flattening, or water tightness and evaluated that HTPP and fittings can withstand concrete pouring.

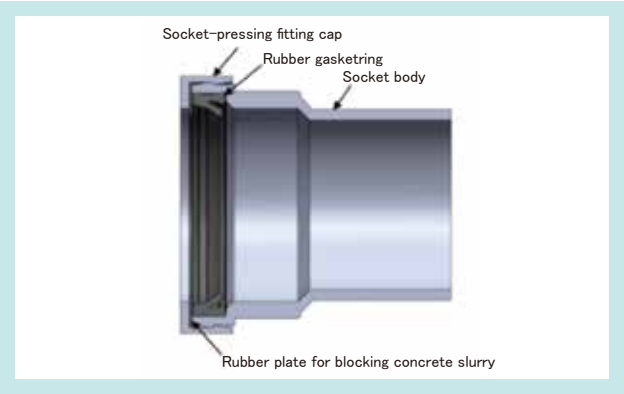

Fig. 9 Fittings Receiving Structure

5. Conclusion

The development of this product has allowed us to propose a lightweight and easy-to-install plastic pipe for the commercial kitchen drainage market. Going forward, we intend to tackle the recycling of glass-fiber-containing resin products to contribute to reducing the environmental impact.

Contribution to SDG targets

8.2 Increase in productivity through innovation
Contribution to reducing construction load with lightweight plastic pipes

9.1 Development of high quality, sustainable, and strong infrastructures
Achieving drainage piping with excellent heat resistance and chemical resistance

Reference
1) Nello Pasquini: Polypropylene Handbook, New Edition (2012), pp.398-400, Nikkan Kogyo Shimbun

Introduction of the KSIS BLUE FRONT Equipment Monitoring System "KEMOS"

KUBOTA Environmental Engineering Corporation

Related SDGs

1.Introduction

KUBOTA Environmental Engineering Corporation (hereinafter referred to as "KKE") is engaged in the business of construction and maintenance at wastewater treatment plants and waste gas treatment plants (hereinafter referred to as "environment equipment") for civilian use in Japan and overseas.

To respond to the recent increase in the importance of maintenance work for the formation of a sustainable society, as well as social issues such as the declining birthrate, aging population, and labor shortages in various industries, KKE sets a goal of "establishing itself as a comprehensive environmental solution company through the expansion of its operation and maintenance (O&M) business by utilizing digital transformation (DX)." This article presents the KSIS Equipment Monitoring System (KEMOS) that has been developed as an infrastructure system to promote the achievement of the above goal.

KEMOS is a system related to Kubota's comprehensive platform for facility management, "KSIS BLUE FRONT," and is also a monitoring function system belonging to the Kubota water environment IoT solution system KSIS[1].

2. Overview

2-1 Overview of the system

This system collects operational data from environment equipment at each location via an internet connection, accumulates the data in a cloud database, and visualizes the data. Fig. 1 shows the overview.

It is basically an internal system, but it also provides a browsing function to customers who own the equipment to allow KKE's maintenance and support division to effectively respond to trouble and give operational advice by sharing the same data on the same screen with the customer.

In addition, by analyzing the data accumulated in the cloud, it is possible to evolve into more advanced and stable equipment operation using AI and more efficient equipment maintenance such as predictive maintenance.

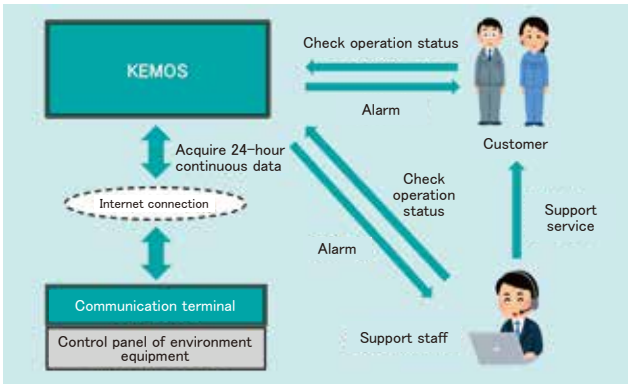

Fig. 1 System Outline

2-2 Features of the system

2.2.1 Cloud system utilizing Azure

Kubota entered into a strategic partnership with Microsoft Japan on DX promotion in 2020 and has been advancing activities such as the introduction of cloud (Azure) IT infrastructure. To facilitate cloud integration with other internal systems and data utilization platforms through the Azure platform, KEMOS is also configured to make maximum use of Azure's functions.

2.2.2 System enabling in-house development and maintenance

To allow integration with various systems and in-house development and maintenance, an open system with a combination of PaaS (Platform as a Service) models has been adopted. However, for the "visualization" function, serving an important role for continuous usability improvement, a commercially available Windows-based business intelligence (BI) tool is used to allow non-IT experts at KKE to easily create the function.

2.2.3 Utilization of commercially available equipment and IoT services

This system requires IoT equipment for collecting on-site data and a network infrastructure for transferring data. To keep up with very fast advancements in the IoT field, commercially available IoT equipment is employed as is. For the network, an IoT platform by a provider with enhanced IoT features is used.

3. Detailed description

Fig. 2 shows a system configuration.

The communication terminal is installed in the control panel of the environment equipment to periodically transfer data in the PLC controlling the equipment to the cloud via the LTE network.

The transferred data is accumulated in a database, and alarm information is transmitted immediately by email from a mail server. The accumulated data is visualized by the BI tool, which displays a screen according to a request from an internet browser.

The cloud environment consists of Azure PaaS models and VMs, which are combined in a typical manner. In addition, for other functions such as user authentication and remote system maintenance, the functions of the company-wide common infrastructure are utilized.

The accumulated data is viewed through the internet browser. Fig. 3 shows an example of the browsing screen.

The screen displays content such as a workflow diagram, current values, and set values, which are equivalent to those of the on-site control panel, and it can also display historical data. In addition, the trend graph of any item, a daily report, a monthly report, and an alarm history are displayed.

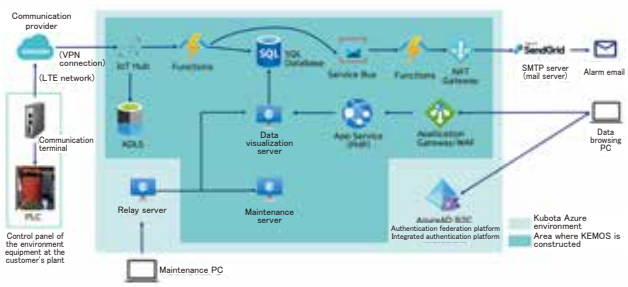

Fig. 2 System Configuration

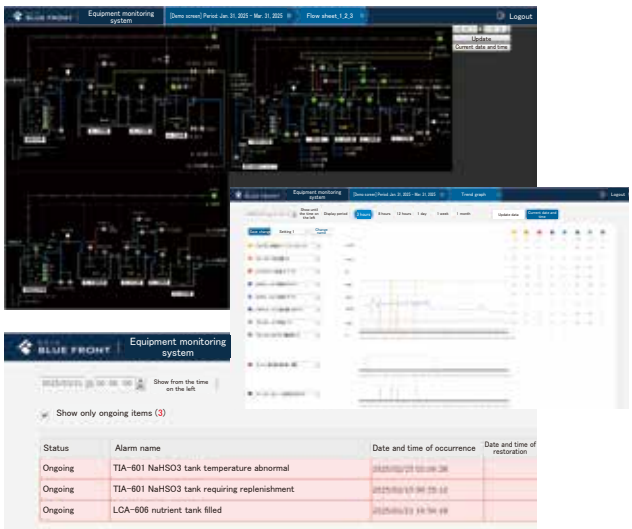

Fig. 3 Example of the Data Browsing Screen

4. Achievements

Since its release at the end of 2022, KEMOS has been introduced and operates at 60 locations in Japan and overseas. From FY 2025, the system has been introduced to facilities of other divisions in the Kubota Group, such as equipment for the public sector and large-sized septic tanks.

Currently, an analysis and AI operation platform based on the accumulated data is under development, together with an operation optimization program for wastewater treatment equipment using a machine learning simulation model, which will run on the platform. We aim to achieve “optimized operation automation of environment equipment through the cloud” by integrating the above with KEMOS.

5.Conclusion

Because data accumulation has been progressing while three years have passed since the system’s release, effective utilization of the data is important going forward. By developing this data analysis platform described above and other KSIS systems while strengthening collaboration with other divisions of Kubota Group, we will promote more advanced data utilization to contribute to delivering higher value to customers and society.

Contribution to SDG targets

14.1 Prevention and reduction of marine pollution, contribution to the prevention of river basin and ocean pollution through appropriate treatment of contaminated water

Reference

1) Introduction of KSIS solutions and services
https://www.kubota.co.jp/product/ksis/

Flat-installation Type / Waterproof Type for the "WATARAS", Water Remote Management System in Paddy Fields

1.Introduction

WATARAS is a field water supply/drainage management system enabling remote and automatic control through monitoring of water conditions on smartphones or PCs. It offers the advantage of being capable of reducing labor for water management, saving water, and accumulating and utilizing water management data (Fig. 1). This article presents two types of new electric actuators, a flat installation type that is installable inside a water valve box, and a "waterproof type," which can withstand submersion in water and will not fail under certain conditions.

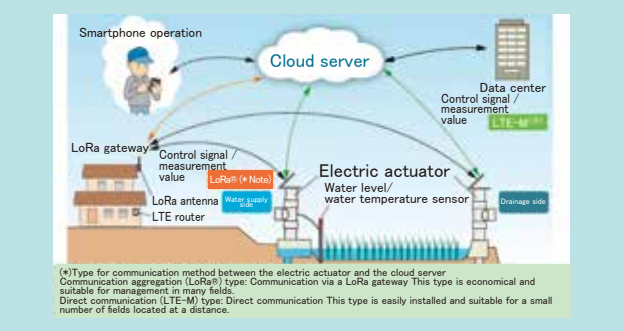

Fig. 1 Outline of "WATARAS"

Note: "LoRa®" in Fig. 1 is a trademark of Semtech Corporation.

2.Outline and features of the product

2-1 Flat installation type

This electric actuator is intended to avoid obstructing ridge grass cutting or other agricultural machinery work. Its features are as follows (Fig. 2):

(1) The actuator has separate drive and control units, reducing the product height. It can be stored and installed inside the water valve box, so that the top is at the same level as the farm road.

(2) Due to storage inside the water valve box, the actuator does not need to be removed during the off-season in snowfall areas (but needs to be powered off to prevent battery discharging).

2-2 Waterproof type

This actuator is capable of withstanding immersion in water up to a certain depth, even when a paddy field is submerged during inland flooding or other events due to heavy rain. Its features are as follows (Fig. 3):

(1) Waterproof rating IPX8 (No failure occurs after submersion in water at 1 m depth for 72 hours.)

(2) Lightweight and compact body

Mass: 70% compared with the Existing product (10 kg⇒7 kg)

Height: 82% compared with the conventional product (650 mm⇒530 mm)

(3) Load capacity to withstand a load equivalent to 6 m of snow accumulation (corn snow, vertical)

Fig. 2 Flat-installation Type

Fig. 3 Waterproof Type

3.Conclusion

For the waterproof type, a new type for valves requiring greater open/close torques is planned to be added to the existing lineup for open channel gates.

WATARAS, which helps promote remotely and automatically control for the water supply and drainage of the paddy fields, will be applied to a system that can be utilized for a wider range of purposes, including the automatic setting of the water supply/drainage schedule and the prevention of high-temperature and low-temperature damage, contributing to the development of agriculture.

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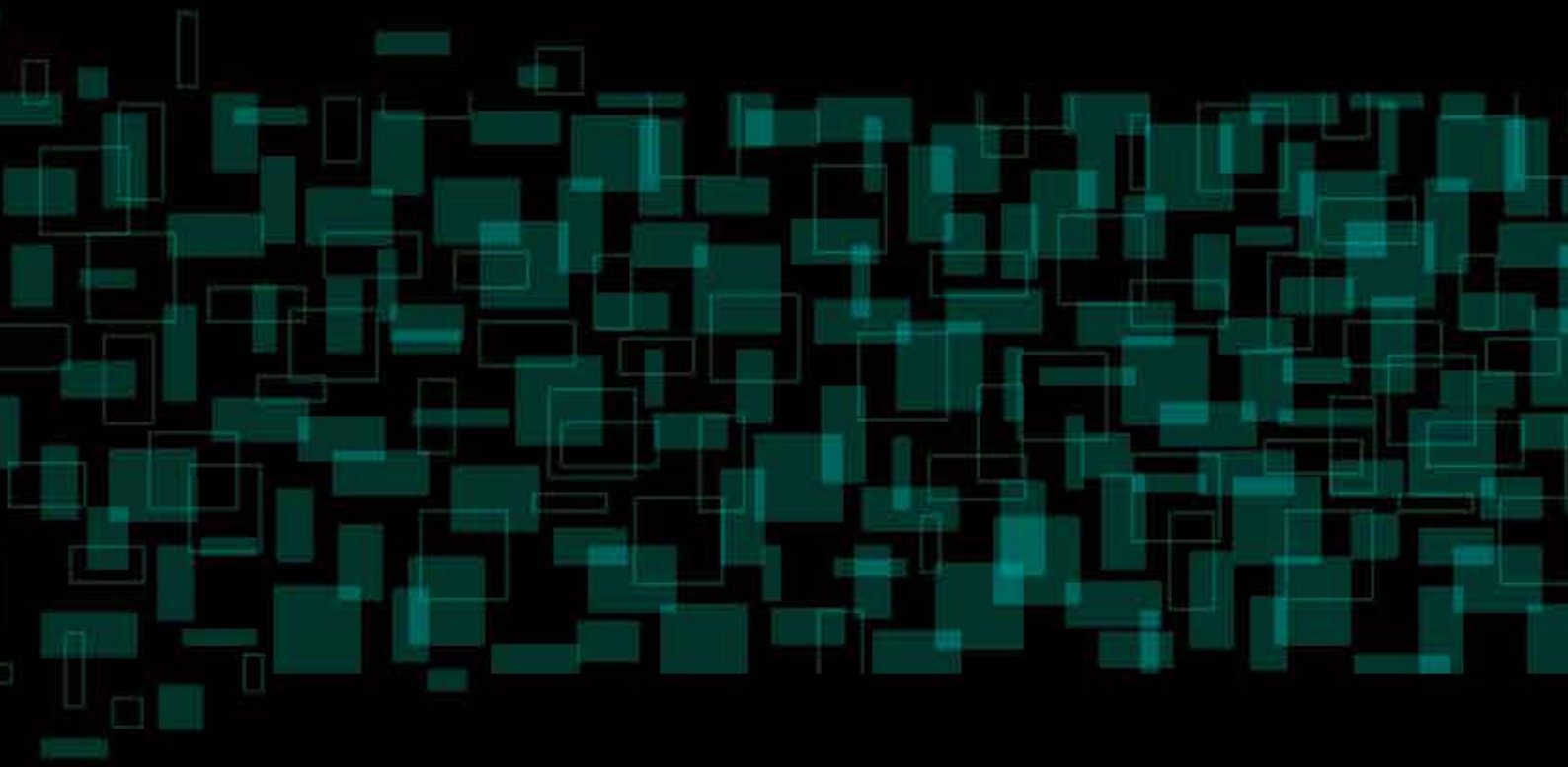

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