For Earth, For Life
Kubota

KUBOTA TECHNICAL REPORT

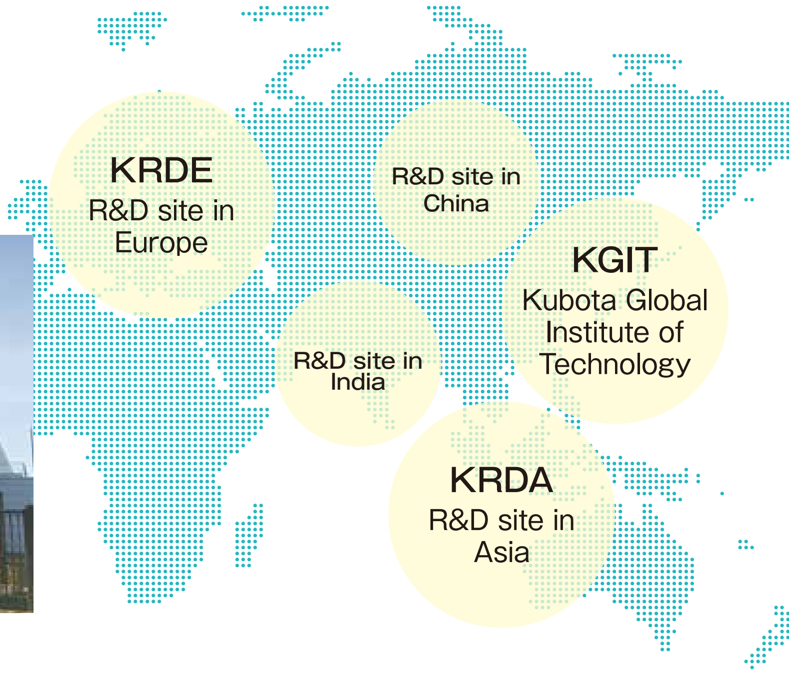
JANUARY 2024

56

ISSN 0916-8249

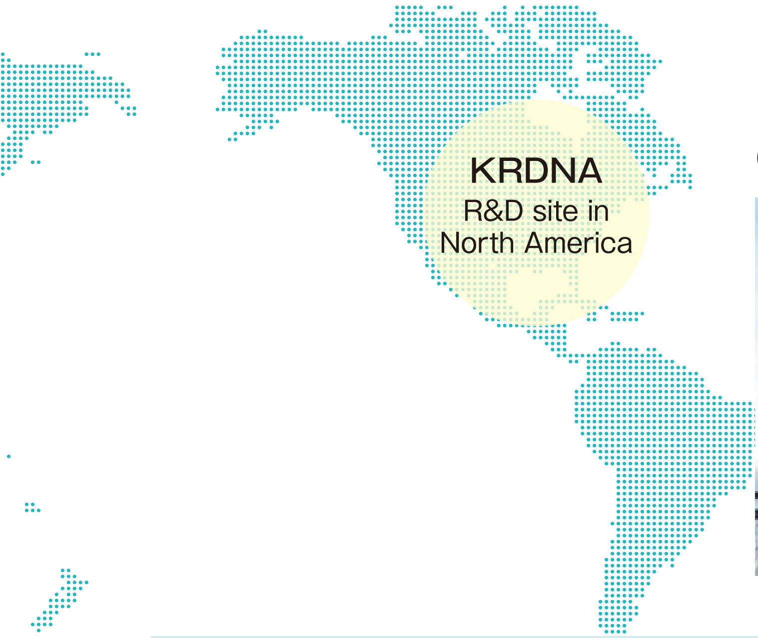
R&D System Based Around Six Global Sites

KRDE established in 2021
Kubota R&D Europe S.A.S.



KRDA established in 2016
Kubota R&D Asia Co., Ltd.

Kubota Global Institute of Technology established in 2022



KRDNA established in 2022 Kubota R&D North America Corporation

As the globalization of business, it is becoming increasingly important to offer products, services, and solutions that not only satisfy the needs of customers throughout the world, but also contribute to solving social issues in every community. To respond to diverse and unique local issues, Kubota is improving its global R&D system by clarifying the roles of its R&D sites in Japan and overseas.

KUBOTA TECHNICAL REPORT

No.56 JANUARY 2024

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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 Compact Electric Tractor LXe-261 for the European Market
■		Development of REXIA Series Tractor for Domestic Market with “Go-Straight Function”
■		Development of Electric Zero-Turn Mower Ze series for the European Market
■		Development of Seven-Row Head-feeding Combine Harvester DR7130
■		Development of Autonomous Driving Rice Transplanter NW8SA
■	■	Development of the Electrically Controlled Small Diesel Engine D902-K
	■	Development of Hydraulic System for 3-Ton Class Mini Excavator “U-30/35-6α Series”
■		Development of Rotary for Upland Farming with SL Series Tractor for the Domestic Market
■		Development of Drone Sprayer and Kubota IoT Intelligence Drone (K-iDrone)
■		Development of TIM Rear Top Linkage and TIM Spreader
■		Development of PUDAMA - A Spot Fertilizing System for Maize Seeders
	■	Development of “WATER PIPE COM”, Equipment for Monitoring in Water Pipe
	■	Development of Rotating Panel Filter for Membrane Bio-Reactor
	■	Development of Flocculation Sensor for Industrial Wastewater Treatment
	■	Development of All-plastic Flange
■	■	Introduction of Kubota Research & Development North America (KRDNA)
	■	Introduction of Large-Scale MBR Operation Case at Nakahama Sewage Treatment Plant, Osaka City
	■	Introduction of ASB System and Its Effects on Night Soil Treatment

SUSTAINABLE DEVELOPMENT GOALS

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																
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R&D to become an “Essentials Innovator for Supporting Life”

President and
Representative Director
Yuichi Kitao

The Kubota Group’s business performance has more than doubled over the past 10 years. Meanwhile, the proportion of overseas sales has increased 1.4 times in the same period to approximately 78%, indicating that the globalization of our business is accelerating.

While what society demands of a company changes with the times, Kubota, since its founding, has been growing by offering products and services that solve social issues. I believe that this is because we have inherited the belief of our founder, Gonshiro Kubota, that “Our products should not only be technically excellent, but also useful for the good of society.”

Our mission is to provide products, services, and solutions that contribute to solving social issues around the world.

In Japan, we opened a new R&D base, the Global Institute of Technology, in 2022 to consolidate the personnel and facilities of our R&D bases, which had been dispersed in various regions. We believe this will significantly improve R&D efficiency. The Institute also plays a role in coordinating all R&D bases around the world, realizing truly global R&D where the characteristics and strengths of each base are demonstrated as One Kubota.

Climates, soils, crops, customs, and social conditions vary from region to region around the world, and social issues too are diverse. To quickly provide solutions that are useful for the conditions of each of our customers, we will build a truly global R&D system with six regions around the world, adding China and India to the existing bases of Thailand, North America, Europe, and Japan.

We will work to build a system where locally oriented R&D bases are organically bound so that we can quickly solve social issues in each region.

The KUBOTA TECHNICAL REPORT No. 56 introduces some examples of global R&D, such as IoT drones that contribute to improving the efficiency of agricultural work in Thailand, optimal fertilizer application using TIM (Tractor Implement Management) in Europe, and R&D bases in North America.

In the area of “food,” smart agriculture is an important theme. Implements connected to tractors in farming operations vary significantly from region to region. In this issue, you can read the results of our R&D—on rice transplanters and tractors equipped with autonomous driving and straight-line assist functions, EV tractors and zero-turn mowers in Europe, and implements developed to meet the needs of specific regions both in Japan and in other countries.

In the area of “water and the environment” there are important social issues, such as measures for aging water pipe systems, improvement of the capacity and maintainability of sewage and wastewater treatment, and measures to prevent flood damage in the event of a natural disaster. Topics introduced in this issue include: monitoring equipment contributing to the maintenance and management of water pipe systems, synthetic resin pipes that improve workability, examples of improving the maintenance and manageability of membrane bioreactor (MBR) systems and their large-scale operation, industrial wastewater treatment technology using diagnostic imaging technology, and ultra-lightweight pumps for flood damage control.

For carbon neutrality, which is an issue common to all industries, we are working on R&D with various themes, including electrification, which is introduced in this issue.

Kubota’s “Vision for Future” is to become an “‘Essentials Innovator for Supporting Life,’ Committed to a Prosperous Society and Cycle of Nature,” always facing issues from the perspective of our customers and society and doing our utmost to solve them. I believe that this spirit of “On Your Side” is what we need to keep the presence that is needed by society. We will continue working on innovation in the spirit of “On Your Side” in R&D that supports the Kubota Group’s technological foundation. As always, I am deeply grateful for your continued support into the future.

Development of Compact Electric Tractor LXe-261 for the European Market

Tractor Engineering Dept. Ⅰ

In response to growing environmental concerns and the pursuit of carbon neutrality, European regulatory bodies are tightening restrictions on internal combustion engine emissions, which necessitates the development of compliant products that adhere to these regulations. In line with the European market's commitment to carbon neutrality, Kubota has developed the Compact Electric Tractor "LXe-261" as its first electric tractor. This paper focuses on the engineering challenges encountered during the development of this groundbreaking electric tractor, including issues related to ensuring frame strength and handling high-voltage harnesses.

【Key Word】
Electric Tractor, Electrified Devices, Strength Analysis

Related SDGs

1. Introduction

In Europe, regulations on internal combustion engines are becoming increasingly stringent as a measure against air pollution and as a carbon-neutral solution. For example, the city of Paris has announced a ban on diesel vehicles, including cars, inside the city's ring road in 2024, and plans to ban gasoline and other internal combustion engine vehicles by 2030. Many other cities have also put forward proposals to meet the "Fit for 55" target of a 55% reduction in CO_2 emissions by 2030 compared to 1990 levels across Europe, and further discussions will take place in the future. This trend is expected to accelerate, as many European municipalities and public authorities are already converting their fleets (cars, work vehicles, etc.) to carbon-neutral products such as electric vehicles (EVs) and fuel cell vehicles (FCVs), as well as providing subsidies and additional budgets for charging electric products.

In response, Kubota has developed the LXe-261 compact electric tractor to meet the European market's carbon neutrality efforts, as the company's first electric tractor, based on the B2 Series tractor, which are among the top sellers in Europe. The company's primary target customers are local governments transitioning to carbon neutrality, and the expected tasks include towing trailers, mowing lawns with mowers, and clearing land with rotary tillers.

In developing the LXe-261, we faced and responded to challenges unique to electric tractors. This paper introduces some of the challenges and our efforts to address them.

Fig. 1 Compact Electric Tractor "LXe-261"

2. Development concept and target values

2-1 Development concept

Even if tractors are electric, they still have to do the same job as engine-driven machines. In addition, the LXe-261, which is targeted at European local governments, should be able to be fitted with existing implements without modification. Therefore, our concept was to keep the same vehicle size as the base engine-driven machines so that the new electric machine could be fitted with existing implements, performing the same work as the engine-driven machines for a full day of park management work in Europe.

2-2 Development goals

To develop a compact electric tractor that meets the above concept, we set the following development goals.

(1) Provides a full day's work equivalent to that of engine-driven machines

Equipped with a large-capacity battery that provides an average of 3 to 4 hours of continuous operation on one charge, the first compact tractor with rapid charge capability can provide a full day's work (about 6 to 8 hours), equivalent to the work done by the base engine-driven machines, by quickly charging during the lunch break.

(2) Keeping the size of base engine-driven machines

The electric system components (battery, motor, inverter, etc.) and high-voltage wiring harness, including a rapid charging inlet, are located in the front part of the machine, where an engine used to be, to keep the machine size comparable to the base engine-driven machines.

3. Technical issues to be solved

3-1 Insufficient frame strength due to added weight of electric equipment

A large-capacity battery capable of 3 to 4 hours of continuous operation to achieve a full day's work equivalent to that of an engine-driven machine would increase the vehicle weight by about 25% (approx. 220 kg) compared to the base engine-driven machine. Besides, in the case of engine-driven machines, the engine itself, which is the heaviest component at the front part of the machine, functions as a strength member, whereas in electric tractors, electric equipment such as battery packs and motors, which are heavy components, cannot be used as strength members. For these reasons, the challenge was how to mount the electric equipment and how to ensure strength against the increased weight of an electric tractor compared to the based engine-driven machine.

3-2 Arrangement of high-voltage harness with high risk of damage

In order to keep the size of the electric tractor the same as the base engine-driven machine, it is necessary to fit every component of the electric system and high-voltage harness in the space under the bonnet of the base engine-driven machine. However, high-voltage harnesses, which carry high voltages and currents, are much thicker than general harnesses, and therefore less flexible in routing and require a large bending radius. Moreover, the harness must be protected by exterior components because any external damage could lead to a serious accident. The challenge was to make effective use of the limited space available, route the high-voltage harness in accordance with their characteristics, and provide adequate protection for the harnesses.

4. Developed technology

4-1 Frame strength achieved by changing the frame structure

4.1.1 Correlation of analytical conditions

Strain data from actual field tests were correlated with strength analysis to improve the accuracy of the analysis of electric tractors. The analytical conditions for the initial stage of development are shown in Fig. 2. The fastening part between the center frame and the transmission case was restrained, and an upward load was applied to one end of the front wheel case. On the other hand, Fig. 3 shows the analytical conditions with which the measured strain data were correlated. The major difference from the analytical conditions of the initial development is the addition of downward loads due to electric equipment, etc. This is because actual measurements have shown that when the front axle oscillates and makes contact with the frame, it is subjected to an upward load due to the impact of its fall onto the oscillation control point, and it is also subjected to a downward load as it is held back by the weight of the battery pack and other heavy objects.

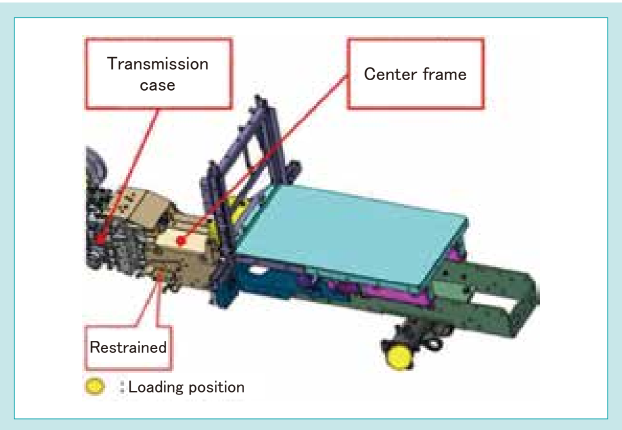


Fig. 2 Analysis of Initial Stage of Development Conditions

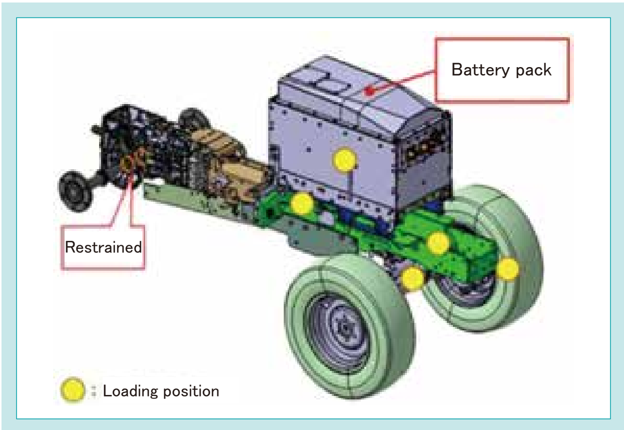


Fig. 3 Analysis of New Conditions

4.1.2 Review of the frame structure

Based on the analysis described in the previous section, we reviewed the frame structure to improve strength. In the early development stage, frame-related parts, such as the motor mount frame and the main frame, were designed separately, and some of their fastening points were structurally weak (Fig. 4). In the area where the front and rear of the vehicle body were fastened, there were two separate parts: the front part, which has a strong structure enclosed by the frame supporting the battery pack and the motor mount frame, and the rear part, which only has the center frame of the existing machine. The strength changed remarkably between these parts, making the structure susceptible to stress concentration. As a result, the results of stress measurement in actual work showed insufficient strength.

We attempted to solve this problem by adopting the frame structure shown in Fig. 5. In the improved front frame structure, the parts that were separate in the early development stage were integrated to reduce the number of fastening points, thereby improving the strength. In addition, the strength balance between the front and rear was improved by adding a sub-frame that bridges the front and rear.

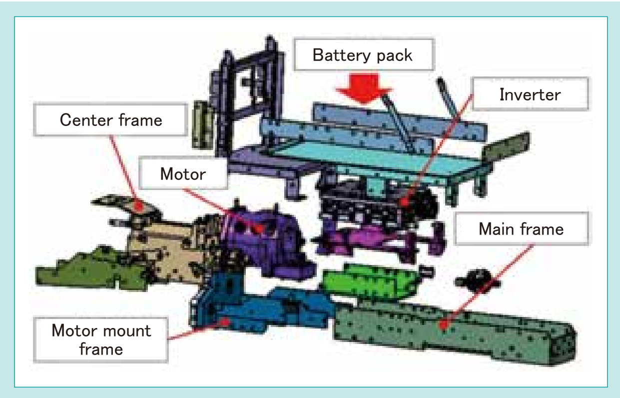


Fig. 4 Front Frame Structure in the Initial Stage of Development

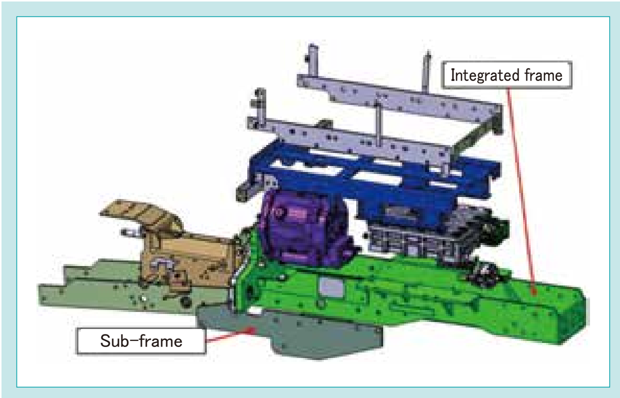


Fig. 5 Front Frame Structure after Improvement

4.1.3 Confirmation of strength improvement effect by analysis

We conducted a strength analysis to verify the strength improvement effect due to the above structural changes. Below are the results of the strength analysis of the front frame before and after the improvement (Figs. 6 and 7, respectively). Stresses were compared at the base of the motor mount frame, which had been subjected to significant strain in tests conducted in the early development stage. Compared to the initially developed frame, the improved frame was subjected to higher stresses, but the stresses were reduced by half and kept below the allowable limits. In addition, actual durability tests using the modified front frame in a real machine showed no damage to the frame and no reduction in torque on the mounting bolts.

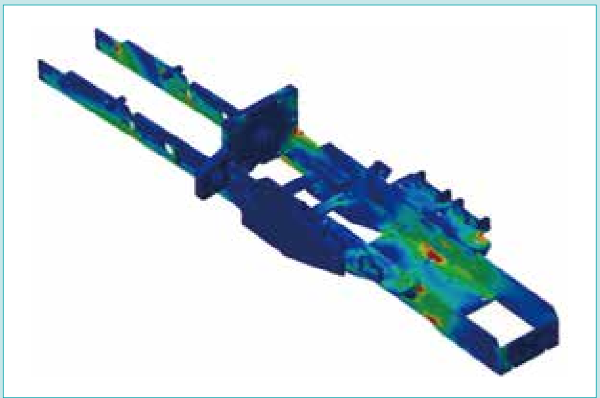


Fig. 6 Analysis Result of Frame in the Initial Stage of Development

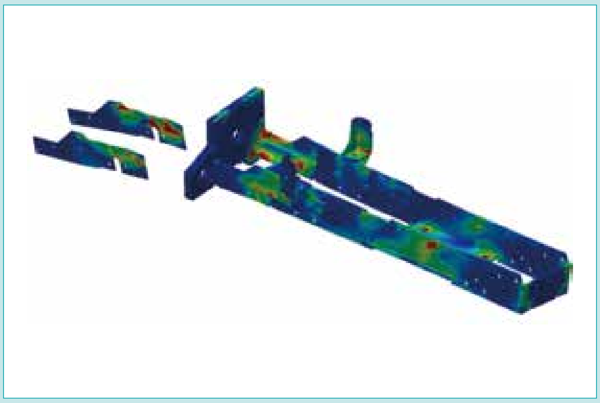


Fig. 7 Analysis Result of Frame after Improvement

4-2 Electric equipment layout and high-voltage harness arrangement and protection

4.2.1 Electric equipment layout

Figure 8 shows the layout of components under the bonnet before a rapid charging inlet was placed under the bonnet. A radiator, DC-DC converter, and 12 V battery were positioned in front of the battery pack, and the headlamps were positioned above the radiator when the bonnet was closed. Thus, the majority of the space under the bonnet was already occupied by electric equipment and cooling system components. It was, therefore, necessary to provide additional space for a rapid charging inlet, mounting stay, and high-voltage harness. We examined the placement of each component for securing space and found the following constraints.

(1) The radiator must be placed on the foremost side to allow airflow from front to back.

(2) The DC-DC converter must be located near the 12 V battery and on the cooling water path.

Due to the above constraints and the component size, the components on the front side of the battery pack had to be placed in the aforementioned positions. Therefore, the battery pack was placed as far back as possible to provide 118 mm of space (Fig. 9), allowing for the placement of the rapid charging inlet, mounting stay, and high-voltage harness.

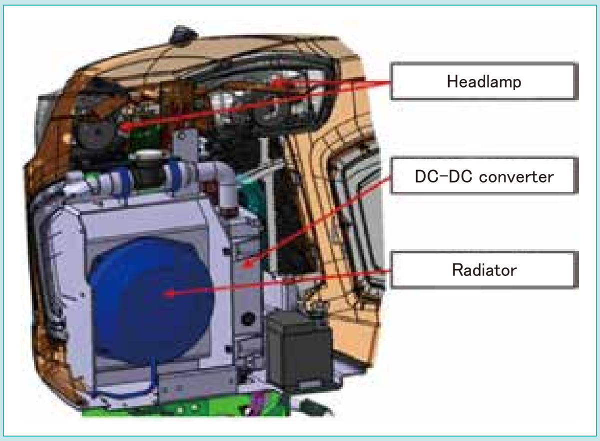


Fig. 8 Layout in Front of Battery Pack

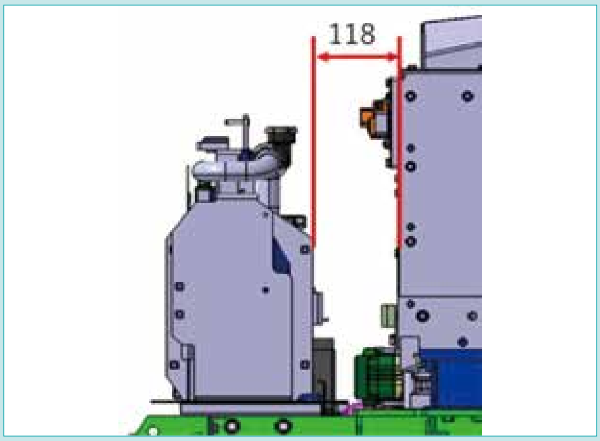


Fig. 9 Space for High-voltage Harnesses

4.2.2 Positioning of rapid charging inlet

In addition to the size issue, there were the following three constraints in placing the rapid charging inlet and high-voltage harness in the space mentioned above.

(1) The rapid charging inlet must be properly oriented.

(2) The high-voltage harnesses must have a straight section of at least 100 mm.

(3) The bending radius of the high-voltage harness must be at least 80 mm.

The rapid charging inlet had the structural constraint of not being able to point straight up in order to allow moisture that had entered the inlet connector to escape. For the high-voltage harness, it was necessary to convert the harness on the rapid charging inlet side to the size of the battery pack connector, and a straight section of at least 100 mm was required due to the convenience of manufacturing. The harness on the battery pack side had to have a bending radius of 80 mm or more due to a reduced flexibility.

Considering the above constraints, the rapid charging inlet was positioned as shown in Fig. 10. The inlet was positioned on the left side of the machine and angled upward for easy attachment of the charging gun. The high-voltage harness was routed between the battery pack and radiator to meet the constraints as shown in Fig. 11. This reduced the size of the wiring without exposing the high-voltage harness to the outside, reducing the risk of damage.

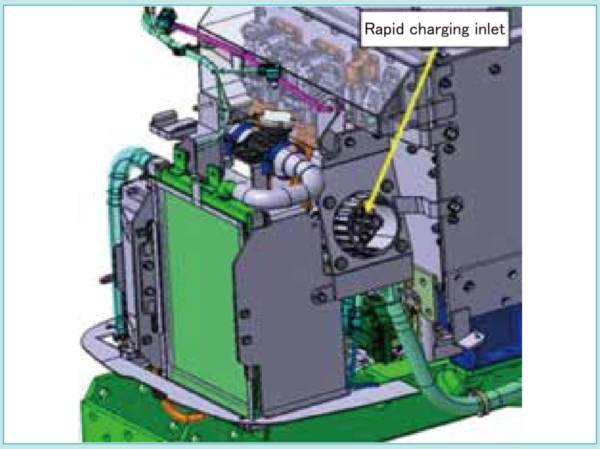


Fig. 10 Placement of Rapid Charging Inlet

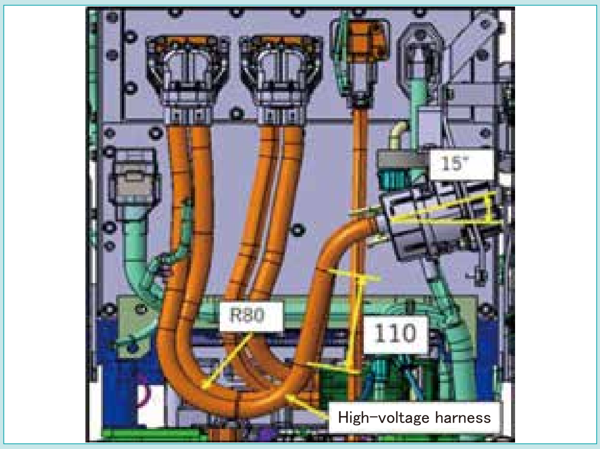


Fig. 11 Routing of High-voltage Harnesses (front cross-section of Fig. 10)

4.2.3 Protection of electric equipment and high-voltage harness

Due to space constraints, electric equipment was also installed close to the ground. A cover was provided at the bottom of the frame to protect the equipment from stepping stones and water spray during traveling, and a cleaning port was also provided to allow cleaning of accumulated dust (Fig. 12). To eliminate the risk of damage to the charging cable when opening or closing the bonnet, the side grille was replaced with a retractable cover to allow charging without opening and closing the bonnet (Fig. 13).

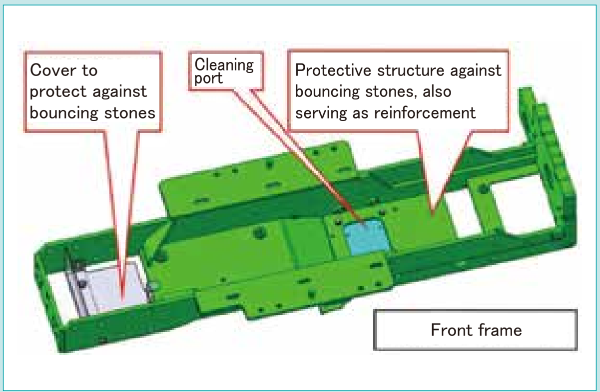


Fig. 12 Protection for High-voltage Harnesses and Electrified Devices

Fig. 13 Storage of Rapid Charging Inlet in Bonnet

5. Conclusion

With regard to the development of Kubota's first electric tractor, we presented the challenges unique to electric tractors and the efforts made in response to these challenges. Through understanding the unique characteristics of electric tractors, we were able to solve the challenges. By developing the electric tractor, we were able to provide an alternative to the use of conventional fossil fuels for tractors. As the global movement toward carbon neutrality continues, expectations are likely to grow for the decarbonization of motive power, such as the use of electric, hybrid, and fuel cell vehicles. We will continue to contribute to the realization of a sustainable society by developing electric tractors and other decarbonizing products.

Contribution to SDG targets

7.2 Expansion of renewable energy
Contribution to decarbonization through electrification

9.4 Improvement of infrastructure and industries by introducing environmentally friendly technologies and industrial processes
Contribution to decarbonization through electrification

Farm & Industrial Machinery

Development of REXIA Series Tractor for Domestic Market with "Go-Straight Function"

Tractor Engineering Dept. Ⅱ / Farm and Industrial Machinery R&D Dept. Ⅰ
Farm and Industrial Machinery R&D Dept. Ⅳ / Farm and industrial Machinery R&D Dept. Ⅵ

The Japanese agricultural sector is undergoing a significant transformation, characterized by an aging workforce, farm consolidation, and increasing farm sizes. These larger-scale farms face the challenge of managing their operations efficiently and sustainably. To address these challenges, Kubota is actively developing smart agriculture technologies that attempt to enhance production efficiency, reduce labor requirements, and alleviate the physical demands of farm work. Kubota has already launched a self-operating tractor,however, now it has developed the "Rexia-GS" tractor that features a go-straight function for entry-level model. This innovative feature demonstrates Kubota's commitment to providing farmers with practical and effective smart agriculture solutions.

【Key Word】
Smart Agriculture, AutoSteer Systems, GNSS, Electronic Control

Related SDGs

1. Introduction

The number of farmers in Japan is declining due to an aging population and a lack of successors. On the other hand, the area of arable land per agricultural management entity is increasing due to the concentration and consolidation of farmland, and thus, agricultural machinery needs to be more efficient and less labor-intensive for farmers to use. To achieve greater efficiency, higher precision, labor savings and lighter labor, Kubota is marketing a straight-ahead automatic steering function (go-straight function) for rice transplanters and small-to-medium horsepower tractors using the Global Navigation Satellite System (GNSS). Kubota already sells the AgriRobo tractor in the large horsepower range but has expanded its lineup by adapting the go-straight function to the 60-70 horsepower range to offer an entry-level model for smart agriculture (Fig. 1).

Fig. 1 "Rexia-GS" with Go-Straight Function

The go-straight function is a function that automatically controls the steering wheel based on GPS location information to drive straight in the direction along a reference line. The main procedure for using the go-straight function is shown in Fig. 2. (1) Drive the tractor in the field to the position where the reference line starts and operate the monitor mounted on the tractor to acquire point A. (2) Manually drive straight ahead to reach the end point and acquire point B. From the starting points A and the end point B, an azimuth angle is calculated by the electronic control unit (ECU) that controls the go-straight function. The straight-line connecting points A and B is the reference line. (3) After moving to the driving start position and turning on the go-straight function, straight driving parallel to the reference line starts under the control of the ECU. (4) After driving to the final position, the go-straight function is turned off to end the straight driving. This report explains the newly developed Rexia tractor technology with the go-straight function.

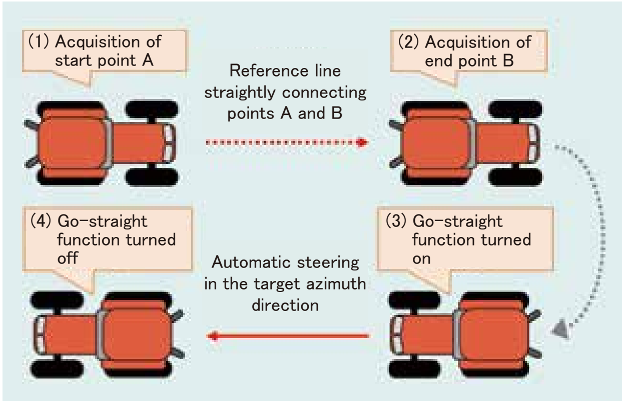


Fig. 2 Main Procedure for Go-Straight Function

2. Development concept and target values

2-1 Development concept

A greater need for simple and easy-to-understand operation is expected as the number of operators less familiar with farming increases due to the aging and retiring of farmers. As the working time gets longer and lighter labor is desired due to the increasing area of farmland per farmer, we have set the development concept as follows.

(1) The product developed must provide versatile, high-precision straight driving control that can be adapted to a wide variety of field crop operations.

(2) The product must be easy for inexperienced operators to use.

(3) The product must allow comfortable operation.

2-2 Development goals

The goals for development according to our concept are as follows.

(1) Supporting a wide variety of models and work

Highly accurate straight driving control should be possible for a total of 32 models, including wheel and crawler models with different horsepower ratings and different tire and crawler types. The product should be able to handle the field crop work specific to Rexia tractors.

(2) Easy operation

The product should allow the reuse of target azimuths used in past work so that even operators unfamiliar with the operation can easily set target azimuth.

(3) Improved usability

A telescopic mechanism should allow the operator to work comfortably. In addition, voice guidance that acts on the worker's auditory sense should allow the worker's visual sense to focus on the job.

3. Technical issues to be solved

3-1 Straight driving control technology

3.1.1 Challenges of adapting go-straight technology to many models and many types of work

Since each type of work has different conditions, such as driving speed and load on the tractor, automatic steering control suitable for the work is required. In addition, optimal control depends on equipment conditions such as the type of tires and tread of the tractor being used, as well as field conditions, so the challenge was to provide versatile control.

3.1.2 Forced steering control during hill-based plowing

One of the operations that require operator proficiency is plowing. There are two types of plowing operations: hill-based plowing, in which all wheels keep on the hill away from the furrow created by the previous plowing process, and furrow-based plowing, in which the wheels on one side of the tractor fall into the furrow. In hill-based plowing, it is necessary to maintain a constant distance from the track of the previous process to prevent the wheels from falling into the furrow. Nevertheless, when actually driving a tractor using the go-straight function on a trial basis, it was found that the front wheel fell into the furrow and became uncontrollable. Therefore, the challenge was to control the tractor so that its wheels would not fall into the furrow.

3-2 Setting target azimuth

To use the go-straight function, a tractor must be manually driven along a field edge to establish a start point A and an end point B to determine a target azimuth. The challenge was how to save the time and effort of driving in the field in advance to set a target azimuth each time.

3-3 Adoption of support functions

3.3.1 Telescopic structure

A telescopic mechanism was adopted to reduce labor requirements, but because the motor for automatic steering in the go-straight function is located under the steering wheel, there were issues of providing the force to hold the telescopic mechanism and of keeping enough foot space.

3.3.2 Voice guidance

Voice guidance is a support feature that helps the operator focus on the work equipment and operation by reading out instructions and error information displayed on the monitor. We decided to add voice guidance for the first time in tractors. By using the voice guidance, the operator can understand the operation and control status of the machine in a timely manner. However, the challenges were in developing a voice that could be easily heard in the cabin during operation and in developing a system that could be easily updated and maintained to reflect functional enhancements, etc.

4. Developed technology

4-1 Versatile control technology with high straight driving accuracy

4.1.1 Go-straight technology for many models and many types of work

To achieve high accuracy of straight driving control regardless of implements and work conditions, control tuning is performed specifically for each job. Since the required control conditions vary for many models with different horsepower and tire specifications, as well as tread and field conditions, versatility was ensured by providing seven levels of control sensitivity, selectable for each operation (Fig. 3). As shown in Fig. 4, there are seven sensitivity levels: 0 for the normal setting; +1 to +3 for higher sensitivity levels for higher ground resistance, such as on muddy or clayey ground, where steering requires a lot of force; and -1 to -3 for lower sensitivity levels for lower ground resistance, such as on hard, dry ground, where steering can be done with small force or where the vehicle swings easily to the left or right.

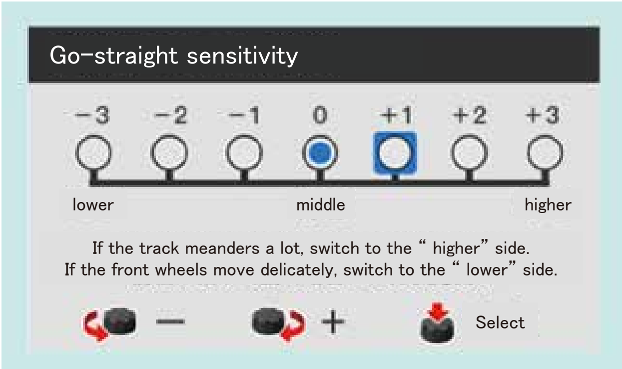


Fig. 4 Sensitivity Setting on Monitor Screen

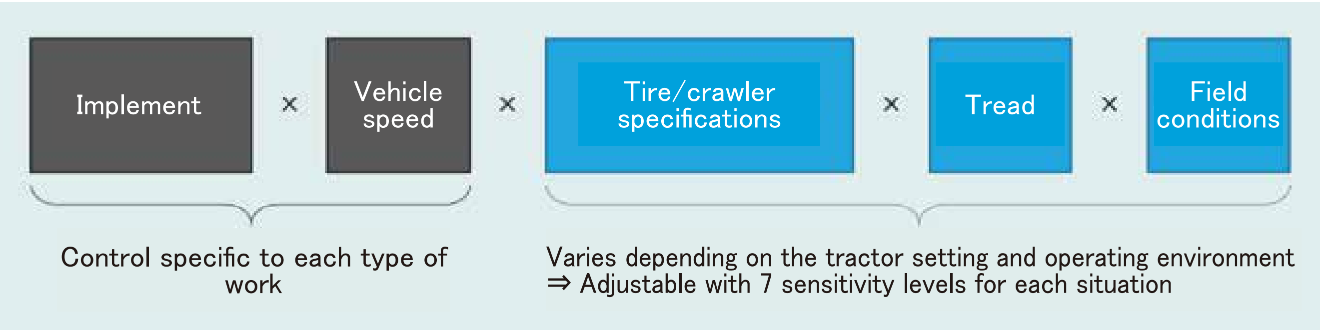


Fig. 3 Combination of Required Controls

4.1.2 Adding the function of forced steering control during hill-based plowing

In the process of the control tuning of hill-based plowing, it was found that a front wheel falls into the furrow because the way the load is applied to the plow varies greatly depending on the soil and field conditions and because the system cannot handle a sudden load due to unevenness in the residual tillage, and therefore, the normal straight driving control alone cannot handle the sudden load applied to the plow. Since skilled operators anticipate these conditions and respond by steering, a function that could respond to the above irregular conditions, in addition to straight driving control, was needed. To avoid a wheel from falling into the furrow created in the previous process, which is a particular problem of hill-based plowing, a function has been added to the normal straight driving control to allow the steering to be turned away from the furrow by means of a correction switch. Specifically, the straight driving control is temporarily suppressed only while the correction switch is held down continuously, allowing the driver to force the steering to turn in the direction indicated by the pressed switch. An upper limit on the steering angle was set to prevent the tractor from excessively deviating from the target line due to a long push. When returning to straight driving control after forced steering, the controller will moderate the re-entry until the target line is reached. As a result, the ability of a skilled operator to avoid falling into the furrow by steering and to continue working without disturbing the created track is reproduced only by operating the correction switch (Fig. 5).

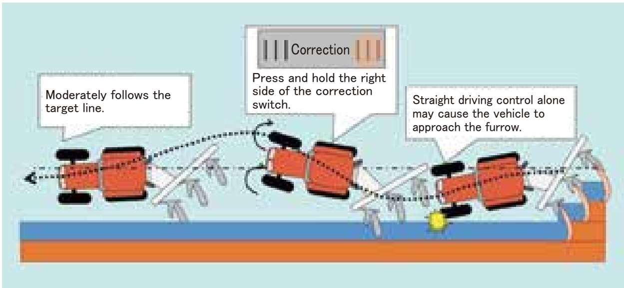


Fig. 5 Example of Forced Steering Control

4-2 System developed for reusing target azimuths

If the target azimuths used in previous work can be reused, the work can be made more efficient by eliminating the need to drive accurately over the field in advance to set a target azimuth each time. To implement this function, we developed a system that can reuse target azimuths by using the Kubota Smart Agri System (KSAS), a farm management support system provided by Kubota. Figure 6 shows a typical case of using the KSAS-based target azimuth reuse system. (1) Acquire start point A and end point B in the field and determine a target azimuth (set the work type, work width, etc., if necessary) or input a target azimuth via the in-vehicle monitor. (2) Use the target azimuth to perform automatic steering with the go-straight function. The target azimuth used here is automatically uploaded to the KSAS. (3) In the next plowing process, operate the tractor and smartphone to download the target azimuth uploaded to the KSAS. (4) Use the downloaded target azimuth to perform automatic steering by the go-straight function.

Regarding the system development, we describe below the automatic saving function when uploading a target azimuth and the pre-configuration screen for downloading.

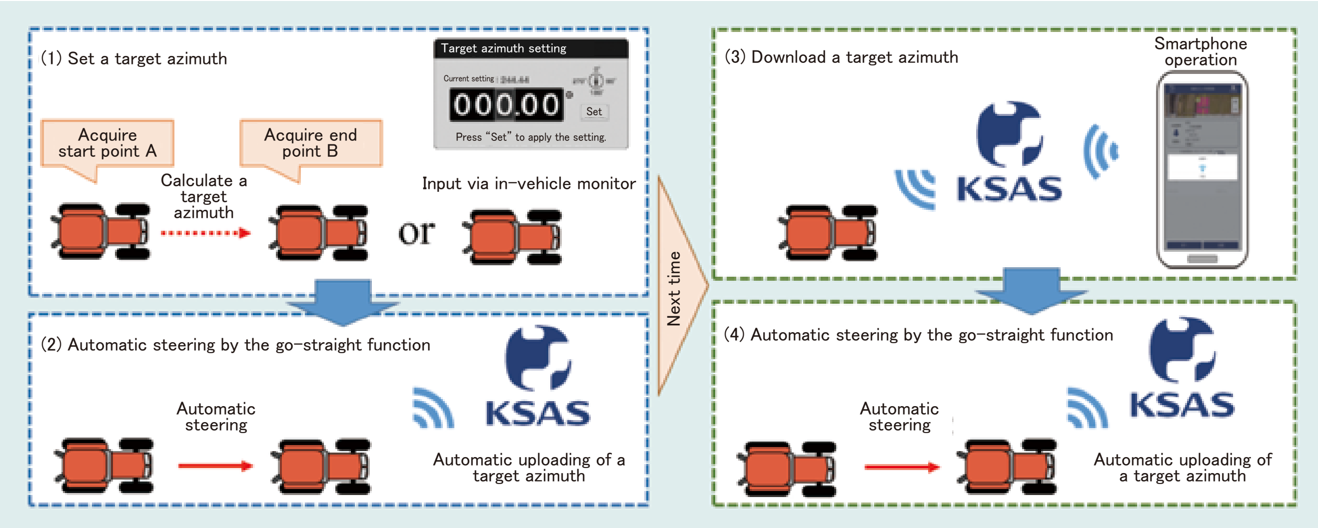


Fig. 6 System for Reusing Target Azimuth

4.2.1 Automatic saving of target azimuths

Kubota already offers a service that uses a direct communication unit to provide wireless communication between the tractor and the KSAS server. The direct communication unit has the ability to automatically store vehicle information and upload it to the KSAS server. All target azimuth information, set using this function, can be uploaded to the KSAS server, making it easy to store target azimuths. However, if target azimuths are created incorrectly, unnecessary reference lines are also saved, and when trying to reuse data, it takes time to find a needed target azimuth. To solve this problem, we decided to save only the target azimuth at the time of starting and ending the go-straight function. This prevents unnecessary target azimuths from being stored by saving only the target azimuths actually used for the go-straight function.

4.2.2 Target azimuth pre-configuration function

To shorten the time required to operate smartphones in the field when reusing target azimuths, we have made a design which separates the operations of the work instructor from those of the field operator. The work instructor can set the target azimuth and other information to be downloaded for each field in advance, and the field operator driving the tractor in the field need only perform the download. The flow of smartphone operation for pre-configuration and in-field downloading is shown in Fig. 7. This approach is expected to improve work efficiency by eliminating time-consuming and judgment-intensive operations for workers in the field.

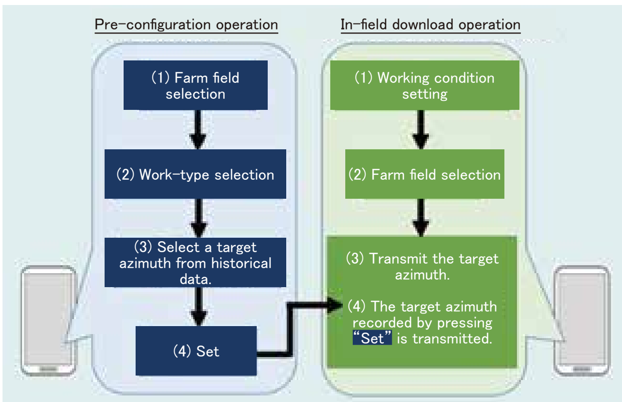


Fig. 7 Operation Flow for Pre-Configuration and In-Field Downloading

4-3 Development of support functions

4.3.1 Development of telescopic structure

4.3.1.1 Telescopic structure with go-straight function

Since the gearbox and motor for the go-straight function are added below the steering wheel, it is necessary to introduce a telescopic locking mechanism that can withstand the weight of the added gearbox and motor. By adopting a structure that generates a telescopic locking force by deforming the cylinder with the entire cylindrical wedge section as shown in Fig. 8, a large holding force can be applied. This forms a telescopic structure with the go-straight function.

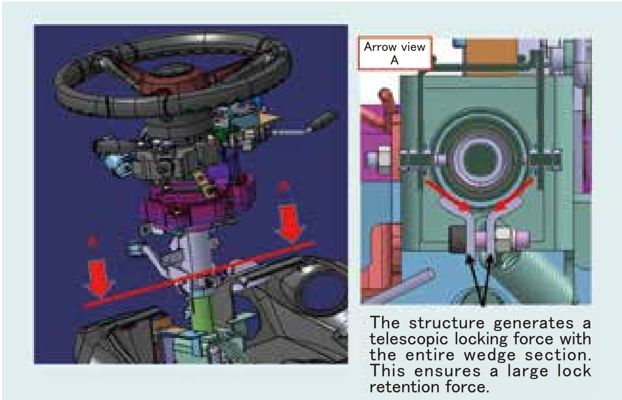


Fig. 8 Structure of Telescopic Mechanism

4.3.1.2 Structure of the telescopic locking lever

To allow room for the feet, the telescoping locking lever is designed to lock the steering wheel position by pulling the lever down. In this structure, when the steering wheel position is unlocked by pulling the lever upward, the lever moves downward under its own weight, resulting in a semi-locked state, which increases the sliding resistance during position adjustment and makes the adjustment difficult. Therefore, the lever is secured by a retainer to prevent the lever from moving down under its own weight and to keep the steering wheel in the unlocked state. Accordingly, this structure prevents a semi-locked state, allows easy operation, and creates foot space (Fig. 9).

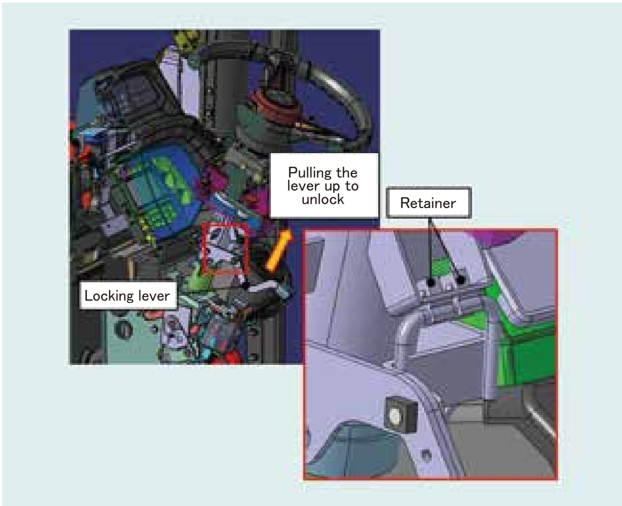


Fig. 9 Structure of Telescopic-Locking Lever

4.3.2 Voice guidance technology

The three elements required to realize voice guidance, that is, voice data, voice playback software and voice playback hardware, were previously provided by an off-the-shelf guidance unit installed on other Kubota products, but are now being produced in-house to facilitate maintenance and improve development efficiency.

4.3.2.1 Implementation of voice guidance

In the new configuration, a microprocessor and playback circuitry are built into the ECU, and audio is played on demand via software (Fig. 10). To obtain the loudest sound possible, the dynamic range of audio waveforms is compressed to increase the average sound pressure level, and a large-diameter loudspeaker typically for car stereo applications has been adopted. In addition, the speakers are housed in a rigid sheet metal case to ensure sufficient sound pressure in the low-frequency range and to prevent resonance. This allows the volume to be loud enough for the operator to hear over the noise while working. In addition, the volume can be selected from three levels to meet the user's preference. Speech speed has been optimized through usability testing on a real machine to ensure that messages are delivered reliably. The approach above has made it possible to implement a voice guidance unit that easily conveys information to the operator.

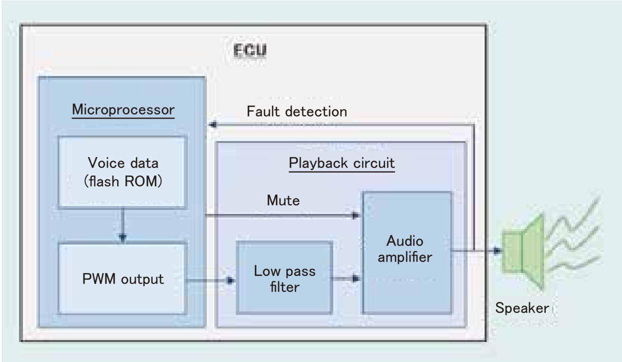


Fig. 10 Hardware Configuration for Audio Playback by ECU

4.3.2.2 Voice data development

In the development of this product, automatic speech synthesis was introduced to eliminate the need to record a physical voice and to enable easy replacement and maintenance of the voice data required for the go-straight function. Although a higher sampling frequency improves the sound quality, a larger amount of memory is required for the audio data. In terms of this trade-off, a sampling frequency was chosen at the minimum specification required for accurate comprehension of the message by actual listening of voice data at multiple sampling frequencies in a real vehicle. The voice phrases were divided into multiple voice parts, retaining natural intonation, so that the volume of voice data could be reduced by using the same words and phrases over and over again, which contributed to lowering the product price by storing a reduced volume of data in the microprocessor's internal memory.

5. Conclusion

With this development, Kubota's lineup of tractors with the go-straight function is now complete, from low to high horsepower, and the newly developed model can be used as an entry-level machine for smart farming. We also believe that this development can contribute to reducing user fatigue because even operators unfamiliar with agriculture can work easily and comfortably. The market for smart agricultural machinery is expected to continue growing, and automation technology is essential to Japanese agriculture. We intend to further extend our technology, develop better products and contribute to Japanese agriculture.

Contribution to SDG targets

2.1 Eradication of hunger
Contribution to increased food production through labor-saving agricultural production

8.2 Increased productivity through innovation
Contribution to increasing the efficiency of agricultural operations through the automatic steering function

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

Farm & Industrial Machinery

Development of Electric Zero-Turn Mower Ze series for the European Market

Tractor Engineering Dept. Ⅲ
Farm and Industrial Machinery R&D Dept. Ⅱ

In 2024, Kubota will introduce the electric Zero Turn Mower Ze series (Ze-481/Ze-421) for the European market. The Ze series is Kubota's first lithium-ion battery-powered riding lawn mower developed for professional markets such as municipalities and contractors operating within the Europe. It features a replaceable battery pack mechanism, multiple motors, and inverters for driving and mowing to enable the one-day work required by professionals. We will introduce novel developed mechanical structures and vehicle control technology, battery packs, and an electrification system development technology that contribute to the conservation of the global environment and achieve these goals.

【Key Word】
Electrification, Lithium-Ion Batteries, Motors/Inverters, Coordinated Control

Related SDGs

1. Introduction

As a sustainable company that promotes environmental management, Kubota has set the challenge of achieving zero environmental impact in its Environmental Vision for 2050, taking into account various societal trends such as the SDGs and the Paris Agreement. To achieve this goal, Kubota is launching the Ze Series Electric Zero Turn Mower (Ze-481/Ze-421) as an environmentally friendly product for the European market, where interest in electrification is high (Fig. 1). The Ze Series is Kubota's first lithium-ion battery-powered riding lawn mower developed for the professional market, including customers such as municipalities and contractors in Europe.

Fig. 1 Ze Series (Ze-481)

2. Development concept and target values

2-1 Development concept

In developing an electric zero-turn mower for the professional market, customers asked for the ability to run the machine all day with a high level of operability and performance comparable to conventional engine-driven machines. As Kubota's first full-electric zero-turn mower, it uses electrified components such as a battery pack, inverters, and motors that have not been adopted in conventional engine-driven machines. This made it necessary to ensure safety, reliability, and durability, especially for products using lithium-ion batteries.

Therefore, the development concept was to offer a safe and reliable electric zero-turn mower for the professional market, capable of working all day long with a high level of operability, performance, and durability.

2-2 Target values

In order to realize an electric zero-turn mower that meets the above concept, we set the following development goals.

(1) Achieving a full day's operation (6-8 hours) required by professionals

It is difficult to install a battery pack with sufficient capacity for a full day's work due to space and weight constraints associated with meeting the required features and performance of a zero-turn mower. Therefore, the battery pack should be replaceable and easy to charge, replace, and connect to a vehicle.

(2) High operability and mowing performance for professional users

It is necessary to ensure the operating feel of hydrostatic transmissions (HSTs), which have been improved over and over, and the same work performance as engine-driven machines through logical electronic control.

(3) Ensuring safety, reliability, and durability for long-term use

It is necessary to ensure the level of safety, reliability, and durability of conventional Kubota products, even in the company's first electrified model, while meeting the UN transportation standards, European battery pack standards, and other battery standards.

3. Technical issues to be solved

3-1 Realization of 6 to 8 hours of operation time required by professionals

A 10 kWh battery pack of about 90 kg in weight was adopted. The main challenge was to install the heavy battery pack as a replaceable structure at the rear of the zero-turn mower, while adapting the structure to the vibration and environment of the vehicle.

To make the replaceable battery pack rechargeable both while mounted on the vehicle and independently, the challenge was to develop a replacement battery pack that could be recharged during mowing operations without control from the vehicle control unit (VCU) by adding a charger control function to the battery management unit (BMU).

3-2 High operability and mowing performance for the professional market

Zero-turn mowers are popular in the professional market because they can run straight ahead or make agile movements with a single point turn using the left and right control levers. The independent left and right HSTs that make this possible were replaced by electric transmissions consisting of a VCU, inverter, and motor. However, implementing precise speed control resulted in poor straight driving performance, and changing control parameters to improve the straight driving performance resulted in poor turning performance. This is because when the operator corrects the travel path, lever actions result in simultaneous forward/reverse and turn commands, losing the analog characteristics of the HSTs. A major challenge was to use digital control to achieve the agility and smoothness of operation comparable to the HSTs on the existing zero-turn mowers.

Fig. 2 shows the configuration of a conventional engine-driven machine.

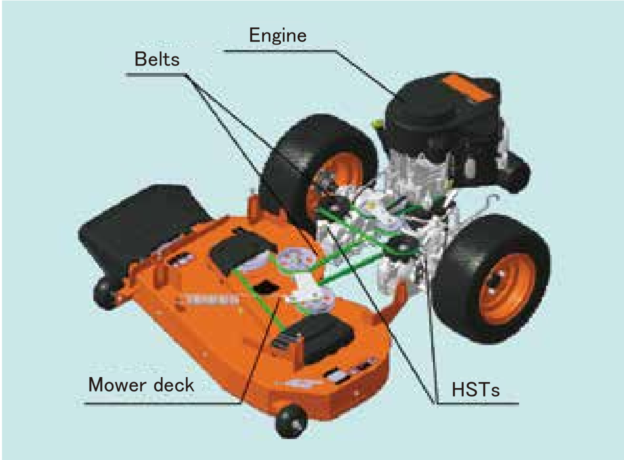


Fig. 2 Drive Unit Configuration of Engine-type Zero Turn Mower

In engine-driven machines, when a large load is applied to cause the blade rotation to drop, the engine rotation and the HST speed will also drop, allowing the blade rotation to return naturally. The newly developed Ze Series is equipped with a single deck motor on the mower deck, which is responsible for mowing, in addition to independent electric transmissions on the left and right sides. Motors and inverters can deliver more than their rated power in a short period of time, and the output balance must be controlled not by the operator but by the VCU, which is responsible for vehicle control, via coordinated control of multiple motors (Fig. 3).

When the travel motors and deck motor are controlled separately and a large load is applied to cause the blade rotation to drop, the machine can continue to run even when the blade is stopped, and the operator may operate the machine without noticing the lawn left uncut. Therefore, the operator must always be concerned about whether or not the lawn is left uncut during operation.

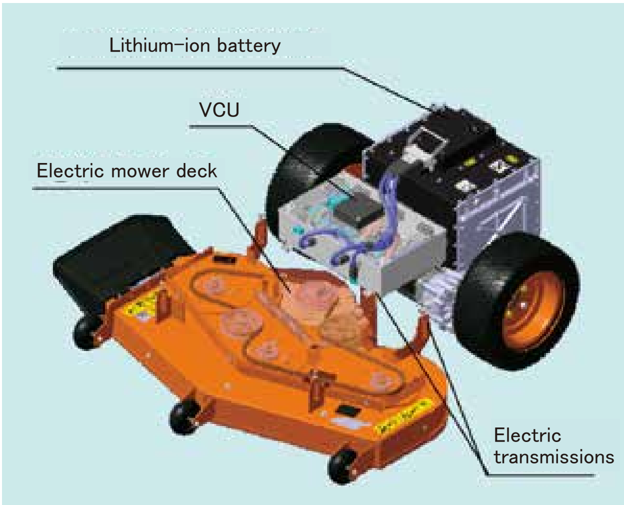


Fig. 3 Drive Unit Configuration of Electric Zero-Turn Mower

3-3 Ensuring safety, reliability, and durability for the first electrified model

In achieving safety, reliability, and durability as Kubota's first electrified model, the challenge was to make the battery pack comply with the UN transportation standard UN 38.3[1)] for export from Japan, which is the place of manufacture, to Europe, as well as the European industrial lithium-ion battery standard EN 62619:2017.[2)]

For the motor, inverter, and charger, the challenge was to divert components adopted in industrial machines, such as forklifts, and to pass the various performance, durability, and reliability tests traditionally performed in the development of engine-driven machines.

4. Developed technology

4-1 Replaceable battery pack technology

4.1.1 Development of replaceable battery pack technology

To make the battery pack replaceable, which is a heavy item, it was necessary to create a structure that can be easily replaced by human labor and develop a mechanism and control function that can charge the battery both while mounted on the vehicle and independently.

4.1.2 Solutions for replaceable battery pack technology

The battery pack mounted at the rear of the vehicle needs to be raised approximately 190 mm to allow the vehicle to drive over roadside curbs and other obstacles. The structure developed to perform this task manually is shown in Fig. 4. By moving the center of gravity of the battery pack closer to the roller support on the vehicle side and by providing at least 10 times longer distance between the support and the point of effort on the lever of the carrying kit, the heavy battery pack can be easily lifted with 1/10th or less of the force.

Furthermore, instead of a bolt-fixing structure that requires a tool to replace the battery pack, a locking structure, which is conventionally used to attach heavy objects such as implements, was adopted to facilitate replacement. The replacement mechanism developed can withstand the vibration and shock of zero-turn mowers.

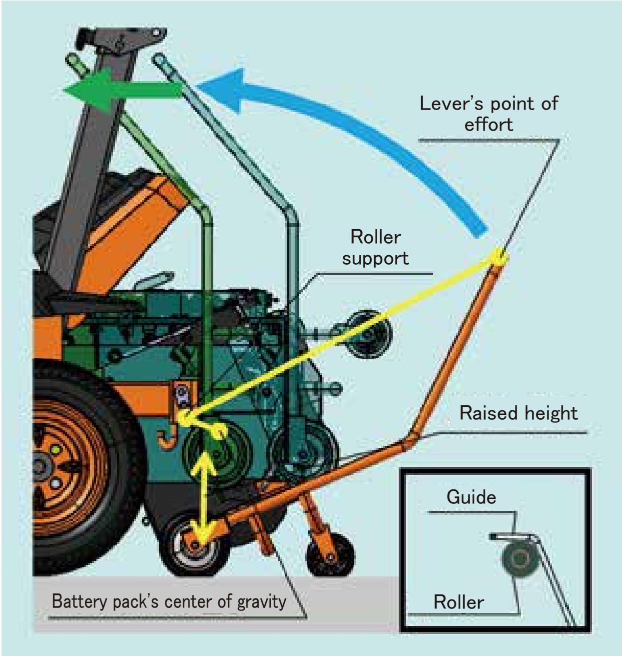


Fig. 4 Operating Force of Replaceable Battery

To function as a replaceable battery pack, it must be able to be recharged both while mounted on the vehicle and independently. To provide this function, the battery pack was designed to have a power connector for connecting with the vehicle side and a charging connector on the top of the battery pack (Fig. 5). In addition, the BMU built into the battery pack acts as a master, providing optimal current commands based on charging conditions such as temperature and voltage, thereby enabling safe charge control.

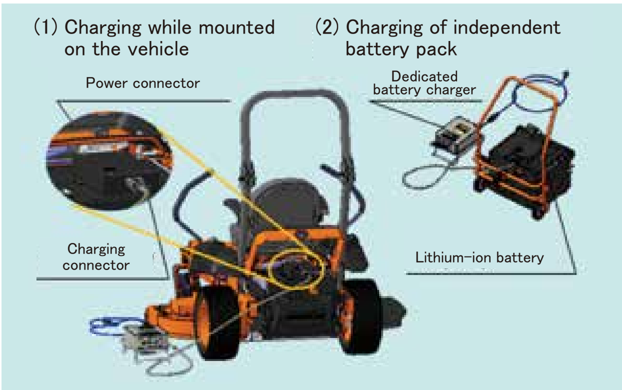


Fig. 5 How to Charge the Battery Pack

4-2 Technology for coordinated control of multiple motors

4.2.1 Development of coordinated control technology for multiple motors

When each of the three on-board motors (the left- and right-drive motors and the deck motor) is controlled separately, straight driving operation is difficult because, for example, the movement of the vehicle by the right-drive motor becomes a disturbance to the speed control of the left-drive motor. Since the drive motors are not affected even if the deck motor is overloaded, an unfavorable situation occurs where the vehicle runs with reduced blade rotation. The challenge was to solve such problems and achieve clean cutting marks while maximizing the performance of the deck motor.

4.2.2 Solutions for operational control technology

The Zero-turn Mower is a smooth-running, small-turn riding lawn mower, in which the speed of the left and right tires is controlled independently with the left and right control levers. For full electrification, HSTs were eliminated and replaced with electric motors, which resulted in precise speed control of the left and right tires, causing meandering cutting marks due to oversensitive jerky operation. Therefore, the problem of untidy cutting marks arose in the early stages of development (Fig. 6).

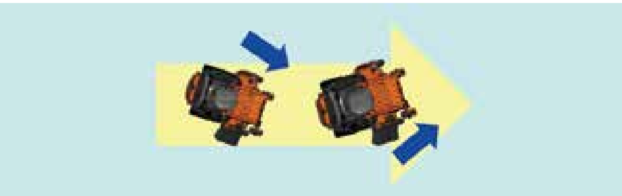


Fig. 6 Hypersensitivity of Electric Zero-Turn Mower (Early Development)

Since conventional machines had a parking brake lever separate from control levers, there was a need for an easy-to-use brake mechanism. We therefore realized smooth driving performance equivalent to HSTs even with electric motors by adjusting control parameters, and we have developed an automatic parking brake function with control levers, utilizing precise control provided by electrification.

(1) Smooth electric driving system

We developed a control algorithm to incorporate the dynamic characteristics of HSTs into the electric driving system. An example of the dynamic characteristics of HSTs on an engine-driven machine is shown in Fig. 7. The area enclosed by the square shows a left-turn situation, where the left tire (L-tire) rotates at a higher speed than the speed commanded by the L-lever, and the right tire (R-tire) rotates at a slower speed than the speed commanded by the R-lever. In the zero-turn mower, the left and right control levers independently control the tire speed, and the rotation of one tire acts as a disturbance to the other tire, whereas the hydraulic response delay (analog characteristic) in the HSTs reduces the speed control sensitivity of the control levers and suppresses oversensitive responses.

In the electric driving system, this characteristic is also implemented through arithmetic operations; i.e., smooth operation control is achieved by logic control using formulas expressing natural output torque responses that reflect the hydraulic control characteristics of HSTs (Fig. 8).

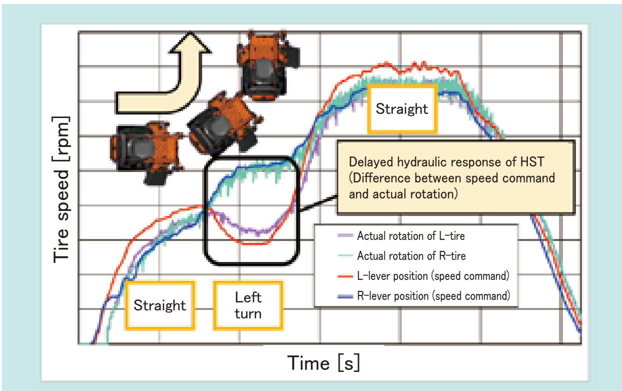


Fig. 7 Engine Machine Operation Command and Actual Tire Rotation

Fig. 8 Straight Forwardness Improved by Control Algorithms

(2) Automatic parking brake function

Unlike HSTs, electric transmissions can precisely control the rotation speed of the wheels. Using this characteristic, when the left and right control levers are coincident, the control becomes faithful to the lever commands. By combining this performance with a mechanism that always opens the left and right control levers when the operator leaves the driver's seat, the vehicle can be decelerated as if using the dynamic brake of HSTs and then the speed is precisely controlled to zero using electric technology. This has led to the development of an automatic parking brake that enables safe and smooth start/stop operation even on a slope by opening the left and right levers when the operator leaves the driver's seat (Fig. 9).

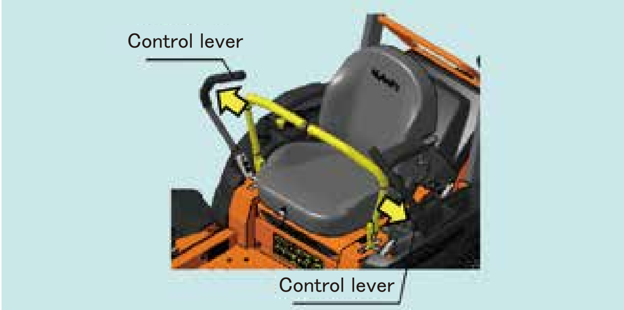


Fig. 9 How to Apply the Automatic Parking Brake

4.2.3 Solutions for mowing performance control technology

It is important to maintain the set speed of the deck motor to achieve high mowing performance acceptable to professionals. In order to maintain blade rotation under high loads and to work with no uncut areas remained, we developed a load-based, work speed coordinated control technology (K-SENSE™) (Fig. 10).

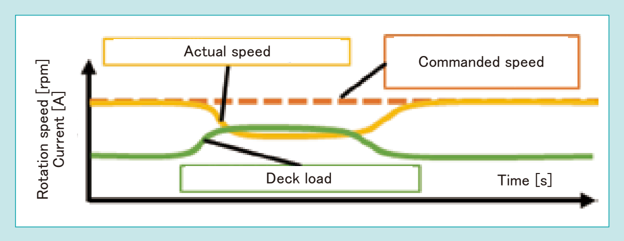


Fig. 10 Coordinated Control of Drive Motors for Mowing Loads

Even if the operator's driving lever operation (rotation speed command to the drive motors) is constant, the embedded coordinated control system automatically reduces the commanded speed of the drive motors temporarily according to the load and restores the speed when the load is removed. The load varies not only with the mowing width and the set cutting height of the mower deck, but also with various conditions such as the type and density of the grass in the field. To handle the various mowing conditions, the threshold value of the motor current is set in stages so that the running speed is reduced less if the load is small and reduced more if the load is large. As soon as the load decreases due to a reduction in grass density or other factors, the running speed is automatically increased to minimize the reduction in working speed while improving mowing performance. It eliminates the need for the operator to perform delicate lever operations to create clean cutting marks and allows the operator to fully use the power of the deck motor by controlling the amount of grass fed into the mower (Fig. 11).

Fig. 11 Cutting Marks with and without Cooperative Control

4-3 Development of battery pack and electrified system technology

Important technologies for developing safe and durable battery packs while ensuring required performance include technologies for battery cell selection, safety control, and reliability assurance. These were combined to develop battery packs dedicated to the Ze Series. We also worked to develop technology that accurately calculates remaining battery capacity for professional customers to schedule work. These technologies are described below.

For the battery cell selection technology, we adopted Company A's battery module for mass-produced electric vehicles, based on our years of independent evaluation of each battery module's characteristics for charge/discharge, heat generation, ambient temperature, and degradation. By adopting laminated battery modules with good volumetric energy density and output characteristics, we have developed a battery pack that is compact (approximately 64 L), powerful (up to 10 kW), and long-lasting (warranty period: 3 years of 1500 hours) (Fig. 12).

Safety control technologies were applied to a dedicated BMU to develop two new functions: (1) battery cell control and (2) battery cell balancing functions.

(1) Battery cell control function: Six modules are arranged inside the battery pack, with battery cells in each module. Thermistors are installed to monitor module temperatures, and the BMU constantly monitors the voltage, current, and temperature status of each module and controls charging and discharging to ensure that the threshold values are not exceeded. Furthermore, a fail-safe system is incorporated to ensure safety by adding a relay that can release both poles of the main circuit and a fuse that interrupts the circuit in the event of a battery pack malfunction due to unforeseen circumstances.

(2) Battery cell balancing function: Repeated charging and discharging results in variations in battery cell voltages. The greater the voltage variation, the greater the load on a single cell and the possibility of excessive discharge or charge. We have, therefore, developed a balancing function that monitors all cell voltages and currents and automatically balances cell voltages by connecting the cell with the highest cell voltage to a balancing discharge resistor even during operation. We have also developed a control technology that prevents overcharging even in the event of voltage imbalance by calculating the charging current based on the maximum cell voltage and module temperature, rather than on the total battery voltage.

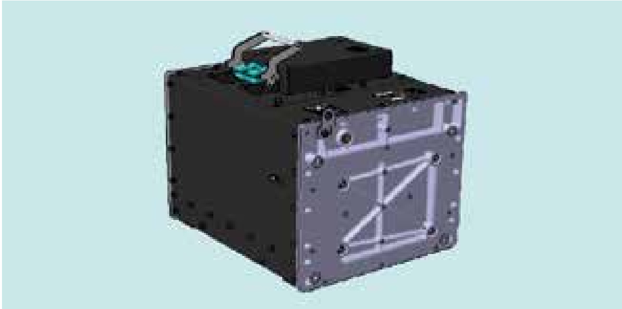


Fig. 12 Battery Pack for Ze Series

As another important reliability technology to ensure safety, we developed a thermostatic chamber to reproduce the working environment and a charge-discharge cycle test system that can reproduce actual workload conditions. The durability and cycle life required for professional applications were efficiently verified in-house by conducting multiple tests of more than 1,000 hours with this equipment. In addition, an environment was created that allows in-house testing of vibration, shock, and high temperature under the test conditions specified in UN 38.3 and EN 62619:2017, reducing the time required to pass certification tests.

In addition, an important technology for battery packs is the highly accurate calculation of remaining capacity. Batteries are prone to variations in remaining battery capacity at low temperatures and low remaining capacity. We have, therefore, developed a remaining capacity correction algorithm that correctly displays the remaining capacity by determining the ratio of the cumulative discharge current to the amount of current that can be discharged and then multiplying this ratio by a correction factor to determine the remaining capacity.

We have also provided maintenance tools and telematics devices to monitor data such as module temperature, cell voltage, and the number of recharges for these modules. The combination of these technologies has resulted in a safety function that meets the safety level of ISO 13849-1 (PL level C or higher) as required by the EN 62619:2017 standard.

Since motors and inverters are items that are purchased, it is important to conduct follow-up tests in a vehicle test environment to re-evaluate them according to Kubota's standards to ensure their safety and quality. Therefore, using a newly built electric system evaluation system for reliability and durability evaluation, we conducted a total of more than 30 reliability tests. They include various temperature and vibration endurance tests of motors, inverters, and VCUs, as well as endurance tests of more than 1,000 hours, and tracked reliability and durability performance in the mower's workload environment. In addition, the dedicated charger was tested together with the battery pack for durability during insertion and removal from the charger port, and its durability was confirmed to exceed the number of uses assumed by the vehicle endurance time. Finally, a control system that takes the heat balance into account was implemented, and a high-temperature bench test simulating the real load environment confirmed that the mower can operate continuously from the fully charged state to the empty state of the battery pack, thus achieving an electric system adaptable to the high temperature environment of Europe.

We have developed the battery pack and other technologies, conducted preliminary evaluation and verification tests, and passed the European field test in a single attempt. We have thus developed technologies including Kubota's first battery pack for electric mowers and achieved an electrified system that is safe, reliable, and durable.

5. Conclusion

Kubota has developed the Ze Series Electric Zero-Turn Mower powered by lithium-ion batteries to help realize a sustainable society. In light of market evaluations and requests, we will develop mowers that are even easier to use and operate by improving product specifications and controls.

Based on the technologies developed, we will expand our lineup of electrified products, such as other models of lawn mowers and compact tractors, and continue our efforts to provide attractive electrified products to the market and contribute to attaining the SDGs.

Contribution to SDG targets

7.3 Improvement of energy efficiency
Energy efficiency improvement of 50% or more compared to fossil fuel use

9.4 Improvement of infrastructure and industries by introducing environmentally friendly technologies and industrial processes
Development of electric system control technology

13.2 Formulation of policies on climate change measures
Introduction of products that conform to European policies to contribute to a 90% reduction in CO_2 emissions

Reference

1) UN Recommendations on the Transport of Dangerous Goods: UN 38.3 (Primary and Secondary Lithium Batteries and Their Transportation)
2) EN 62619:2017 Secondary cells and batteries containing alkaline or other non-acid electrolytes
-Safety requirements for secondary lithium cells and batteries for use in industrial applications

Development of Seven-Row Head-feeding Combine Harvester DR7130

Combine Harvester Engineering Dept.

In Japan, fallow land, which is increasing due to the aging of farmers and shortage of successors, is being consolidated to large-scale farmers. Consequently, the amount of crop fields per household to farmers is increasing, which necessitates the improvement of work efficiency. In addition, to improve management efficiency, the planting of new demand rice such as feed rice is increasing; however, these varieties have limitations such as long culms that are difficult to reap. To address these limitations, Kubota has developed a novel seven-row combine harvester "DR7130" that combines "optimal handling" and "crop transport performance." This paper introduces the development technologies that facilitate this novel concept.

【Key Word】
Combine Harvester, High Working Capacity, Good Handling, High Performance

Related SDGs

2 ZERO HUNGER, 8 DECENT WORK AND ECONOMIC GROWTH, 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE, 16 PEACE, JUSTICE AND STRONG INSTITUTIONS, 17 PARTNERSHIPS FOR THE GOALS

1. Introduction

In recent years in Japan, fallow land, which is increasing due to the aging of farmers and lack of successors, has been consolidated under operating farmers.[1] On the other hand, in order to make effective use of fallow land, the government has taken the initiative to provide a lot of subsidies for planting new demand rice products such as feed rice that are not for human staple food. Despite the long crop length of such varieties (hereinafter referred to as "long-culm varieties") and the difficulties involved in their reaping, farmers are increasing the acreage of such varieties to improve their business efficiency.[2] Under these circumstances, farmers need to harvest more area during the limited reaping season, and there is a growing need to improve work efficiency.

As a means of improving work efficiency, for example, it is possible to increase the number of farm machines and work with several machines at once to harvest a larger area. At the same time, however, the burden on farmers will increase as management costs increase due to the need to secure machines and personnel to operate the machines.

In addition, some users of the six-row combine harvester DR6130, which has been the flagship model so far, do the reaping work slowly rather than attaining the maximum speed of 2.05 m/s in order to reduce fatigue, and therefore it is not possible to meet their need for increased efficiency by increasing the vehicle speed.

For these reasons, we decided to develop a seven-row combine harvester that can reap more rows than the current DR6130 model to improve efficiency without burdening farmers.

2. Development concept and target values

2-1 Development issues and concept

Concerns with seven-row machines include poor handling due to the larger machine size, and a higher incidence of poor conveyance due to the increased crop handling volume and the additional conveyance path for the extra row compared to the DR6130, resulting in reduced work efficiency. We have developed a combine harvester that overcomes these issues caused by the increased number of rows and contributes to improved work efficiency.

As an optimal solution to the above issues, the new machine was designed to be equipped with Kubota's first seven-row reaper on the body of the DR6130, which is highly regarded in the market for its maneuverability and work capacity. Accordingly, our concept was to develop a seven-row head-feeding combine harvester that would combine ease of handling with adequate crop conveying performance (Fig. 1).

Fig. 1 Seven-row Head-feeding Combine Harvester DR7130

2-2 Target values

The increased number of rows reaped compared to the DR6130 reduces the number of turns required to harvest the same area of land. The efficiency of straight-line reaping is maintained at the same level as in the DR6130, and the overall efficiency is expected to improve by approximately 10% due to the reduction in the number of turns. The maximum working speed required for the DR7130 in this situation is calculated to be 1.8 m/s, compared to 2.05 m/s for the DR6130. In addition, market research indicates that not a few DR6130 users only use the machine at speeds up to 1.8 m/s because working at the maximum speed would cause high levels of fatigue. By operating the DR7130 at 1.8 m/s, it is also possible to reduce user fatigue.

3. Technical issues to be solved

3-1 Ensuring easy handling

The increased left-right width of the reaper due to the increase in the number of rows to seven can worsen maneuverability and operability, especially in the following two aspects.

3.1.1 Compatibility between the seven-row reaping width and truck loadability

Many operating farmers have a work system in which combine harvesters are loaded onto trucks and transported between scattered fields. However, if the seven-row reaper is configured in the conventional way, some parts have to be removed to load the machine onto a truck. There is concern that performing this task each time the machine is moved from one field to another would impair mobility and significantly reduce the overall efficiency of the harvesting operation.

3.1.2 Reaping work at edges facing walls and field ridges

Harvesting with a combine harvester is normally performed counterclockwise from the periphery of a field (Fig. 2). If the field is surrounded by walls or field ridges, and the right end of the reaper is situated inward from the outermost right side of the vehicle body, there is a possibility that some areas are left unreaped when the machine reaps along the perimeter (shown by red arrows in Fig. 2) or the side mirror may have to be folded each time to avoid contact, thereby reducing work efficiency. In particular, when the cabin was enlarged in the DR6130 to improve the comfort of the driver, the outermost edge of the cabin protruded beyond the right edge of the reaper. This issue needed to be solved in the new model, for which improved maneuverability was important.

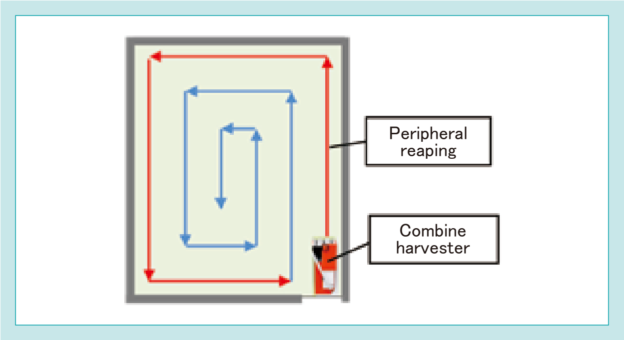


Fig. 2 General Reaping Work Path

3-2 Ensuring crop conveyance performance

In order to improve work efficiency with the seven-row harvester, it is essential that the harvester speed can be maintained as intended. However, there was concern that the increased number of crop conveyance paths and the characteristics of new rice varieties whose demand is expected to grow would increase the load on the machine and make it impossible to keep the targeted vehicle speed. In this regard, the following two challenges have been identified to ensure sufficient crop conveyance performance.

3.2.1 Reduction of load when reaping long-culm crops

In the reaping work of high-volume or long-culm crops, their ear tips tend to come into contact with various parts during conveyance, which creates resistance and tends to disrupt the posture of conveyance. If the crop is fed to the thresher in a disorderly manner, the threshing load increases, and it becomes difficult to maintain the targeted vehicle speed, resulting in reduced work efficiency.

3.2.2 Ensuring conveyance performance of the extra one-row frame

Some seven-row harvesters made by other manufacturers have a configuration in which the drive unit of the extra intermediate conveyor is located upstream of the conveying action section. In this configuration, force is transmitted in the direction of pushing the conveying action section. As a result, the conveyor chain tends to loosen and the conveying performance becomes unstable.

4. Developed technology

4-1 Compact reaper

4.1.1 Consideration of compactness

In order to load the machine as it is on the bed of a typical 7-ton truck, the portion of the machine within a side panel height of up to 400 mm must be kept within a width of 2,400 mm, which is the inside dimension between the side panels. Meanwhile, the spacing between planted rice rows is generally 300 mm, or 330 mm in some areas such as Hokkaido, and a simple calculation indicates that a reaping width of 2,310 mm is required to reap seven rows of rice. Although this width is within the internal dimension between the side panels, in reality, functional and exterior components such as reinforcement members associated with split pipes, as well as side covers and a left split pipe are required. Based on the dimensions of the exterior components of the existing six-row reaper, the overall reaper width was determined to be 2,460 mm, which would exceed the width of the truck bed.

4.1.2 Solutions for compactness

(1) Split pipe arrangement

While the standard crop spacing is 300 mm, it is possible to accommodate 330 mm spacing by simply increasing the spacing between some split pipes. This reduces the reaping width from the originally calculated 2,310 mm to 2,230 mm, minimizing the overall width increase (Fig. 3).

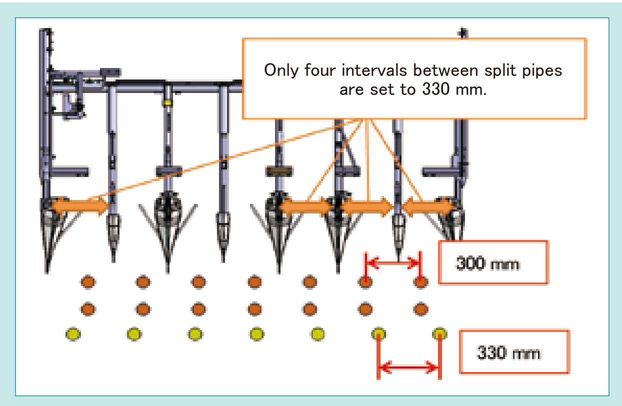


Fig. 3 Split Pipe Arrangement

(2) Consideration of crop conveyance system arrangement

The crop conveyance paths must be arranged to fit within the reaping width determined in the previous section. However, making the width of each crop conveyance path narrower than that in the existing model can cause jams depending on the crop volume. We, therefore, narrowed the non-acting area as much as possible while maintaining the space of the path itself, and were able to fit the conveyance system in a limited space (Fig. 4).

(3) Changing the side cover shape

We adopted the solution of designing a new side cover. The side cover has a recess that allows the left split pipe to fit inside the cover when stowed, reducing the influence of functional and exterior components on the overall width (Fig. 5).

As a result of the above solutions (1) through (3), the portion within the side panel height of up to 400 mm was narrowed to 2,330 mm to facilitate truck loading, well below the width based on the conventional concept (330 mm × 7 rows + exterior components = 2,460 mm).

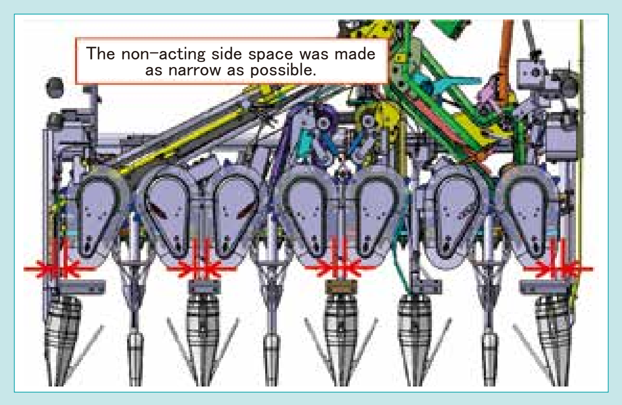


Fig. 4 Layout of the Transport System

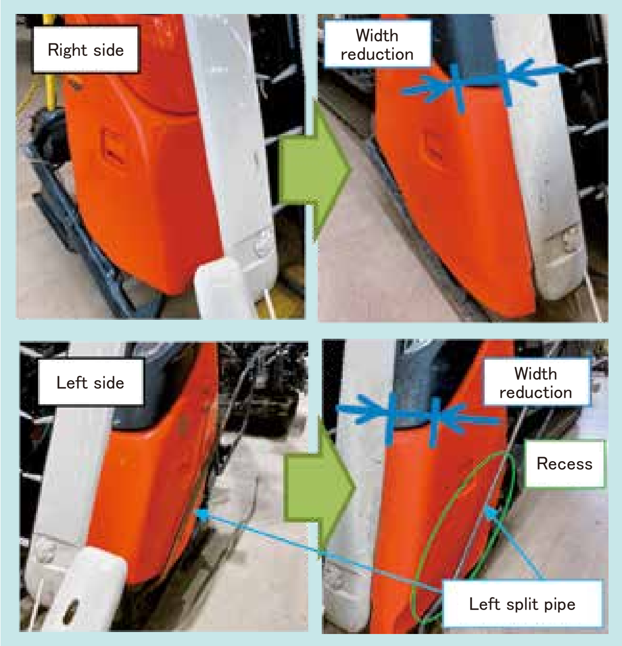


Fig. 5 Changing the Shape of the Side Cover

4-2 Optimization of reaper mounting position

4.2.1 Consideration of reaper mounting position

When reaping along the perimeter of a field surrounded by walls or field ridges, it is necessary to position the reaper as far to the right as possible relative to the machine body to reduce the influence of these objects. However, if the reaper is positioned too far to the right, the visibility of the right divider position for alignment with the rows will be impaired. In addition, the increased overall width of the vehicle also impairs the aforementioned truck loadability. It was thus necessary to optimize the reaper mounting position.

4.2.2 Optimization of reaper mounting position

As a result of repeated investigation, the right end of the reaper has been moved 190 mm to the right from its position on the DR6130, placing the reaper almost in the center of the machine body. This extends the range of reaping into areas where reaping was not possible in the past, without compromising other performance, and ensures workability along the edges facing walls and field ridges (Fig. 6).

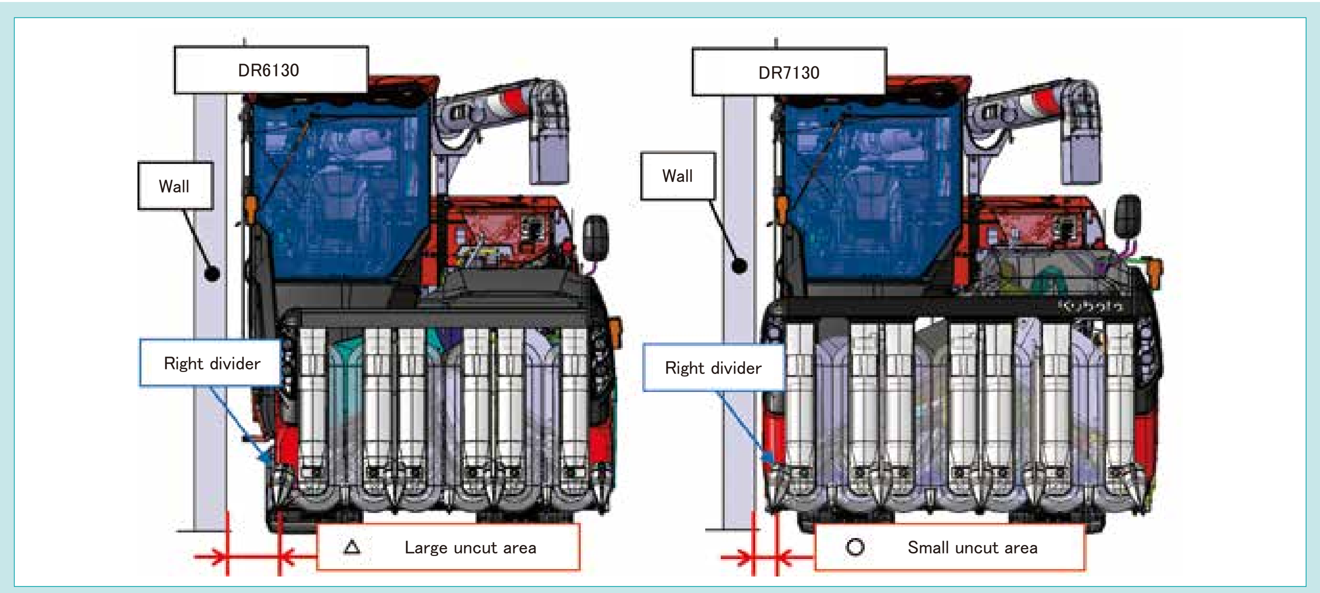


Fig. 6 Comparison of Cutting Performance at the Wall

4-3 Expanding the upper space of the raising part

4.3.1 Improved feeding posture when reaping long-culm crops

Crop feeding posture is important to prevent increased threshing load. The ideal feeding posture is a slanted posture where the ear tip end enters the threshing area prior to the stubble end. This proper feeding posture is often not achieved when reaping long-culm crops such as new demand rice varieties.

This is because when a long crop is conveyed through the reaper by the conveyor chain and passes through the raising part, the ear tips come into contact with the top of the raised part as shown in Fig. 7. At this point, the plant bases are conveyed while the ear tips encounter resistance, causing the crop to fall toward the front of the machine. Even after passing through the raising part, the ear tips continue to rub against the inside of the dust cover, causing further delay in conveying relative to the plant bases. As a result, when the crop is fed to the thresher, it cannot achieve the ideal posture due to the delayed delivery of the ear tips, resulting in increased threshing load and reduced work efficiency.

4.3.2 Method of expanding the upper space of the raising part

To improve the feeding posture of long-culm crops, the upper space of the raising part was enlarged to reduce the contact resistance of the ear tips.

In order to lift the horizontal drive shaft extending in the left-right direction of the machine in the upper space of the raising part, the pipe case shown in Fig. 8 was extended in the axial direction, and the raising part and the upper frame were moved with respect to the lifted horizontal drive shaft. At that time, in order to maintain the raising capability, the lowest point where the raising pawl acts and the position of the drive sprocket were left unchanged. The above changes extended the upper space of the raising part by 50 mm and moved the dust cover position 115 mm higher compared to the existing model, allowing the ear tips to pass smoothly.

4.3.3 Effect of expanding the upper space of the raising part

The new configuration in the DR7130 has alleviated this problem and also allowed sufficient space between the inner surface of the dust cover and the ear tips (Table 1). In addition, the threshing load has been reduced by about 36%, ensuring work efficiency for long-culm varieties.

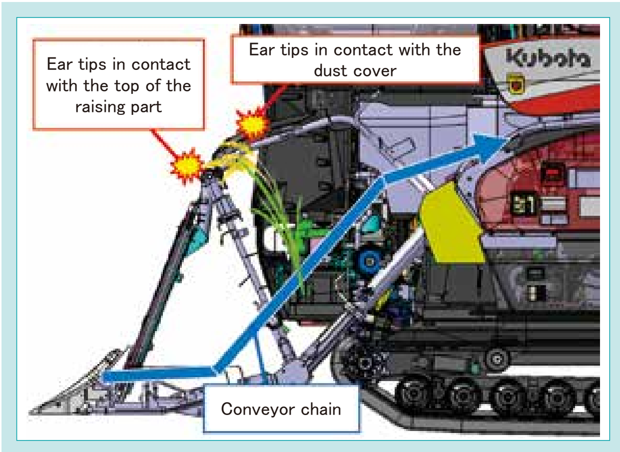


Fig. 7 Problems of Conveying Long-culm Crops

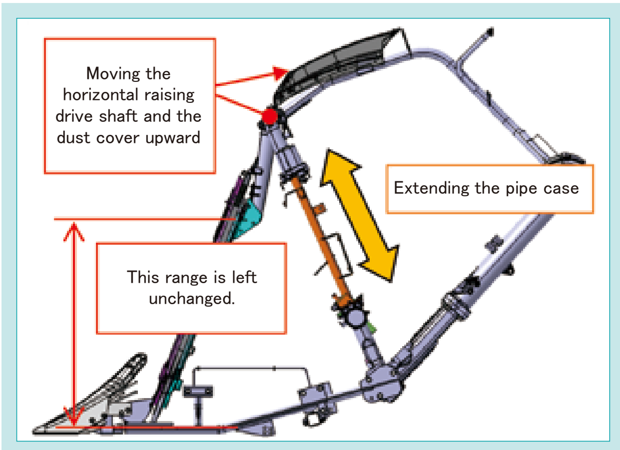
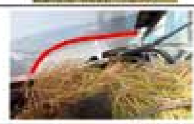


Fig. 8 Method for Enlarging Upper Space of the Raising Part

Table 1 Performance Comparison by Enlarging Upper Space

	DR6130	DR7130
Upper space of the raising part		
Dust cover		

4-4 Independent drive of the extra one-row frame

4.4.1 Drive system of the extra one-row frame

As mentioned above, some seven-row harvesters made by other manufacturers have a configuration in which the drive unit of the extra intermediate conveyor is located upstream of the conveying action section. In this configuration, force is transmitted in the direction of pushing the conveying action section. As a result, the conveyor chain tends to loosen and the conveying performance becomes unstable.

To overcome this weakness, the DR7130 has Kubota's unique configuration in which the intermediate conveying section is driven independently so that the crop can be conveyed by pulling the conveying action section.

4.4.2 Independent drive of the extra one-row frame

The main difference from other manufacturers' machines in securing conveying capacity is the placement of an extra one-row conveyor to expand from six- to seven-row reaping. While other manufacturers' machines add a conveyor in the third frame from the right, the newly developed machine adds a conveyor in the third frame from the left. This allows the drive shaft of the extra one-row frame to be located relatively close to the drive case, which is the drive source for the entire reaper, creating an independent drive system with the minimum branch configuration required. As shown in Fig. 9, this configuration allows the drive sprocket to be placed downstream of the conveying action section, driving the conveyor chain in the pulling direction, thereby ensuring stable conveying capacity.

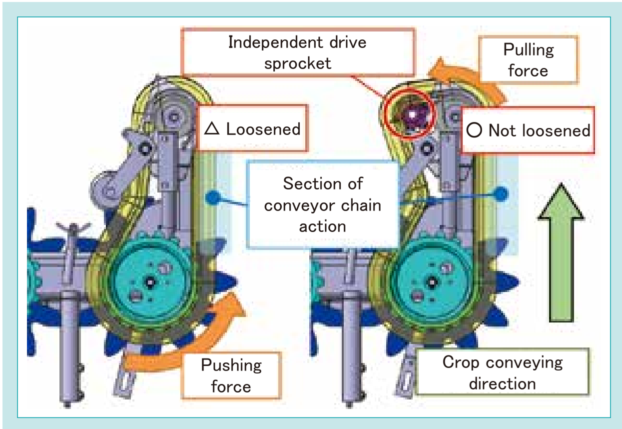


Fig. 9 Difference in Driving System of Extra Parts

4-5 Development results

By incorporating the technologies developed, we have achieved a seven-row combine harvester that improves work efficiency and eliminates the negative factors that can accompany increasing the number of rows to seven. Table 2 shows the results of the comparison with the DR6130 in terms of actual working time under the same conditions.

As a result, work efficiency improved by approximately 10%, achieving the targeted goal of development.

In a user monitoring survey conducted in 2022, we also gained a reputation for improved efficiency and high performance for each technology developed, as well as less fatigue.

Table 2 Comparative Results of Work Efficiency

Item	Working time	Number of lengthwise reaping strokes	Number of crosswise reaping strokes	Number of turns	Fatigue level
DR7130	19 min and 36 sec	24	24	47	○Low
DR6130	21 min and 45 sec	27	27	53	△High
Reduction	2 min and 9 sec	3	3	6	–

5. Conclusion

We have achieved the workability and performance targets for each technology developed for the DR7130, as well as an improvement in work efficiency of approximately 10% over the DR6130. This contributes to the market need for improved work efficiency for farmers.

In the future, we plan to further improve the overall efficiency of reaping work by reducing downtime in areas where it has been difficult to ensure work efficiency.

Although this development has resulted in improved work efficiency, it is believed that there will continue to be demand for longer hours of work as the number of fields to manage expands. Therefore, we will work to develop ways to save labor and reduce the workload for users by expanding automatic operation and various assistance functions, making full use of information and communication technology.

Contribution to SDG targets

2.4 Realization of sustainable and robust agriculture
Contribution to labor-saving and lightening of reaping work by improving work efficiency

8.2 Increased productivity through innovation
Contribution of Kubota's first seven-row head-feeding combine harvester to improving farmers' management efficiency

9.2 Strengthening of inclusive and sustainable industrial infrastructure
Addressing the issue of labor shortages in agriculture by saving labor in reaping work

Reference

1) Ministry of Agriculture, Forestry and Fisheries: "FY2021 White Paper on Food, Agriculture and Rural Areas" https://www.maff.go.jp/j/wpaper/w_maff/r3/pdf/zentaiban.pdf (referenced on September 21, 2023)

2) Ministry of Agriculture, Forestry and Fisheries: "The Situation Concerning Rice for Animal Feed" https://www.maff.go.jp/j/seisan/kokumotu/attach/pdf/siryouqa-121.pdf (referenced on September 21, 2023)

Farm & Industrial Machinery

Development of Autonomous Driving Rice Transplanter NW8SA

Transplanter Engineering Dept. / Farm and Industrial Machinery R&D Dept. Ⅲ
Farm and Industrial Machinery R&D Dept. Ⅵ / Farm and Industrial Machinery R&D Dept. Ⅰ

Kubota introduced a rice transplanter with a straight-line motion function (hereinafter called “Go Straight (GS)” function). However, it is difficult for unskilled workers to achieve rice planting on entire rice fields via the GS function alone. Therefore, to realize the objective behind this development concept, which was to enable even unskilled/inexperienced rice-farm workers to easily and stress-freely plant entire rice fields, we developed a rice transplanter with an automated driving function. In this paper, we described the working route for automated driving, trace running control at the outer areas of rice fields, and characteristic technologies unique to autonomous driving.

【Key Word】
Rice Tansplanter, Autonomous Driving, Working Route, Trace Running

Related SDGs

1. Introduction

While the number of farmers in Japanese agriculture is declining, farmland is being concentrated in the hands of operating farmers, and the size of each farmer’s operation is increasing.[1] Farmers want to secure labor as they expand their operations, but this has become difficult due to the decline in the number of farm workers. When transplanting rice, the planted seedlings must be straight and neatly aligned, with no overlap or empty space in the field. Because the operation cannot be redone, rice transplanting is physically and mentally demanding and requires skilled operating techniques. In addition, it requires the operator to work on a given plot in a limited amount of time, so the skill of the operator is important. Under these circumstances, there is a growing need for labor-saving and automated operation of rice transplanting on par with skilled workers.

To meet these needs, we have developed a new rice transplanter with an automated driving function (Fig. 1).

Fig. 1 Autonomous Driving Rice Transplanter NW8SA

2. Development concept and target values

2-1 Development concept

Kubota introduced a go-straight (GS) rice transplanter to the market in 2016 to help farmers eliminate labor shortages and save labor (Fig. 2). The GS rice transplanter was praised for its automated straight-line travel, but manual operations such as turning, planting according to the field shape, and planting along the field perimeter were still required. It is, therefore, difficult for a single unskilled person who is not used to rice transplanting to complete a single paddy plot. Under these circumstances, it was desired to extend the scope of automated operation so that even unskilled operators could complete a single plot. Therefore, we set out to develop the industry's first autonomous driving rice transplanter that can cover the entire field, based on the following development concept: easy, stress-free, and orderly planting over an entire field, even for those who are not accustomed to rice transplanting work.

Fig. 2 Go-Straight Function Rice Transplanter EP8D

2-2 Target values

The goal of the development was to enable automated rice transplanting operation across the entire field with a finish as good as or better than that of a skilled operator. A finish that is as good as or better than that of a skilled operator means that the seedlings are planted in the field at regular intervals without gaps, following the shape of the field in curved areas. Another goal is to achieve an automation ratio of at least 90% for the mappable area. Here, automation ratio is defined as the ratio of the area where automated planting operation is possible to the total field area.

3.Technical issues to be solved

3-1 Creation of an optimal automated driving route

The following three requirements are important to achieve a finish that is as good as or better than that of a skilled operator.

- Create an optimal work route according to the field shape.
- Create an efficient work route.
- There must be no unplanted areas or overlapping of seedlings.

These requirements are important because if they can be met, work efficiency will be improved over manual operations, and consistent yields will be achieved by planting the entire field with no unplanted areas. It is also beneficial for farmers to install machinery that can perform automated operations.

3-2 Driving on the field periphery

In order to plant the entire field, it is necessary to drive around obstacles such as field ridges and inlets in the ridges that allow water to enter the field (Fig. 3). In addition, the field may have curved edges rather than straight edges forming a rectangle. Therefore, two issues must be addressed.

- Avoid obstacles.
- Drive on curves that follow the field shape.

Fig. 3 Example of Obstacle Around the Field

3-3 Technologies specific to automated operation

The following two issues have traditionally been faced in the mechanical design of rice transplanters.

- Elimination of needless scraping of seedlings at the end of planting
- Improvement of uneven supply of fertilizer when starting and stopping

If these issues that rice transplanters have traditionally faced can be solved, we can provide original features unique to automated operation that even skilled operators cannot provide.

4.Developed technology

4-1 Creation of an automated driving route

4.1.1 Automated driving route

In creating an automated driving route, it is necessary to know the field shape (field map). The vehicle is driven along the field shape in advance to obtain highly accurate field shape data. The obtained field map makes it possible to identify areas that must be planted and determine the planting sequence to create an efficient work route. On a route of conventional human-operated work, the operator must drive a rice transplanter very close to the field ridge. However, when an unmanned machine is operated automatically, there is a high risk of coming into contact with obstacles that exist near the field ridge as shown in Fig. 3. In order to secure turning areas for unmanned, automated driving, we decided to redesign routing that would be suitable for automated driving, consisting of two laps around the inner and outer perimeter areas of the field as shown in Fig. 4. This has enabled unmanned, automated driving in the round-trip planting area and the inner perimeter area. The outer perimeter area is operated automatically with a manned vehicle because the risk of contact with obstacles remains. As a result, an automated work route is established for the entire field.

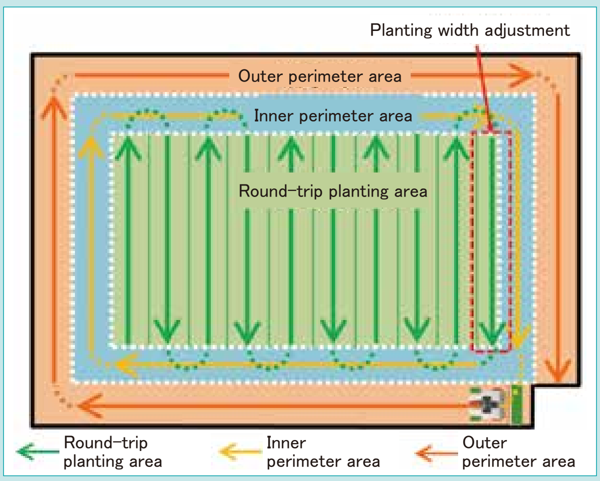


Fig. 4 Working Route for Auto Driving.

4.1.2 Distance adjustment between adjacent rows

In the final process of the round-trip planting area (red dashed frame in Fig. 4), it is necessary to adjust the planting width so that there is no overlap or gap in the seedlings, with the two laps of the inner and outer perimeter areas in the field left unplanted. The rice transplanter is equipped with a field edge clutch mechanism to adjust the planting width, which can be changed in 60 cm increments (corresponding to two rows). Generally, the operator adjusts the planting width by using the field edge clutch mechanism. Even for experienced operators, it is difficult to estimate the width of the field by eye and adjust the planting width, which requires experience and a high degree of skill. In order to eliminate this difficult adjustment operation, our automatic operation scheme designs a route to achieve the optimum planting width calculated in advance from the field map data, allowing the automatic operation of the field edge clutch. We have also developed a function to adjust the spacing between adjacent rows, as shown in Fig. 5, to fine-tune the distance between adjacent rows in the round-trip planting process to eliminate seedling overlap. This function contributes to reducing overlap in the final process of round-trip planting. The automatic operation of the field edge clutch and the row spacing adjustment function have enabled efficient planting. With these features and a prepared field map, even unskilled operators can plant the entire field by simply feeding seedlings and riding on the vehicle only on the outer perimeter.

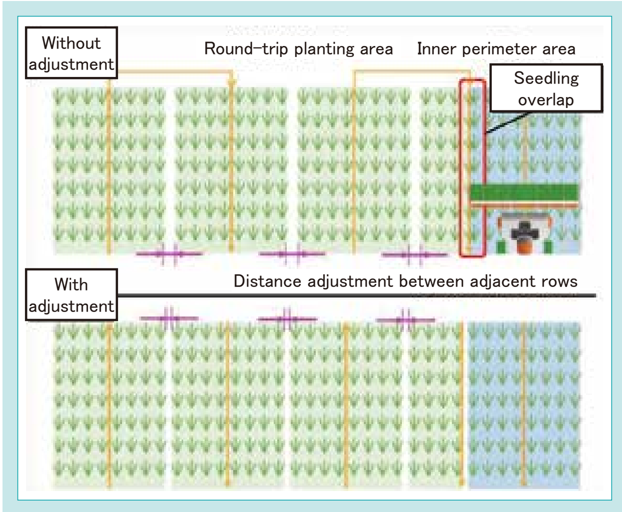


Fig. 5 Function of Adjusting Distance of Adjacent Row

4-2 Technology for driving on the outer perimeter of the field

In order to avoid contact with obstacles on the field periphery and to drive along curved areas, we have devised an automated driving method that traces the vehicle trajectory obtained at the time of mapping, and to this end, we have worked on the development of mapping technology and technology for outer perimeter trace running.

4.2.1 Mapping technology

We first obtain a vehicle trajectory at the time of field mapping and use the acquired point cloud data to generate a travel route for the outer perimeter. This allows us to reproduce manually operated movements to avoid water intakes, etc., as well as movements along curved field ridges. However, while the acquisition of detailed travel data points in the outer perimeter allows for more accurate running, meandering is observed in the planted seedlings in the straight sections due to too detailed tracing of manual driving. For this reason, we added a process that acquires detailed point cloud data at locations where obstacles are to be avoided and acquires thinner point cloud data in straight sections (Fig. 6). This thinning process establishes a mapping technique for moving around obstacles and curved field edges while moving straight on straight sections.

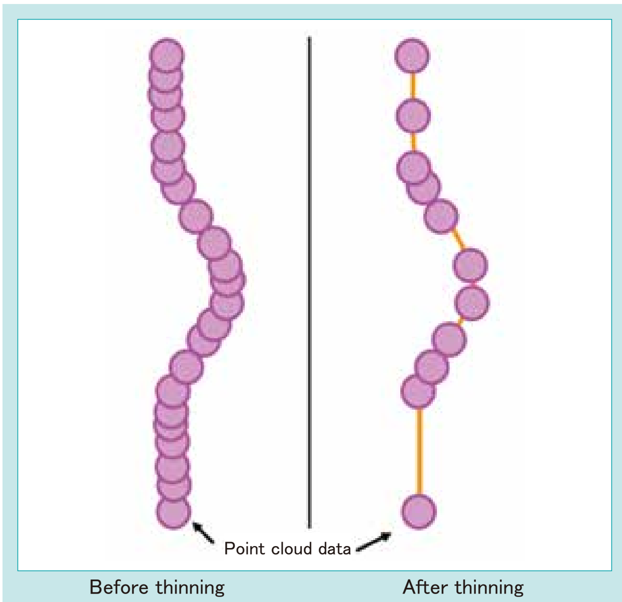


Fig. 6 Smoothing Control of Point Data

4.2.2 Technology for outer perimeter trace running

We also worked to improve the accuracy of trace running on the outer perimeter. There are many curved sections as well as straight sections on the outer perimeter of the field. Therefore, the technique for running on curved sections is also important for neatly planting the entire field. We tried to make the traveling control of curved sections based on the traveling control of straight sections. When a vehicle runs automatically on a curved section, which is interpreted as a series of straight lines, the steering is delayed at the transition between straight lines, resulting in a situation where the vehicle cannot smoothly follow the shape of the field or sways closer to or away from the field edge. Therefore, as shown in Fig. 7, we developed an original traveling control system that linearly changes the target azimuth based on the current vehicle position, the distance from there to the transition point with the next straight line, and the azimuth of the next straight line. By optimizing the values of the traveling control parameters, we have achieved a control that allows the vehicle to run more smoothly on curved sections. By improving the mapping technology using point cloud data and the traveling control technology for curved sections, we have established highly accurate traveling control that traces the vehicle trajectory obtained at the time of mapping. In a real field, as shown in Fig. 8, it was possible to achieve smooth and orderly planting marks in curved sections, comparable to those made by a skilled operator, without coming into contact with obstacles on the field periphery. With the establishment of the driving technology for the periphery of the field, the automated operation of the entire field area is now established. The realization of automated driving on the field perimeter has allowed us to exceed the target automation ratio of 99% for the mappable area.

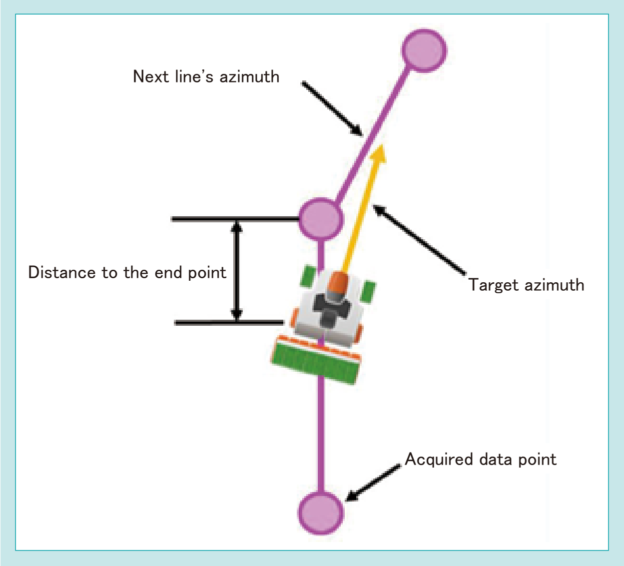


Fig. 7 Overview of Target Azimuth

Fig. 8 Smooth Planting Work Using Trace Running

4-3 Solving problems with conventional rice transplanters

4.3.1 Elimination of needless scraping of seedlings

In existing rice transplanters, there was a situation where seedlings were needlessly scraped and not planted in the field, depending on the position of the planting claw when planting was finished (Fig. 9(a)). Therefore, a modification has been made in the autonomous driving rice transplanter to preliminarily adjust the end-of-planting line from the known work route and to finish planting seedlings within the field before moving on to the next driving line. Although it is difficult to adjust the timing of the end of planting to eliminate needless scraping of seedlings, we have enabled an orderly finish that even skilled operators cannot achieve (Fig. 9(b)). This also reduces waste caused by needless scraping of seedlings.

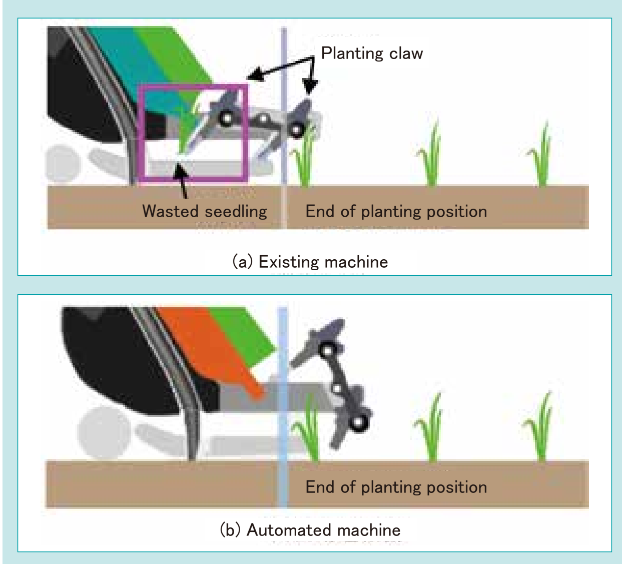


Fig. 9 Improvement of Scraping of Seedling

4.3.2 Improvement of uneven fertilizer supply

Some models of rice transplanters apply fertilizer evenly at the same time as planting seedlings. The mechanism for delivering fertilizer to the seedlings involves unloading fertilizer from a fertilizer applicator mounted in the center of the machine, passing it through a fertilizer application hose, and delivering it near the seedlings (Fig. 10). Since the fertilizer applicator is mounted in the center of the vehicle body, there is a time lag before the fertilizer reaches the vicinity of the seedlings. In the existing machine, as shown in Fig. 11(a), fertilizer supply is sometimes delayed at the beginning of planting and excessive fertilizer is supplied at the end of planting, resulting in an uneven supply of fertilizer to the seedlings. On the other hand, in the case of automated operation, since the start and end positions of planting are known in advance, the machine is equipped with a function to start the delivery of fertilizer before the planting starts and to stop the delivery before the planting is finished, taking into account the time required for the delivery. In the automated machine, as shown in Fig. 11(b), fertilizer is supplied to the planted seedlings with pinpoint accuracy, thereby eliminating uneven application of fertilizer. By developing technologies unique to automated operation, we have solved the problems rice transplanters have faced in the past and realized rice planting work that surpasses that of skilled operators. Improving the uniformity of fertilizer application also helps to eliminate uneven growth and improve crop quality.

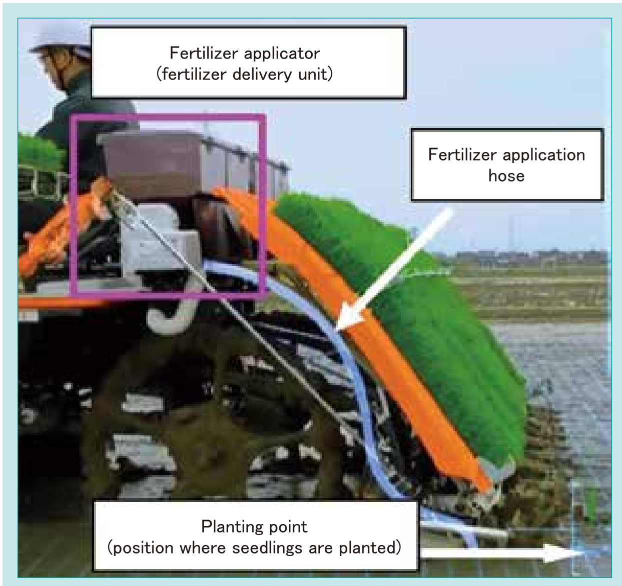


Fig. 10 Mounted Location at Fertilizer Machine

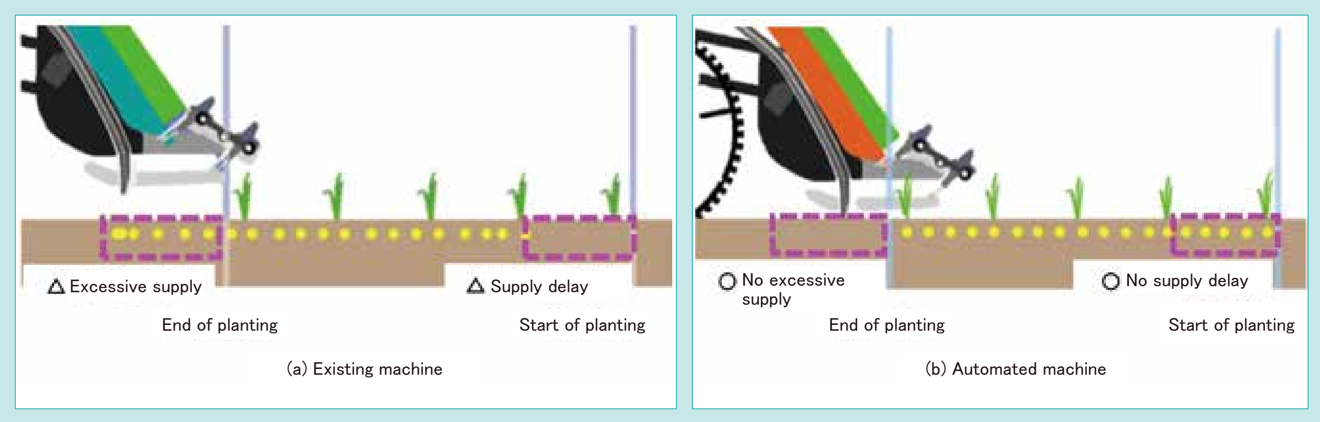


Fig.11 Improvement of Suppling to Fertilizer

5. Conclusion

In 2020, we launched the industry's first autonomous rice transplanter capable of automatically transplanting an entire field. In the case of an irregularly shaped field, as shown in Fig. 12, it is difficult to operate a machine even for a skilled operator. Even in such a field, with the new model, an automatic work route can be created that allows an unskilled operator to operate the machine and plant the entire field with a finish as good as or better than that of a skilled operator. As a result, we received high evaluations from users, who said that the machine led to labor savings and that its movements were equivalent to those of skilled operators. Accordingly, we have been able to achieve our development concept of "easy, stress-free, and orderly planting over the entire field, even for those who are not accustomed to rice transplanting work." Based on the technology obtained through this development, we aim to develop new automated operation functions to further improve work efficiency. We will also develop a function that automatically adjusts the planting and other areas, in addition to the traveling areas, according to field conditions. In this way, we will contribute to Japanese agriculture by further developing automation technology.

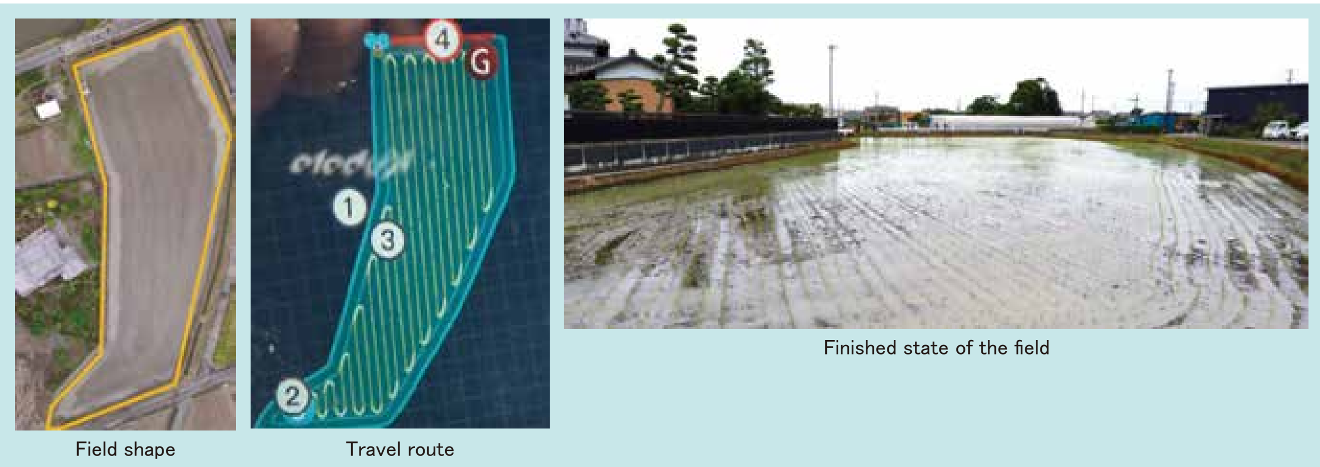


Fig.12 Result of Automatic Operation for Deformed Field

Contribution to SDG targets

2.3 Increase of agricultural productivity and incomes
Contribution to increased productivity by reducing labor through automated operations

2.4 Realization of sustainable and resilient agriculture
Contribution to reduced consumption of seedlings, fertilizer, and other materials during rice transplanting

8.2 Increase of productivity through innovation
Reduction of rice transplanting time by increasing the automation ratio

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Reference

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Development of the Electrically Controlled Small Diesel Engine D902-K

Engine Engineering Dept. Ⅰ

The NSM series engine, which has high power density and high environmental performance by improving its unique combustion system, E-TVCS, to achieve both high power density and high environmental performance, contributes to the increased competitiveness of products. In recent years, in addition to strictly exhaust gas regulations, the need for CO_2 reduction has increased. In order to achieve both lower emissions and lower CO_2, we have developed the new combustion system, TVCR by changing from the current mechanical fuel injection system to electrical fuel injection system and designing the optimal combustion chamber shape. This article describes the development of the optimal combustion chamber shape for TVCR and an approach that maintains installation compatibility equivalent to that of current models.

【Key Word】
D902, IDI Combustion, TVCR, Small Cylinder Bore, Compactness, Electronic Control

Related SDGs

1. Introduction

The NSM series engines, which are widely used in Kubota's agricultural and construction machines and OEM industrial machines, have achieved high power density and high environmental performance by upgrading the company's unique combustion system, E-TVCS (Three Vortex Combustion System), and are increasing the competitiveness of products equipped with these engines.

Small-displacement engines with outputs of less than 19 kW are facing tighter emissions regulations around the world, including in Europe and the United States. EU Stage V regulation was enforced in 2019, and China Ⅳ regulation was enforced in 2022. In particular, in urban areas of China, not only emissions regulations for engines alone, but also strict smoke regulations that require no visible smoke from engine-mounted products are in effect. In recent years, the California Air Resources Board (CARB) in the United States has initiated the process of considering the next Tier 5 emissions regulation, with the expectation of more stringent emissions regulations in the future. Meanwhile, there is a growing need to reduce CO_2 emissions to achieve carbon neutrality worldwide, with each country aiming to meet its mid- to long-term CO_2 reduction targets. To this end, it is important to reduce the amount of fuel used by improving the fuel efficiency of engines. By achieving high levels of both global emissions compliance and fuel economy, we can contribute to carbon neutrality and improve the competitiveness of our products.

2. Development concepts and target values

2-1 Development concepts

Based on Kubota's proprietary E-TVCS combustion system, which has been refined over the years, we established the following two development concepts.

1) Develop an engine that not only meets emissions regulations in various countries and reduces fuel consumption, but also achieves a level of workability and environmental friendliness that cannot be achieved with mechanical fuel injection engines.

2) Develop an engine that maintains compatibility with the current D902 model and can contribute to investment saving.

2-2 Development goals

The specifications of the newly developed engine are shown in Table 1 and its external view in Fig. 1. We set the following four development goals with the aim of achieving high levels of both low fuel consumption and low emissions by creating an optimal combustion system for small displacement engines.

1. At least 5% lower fuel consumption
2. Compliance with global emissions regulations for engines below 19 kW (North American EPA Tier 4, EU Stage V, Chine Ⅳ (including China's national smoke regulations), and the Regulation of Non-road Special Motor Vehicles Emissions)
3. Maintaining compatibility with the current D902
4. Improved load response and workability

Table 1 Engine Specification

Model	D902 (current model)	D902-K (new model)
Combustion method	IDI (Indirect Injection)	
Fuel injection method	Mechanical control	Electronic control
Number of cylinders	3	
Bore diameter × Stroke (mm)	ϕ72 × 73.6	
Displacement (L)	0.898	
Length × Width × Height (mm)	453 × 425 × 544	
Rated output (kW)/Speed (rpm)	18.5/3600	

Fig. 1 D902-K

3. Technical issues to be solved

3-1 Adoption of an electronically controlled fuel injection system optimized for small engines and upgrading of the E-TVCS combustion system

While mechanical injection control has been the mainstream for small diesel engines of less than 19 kW, we have been working to improve their performance, placing the highest priority on compliance with emissions regulations. In mechanical injection control, it is difficult to optimize the fuel injection amount and timing for each revolution because the injection amount and timing are determined mechanically at the design stage. This makes it difficult to realize the development concept of achieving low fuel consumption while complying with global emissions regulations. In electronically controlled engines, on the other hand, the amount and timing of fuel injection can be controlled according to operating conditions. High-end, larger engines generally use a high-pressure, common-rail system with a fuel injection pressure of 160 MPa or more to comply with stricter emissions regulations and reduce CO_2 emissions. However, it is generally difficult to use the same system for small engines due to differences in combustion systems and smaller bore diameters. Therefore, in order to increase the degree of freedom of injection control and achieve optimal combustion control through precise fuel injection control at each revolution, an electronically controlled fuel injection system is required that is best suited for small engines adopting the IDI combustion system. In addition, it is necessary to develop combustion system components that are optimal for the new electronically controlled fuel injection system to meet emissions regulations in various countries and reduce CO_2 emissions.

3-2 Introducing electronic control of engines while maintaining installation compatibility

Electronically controlled fuel injection systems require a common rail-shaped holder assembly that regulates fuel to a constant pressure (Fig. 2). Therefore, besides the conventional configuration of a supply pump, injection pipes, and injectors, the electronically controlled engine requires a holder assembly designed compactly for mounting. In order to electronically control fuel injection, it is necessary to add rotation sensors to detect engine speed (hereafter referred to as “NE sensors”), phase detection sensors (hereafter referred to as “G sensors”), and pulsar gears as detection elements (Fig. 2). High-end models have already achieved the integration of pulsar gears into the gear case, but if the newly developed model were to do the same, it would result in an increase in engine package size as shown in Fig. 3. In order to maintain the same body size as the existing mass-produced machines and achieve drop-in replacement of equipment, the layout must be designed to limit the increase in body size due to the addition of new parts.

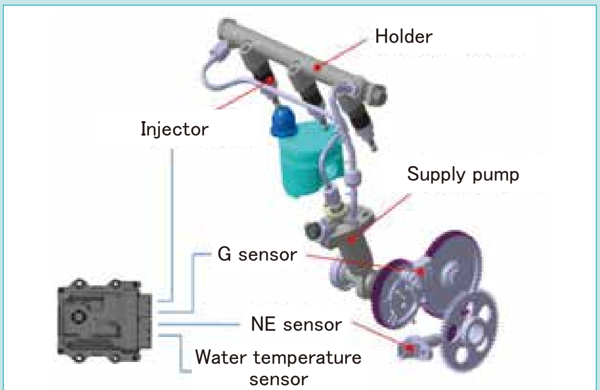

Fig. 2 Electrical Fuel Injection System Configuration

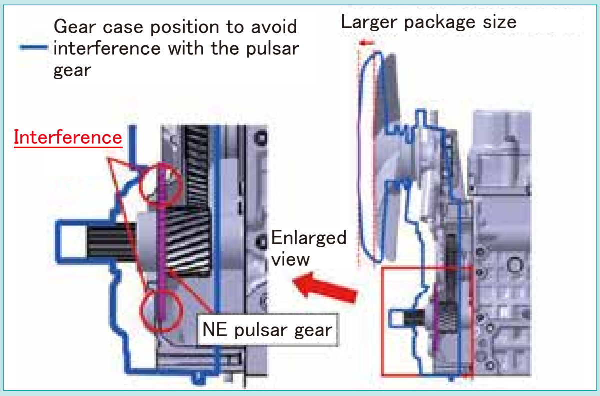

Fig. 3 Mountability of Pulsar Gear

4. Developed technology

4-1 Combustion-improvement technology to meet compliance with emissions regulations in various countries while reducing fuel consumption

4.1.1 Adoption of electronic fuel injection system best suited for small engines

Figure 4 shows the injector of the current D902 model and the injector of the common rail system (CRS) used in larger engines. The CRS injector cannot be used in small engines with a small bore diameter because it is approximately 2.5 times larger than the injectors used in the current IDI engines and requires a high injection pressure. Therefore, to convert the current D902 to electronic control, we adopted an electronically controlled injector that allows lower injection pressure than CRS injectors, instead of diverting CRS injectors, while maintaining the compactness suitable for IDI engines.[1] This allows the engine assembly space to be about the same as the injector assembly space in the current model.

On the other hand, the electronic controls of injectors and conventional mechanical injection systems have different injection characteristics. As shown in the comparison of the injection rate curves of the current and newly developed machines in Fig. 5, the shape of the curve of the electronically controlled injector is more rectangular because of the electrical control of injection. The injection rate values of the electronically controlled injector are higher than those of the current machine's injector in the initial and final stages of injection because the former injector maintains a constant injection rate from the initial to final stages of injection. Therefore, it is necessary to consider a combustion chamber shape that is optimal for electronically controlled injectors. A detailed study of the combustion chamber shape is described in the next section.

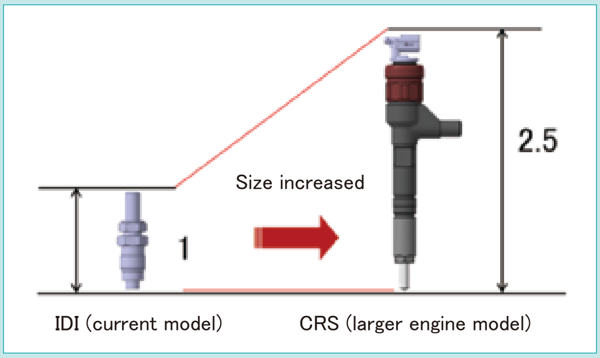

Fig. 4 Injector Comparison

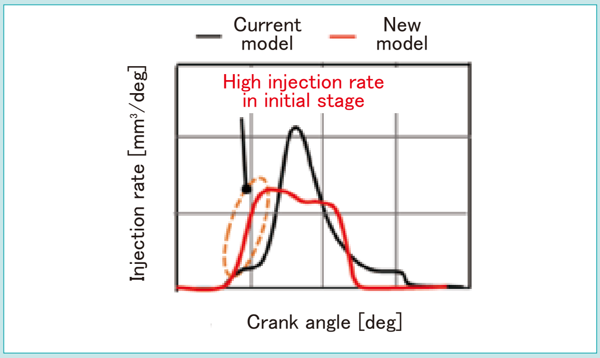

Fig. 5 Comparison of Injection Rates

4.1.2 Establishment of new combustion method, TVCR

As mentioned in the previous section, it is necessary to optimize the shape of the combustion chamber to optimize combustion using electronically controlled injectors.

The IDI combustion chamber is divided into the main chamber and the sub-chamber for two-stage combustion, as shown in Fig. 6, namely, the combustion gas that has fully self-ignited in the sub-chamber flows through the path (adapter throat) connecting between the sub-chamber and the main chamber to complete combustion in the main chamber.[2] The mixing of fuel and air in the sub-chamber is important to improve combustion. In particular, electronically controlled injectors require increased vortex flow in the sub-chamber because of the high injection rate from the initial stage. In general, a smaller cross-sectional area of the adapter throat is effective in enhancing the vortex flow in the sub-chamber. On the other hand, to improve fuel consumption, it is necessary to reduce pressure loss by throttling the adapter throat in the sub-chamber. Therefore, introducing an IDI combustion system with a sub-chamber has a trade-off between reducing particulate matter and smoke and reducing fuel consumption. Figure 7 schematically shows how the relationship between the pressure drop at the adapter throat and the average angular velocity in the sub-chamber affect engine performance. In developing the new model, we worked to optimize the shape of the swirl chamber throat to achieve a breakthrough in this trade-off.

Fluid analysis has shown that the vortex flow in the sub-chamber is dominated by tumble flow. In the swirl chamber throat, it has been found that the further away from the auxiliary throat, the lower the average angular velocity as shown in Fig. 8. This suggests that the vortex flow from the auxiliary throat into the sub-chamber has little effect on the fuel-air mixing in the sub-chamber. We therefore investigated a shape that enhances vortex flow at the main throat and reduces pressure loss according to the size of the auxiliary throat. The flow velocity contour plot in the fluid analysis of D902-K in Fig. 9 shows that the change in the swirl chamber shape has resulted in an improved angular velocity of D902-K over the current D902 for the same throat area.

As a result of incorporating the optimized specifications of the adapter throat shape and confirming the engine performance, the developed D902-K achieved a fuel consumption reduction of more than 5% and a smoke reduction of more than 20 points at the maximum torque point compared to the current D902, and eliminated visible smoke over the entire operation speed range (Fig. 10).

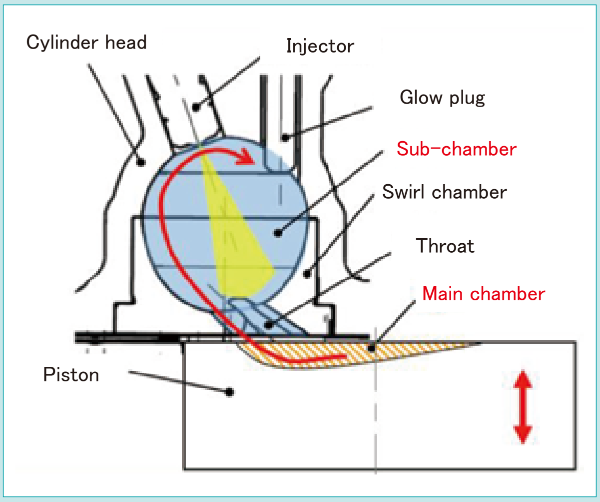

Fig. 6 Combustion Chamber of IDI Combustion System

As described above, we have upgraded the E-TVCS and established a new combustion method, TVCR, by selecting the most suitable electronically controlled injector for small engines and applying the most suitable swirl chamber throat to the injector.

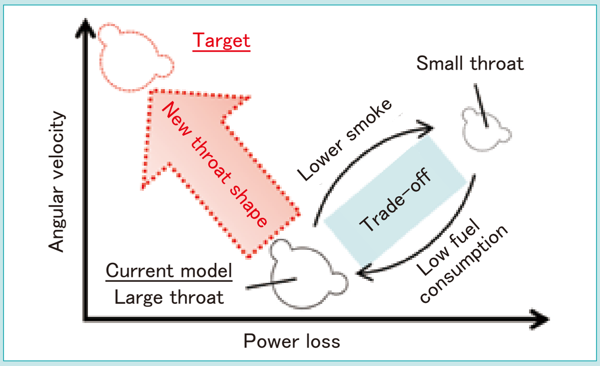

Fig. 7 Relationship Between Analysis Results and Experimental Results Based on Throat Shape

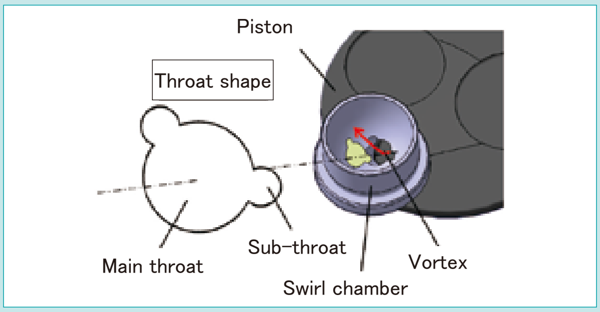

Fig. 8 Cross-sectional View of Throat Shape

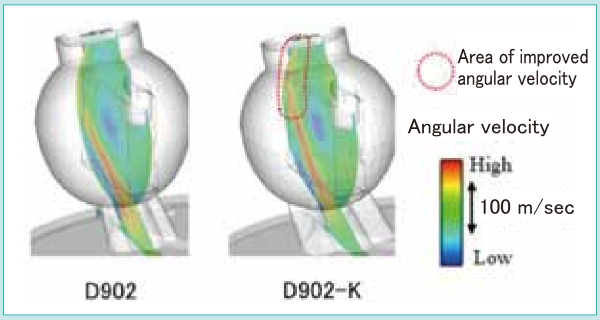

Fig. 9 Fluid Analysis Results in the Sub-chamber

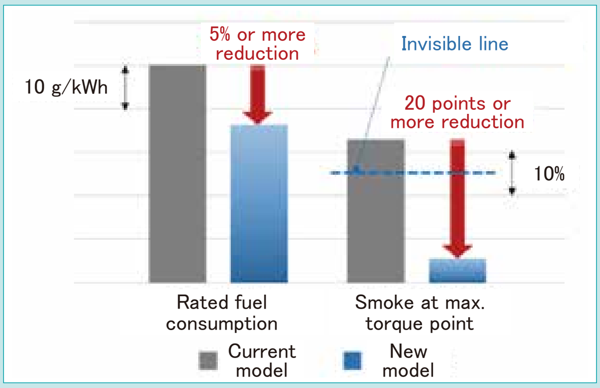

Fig. 10 Engine Performance Comparison

4-2 Compact mounting design maintaining compatibility

4.2.1 Injector holder mounting layout

In electronically controlled engines, it is important to design a holder assembly that is compactly structured for mounting and has the same shape as the common rail, which regulates fuel pressure at a constant level. By adopting a structure in which the holder assembly is directly attached to injectors, not only the installed height is reduced, but also the number of parts is reduced by eliminating the injection pipes required between the holder assembly and the injectors. The holder assembly is fixed to the cylinder head via a newly designed holder bracket, which allows the three injectors to be fixed and positioned at the same time, and the resulting package height is the same as that of the current model (Fig. 11). The size of the cylinder head is made equivalent to that of the current model, allowing the current machining line to be diverted, helping to save capital investment.

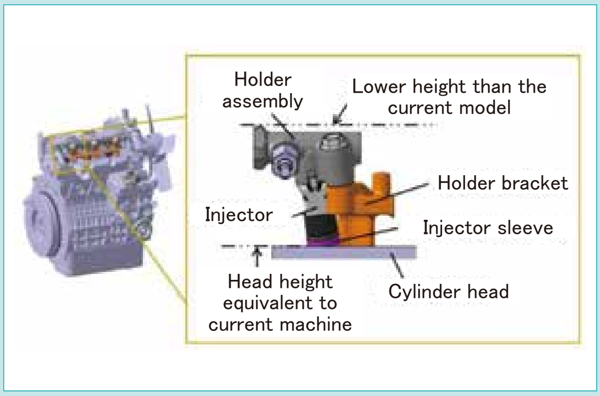

Fig. 11 Injector Support Structure System

4.2.2 Pulsar gear integration

To control engines electronically, rotation and phases need to be detected, requiring the installation of gears and sensors, respectively. Pulsar gears are built into the gear case in anticipation of use in various applications such as agricultural, construction, and industrial machinery. This requires space on the fan side, but moving the fan outward would require a change in the mounting position of the radiator, which would increase the impact of the mounting on the product. Therefore, in order to keep the engine size the same, we made use of the space created by removing the governor parts used in the mechanical-type engine, and also worked to reduce the width of the oil pump, thus moving the gear position 8 mm closer to the crankcase side (Fig. 12). By designing the pulsar gear with the smallest diameter, we kept the engine size at the same level as the current model and maintained installation compatibility (Fig. 13).

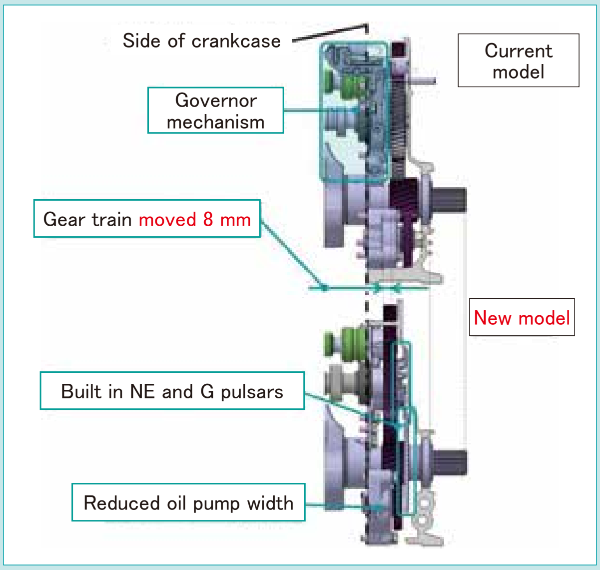

Fig. 12 Layout of Pulsar Gear

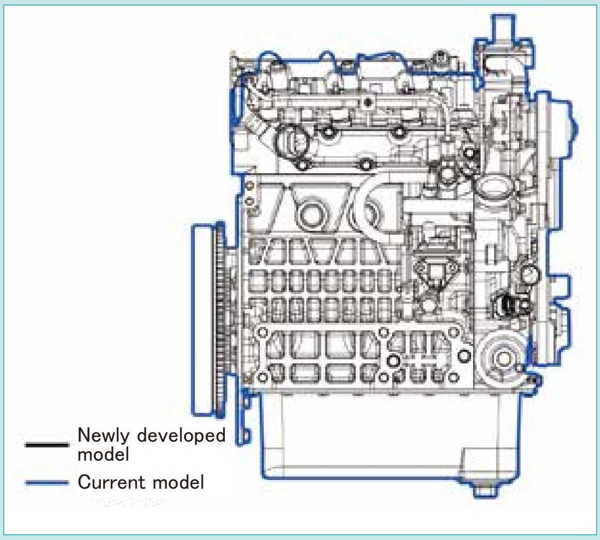

Fig. 13 Comparison of Engine Size Between the New Model and Current Model

4-3 Improvement of load response and power curve design flexibility by electronic control

We used the electronic control of fuel injection to improve load response. Figure 14 shows the results of load response evaluation assuming the occurrence of a sudden load. Compared to the current model (black line), the new model D902-K is shown to have reduced the drop of engine speed while keeping the smoke at an invisible level. This allows machines equipped with this engine to control the engine speed drop and return to work early when a sudden load occurs while working in a field for digging or lawn mowing.

Figure 15 shows the engine power and torque curves. The use of electronically controlled injectors has increased the flexibility of fuel injection and, therefore, the flexibility of power curve design. Therefore, torque is increased in the mid- to high-speed range, and the flat output region near the rated output is widened in terms of rpm. In addition, the electronic control allows the choice of isochronous control, which makes it possible to work at a constant engine speed in response to the load (Fig. 16).

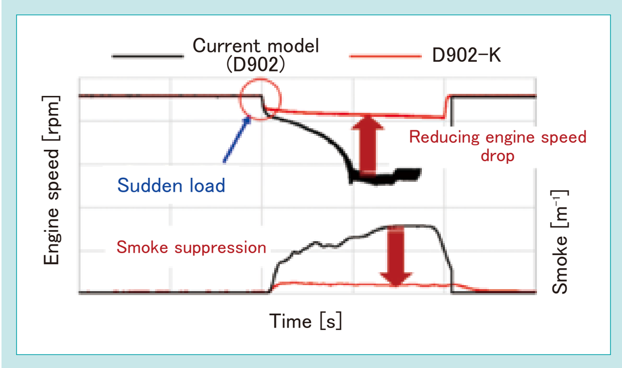

Fig. 14 Engine Behavior Under Sudden Load

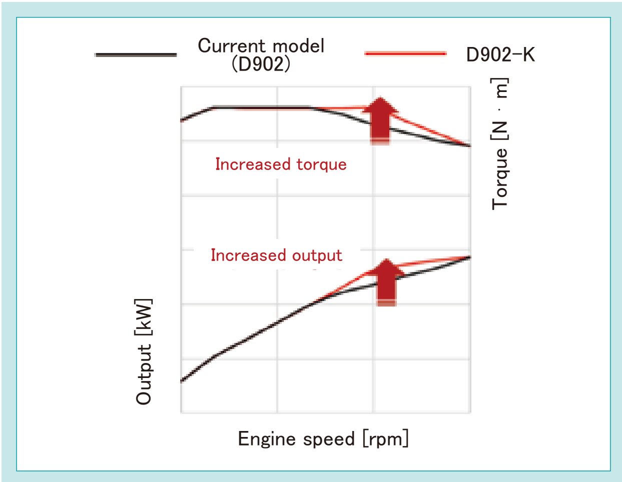

Fig. 15 Output Curve and Torque Curve

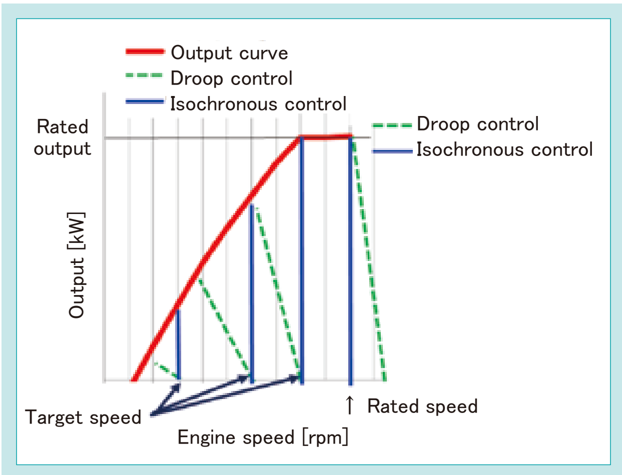

Fig. 16 Isochronous Control and Droop Control

5. Conclusion

We have established a new combustion method, TVCR, by adopting an electronically controlled fuel injection system optimal for small diesel engines and by upgrading the E-TVCS accordingly. As a result, the newly developed model achieves both low fuel consumption and low emissions at a high level, which could not be achieved with the current model, and this contributes to CO_2 reduction.

In addition, new components such as injectors, sensors, and pulsar gears were designed to be compactly mounted to keep the engine package size equivalent to that of current mass-produced models, maintaining installation compatibility.

The results of this development will be used for other models of less than 19 kW to expand the product lineup, thereby further enhancing our product competitiveness. This will contribute to expanding our engine business and attaining the SDGs through the development of engines with high environmental performance that ensures low exhaust and CO_2 emissions.

Contribution to SDG targets

7.3 Improvement of energy efficiency
Reduction of fuel consumption rate by 5% or more compared to current models

9.4 Improvement of infrastructure and industries by introducing environmentally friendly technologies and industrial processes
Smoke reduction via TVCR development

Reference

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Farm & Industrial Machinery

Development of Hydraulic System for 3-Ton Class Mini Excavator "U-30/35-6α Series"

Construction Machinery Base Technology Engineering Dept.
Construction Machinery Engineering Dept. for Excavator

The 3–3.5-ton class mini excavators are crucial conventional products shipped worldwide. The mini excavator U-30/35 series, is a main model, especially for Japanese market; however, there has been growing discontent at its work capacity due to its decreasing engine output with emission regulations. Recently, excavators are required to comply with energy-saving regulations to ptotect the environment. In addition, excavators are required to improve operability due to the increasing number of poor operators. To address these problems, we have developed a novel hydraulic system for the mini excavator U-30/35-6α series. We have achieved energy conservation, including improved work capacity and operability, by adopting a 1-pump load sensing (1pLS) system with a swivel priority circuit.

【Key Word】
Mini Excavator, Load Sensing, Swivel Priority Circuit

Related SDGs

7 AFFORDABLE AND CLEAN ENERGY, 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE, 11 SUSTAINABLE CITIES AND COMMUNITIES, 8 DECENT WORK AND ECONOMIC GROWTH, 13 CLIMATE ACTION, 16 PEACE, JUSTICE AND STRONG INSTITUTIONS, 17 PARTNERSHIPS FOR THE GOALS

1. Introduction

Mini excavators in the 3 to 3.5-ton class, which are the main products of Kubota's construction machinery business, are shipped all over the world, including Japan, Europe, North America, Australia, China, Thailand, and India. In the Japanese mini excavator market, tight tail swing excavators in the 2.5 to 3.5-ton class account for about 30% of total demand, making it a highly competitive class (Fig. 1).[1)]

Kubota's U-30/35 series, consisting of tight tail swing excavators in the 3 to 3.5-ton class, was fully remodeled in 2015 to meet domestic emissions regulations and improve basic performance such as lifting and digging capacity, and the resulting U-30-6 series has become the mainstay models.

However, due to the impact of reduced engine power to meet emissions regulations, there has been a demand for increased work capacity. In recent years, in response to environmental concerns, we have been required to further conserve energy, in addition to meeting emissions regulations. There is also a need to improve machine operability as more unskilled operators are involved due to the declining number of skilled workers on site.

For the U-30/35-6α series, we have developed a new hydraulic system to solve these issues (Fig. 2).

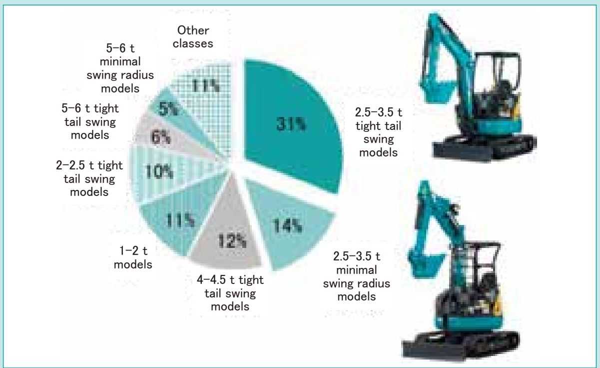

Fig. 1 Japanese Demand of Mini Excavator (2021)

Fig. 2 A 3-Ton Class Tight Tail Swing Excavator U-30-6α

2. Development concepts and target values

2-1 Development concepts

For the new model, we have developed a hydraulic system based on the following two concepts.

(1) Achieving both energy savings and improved work capacity

By selecting a hydraulic system that can efficiently distribute engine power to work machines, we aim to secure sufficient work capacity so that engine power reduction due to emissions compliance is not noticeable, while achieving energy savings.

(2) Improved operability

We aim to create a well-balanced model by optimizing the flow rate set for each work machine and to improve operability by reducing speed changes during simultaneous operation of work machines, making the machines easy to use even for inexperienced operators.

2-2 Target values

Based on the above development concepts, the following target values were set for energy saving, work capacity, and operability.

(1) Energy saving

10% energy saving compared to the conventional U-30-6 series

(2) Work capacity

Equivalent or greater work capacity than the previous U-30-5 series, which was developed prior to meeting emissions regulations

(3) Operability

Smooth operation and ease of use for everyone

3. Technical issues to be solved

3-1 Selection of hydraulic system to save energy and improve work capacity

There are two types of hydraulic systems for Kubota's mini excavators: the open center system (OPEN system) used in the conventional U-30-6 and the closed center load sensing system (LS system) mainly used in 4 t and larger models. The features of each system are described below.

(1) OPEN system

The OPEN system consists of three pumps, each configured independently for each actuator (Fig. 3). Therefore, when pumps operate two independent actuators simultaneously (e.g., combined boom and swivel operation), the system is easy to operate because one actuator is not affected by the load on the other actuator. In particular, swivel operation provides stable speed by using a fixed-displacement gear pump.

On the other hand, the speed of each actuator is limited by the maximum flow of each pump, which limits setting an ideal speed. This makes it difficult to set an optimal balance of work speed.

The flow rate of each pump is always fixed at a constant (maximum) level regardless of whether the work machine is operating, and any unnecessary flow is returned to the tank through a valve. This results in wasted energy consumption, and it is not an efficient system.

(2) LS system

A one-pump LS (1pLS) system, which is the simplest system, is described in Fig. 4. The entire 1pLS system relies on a single large-capacity pump, with a pressure compensation valve in each section to ensure stable diversion performance. Since all the work machines are driven by one pump, there is a high degree of freedom in setting the flow rate for each machine, allowing an optimal balance of working speeds.

In addition, this system constantly controls the flow rate of the pump to deliver only the flow rate required for the workload, resulting in a less wasteful and more efficient system.

(3) Hydraulic system selection

While the OPEN system is used in the conventional U-30-6 series, the 1pLS system is used in this development to save energy, increase work capacity, and improve operability.

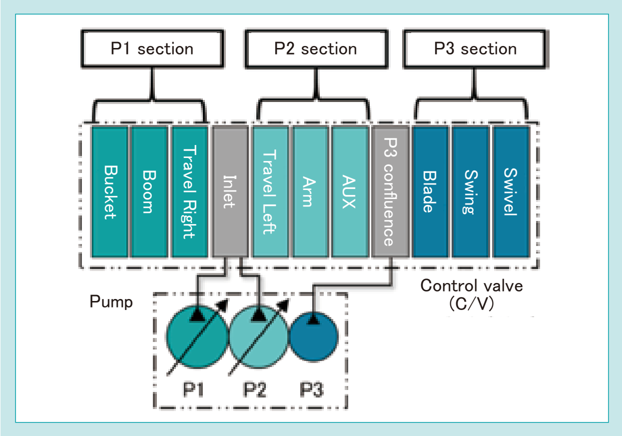

Fig. 3 OPEN System

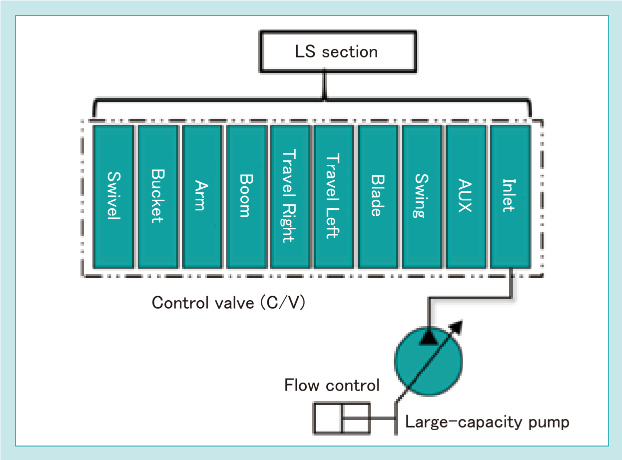

Fig. 4 1pLS System

3-2 Problem encountered when adopting the 1pLS system

This section describes the problem encountered when using the 1pLS system in a hydraulic system. When performing simultaneous boom and swivel operation, the swivel speed is drastically reduced as the boom reaches the most raised position and enters a relieved state. Therefore, when the boom reaches the most raised position during actual work, such as dumping soil and sand, the change in the swivel speed causes soil to spill out of the bucket (Fig. 5). The following describes the mechanism by which this problem occurs.

Since the 1pLS system does not have multiple independent pumps, a pressure compensation valve is provided in each section to ensure stable diversion control when a load pressure difference occurs between sections during simultaneous operation (Fig. 6). The pressure compensation valve is a variable throttle valve that adjusts the throttle to generate a dummy load only in the low-load section. This ensures that the apparent load pressure in each section is equal even when work machines with different loads are operated simultaneously and that stable diversion control is possible without being affected by the load pressure.

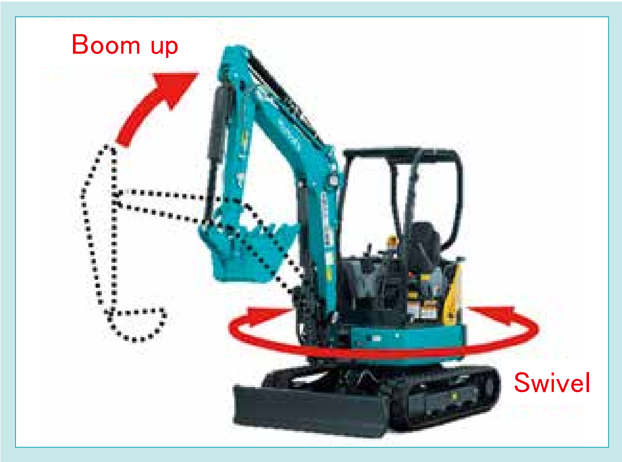

Fig. 5 Simultaneous Operation of Boom Up and Swivel

On the other hand, the pump has a horsepower control function that limits the maximum flow rate so that the torque of the engine is not exceeded when the load increases. Therefore, when the load on a work machine increases, the horsepower control will reduce the pump's discharge flow, resulting in insufficient pump flow for the work machine's needs. In this case, the 1pLS system distributes the flow evenly to each section, resulting in lower speeds than in stand-alone operation. Furthermore, when one work machine is relieved, the horsepower control greatly reduces the maximum flow rate of the pump, resulting in a greater reduction in the speed of the other work machine. The reduction of the swivel speed is particularly problematic as it has a sensitive effect on the operability.

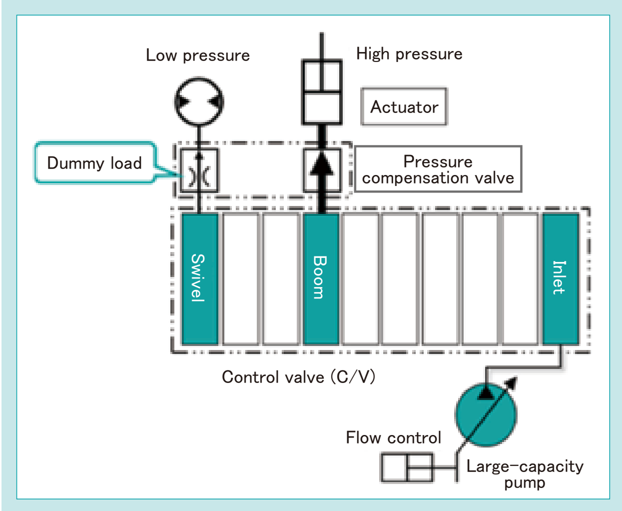

Fig. 6 1pLS System Pressure Compensated Model

4. Developed technology

4-1 Improvement in energy saving and work capacity by changing the hydraulic system

We verified the improvement in energy saving and work capacity achieved by changing the hydraulic system from the OPEN system to the 1pLS system. To improve the accuracy of fuel consumption measurement, we implemented an original measurement method. When the machine's fuel tank was almost empty, the engine was run to stall and 20 liters of fuel was added. Then, excavation, backfilling, and leveling operations were performed continuously, and the time elapsed until the engine stalled again was measured. Workload was measured in terms of the number of cycles per hour for leveling (grading) and simulated excavation, which are typical excavator operations, and energy savings were evaluated along with operating hours. The number of cycles per hour was also used to evaluate work capacity (Table 1).

The newly developed machine U-30-6α showed approximately 10% longer continuous operation time than the conventional machine U-30-6, and the numbers of leveling operations and simulated digging operations, which represent the workload, also exceeded those of the conventional machine. Multiplied by the increase ratios, the energy-saving effect exceeded 10%.

The work capacity of the U-30-6α was equal to or better than that of the previous model U-30-5, which was developed prior to meeting emissions regulations (Table 2).

Table 1 Comparison of Operating Time and Cycle Number

Item	U-30-6α	U-30-6	Increase ratio
Hydraulic system	1pLS	OPEN	–
Operating time	4.90 h	4.46 h	110%
No. of leveling operations	1021 cycles/h	992 cycles/h	103%
No. of simulated digging operations	391 cycles/h	385 cycles/h	102%

Table 2 Comparison of Cycle Number

Item	U-30-6α	U-30-5	Increase ratio
Hydraulic system	1pLS	OPEN	–
No. of leveling operations	1021 cycles/h	973 cycles/h	105%
No. of simulated digging operations	391 cycles/h	390 cycles/h	100%

4-2 Development of new hydraulic system

4.2.1 Swivel priority circuit

Existing technologies to reduce changes in swivel speed during the combined operation of the 1pLS system described in the previous section include additional pumps, priority valves, etc. However, it is difficult to mount them on a 3-ton class mini excavator, both in terms of cost and feasibility of installation. Therefore, we developed a new technology called the swivel priority circuit. The swivel priority circuit is Kubota's proprietary technology, and since it does not require the addition of swivel pumps or priority valves, it can reduce speed changes at low cost without compromising the energy-saving effects of the 1pLS system.

4.2.2 Operation principles

Figure 7 shows the hydraulic circuit diagrams of the conventional 1pLS circuit and the newly developed 1pLS with the swivel priority circuit. In the swivel priority circuit, the pressure-compensation valve used in the conventional 1pLS is replaced by a flow control valve.

First, we will discuss flow rate control during stand-alone swivel operation. During stand-alone operation in the conventional 1pLS circuit, the pressure compensation valve is fully open, and the flow for the swivel is controlled so that the differential pressure before and after the main spool is balanced with the spring force of the LS valve on the pump (differential pressure controlled by LS valve = PPS − PLS).

In the swivel priority circuit, on the other hand, the flow for the swivel is controlled so that the differential pressure before and after the main spool is balanced with the spring force of the flow control valve (differential pressure set by flow control valve = PPS − Pc).

In stand-alone operation, despite the different flow control methods, the same flow rate can be obtained for both circuits by setting the same flow rate.

Next, we will discuss combined operation in terms of flow control during combined swivel and boom operation. In the conventional 1pLS circuit, as explained in the previous section, a high-pressure signal from the boom side causes the pressure compensation valve to generate a dummy load on the lower pressure swivel side for diversion control (Fig. 8). If there is no shortage of pump flow, the speed will be the same as during stand-alone operation. However, as the load increases, the speed will decrease equally in each section relative to the stand-alone operation because the horsepower control causes insufficient pump flow for the work machines. In particular, changes in the swivel speed during combined operation would degrade operability.

On the other hand, in the swivel priority circuit, the flow control valve of the swivel section is not affected by the high-pressure signal from the boom section even during combined swivel and boom operation, so no dummy load is generated on the swivel side. Therefore, even if the load increases due to combined operation and the pump flow rate becomes insufficient due to horsepower control, the swivel speed does not change and good operability is maintained because the flow rate is prioritized to the swivel (Fig. 9).

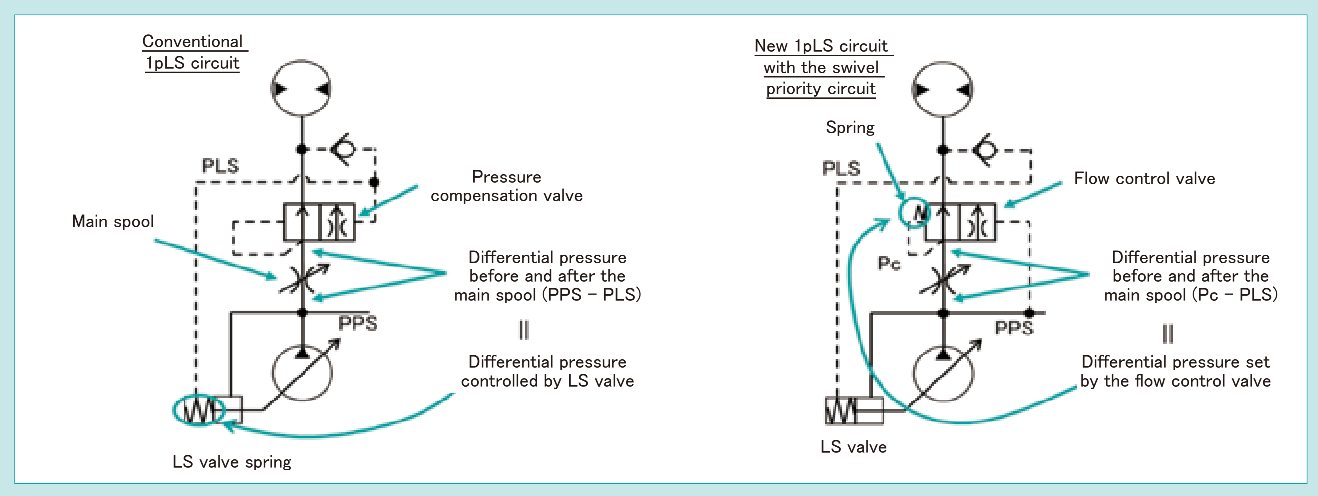

Fig. 7 Comparison of Hydraulic Circuit

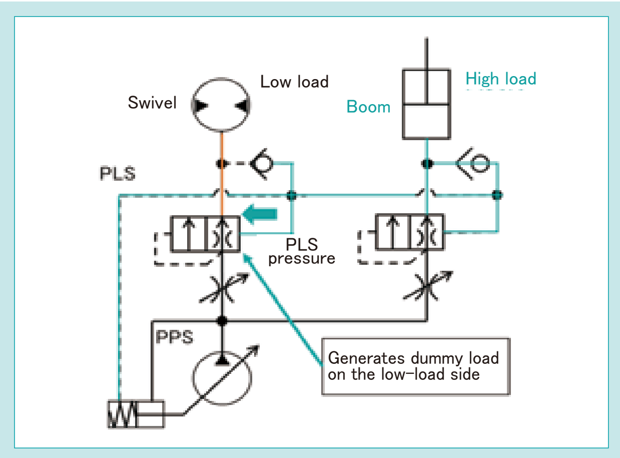

Fig. 8 Simultaneous Operation of Conventional 1pLS

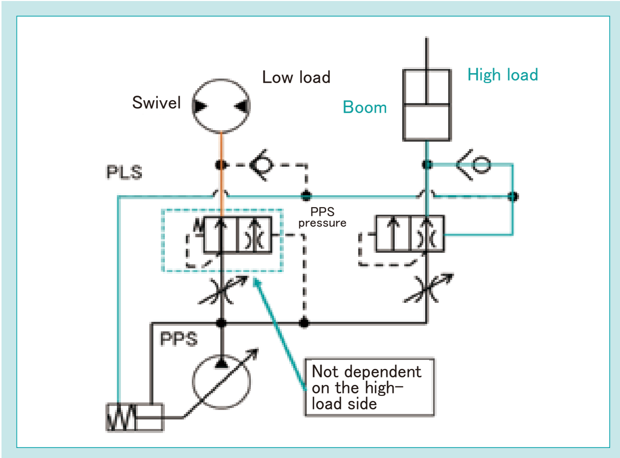

Fig. 9 Simultaneous Operation of Conventional 1pLS with Priority Circuit

4.2.3 Verification of effectiveness

The effect of the newly developed 1pLS with the swivel priority circuit and that of the conventional 1pLS circuit were verified by measuring the change in the swivel flow rate using a bench-top test device (Table 3). Figure 10 shows the change in the swivel flow rate.

When the boom was relieved, the swivel flow rate in the conventional 1pLS circuit was reduced by more than 20%, whereas that in the 1pLS with the swirl priority circuit showed almost no change, confirming the effectiveness of the new circuit in reducing swivel speed changes. We also received comments from people who actually used the system that it improved operability.

Table 3 Comparison of Flow Rate at Each Hydraulic System

Item	Unit	1pLS with swivel priority circuit	1pLS
Swivel flow rate (combined boom and swivel operation)	%	100	100
Swivel flow rate (when the boom is relieved)	%	98	78
Flow rate reduction rate	%	2	22

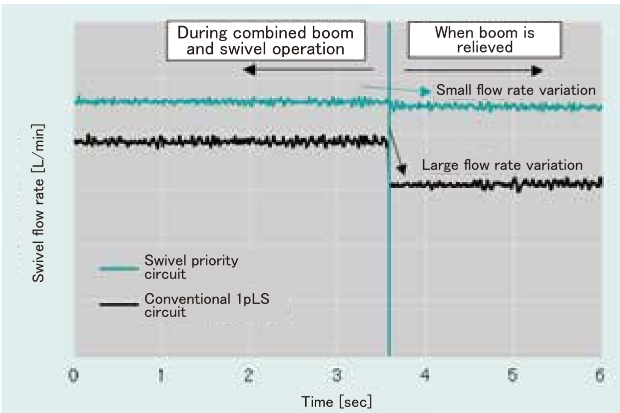

Fig. 10 Change of the Flow at Each Hydraulic System

5. Conclusion

The U-30/35-6α series adopts a new 1pLS system with a swivel priority circuit in the hydraulic system, which simultaneously achieves an energy-saving effect of 10% or more and an increase in work capacity compared to conventional models, while also improving operability by eliminating swivel speed variation that used to be a drawback of the conventional 1pLS system. After introducing models in the domestic market, we have sequentially developed derivative models for overseas markets, which have been well received by customers.

In the future, we intend to use the newly developed 1pLS system with the swivel priority circuit to other machines, thereby contributing to environmental issues and infrastructure development around the world.

Contribution to SDG targets

7.3 Improvement of energy efficiency
Modification of the hydraulic system to achieve 10% energy savings compared to conventional machines

9.2 Strengthening of inclusive and sustainable industrial infrastructure
Improved machine operability

11.a Support of urban-rural connections
Contribution to infrastructure development around the world

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Development of Rotary for Upland Farming with SL Series Tractor for the Domestic Market

Farm Machinery Implements and Products Engineering Dept.

In response to the recent decline in rice prices in Japan, a growing number of rice farmers are transitioning to upland farming. This trend has been further amplified by the Japanese government's policy initiatives aimed at expanding the acreage and production of upland crops. Consequently, the focus of the domestic agricultural machinery market has shifted from catering primarily to rice farming needs to addressing the demands of upland farming practices. To address this market transformation, we have developed the "Up-cut rotary tiller" and the "Riding rotary tiller," specifically engineered to enhance performance and work efficiency in upland farming applications. These innovative tillers make substantial contributions to improving both performance and work efficiency. Furthermore, their lightweight design facilitates stable operation with the SL series tractor, a model specifically designed for the domestic market.

【Key Word】
Upland Farming, Rotary Tiller, SL Series Tractor, Up-Cut, Ridging

Related SDGs

1. Introduction

1-1 Development background

The stagnation of rice prices in recent years (Fig. 1) has led to a shift from rice to upland crops such as wheat, soybeans, and vegetables.[1)] In addition, there are growing calls for domestic production of vegetables for processing and commercial use, as well as fresh vegetables that would otherwise be imported. Recent national policies have set targets to expand vegetable crop area and increase vegetable production to improve farmers' profitability (Fig. 2).[2), 3)] With this tailwind, the number of farmers newly trying to engage in upland farming is on the rise, and the domestic agricultural machinery market is shifting from rice cultivation to upland crop cultivation. Under these circumstances, it is important to develop upland farming machinery products that meet market needs and offer products that are best suited to each type of operation, thereby contributing to greater efficiency in upland farming.

Soil preparation is an important aspect of upland farming. Since soil preparation is the first process in upland crop cultivation and strongly influences later crop growth, the level of performance (such as leveling,[*1] clod breaking,[*2] and plowing in[*3]) required for soil preparation is high. Moreover, field crops require more labor and time than rice cultivation, as there are more work processes involved. Therefore, it is highly desirable to improve the performance and efficiency of tillage machines (hereinafter referred to as “rotary tillers”), which are indispensable for soil preparation.

*1 Ability to finish the field surface without unevenness.
*2 Ability to finely crush soil clods.
*3 Ability to plow in residual matter such as wheat straw and rice stubble.

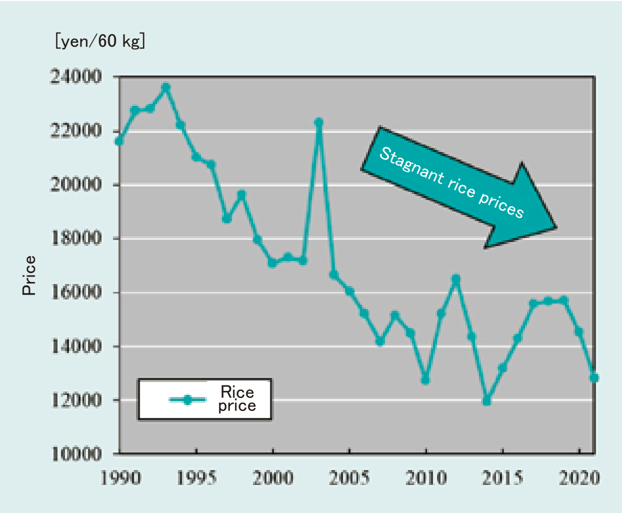

Fig. 1 Transition Concerning the Price of Rice

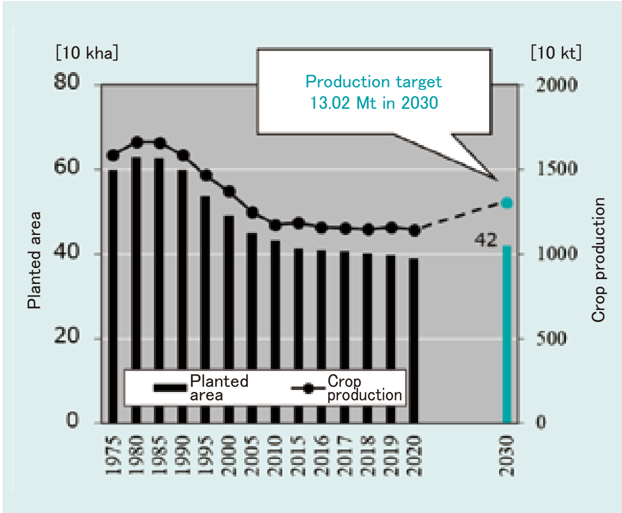

Fig. 2 Transitions Concerning the Crop Acreage and the Production of Upland Farming

1-2 Situation of Japanese market for upland farming rotary tillers

Conventional rotary tillers for upland farming lined up for the SL series tractors in the 17.6 to 44.1 kW (24 to 60 PS) class, which is the volume range of tractor sales in Japan, are overly robust in design so that their front-rear weight balance may be inadequate when a tiller is mounted on a tractor, sometimes making the work itself impossible. This is partly because these rotary tillers are designed to be mounted on tractors with higher horsepower than the SL series tractors, and this is a major issue for users who own SL series tractors as their ability to work may be affected.

While Kubota has a relatively complete lineup of upland farming rotary tillers for tractors in the lower horsepower range than the SL series tractors, the company still does not have enough of such equipment for the SL series tractors.

Therefore, to solve the above issue, we have developed a rotary tiller for upland farming that best matches Kubota's SL series tractors.

2. Development concepts and target values

2-1 Development concepts

We have developed an "up-cut rotary tiller" and a "riding rotary tiller" as rotary tillers for upland farming. The development concepts are as follows.

(1) The new models should be based on Kubota's original lightweight and compact forward rotary tillers for SL series tractors; should be lighter than conventional models; and should provide stable operation when working with the rotary tiller alone or working simultaneously with attachments such as fertilizer applicators, seeders, and mulchers.

(2) It should be possible to attach various attachments such as fertilizer applicators, seeders, and mulchers, and the durability of the attachment mounting area should be improved over that of the base model to allow various simultaneous combined operations.

2-2 Target values

(1) Lightweight and compact machine design

As reducing the weight of rotary tillers is important not only to stabilize the work and improve efficiency, but also to meet the safety standards for agricultural tractors on public roads with a work machine mounted, the front wheel load ratio (the ratio of the weight on the front wheels of the tractor to the total weight of the tractor including the implement and attachment) is targeted at 20% or more.

(2) Support for simultaneous combined operations with attachments

Since an increasing number of users are performing simultaneous combined operations with attachments to shorten work time and increase efficiency, the durability of the attachment mounting area is targeted to be at least 1.5 times that of the base machine.

3. Technical issues to be solved

The issues to be addressed to achieve the aforementioned target values are listed below.

(1) Optimization of rotary tiller weight and strength

Conventional rotary tillers for upland farming on the market are often unsuitable for work with SL series tractors due to excessive tiller weight. In addition, simultaneous combined operations with attachments such as fertilizer applicators, seeders, and mulchers are required in recent years to improve work efficiency, and due to their additional weight, stable work has become even more difficult. Since there is a trade-off between weight reduction and strength in rotary tillers, the challenge is to achieve the required durability while reducing weight.

(2) Improved durability under dimensional constraints

Breakage of the attachment mounting area during simultaneous combined operations with attachments will interrupt the work. Since such a failure could result in, for example, missing the best time to plant soybeans, which must be done between rains during the rainy season, the mounting area must be highly durable. However, there are many dimensional constraints on the attachment mounting area due to standards and the area's relationship to the attachment side. Achieving increased strength within those constraints is another challenge.

4. Developed technology

4-1 Outline of the newly developed models

4.1.1 Up-cut rotary tiller

The up-cut rotary tiller is a general-purpose rotary tiller that, in a single process, can create a sowing bed (two-layer structure) optimal for crop growth, thanks to the action of a blade shaft that, unlike the forward rotary tiller, rotates in the opposite direction to that of the tractor axle and a comb rake placed behind the blade shaft (Figs. 3 and 4).

Note that the two-layer sowing bed is a bed formed with coarse soil in the lower layer and fine soil in the upper layer. It provides good germination due to excellent seeding accuracy and drainage.

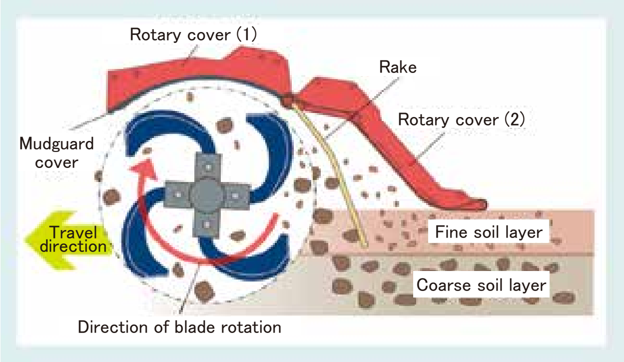

Fig. 3 Effect of "Up-cut rotary Tiller"

Fig. 4 Development Model "KUC Series"

4.1.2 Riding rotary tiller

The riding rotary tiller is Kubota's unique rotary tiller that can sufficiently crush residues such as rice stubble and straw and form a ridge in a single process by using a blade shaft with many blades to break up clods and increasing the rotational speed of the shaft with a speed-increasing sprocket (Fig. 5). It eliminates the need to break the ground, which is usually required prior to ridging, resulting in high efficiency in ridge formation.

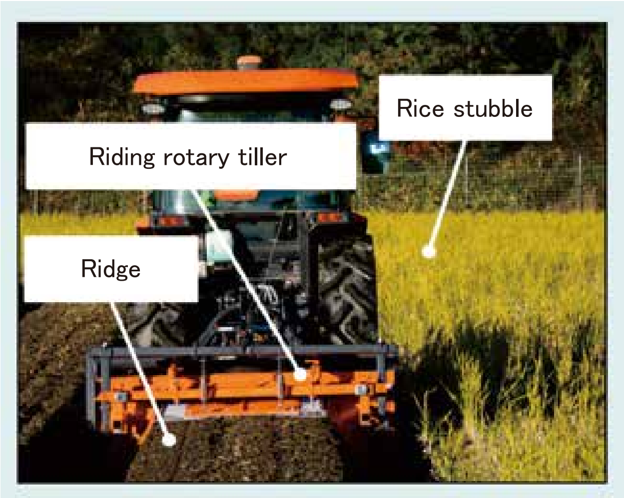

Fig. 5 Development Model "RT-K Series"

4-2 Weight of rotary tiller and front-rear weight balance when mounted on a tractor

Conventional rotary tillers for upland farming on the market today are, as mentioned above, excessively heavy. Mounting attachments on rotary tillers for upland farming is essential in today's agriculture, where high work efficiency is important and simultaneous combined operations are a prerequisite. As a result, it is difficult to satisfy the appropriate front-rear weight balance when attachments are mounted on SL series tractors, making stable work with the tractors even more difficult.

Therefore, in order to achieve stable operation with SL series tractors, the tiller body was designed based on Kubota's original forward rotary tiller developed exclusively for SL series tractors, aiming at meeting the required durability and safety standards for driving on public roads with attachments mounted. Here we present representative comparison cases for up-cut rotary tillers, which have a particularly heavy weight among conventional rotary tillers for upland farming, showing that the newly developed models are significantly lighter than conventional models in all plowing widths (Table 1).

The rotary tiller mounting position is also important to improve the front-rear weight balance when the tiller is mounted on the tractor. The plowing depth adjustment mechanism (gauge wheels) is located at the rear of the tiller to ensure an appropriate front-rear weight balance even when the tiller is mounted on an SL series tractor. This allows the tiller to be mounted approximately 24% (375 mm) closer to the tractor than is possible in conventional models (Fig. 6).

As described above, even if a conventional model alone is mounted on the SL600, which is the top model of the SL series tractors, the maximum possible number of front weights (10 weights) is required to achieve a front wheel load ratio of 20% or more. When an attachment is further added, the front wheel load ratio becomes less than 5%, making it impossible to drive the vehicle on public roads or even to work in the field. On the other hand, the newly developed models achieve a front wheel load ratio of 20% or more both when a rotary tiller is used alone and when an attachment is added, enabling stable operation even under conditions where conventional models cannot work (Table 2).

- Formula for calculating tractor's front wheel load ratio

$$\gamma f = \frac{Mf}{Ma} \times 100 \qquad [1]$$

γf : Front wheel load ratio [%]
Ma : Gross weight [kg]
Mf : Weight on tractor's front wheels [kg]

Table 1 Weight Comparison of "Up-cut Rotary Tiller"

Rotary tiller plowing width [m]	Rotary tiller weight [kg]		
	Newly developed model KUC series	Conventional model (1) series	Conventional model (2) series
1.5	RL15S-KUC 304	Conventional model A 365	-
1.6	RL16S-KUC 316	Conventional model B 375	-
1.7	RM17S-KUC 341	Conventional model C 395	-
1.8	RM118S-KUC 353	Conventional model D 405	-
1.9	RM19S-KUC 366	-	-
2.0	RM20S-KUC 380	Conventional model E 670	Conventional model G 675
2.2	RM22S-KUC 416	Conventional model F 700	Conventional model H 722

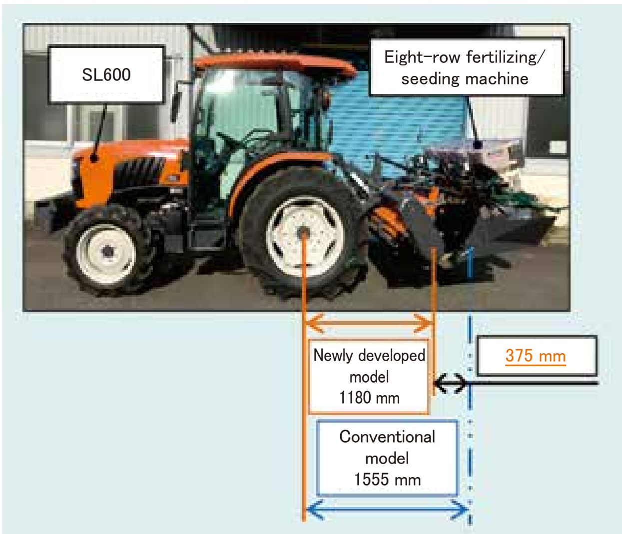

Fig. 6 Distance Between Rear Wheel Axle and Blade Shaft of Rotary Tiller

Table 2 Load Ratio of Front Wheel Comparison of SL600 Tractor with "Up-cut Rotary Tiller" and Attachment

	Newly developed model (RM22S-KUC)		Conventional model H	
	Rotary tiller alone [kg]	With attachment added (416 + 350 kg)	Rotary tiller alone (722 kg)	With attachment added (722 + 350 kg)
Front wheel load ratio (number of front weights)	26.6% (0)	20.5% (10)	21.2% (10)	4.5% (10)

* It is assumed that the attachment is an eight-row fertilizing/seeding machine, with all units fully loaded with fertilizer and seeds.
* The above fertilizing/seeding machine is the heaviest attachment expected to be installed.
* Each front weight weighs 25 kg.

4-3 Improved durability of attachment mounting area

As simultaneous combined operations with attachments have become mainstream, there is a strong need to improve the durability of the attachment mounting area. On the other hand, there are many dimensional constraints, such as square pipe diameter and clearance, on the attachment mounting area due to its relationship to the attachment side. Under such circumstances, we decided to review the shape and thickness of the components of the attachment mounting area (parts (1) and (2) in Fig. 7) to improve durability.

<Details of measures to improve durability>

- Review the shape of part (1) and extend the welding length of parts (1) and (2).
- While the base models have a structure in which the thickness difference between members is large and stress is concentrated at the point of change in section modulus, the newly developed models have a shape that is less likely to concentrate stress due to the reduced thickness difference between members and the elimination of extreme changes in section modulus.

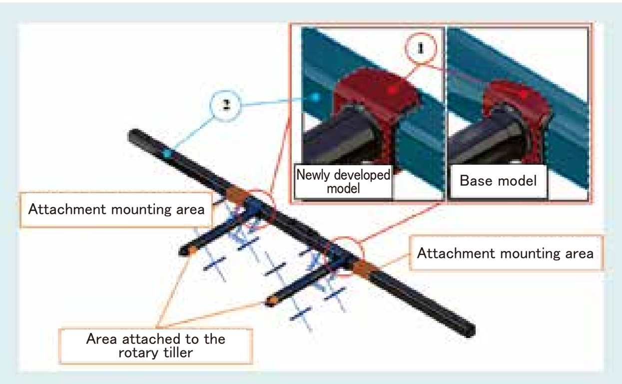

Fig. 7 Analytical Model of Part Mounting Attachments

Therefore, we conducted a strength analysis with the fertilizing/seeding machine (350 kg), which is the heaviest attachment expected to be installed, to verify the strength of the machine when excessive loads are applied to these parts (when driving on rough roads and when the tiller drops). In addition to the strength analysis, the effectiveness of the durability improvement measures was verified through rough road driving and tiller drop tests, resulting in a significant improvement in durability performance over the base machine (Fig. 8 and Table 3).

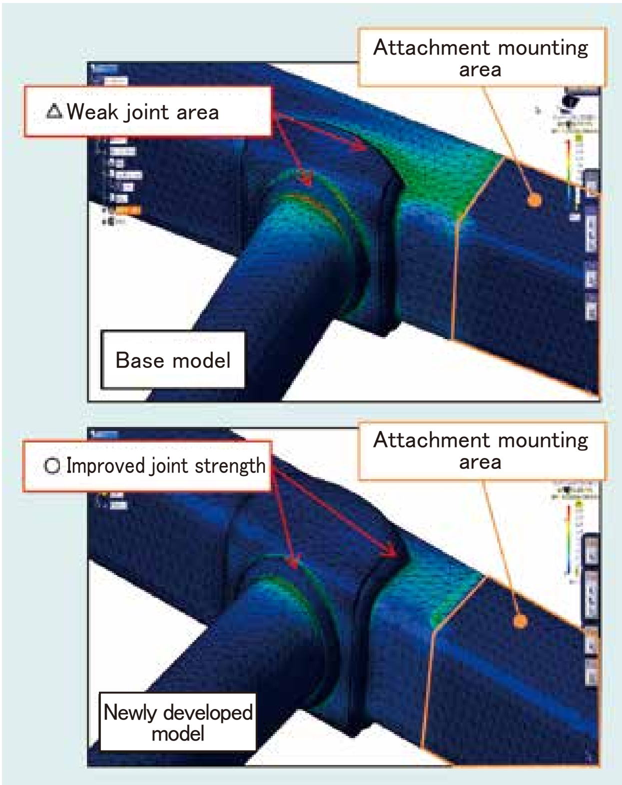

Fig. 8 Strength Analysis Result

Table 3 Strain Comparison of Part Mounting Attachments (Measured Value)

	Newly developed machine [μST]	Base machine [μST]	Reduction rate
Rough road driving test	876	4294	80%
Tiller drop test	1441	4657	69%

5. Conclusion

There were many situations where a rotary tiller for upland farming could not be used with an SL series tractor due to the weight of the tiller, even though the tractor was within the horsepower range suitable for the tiller. Under such circumstances, the newly developed models, designed exclusively for the SL series tractors, allow stable operation with the tractors even when combined with attachments. This has enabled us to achieve high work efficiency. In addition, the newly developed models, which excel in sowing bed preparation, are expected to increase crop yields and contribute to improved productivity.

Since the introduction of this machine to the market, Kubota has continued to develop implements for upland farming. We will continue to develop products that meet customer needs to further improve customer satisfaction and contribute to greater efficiency in upland farming.

Contribution to SDG targets

2.4 Realization of sustainable and robust agriculture
Achievement of improved work efficiency and stable operations

8.2 Increased productivity through innovation
Contribution to the improvement of upland crop production through the development of rotary tillers for upland farming that excel in sowing bed preparation

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Development of Drone Sprayer and Kubota IoT Intelligence Drone (K-iDrone)

KUBOTA Research and Development Asia Co.,Ltd

Agricultural spraying drones have become an important aspect of agricultural industry in recent years. However, these drones are characterized by their technological complexity and sophistication, posing challenges for their effective utilization. Recognizing the inherent IoT nature of drones, KRDA has developed K-iDrone, a cloud-based IoT platform designed to empower users to enhance their work efficiency and refine drone operations by leveraging the power of advanced algorithms and analytical modules to extract actionable insights from data acquired from the drones.

Owing to the rapid increase in spraying drones, KRDA has introduced the K-iDrone with the dual objectives of enabling users to harness the full potential of these drones and positioning KUBOTA as a key differentiator in driving the growth potential of spraying drones across Thailand and the ASEAN region.

【Keyword】
Agricultural Spraying Drones, IoT Platform, Cloud-Based, Analytics, Efficiency Improvement

Related SDGs

1. Introduction

Agricultural spraying drones are growing in popularity in the South-East Asian countries, with about 10,000 units sold and 400 % growth from 2020 to 2022 in Thailand. (Fig.1)

Since spraying drones are one of IoT devices that can generate and deliver huge amount of data, KRDA has identified an opportunity to simplify the complexities of drone operations and allow users to utilize the drones to their full potential by developing K-iDrone which links and analyzes data acquired from the drones.

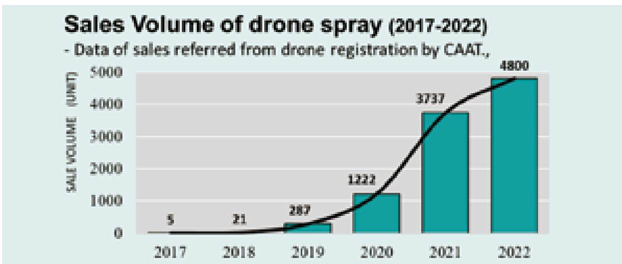

Fig. 1 Thailand's Sales Volume

With the amount of increasing agricultural spraying drones, new or even experienced users use the drones to spray chemicals inefficiently due to a lack of knowledge regarding optimal settings which most of the time causes ineffective and unsatisfied results of the sprays.

Additionally, there are increasing number of reports of drone malfunction and equipment failure, attributed to inadequate maintenance, user error, and other factors.

Therefore, to address these issues, K-iDrone is developed for drone users with the aim to help performance and efficiency when the drone is utilized for spraying tasks, and, with the acquired operation data of the drones, K-iDrone will help detect indications of abnormal operations and notify users before the drone breaks down or malfunctions.

2. R&D Concept and Target Value

2-1 R&D Concept

The development concept is based on the following points.

1) K-iDrone must have the capability to predict spray patterns based on operations of the drone, and provide recommendations for adjustments aiming at enhancing spraying efficiency.

2) K-iDrone must have the ability to alert users when it detects abnormal operations of the drones and provide recommendations for appropriate maintenance timing.

2-2 Target Value

In order to address the common issues stated, K-iDrone is developed with 3 target values below.

1) Spray pattern prediction model

The developed model must be able to predict the pattern of the sprays based on the drone's setting with more than 80 % accuracy.

2) Spray enhancement algorithm

The developed algorithm must be able to suggest adjustments to the drone's setting in order to enhance drone's performance and efficiency.

3) Anomaly detection model

The developed model must be able to detect indications of abnormal operations and notify users before the drone breaks down or malfunctions.

3. Technical challenge to be solved

In order to help users optimize drone's setting for performance improvement:

Firstly, the prediction model was developed to predict spraying patterns in various drone setting conditions such as speed, height, flowrate and environment factors that affect the droplets, which change the spraying pattern. Therefore, data must be collected under all conditions to accurately determine the droplet density profile of the spray coverage area; (Fig.2)

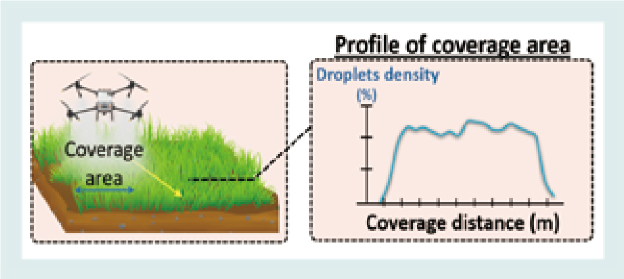

Fig. 2 Spray Pattern by Prediction Model

Secondly, algorithms to assess droplet density profile and adjust drone's setting factors is needed such as speed, height, flow rate to achieve the adequate density and improve the spraying result by accumulating density of each flight path; (Fig.3)

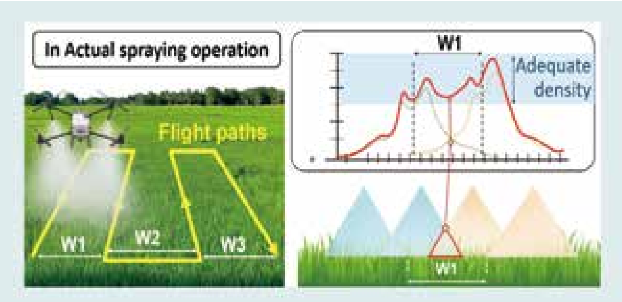

Fig. 3 Improve Spray Pattern with Algorithm

Droplets at adequate density range are maintained and droplets density in concerned range (W1) ≤10 %.

Lastly, to address and prevent unexpected damage of drone parts issues, an anomaly detection model that can detect abnormal behavior of drone parts from behavior patterns in flight record data needs to be developed to notify the users when abnormal operation is detected and to display the remaining life-span. (Fig.4)

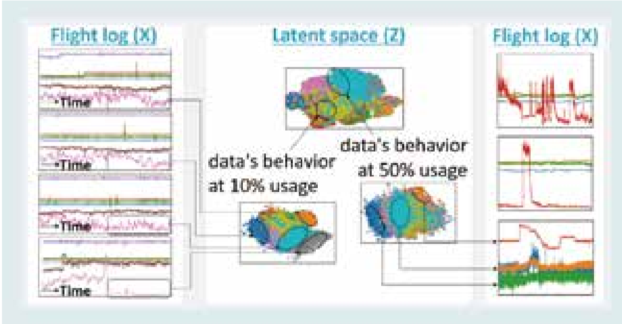

Fig. 4 Machine Learning Model Training by Autoencoder

4. Developed Technology

4-1 Spray pattern prediction model

4.1.1 Spraying results collection and data analysis

In order to build a machine learning model to analyze the spraying performance, samples of spraying results at different conditions are collected and converted into numerical dataset via an image analyzer.

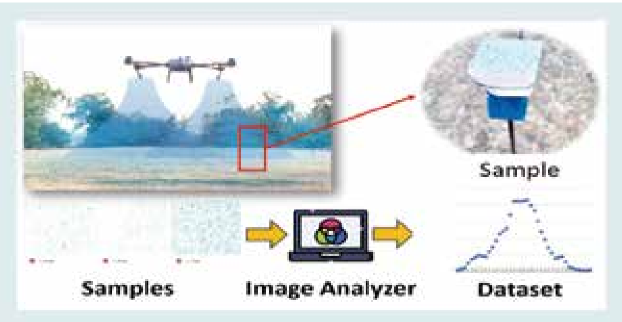

Fig. 5 Spraying Results

4.1.2 Spray pattern prediction machine learning model training

The dataset is then used to train the machine learning model using linear regression, random forest regression, and gradient boosting techniques in order for the model to learn the patterns and relations between each factor that affects the result of the spraying based on settings of the drone.

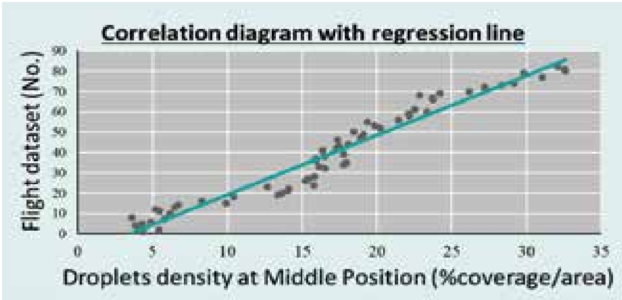

Fig. 6 Correlation of Droplets Density at Middle Position

4.1.3 Model prediction accuracy test

The model's accuracy is tested by inputting unseen data and comparing with the actual result. (Fig.7)

The model achieved outputting spraying density at different positions with the average accuracy of 90 %.

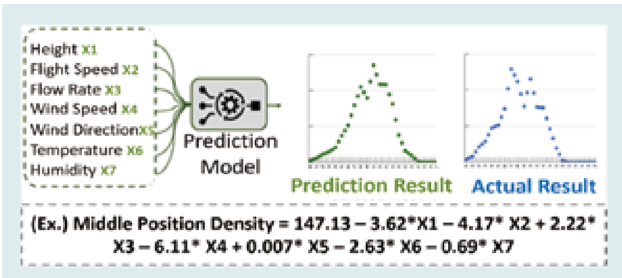

Fig. 7 Results Comparison

4-2 Spraying enhancement algorithm

4.2.1 Spraying enhancement algorithm

Density and dispersion of chemical droplets indicate effectiveness of spray. KRDA conducts inquiries with customers to gather information on the settings utilized by them, and these settings are then employed in testing the results of the spraying. As shown in Fig. 8, the results reveal that the density of droplets is excessive in the central portion and experiences a marked decline towards the edge of the specified range with the difference in density of 33.9 % indicating inadequate dispersion.

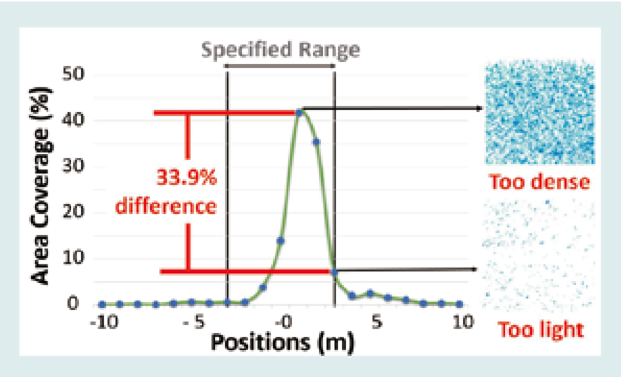

Fig. 8 Spraying Result with Users Setting

Spraying enhancement algorithm is utilized in K-iDrone Spraying Performance Analyzer. It evaluates flight settings input by users and analyzes the spray effect focusing on droplets density, dispersion and row width, and then performs adjustment to factors such as flight speed, height, spray amount and etc. with the aim to maximize spray effect for maintaining droplets density adequate and in appropriate range.

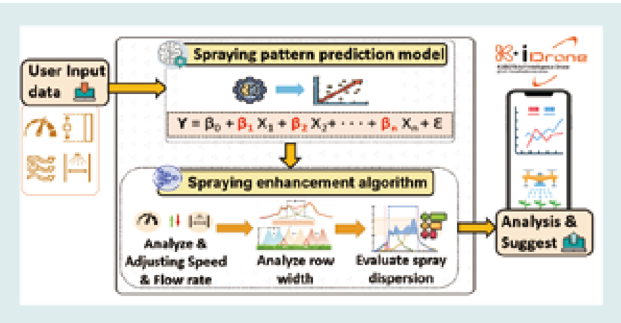

Fig. 9 Diagram of K-iDrone Spraying Performance Analyzer

To evaluate its functionality, the previously used user settings are used. The analyzer provides suggestions for adjustments to improve the outcome, along with the predicted pattern after a setting adjustment.

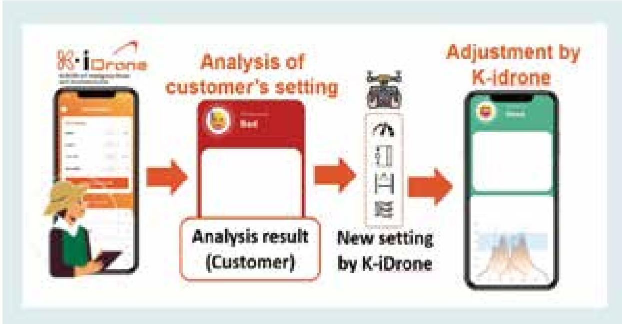

Fig. 10 Suggestion for Settings Adjustment

4.2.2 Field test and result collection

An adjustment is applied to the setting according to the suggestion from K-iDrone. The spray result in Fig. 11 shows a noticeable improvement in the droplets dispersion with adequate density.

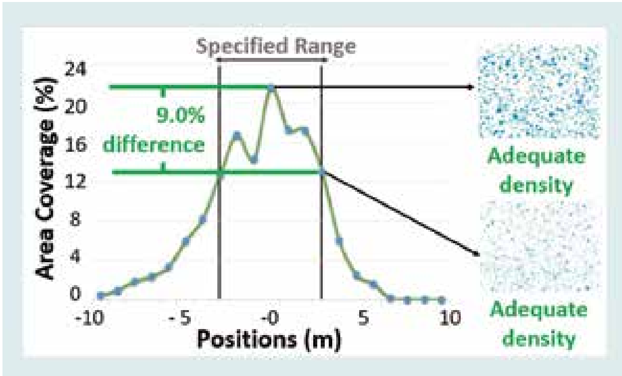

Fig. 11 Spraying Result After Adjustment

In the actual operation, the density of the area at which the sprays between operating line N and N+1 intersects will have a proper density of droplets (the highlighted area in Fig.12 is the accumulated density between the two lines) with ≥90 % droplets at appropriate density being maintained and ≤10 % difference in density in the concerned range (W1).

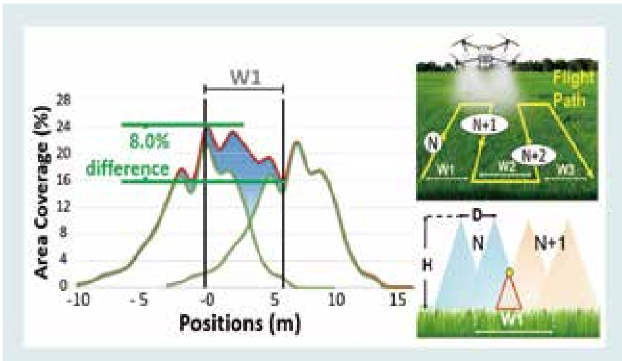

Fig. 12 Adjusted Setting Spraying Result between Operation Lines

4-3 Anomaly detection model

4.3.1 Anomaly detection model development

Like most agricultural machinery, spraying drones are equipped with a number of consumable components. Unfortunately, some models of these drones do not possess maintenance guidelines within their user manuals, making maintenance a challenging task. In light of this, KRDA has developed an anomaly detection model, which utilizes both real-time and historical data from the drone to identify early indications of abnormal operations. This model assesses the drone's operation and any abnormalities that it could have encountered, and assists users to know the appropriate maintenance of their drones in advance.

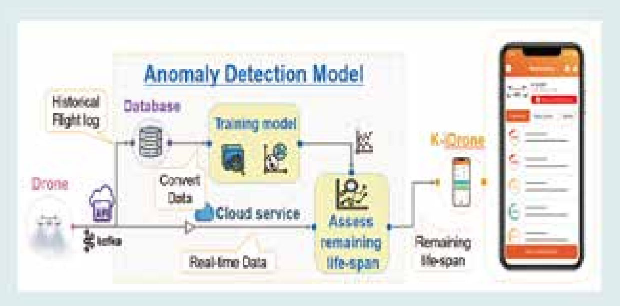

Fig. 13 Flow Diagram of Anomaly Detection Model

4.3.2 Anomaly detection model training

To train the model to recognize anomaly patterns, flight logs from drones reporting issues in their parts are used. In this case, the focus is on the water pump, which is a component prone to frequent damage.

Each flight log contains operational data from a specific flight, such as speed, spray flag, flow rate, water pump RPM, centrifugal nozzle RPM, and so on. Each of these attributes is timestamped.

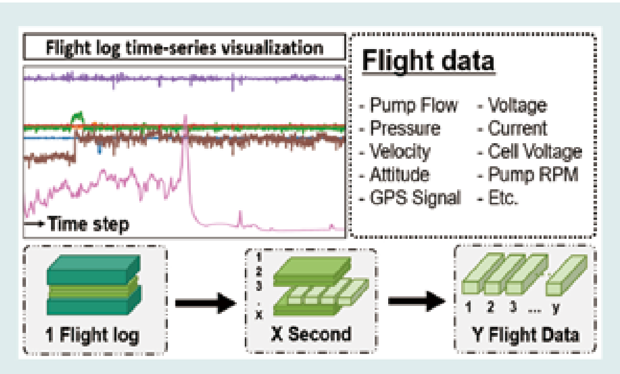

Fig. 14 Flight Log Data Illustration

Due to huge amount of dataset, Autoencoder and K-means Clustering technique are used to compress the dataset in order to capture the most important parts of the input dataset and filter out irrelevant data that is considered as noise.

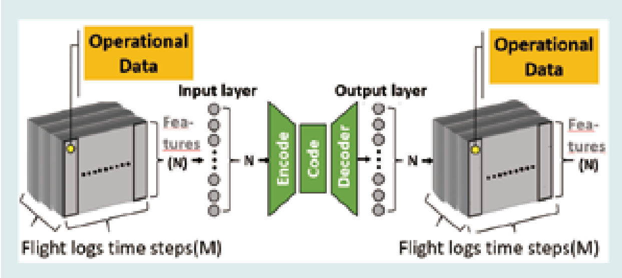

Fig. 15 Autoencoder Network

The trained model recognizes that when use of water pump reaches 80-85 % of its total life-span (100 % is when it fails), behavior of its operation changes which indicates its abnormalities with the 76 % accuracy of detection.

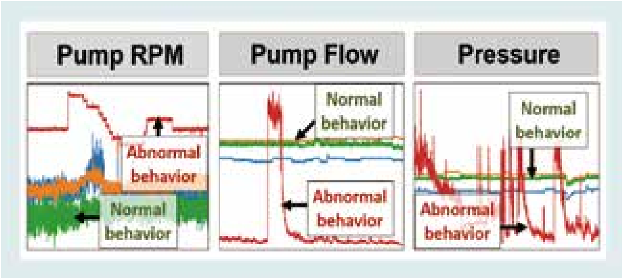

Fig. 16 Water Pump Behavior Changes

4.3.3 Life-span assessment evaluation

To evaluate the model's efficiency, life-span assessment evalution is applied to a K-D20P spraying drone that has been utilized extensively. After the model analyzes the drone's historical flight logs, the model is able to detect the abnormality and assess the remaining life-span of its water pump.

Fig. 17 Life-Span Assessment

5. Conclusion

5-1 Evaluation of the achievements

5.1.1 Spray pattern prediction model

The model is able to predict droplets density at concerned positions with 90 % accuracy compared to the actual data.

5.1.2 Spraying enhancement algorithm

The algorithm is able to suggest and optimize spray setting to maintain 90 % of droplets at appropriate density within the concerned range.

5.1.3 Anomaly detection model

The model is able to detect abnormal operations of drone's water pump with the accuracy of 76 % and able to assess its remaining life-span.

Table 1 Product Evaluation

Item	Target	Result	Evaluation
Spray pattern prediction	≥80 %	90 %	●
Spray enhancement algorithm	≥80 %	90 %	●
Anomaly detection model	≥70 %	76 %	●

5-2 Contribution to the business

The achievement of K-iDrone development serves as a key differentiator for KUBOTA in the market and will significantly enhance the growth potential of the spraying drone industry in both Thailand and the ASEAN region as shown in Fig.18.

Kubota entered the drone market in Thailand in 2021 and has been getting good reviews from customers, increasing sales every year.

We intend to continue to meet customer expectations and contribute to agriculture in Thailand.

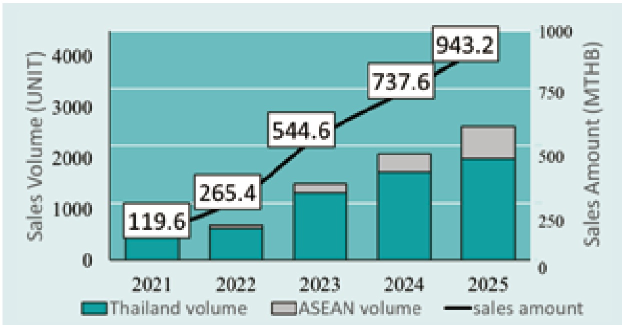

Fig. 18 Sales of Spraying Drones

Contribution to SDG targets

3.9 Minimize illnesses from chemicals and pollution.
Optimizing drone spraying to reduce chemical use and promote healthier ecosystems, while lowering risks to humans.

8.2 Improvement in productivity through innovation.
Finding novel ways to make the process of drone spraying more efficient and effective.

9.2 Strengthening inclusive and sustainable industrial infrastructure.
Optimizing drone spraying for minimal chemicals and maximal yield.

Reference

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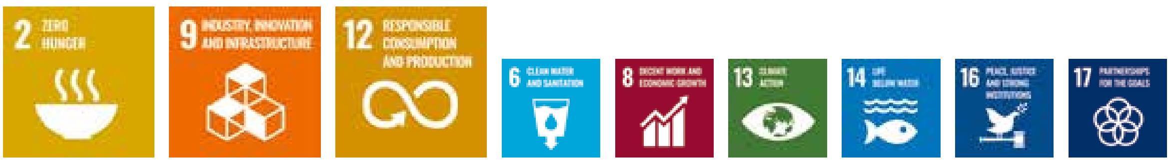
Development of TIM Rear Top Linkage and TIM Spreader

Kubota Research and Development Europe S.A.S.

Spreading fertilizer is a crucial aspect of crop production, and it requires precision and efficiency to achieve optimal crop yields. Optimal and accurate distribution of the fertilizer material is highly desired to minimize waste, reduce input costs, maximize return on the crop (prevent underdosing and overdosing of the fertilizer), and minimize environmental impact. To achieve the desired optimization during spreading, Kubota has enhanced the automation of the tractor-spreader coupling with Tractor Implement Management (TIM) technology. In addition, Kubota has developed an exclusive novel TIM style function to control the Rear Top Linkage, thereby enabling precise management of the spreading inclination. These advancements, coupled with an optimal spreader control algorithm, have resulted in optimized fertilizer consumption, improved crop yields, and reduced operator fatigue.

【Keyword】
TIM, Top Link Length Control, Inclination Control, Autonomous Spreading, Pitch Control, Hitch Control

Related SDGs



1. Introduction

Key parameters for an accurate and uniform distribution of the fertilizer to achieve the best results are correct height and inclination of the spreader with respect to the crop surface and disks rotating speed. These parameters are connected to tractor functions like Rear Hitch (height), Rear Top Linkage (inclination), and tractor Rear PTO (spreader disks rotating speed).

Currently, the operator is supposed to set all the initial parameters and to continuously tune some of them during the spreading phase in order to keep the optimal values. On the spreader side, the automatic adjustment of some of these parameters (like dosing opening and spreading release point) is already existing but, due to the changing weight in the hopper, the main problem is to keep the height and inclination of the spreader optimal against the crop. This is something still not automated that can cause overdosing and underdosing (Fig. 1) due to the hinge effect (weight distribution on the tractor wheels that impacts inclination of the spreader and disks height).

Fig. 1 Result of Wrong Spreading Settings with Under Dosing Between the Passes (Yellow) and Overdosing on the Passes (Dark Green).

Fig. 2 shows an example of the hinge effect in test environment with different tractor tires pressure. The relation between the hopper weight and the hopper inclination and disks height depends on tires conditions, front load, tractor mass and it is mainly linear. A load of about 4,000 kg can result in 16-20 cm decrease in disks height and 2.9° – 3.5° deviation on the spreader inclination.

A typical problem, just before to start spreading, is to decide if the initial parameters (e.g spreader height and inclination) must be adjusted before or after filling the hopper. Fig. 3 demonstrates that both methods have a side effect if a continuous tuning of the spreader parameters is not properly done (ideally the disks height is always 75 cm above the crop and 0° inclination for the spreader).

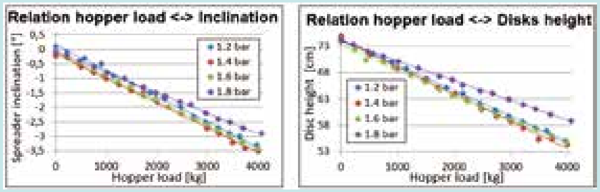


Fig. 2 Hinge Effect with Different Tire Pressures for Disks Height and Spreader Inclination

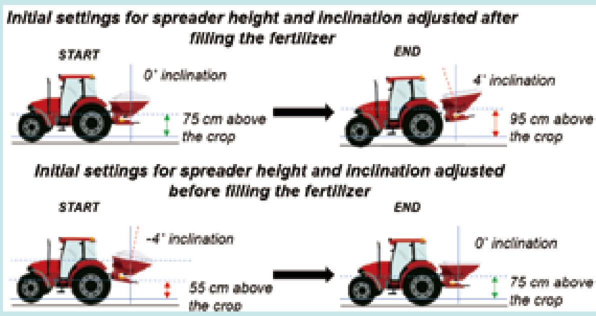


Fig. 3 Different Methods to Set the Initial Parameters and Side Effects (Wrong Inclination and Distance From the Crop)

2. R&D Concept and Target Value

2-1 Concept of development

The main idea is to use the TIM technology to complete the set of automatically tuned parameters allowing the spreader to directly manage the resources of the tractor. To proceed in this direction Kubota developed:

- Both on tractor and spreader side: two already normed TIM functions that are TIM Rear PTO (to manage the disks rpm) and TIM Rear Hitch (to manage the spreader height)
- Both on tractor and spreader side: A new TIM function able to manage the Rear Top Linkage. The TIM Rear Top Linkage function is currently in discussion in the AEF (Agricultural Electronic Foundation) TIM group and is expected to be officially introduced in TIM Norm Gen 2
- A new spreader internal algorithm able to manage the 3 functions at the same time coordinating them.

2-2 Target Value

The target value is to reduce the operator interactions with the system and to maximize the yield of the crop keeping the optimal spreading parameters during the whole operation cycle. The direction of the developments was, therefore, to increase the global level of automation of the tractor/spreader couple (TIM technology plus TIM Rear Top Linkage) and to improve the intelligence on the spreader side, allowing it to develop and drive the best spreading strategy. Accuracy in satisfying the spreader commands for the different functions was also a target of the development.

3. Technical Challenge to be Solved

3-1 Developing the necessary already-existing TIM functions on the tractor and the spreader

The first necessary step was to develop the TIM normed Rear Hitch and Rear PTO functions for a TIM Server (tractor) and the TIM Client (spreader) in order to allow the spreader to manage these resources through ISOBUS following the TIM authentication process and the TIM control loop method.

In Table 1 there are the TIM functions and the TIM functions options (TIM facilities) that allow the spreader to control the necessary tractor features using the TIM norm. These functions had to pass the AEF TIM conformance test in order to get the necessary AEF (Agricultural Electronic Foundation) certificates.

Table 1 TIM Functions and TIM Facilities Developed Both on the Tractor and Spreader Side

TIM Function	TIM Facility	Development necessary to allow the spreader to:	Impacted parameter
Rear PTO	PTO engagement	Engage the Rear PTO when a spreading action is needed	Disks rpm
	PTO disengagement	Disengage the Rear PTO when a spreading action is not needed anymore	Disks rpm
	PTO shaft speed	Manage the speed of the Rear PTO shaft while the fertilizer is spread	Disks rpm
Rear Hitch	Rear Hitch motion	Raise until stop request/lower until stop request/Float and Stop the Rear Hitch	Height of the disks
	Rear Hitch position	Request a specific setpoint position (%) for the Rear Hitch	Height of the disks

3-2 Developing the TIM Rear Top Linkage Function

A completely new function able to manage the spreader inclination, allowing settings like Float, Stop, Raise, Lower, specific setpoint position (%), was developed as a basic tractor function. Then, on top of this development, the function was adapted to the TIM structure, allowing an external source command (the spreader) to command it through the TIM protocol.

The basic challenges were to create a new control loop for a non-existing TIM function replicating the TIM protocol and to reach the proper specific % position of the Rear Top Linkage in a reasonable time, avoiding excessive overshooting and undershooting while allowing different loads on the toplink.

Table 2 TIM Rear Top Linkage Function Developed Both on the Tractor and Spreader Side

TIM Function	TIM Facility	Development necessary to allow the spreader to:	Impacted parameter
Rear Top Linkage	Rear Top Linkage Motion	Raise until stop request/lower until stop request/Float and Stop the Rear Top Linkage	Disks inclination
	Rear Top Linkage Position	Request a specific setpoint position (%) for the Rear Top Linkage	Disks inclination

3-3 Developing the TIM spreader internal algorithm to manage all the functions

All the functions used for spreading must be managed by the spreader at the same time through an algorithm that mixes the commands together and harmonizes them.

1. Disks speed control: to manage the disks speed by controlling the Tractor Rear PTO via the TIM protocol. Different speeds are necessary for main field and border areas.
2. Spreader height control: to manage the disks height against the crop by controlling the tractor Rear Hitch via TIM protocol. This parameter is heavily influenced by the huge load variation in the spreader and the crop height.
3. Spreader inclination: the geometry of a common tractor hitch defines the relation between the hitch height, toplink length and spreader.

In Fig. 4 the measurements show the required Rear Top Linkage length in association with deviating hitch height for various spreading angles. Since the hitch height is continuously controlled by the height control, this needs to be taken into account to control the toplink length.

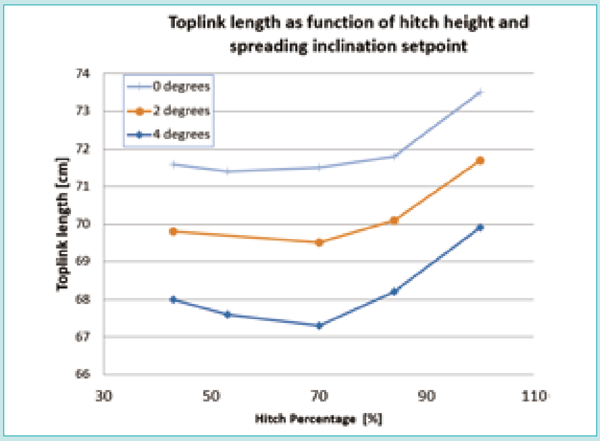


Fig. 4 Rear Top Linkage/Rear Hitch Position Relation

4. Developed Technology

4-1 Tractor Rear Top Linkage control and TIM structure adaptation

4.1.1 Technical Challenge: developing the TIM Rear Top Linkage

The target was to develop a system able to get some position commands from ISOBUS (Raise, Lower, Float, Stop, % position) and to actuate them through the valve connected to the Rear Top Linkage. This Rear Top Linkage is equipped with a length sensor in order to generate a feedback about its status. This system is not yet present in the TIM norm.

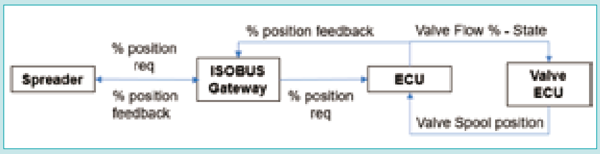


Fig. 5 System Scheme of a TIM Rear Top Linkage Management on the Tractor

4.1.2 Solution of Challenge: PID control and replica of the TIM protocol

Main areas of research and development were:

1. Measurement of the real flow for the valve connected to the Rear Top Linkage in relation with the engine rpm: this activity was necessary in order to guarantee a proper response of the system for the requested flow. For engine rpm lower than 1300 a reasonable flow is not guaranteed.
2. Suitable feedback for the PID controller: experiments and measurements about the communicated valve spool position were conducted, comparing the results with the current method used on the tractor to report the estimated flow (fingertip deflection mirrored as flow estimated status). The spool position and its relation with the flow is a better parameter for the PID control since the spool position does not change if the engine rpms are not enough (no real movement), meanwhile, if the rpms are enough, the spool position has a clear relation with the flow.
3. Spool displacement movement range: following the measurements, the spool displacement in relation with the oil flow has two main linear working areas (0-30 % and 31 %-80 %) and, into these areas, the relation is suitable for a closed loop control. Due to the nature of the requested adjustment while spreading, the spreader requires a relatively slow rear top linkage control; consequently, the lower range (0-30 % oil flow) has been chosen to implement the control.

4.Creating the PID controller and tuning the PID parameters: the experimental tests corroborated the simulations and different P values to extend and retract the Rear Top Linkage were used, while I and D parameters did not have a big influence for the kind of performances that were requested (quite slow and limited movements).

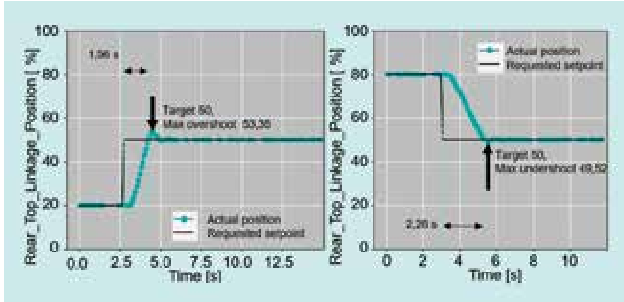


Fig. 6 Extend and Retract Performances with the Optimal Parameters of the Tab Below the Figures

Table 3 Optimal Parameters for the PID Control of the Tear Top Linkage

	P	I	D	Dead band	Weight	Qmax°	Step-size	Overshoot	SP reaching time
Extend	1500	0	0	0.15 %**	2300 kg	10 %	30 %	3.35 %	1.56 s
Retract	2000	0	0	0.15 %**	2300 kg	10 %	30 %	0.48 %	2.26 s

** 1 % position change in the toplink length result in about 0.2 degrees inclination movement, so 0.15 % dead band means a maximum deviation of 0.03 degrees in the inclination. ° Flow command sensitivity

4-2 Spreader controls

4.2.1 Technical challenge: developing the spreader controls

Disks speed control (Tractor Rear PTO control): a straight forward control based on the tractor Rear PTO was developed; based on the spreading job and specific location into the field, different disks rotation speed setpoints are defined. An accuracy range within ±5 Rear PTO rpm would generate the best results.

The spreader defines one fixed rotation speed for the main field and another one while going into border areas, depending on the type of border spreading application. In the spreader, the disks necessary speed is converted into rear PTO speed and communicated via TIM protocol to the tractor. Upon reaching the border areas, border spreading unit is hydraulically moved into the spreading flow, then the disks speed setpoint is automatically adjusted accordingly.

Spreader height control (Tractor Rear Hitch control): a control system was developed using ultrasonic distance sensors mounted on the spreader (one per side) . A PID control strategy manages hitch height control setpoints via TIM protocol to the tractor, allowing the system to react to hopper content and crop height variations. An accuracy range within of ±5 cm for the hitch height would generate the best results.

Spreader inclination (Tractor Rear Top Link control): a new control strategy was defined where the toplink length is controlled based on spreading inclination setpoint, actual hitch height and actual hopper content (currently under IP).

The implemented solution solves also the problem of a spreader inclination control referred to the field slope and not to earth horizon while driving on hilly conditions. Indeed, in these conditions, it is not possible to generate a standard control based only on an inclination sensor on the spreader; including a secondary inclination sensor on a tractor could partially resolve the relation problem with the rear hitch, but will be still affected by the load in the spreader hopper (hinge effect) .

4.2.2 Solution of Challenge and results: TIM compliancy

Using the TIM protocol to manage the Rear Hitch and the Rear PTO, developing a TIM Rear Top Linkage function and implementing all associated necessary control algorithms in the spreader gave the expected results, even if some deviations on the Rear PTO performances are still present in corner cases on hilly conditions.

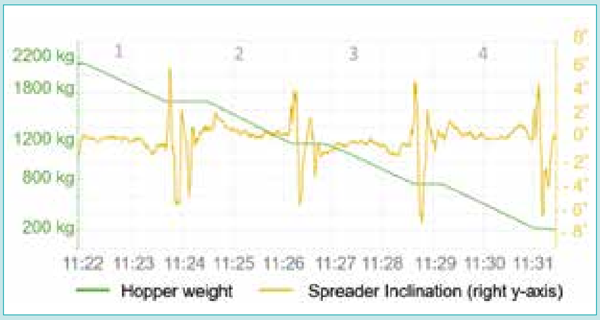


Fig. 7 Hopper Content and Spreading Inclination During the Field Tests Over the Time

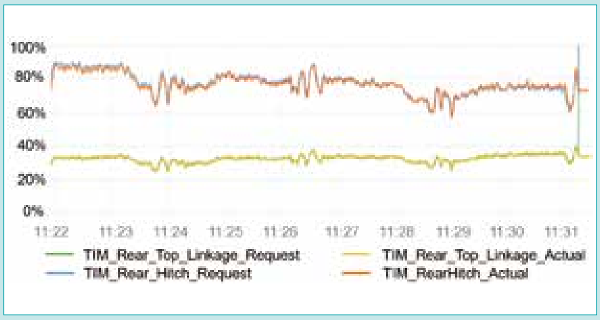


Fig. 8 Rear Hitch and Top Link Performances During the Field Tests Over the Time

5. Conclusion

Kubota was able to adapt an already existing technology like TIM to a new feature (Rear Top Linkage electronically controlled) able to satisfy some concrete needs coming from the field. The results are corroborating the chosen development direction and some preliminary tests were already conducted into the field in Q1 2023 in a real spreading season.

Getting, in the future, the Rear Top Linkage in the TIM norm is expected to expand the spreader business since more tractors compliant with the requested Rear Top Linkage management will be available. At the status, Kubota is an unique manufacturer who is able to offer an electronically controlled Rear Top Linkage that is managed as a TIM function, a spreader able to manage TIM functions plus the TIM Rear Top Linkage and the complete TIM couple for a spreading task.

Contribution to SDG targets

2.3 Increasing agricultural productivity and income
Reducing the quantity of unused fertilizer and optimizing its distribution determining a crop yield increase (no overdosing and underdosing)

9.2 Improvement in productivity through innovation
New TIM technology applied to solve an existing problem still unsolved

12.2 Strengthening inclusive and sustainable industrial infrastructure
Easy to use technology asking only a software update without any additional part produced

Reference

"AEF 023 – ISO 11783 –ISOBUS Automation Principles"

Development of PUDAMA - A Spot Fertilizing System for Maize Seeders

Kverneland Group Soest GmbH

From the view point of sustainability, in many countries there is a necessity laws that restrict the usage of fertilizers in crop production, which may result in lower yields, less food and less income of farmers. To overcome this challenging situation, farmers require high-efficient machinery to guaranty high yields and sufficient income. Pudama is a newly-developed spot fertilizing system for maize seeding, which replaces a conventional continuous fertilizer placement. Pudama creates a fertilizer depot, which is precisely aligned to the single maize seed. As a result, the fertilizer is more easily accessible for maize roots in a higher concentration. This allows reducing fertilizer application rate by 25 % without any decrease of yield! This result was proven in field test in several locations over 3 years. The additional cost of Pudama techniques pays off after 2 years and saves on top 40 000€ for the farmer related to the fiscal lifetime of the machine under European conditions. Furthermore, this significant fertilizer reduction helps mitigate climate damage by brown energy input and reducing the risk of fertilizer trickling off into groundwater. Pudama is a unique and sustainable solution on the market; it is compatible with several Optima precision seeders that Soest is producing. This is an important step forward to increase market share and turnover for Kverneland Soest.

【Keyword】
High Speed Planter, Spot-Fertilizing, Pressure System, Fertilizer Savings

Related SDGs

1. Introduction

In fact maize is grown on 203 million hectare, which is more than 5 times larger than the size of Japan, worldwide every year and this causes a high fertilizer consumption (Fig. 1). On the other side we have too much fertilizer in ground water, lakes and rivers, and many countries are limiting the use of fertilizer. The consequence is the loss of crop yield and income for farmers, and a significant drop down in sales of maize seeders.

Fig. 1 Seeding Maize PP1601 SX

Another fact is that producing nitrogen fertilizer needs a lot of energy, which today becomes a cause of climate-damaging brown energy. Similarly, phosphate fertilizer production involves energy-intensive mining process and transportation. For those reasons, the task is to develop a machine-technology which compensates reduction of fertilizer amount without decreasing yield and without increasing production cost of maize. The fertilizer application for maize is done with the seeding in one go.

The maize seed is placed in a defined spacing to each other and the fertilizer is applied in a continuous band positioned 5cm below and beside (Fig. 2).

Fig. 2 Conventional Fertilizer Application

Due to the slow growth of maize roots, they cannot access the complete amount of the fertilizer before fertilizer is fixed in the soil or in case of Nitrogen eventually washed down into deeper soil horizons. Hence, the amount of fertilizer between triangles in Fig. 2 are wasted. To save this quantity of fertilizer, a different application technique must be developed. The task is to place the fertilizer close to the corn in a spot (Fig. 3).

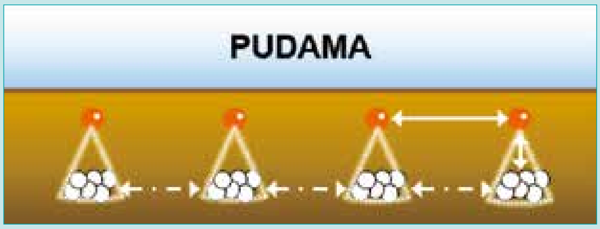


Fig. 3 PUDAMA Spot Fertilizer Application

Pudama spot application saves 25 % of fertilizer amount while achieving 100 % yield in maize. For this reason Pudama is sustainable, saves brown energy, reduces fertilizer amount, prevents fertilizer leaching into water, cuts maize production cost and guarantees an improved income for the famer. The Pudama project was conducted in cooperation with Cologne University of Applied Sciences.

2. R&D Concept and Target Value

2-1 R&D Concept

The Pudama project has two main tasks. First task is on the agriculture production side. The precondition before starting the development was to prove the theory of saving 25 % of fertilizer by creating fertilizer spots aligned to the maize seed. Cologne University of Applied Sciences, conducted field tests over three years. The second task is to design a new metering unit, which creates fertilizer spots and place this 60 mm away from the maize seeds. The new unit must be able to work at high operating speed of Optima seeder, which can reach speeds of up to 16 km/h, which means 25 portions of fertilizer per second! The metering unit must be reliable under tough conditions like heavy dust, high humidity and in a corrosive environment. The Pudama system must fit on all Optima SX seeders as an option.

2-2 Target Value

Pudama saves 25 % of fertilizer consumption but achieves 100 % yield in comparison to conventional application where 100 % of fertilizer amount is necessary to get 100 % yield (Fig. 4). The cost of maize production is reduced; the total amount is depending on actual fertilizer prices. In average, the Pudama system pays off after two seasons. In total the farmer saves approximately 40 000€ over fiscal lifetime of machine (Fig. 5).

Pudama represents a unique selling point! No other supplier can offer this or something similar in the market. For that reason, we think to increase our Optima turnover by 20 % in the long run.

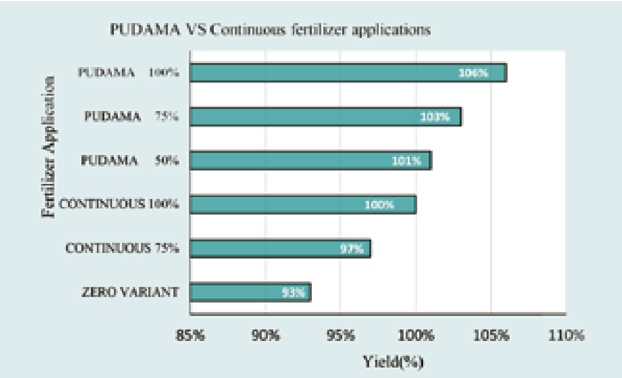


Fig. 4 Yield Comparison

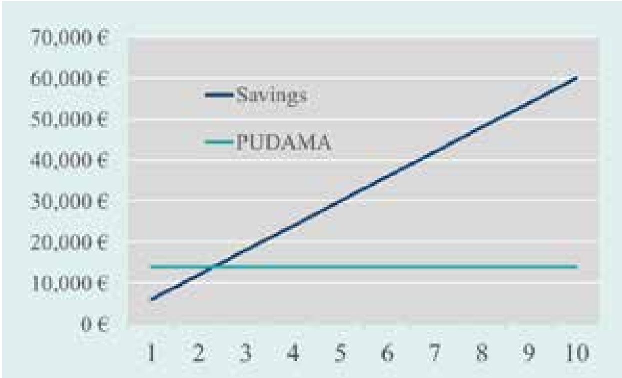


Fig. 5 PUDAMA Cost Saving

3. Technical Challenge to be Solved

As there is no comparable technique in the market we need to start from scratch. The challenge was to develop a metering unit, which creates a defined portion of fertilizer in a quick sequence, 25 spots/s. During transport of this portion towards the furrow ground, it is important that all granules of the portion stay together instead of dissolving. Additionally, when the fertilizer reaches its final position, the distance from the first granule to the last granule of a portion should not exceed 60 mm (depot length). This portion of fertilizer must be precisely synchronized with the maize seed and to allow it to work stably at high speed (Fig. 6). The fertilizer itself is challenging due to the fact that granule size and stability varies very much. Beside the granules there is a undefined percentage of fertilizer powder which is getting sticky under humid conditions. This sticky powder may be built up to block mechanics, resulting in a high corrosion supporting area. To find the best components for working in these conditions were challenging.

Fig. 6 Depot Size and Synchronization with Seed

4. Developed Technology

4-1 Technology for metering unit

4.1.1 Technical Challenge

The challenge has been to invent a metering unit for spot application under above mentioned circumstances. The conventional metering delivers a continuous flow of fertilizer which looks like a band of fertilizer when it lays in the furrow. It is not possible to generate requested fertilizer spots by switching the drive on and off.

4.1.2 Solution of Challenge

The continuous fertilizer flow must be split up into variable portions. Various ideas were tested in order to achieve this target. The conventional metering feeds the oscillating system, which has two cells (Fig. 7). A shutter turns forward and backwards and allows one cell to be filled while the other cell is emptied. First challenge has been the time for clearing the cell. It takes too much time therefore this process is assisted by air pressure. When the system failed due to critical dynamic, filling and draining of fertilizer takes too long. Since a lot of mechanical wearing is expected, the above idea has been given up.

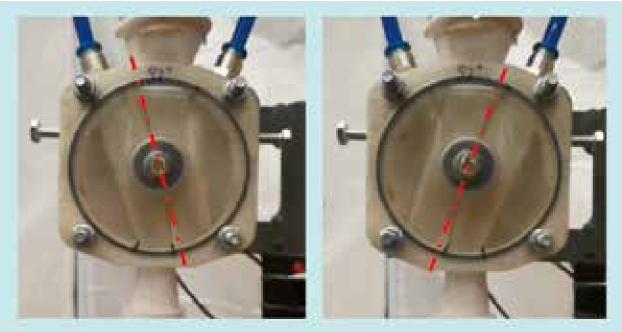


Fig. 7 Oscillating System

The second idea is a rotating cell wheel with air support (Fig. 8). The fertilizer filling process and variable depot distance speed control are ideal, but unfortunately, we couldn't get fertilizer out accurately. The process of empting the cells is critical. The depot length is not short enough and this is the knock out criteria for this solution.

Fig. 8 Rotating Cell Wheel

Working on an Impulse System is the final idea (Fig. 9). The conventional/ continuous fertilizer flow is stopped by a flap, which is frequently opening and closing. Those flaps are spring-loaded and opened by a shock blast. The big advantage of this system is a simple and easy filling process and a very quick draining of the cell due to air assistance. A pneumatic valve is able to do more than 30 shock blast/s. The impulse system shows the best character for the use case and is the base for further developments.

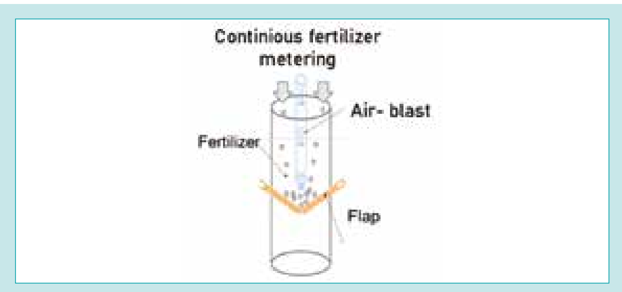


Fig. 9 Impulse System

The fertilizer depot length is the most critical attribute for Pudama and means the distance between the first and last fertilizer particle in the furrow belonging to the same depot. The task is to generate a depot length of approximately 60 mm. If this distance is too long, for example 120 mm and more, the depot borders are too wide and the application is going in direction band sowing again. To get valuable measurement about the depot length while testing the different systems, a test rig was designed to measure the duration from the first to the last fertilizer particle of a portion hitting the plate of a piezo element (Fig. 10). With the help of this test we were able to identify the potential of a design idea in regards of fertilizer depot length.

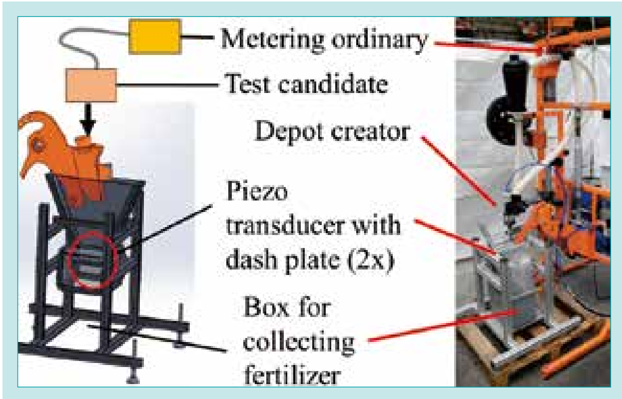


Fig. 10 Measurement by Piezo Element

The result of Piezo measurement is shown (Fig. 11). It represents an average result with a calculated depot length of 76 mm. The bar graphic demonstrates the border of the depot respective the gaps between the depot.

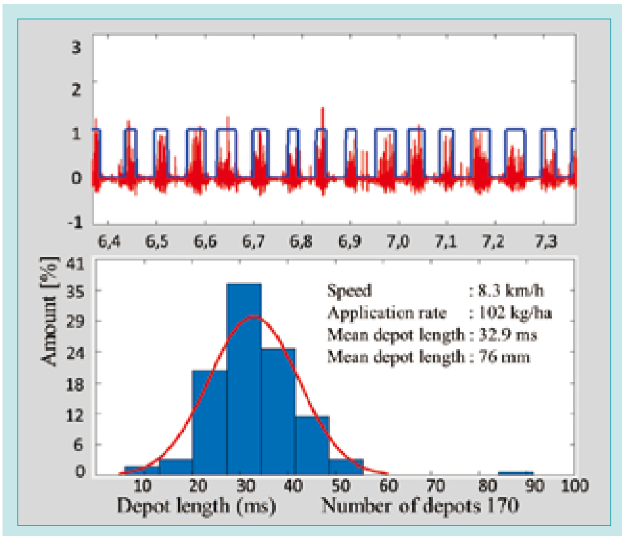


Fig. 11 Result Determined by Piezo Element

4-2 Technology for brush

4.2.1 Technical Challenge

The impulse - system was chosen but still the mechanical flaps are a challenge in respect of speed and duration between open and close. The spring mechanic is not reliable and the surrounding conditions limit the lifetime significantly. The consequence; we decided to look for new solution to replace mechanical flaps.

4.2.2 Solution of Challenge

Instead of using spring-loaded flaps, we searched for material which has similar properties i.e. plastic stripes. Unfortunately, the fertilizer adhered and accumulated on the plastic and caused blockage. At least a funnel-shaped brush hair was considered (Fig. 12).

The funnel shape brush solution covers the demand for speed of 25 portion/s and has no mechanical part. The lifetime of the flap/brush is no longer an issue. Due to ongoing open and close movement of brush hairs fertilizer has no chance to block or connect.

Fig. 12 The Brush Functions as a Valve

4-3 Technology for spot fertilizing

4.3.1 Technical challenge

Initially, the calculation of depot length based on time did not tell us about the shape of depot. The first tests showed that an improvement is necessary (Fig. 13). For that reason we simulated the field surface by a special rubber band. The surface was covered by small rubber cones to prevent fertilizer from moving after landing on the “field”.

Fig. 13 Testing Spot Shape and Size

4.3.2 Solution of Challenge

Through iterative tests, we were able to select the best combination of brush attributes– material, diameter of hair, number of hairs and furthermore the brush funnel position related to vertical direction of the pneumatic system to open the brush. Important points are end position of pneumatic tube within funnel, duration and strength of air blast (Fig. 14).

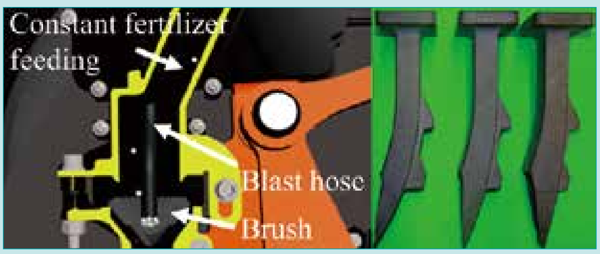


Fig. 14 Left-design of Fertilizer Spot Generator

Further improvements in the length and shape of the fertilizer depot were around the coulter, which leads the fertilizer into the furrow. Tests have been conducted regarding the angle of coulter outlet measured to the furrow and, the outlet shape of coulter itself. The result indicated that the optimum angle for the coulters should be between 15° and 25°.

All of the mentioned attributes were taken into consideration in the final design of Pudama fertilizer coulter (Fig. 15). The spot applicator is integrated within the fertilizer coulter to minimize the fertilizer transport distance into the furrow. The kinematics of fertilizer support guaranties always a fixed angle of the coulter outlet on all depth adjustment positions. This design fulfills all requirements and generates a short depot length (Fig. 16).

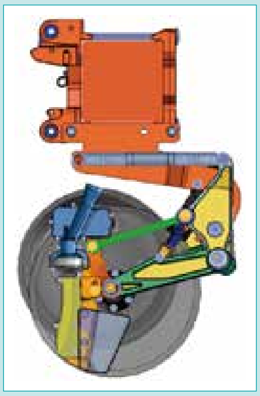


Fig. 15 PUDAMA Unit

Fig. 16 Fertilizer Depot in Field

4-4 Technology for synchronization seeds with fertilizers

4.4.1 Technical Challenge

The fertilizer spot application must be precisely synchronized with placement of seeds analogous to drive speed and seed distance in the furrow. Seed and fertilizer application work independently. Hence we need to connect systems via electronic.

4.4.2 Solution of Challenge

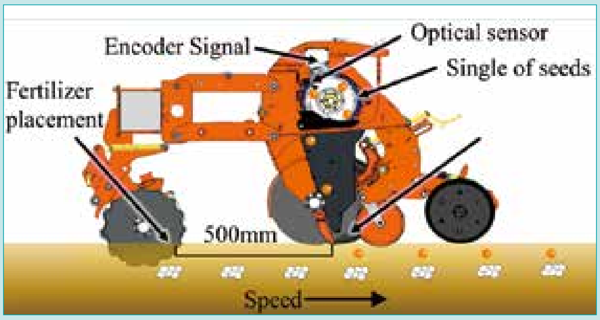


Fig. 17 Synchronizing Principle

The synchronization process starts with the optical sensor that scans the seeds when it comes off the singling disc. To calculate the placement of seed we need to add duration from scanning until it sits in the furrow (Fig. 17). Precondition is an absolute precise placement of seeds like Optima SX is providing. We have a similar process in the fertilizer system; here it is the time from opening pneumatic valve until the fertilizer is completely in the furrow. Because fertilizer coulter is fitted in front of seed outlet, a delay time for the distance between both positions is included. At the end, all dead times of the system are added. Different speed or spacing are detected through the frequency of seeds scanned by the optical sensor. Soft and Hardware development leads to precise synchronization of seed and fertilizer (Fig. 18).

Fig. 18 Positioning Seed and Fertilizer with PUDAMA

5. Conclusion

Farming is currently facing significant tension and criticism, particularly in regards to the excessive consumption of fertilizers and brown energy consumption. Pudama has developed innovative solutions to address these issues and promote sustainability. Pudama is an excellent example how to improve the situation. Pudama changes the fertilizer application method where each individual seed receives a specific portion of fertilizer instead of having a continuous band of fertilizer along the maize seeds. This method saves 25 % of fertilizer at 100 % yield. The key to Pudama design is the generation of fertilizer portions and quick release to achieve a defined spot of fertilizer. Kverneland patented the unique valve mechanism, in the form of a brush with a funnel-like shape. This unique idea is extremely reliable and neither fertilizer nor acids make any harm to the brush itself or its function. This technique allows 25 portions/s respectively, enabling a seeding speed of 16 km/h. The additional cost for Pudama will be paid off after two years. Based on the fiscal life time of the machine and depending on fertilizer cost, application rate and total hectares, the farmer saves 40 000 €. Pudama is unique on the market. Hence Kverneland plans to increase sales of Optima precision seeders by 20 % long term. The project was done in cooperation with Cologne University of Applied Sciences.

Contribution to SDG targets

2.4 Ensure sustainable and resilient agricultural practices
Sustainable food production system with increasing agricultural productivity and income.

12.5 Substantially reduce waste generation
Reduce waste generation through reduction using brown energy.

Reference

Entwicklung eines Verfahrens zur punktuellen Düngerapplikation bei der Maisaussaat, Dissertation Max Bouten 2020
https://ien.kverneland.com/News/Product-news/PUDAMA-High-Yield-with-Less-Fertiliser-in-Maize-Sowing
https/www.umwelt.nrw.de NRW für neuartige und umweltschonende Einzelkornsämaschine:Effizienzpreis-NRW (effizienzpreis-nrw.de)

Water & Environment

Development of "WATER PIPE COM", Equipment for Monitoring in Water Pipe

Pipe Systems Networks R&D Dept. / Pipe Systems Quality Assurance Dept.
Water and Environment R&D Dept. Ⅱ

In an ongoing effort to enhance operational efficiency across various stages of their operations, including planning, construction, and maintenance management, water utilities are constantly seeking innovative solutions. Among these tasks, we have focused specifically on pipeline maintenance and management, conducting in-depth interviews with water utilities to identify key challenges and potential countermeasures. Consequently, a critical challenges identified is the need to garner a deeper understanding of the internal conditions of pipelines. By visualizing information such as hydraulics (flow direction, velocity, and water pressure) and water quality parameters (residual chlorine concentration, turbidity, and water temperature), water utilities can significantly improve the efficiency of their maintenance activities. To achieve this objective, it is essential to gather comprehensive pipeline data from multiple points and manage it centrally.

With this in mind, we are exploring the potential of valves, which are ubiquitous components in water pipelines. We are currently developing a device with an integrated sensing function for resilient seated sluice valves (product name: WATER PIPE COM) and associated communication equipment.

【Key Word】
Monitoring, Multi-Point Measurement, Resilient Seated Gate Valve, Sensor Installation Part, Sensor Maintenance Method, Flow Direction/Velocity Sensor, Communication Device

Related SDGs

1. Introduction

Water utilities install flowmeters and water quality monitoring equipment primarily at locations deemed important, such as pipelines that deliver water to areas with large water service populations, in order to monitor conditions on a daily basis. Due to the high cost and limited number of such devices installed, their use is limited to collecting data on the base locations of pipelines, and in most cases without providing a detailed understanding of the condition of the entire area (Fig. 1). On the other hand, by installing sensors at as many locations as possible and analyzing the collected data, it is possible to understand the internal state of pipes in detail from the observed trends, although the following issues remain to be solved.

(1) Existing sensors (especially flowmeters) are difficult to install in multiple locations due to budget constraints as they require a dedicated measurement chamber and a commercial power source for measurement.

(2) Existing sensors are difficult to install at multiple locations because they are expensive and require extensive maintenance involving water shut-offs, etc.

(3) Even if the number of measurement points is increased, it is not possible to visualize the information without a tool to manage the data for the entire pipelines.

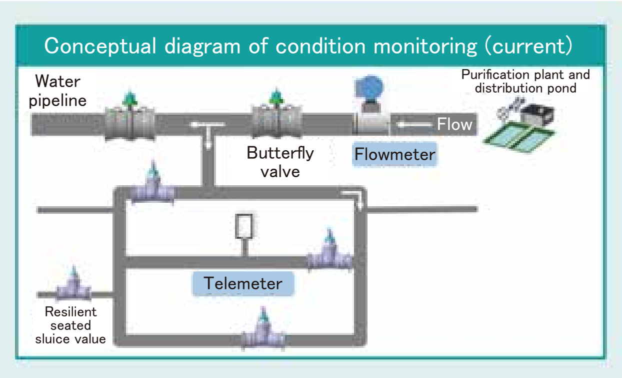


Fig. 1 Image Diagram of Status Monitoring (Current)

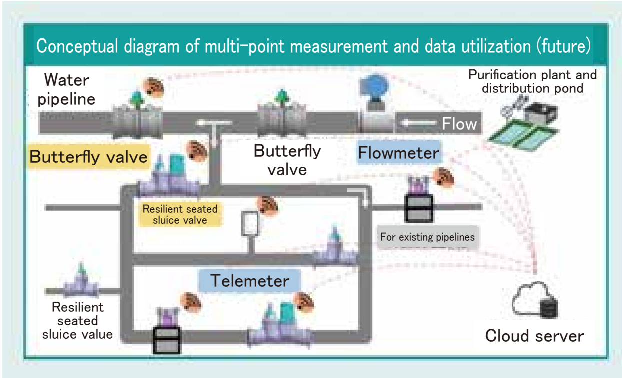


Fig. 2 Image Diagram of Multi-Point Measurement and Data Utilization (Future)

To solve these issues, we turned our attention to the use of water valve products (Fig. 2). Specifically, we considered the following: (1) sensing and communicating information inside the pipes at water supply valve installation points (many points with space saving), (2) developing original flow direction/velocity sensors that are less expensive than existing products, and (3) centrally managing communication data on a cloud server.

We have developed a water pipeline condition monitoring device, Water Pipe Com (Fig. 3), which has a sensor mounting section on a resilient seated gate valve; it enables sensing and data communication of flow direction and velocity, water pressure, water temperature, etc. at valve installation points; and it enables replacement and inspection of sensors under water pressure. This paper reports on the details of the development.

Fig. 3 WATER PIPE COM

2. Development concepts and target values

2-1 Development concepts

To achieve visualization by multi-point measurement as early as possible, the following development concepts were set up for the Water Pipe Com.

(1) Sensing using resilient seated gate valves

To obtain information about the inside of pipes from multiple points, it is necessary to increase the number of installation points by using measurement devices that are less expensive to install and measure than existing devices such as electromagnetic flowmeters and telemeters. Therefore, resilient seated gate valves, which are often installed in water pipelines, are used for setting sensing points.

(2) Trend monitoring with simple and inexpensive flow direction/velocity sensors

Sensors capable of high-precision measurement are often expensive, and their installation would not fit the abovementioned product concept. We, therefore, decided to develop flow direction/velocity sensors with a simple structure that are less expensive than existing sensors (e.g., electromagnetic flowmeters) and have slightly lower measurement accuracy, but still allow trend monitoring. We also decided to develop a construction method that allows easy maintenance under water pressure and from the road surface.

(3) Wireless data communication

In order to effectively utilize the space in a valve box installed in combination with a water supply valve, we decided to develop a communication terminal that can be installed in the valve box and enables measurement and communication without the need for a commercial power source. To view data in real time, we also decided to develop a system that transfers sensor data to a cloud server for centralized management.

2-2 Target values

To realize the above concepts, we set up the following development goals. The development goals for the main body of the Water Pipe Com, flow direction/velocity sensors, and wireless communication are shown in Tables 1–3.

Table 1 Development Objectives for WATER PIPE COM Body

Item	Development goal
Type	Earthquake-resistant (GX type) double-socket type
Nominal diameter	75 to 250
Overall length	300 mm or less plus the length of the current GX-type double-socket resilient seated gate valve (to allow the use of the standard size valve box)
Applicable parts	Common to current products except for the sensor section

Table 2 Development Objectives for Flow Direction/Velocity Sensor

Item	Development goal
Structure	Compact shape, insertion type
Cost	Less than 10% of the existing electromagnetic flowmeter (based on our price research)
Maintenance	Maintenance can be performed with simple operations from the road surface
Measurement accuracy	Less than ±0.02 m/s for less than 0.4 m/s Less than ±5% for 0.4 m/s or more (in-house standard determined based on interviews)

Table 3 Wireless Communication Development Objectives

Item	Development goal
Installation location	Inside the valve box
Driving method	Battery (one-year capacity with measurement and communication at 10 min intervals)
Communication	Communication is possible from inside the valve box (even under conditions of sediment inflow and snow accumulation)
Data management	Measurement data are retained even during periods of unstable communication.

3. Technical issues to be solved

(1) Main body of Water Pipe Com

The main body of the Water Pipe Com must have an additional sensor mounting section while maintaining the water sealing performance as a valve. The sensor mounting section must be large enough to accommodate sensors and allow for maintenance, but it will be difficult to use a commonly distributed valve box if the overall length of the product becomes too long. Therefore, the challenge was to keep the mounting section within the standard dimensions.

(2) Flow direction/velocity sensors

To achieve low-cost flow velocity sensors, they must have a compact and simple configuration of components. Since the sensors are always in a wet environment, waterproof protection is required to achieve stable measurements over a long period of time. In addition, the maintenance of flow direction/velocity sensors must be able to be performed quickly from the road surface without stopping water operations.

(3) Wireless communication from inside the valve box

In basic tests to determine the communication method, it was found that the radio wave intensity was reduced when communicating from inside the valve box due to the effect of the steel lid. It was also known that radio wave intensity fluctuates with the position relative to the steel lid, so it is necessary to use a communication method and installation position that allows stable communication. There is also a requirement that the data will not be lost under the expected environmental conditions (snow accumulation, sediment inflow, submersion, etc.).

4. Developed technology

4-1 Main body of Water Pipe Com

To reduce product cost and ensure parts compatibility, the parts of the current GX double-socket type valves (Fig. 4) were applied and a sensor mounting section was added between the valve body and the joint (Fig. 5). The sensor mounting section was set in two sizes (for nominal diameter ranges of 75–150 and 200–250) to allow common use of protective covers, sensor mounting jigs, etc.

(1) Longitudinal dimension (A in Fig. 5)

The sensors to be installed are of a common size regardless of the nominal diameter. Therefore, the longitudinal dimension of the sensor mounting section was set uniformly at 190 mm for all nominal diameters to facilitate storage and maintenance of the sensors.

(2) Width dimension (B in Fig. 5)

For the nominal diameter range of 75–150, the width dimension was set at 222 mm, which, as in the longitudinal direction, is the minimum dimension required to facilitate storage and maintenance of the sensors. On the other hand, for the nominal diameter range of 200–250, a width dimension of 350 mm was designed because a smaller B dimension would result in a complex shape that would lessen castability.

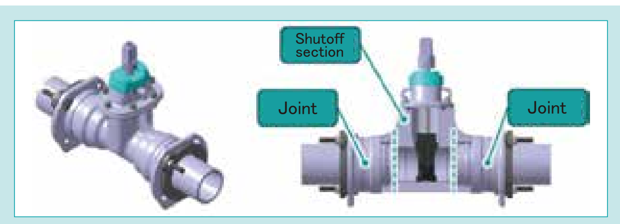


Fig. 4 Current Resilient Seated Gate Valve

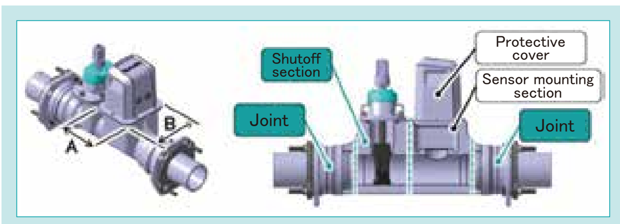


Fig. 5 Size of Sensor Installation Part

4-2 Flow direction/velocity sensors

4.2.1 Specifications of flow direction/velocity sensors

The mechanism for detecting flow direction and velocity uses a plate strain detection structure, that is, the flow velocity is calculated from the strain produced in the plate by the flow load. To ensure stable measurement over a long period of time, the strain gauge is covered with four layers of protective material for waterproofing (Fig. 6).

The amount of strain generated in the plate is greatly affected by the flow velocity. In order to ensure both sensitivity in the low flow velocity range and strength in the high flow velocity range, three types of sensors have been developed to allow selection according to flow velocity conditions. The production cost has been confirmed to be within the development target (Table 4).

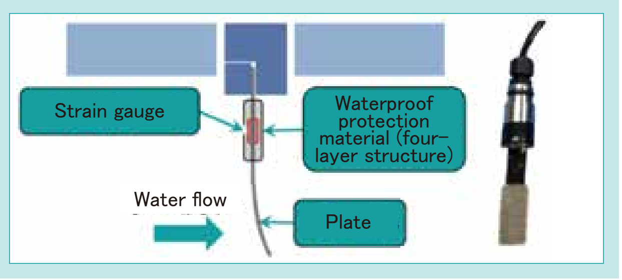


Fig. 6 Structure of Developed Flow Direction/Velocity Sensor

Table 4 Specifications of Flow Direction/Velocity Sensor

Sensor specifications	Measurable range	Measurement error	Cost
Low flow velocity	0.05 to 0.5 m/s	- Less than ±0.02 m/s for less than 0.4 m/s - Less than ±5% for 0.4 m/s or more	6% of the price of an existing electromagnetic flowmeter
Medium flow velocity	0.2 to 1.8 m/s		
High flow velocity	0.4 to 3.0 m/s		

4.2.2 Accuracy of flow direction/velocity sensors

The accuracy of the flow direction/velocity sensors was evaluated by conducting a water flow test in a test pipeline with a flow direction/velocity sensor attached to the Water Pipe Com with a nominal diameter of 100 and comparing the measured values with those of an electromagnetic flowmeter installed in the same pipeline. The test results confirmed that all sensors (for low, medium, and high flow velocities) met the target accuracy (Fig. 7).

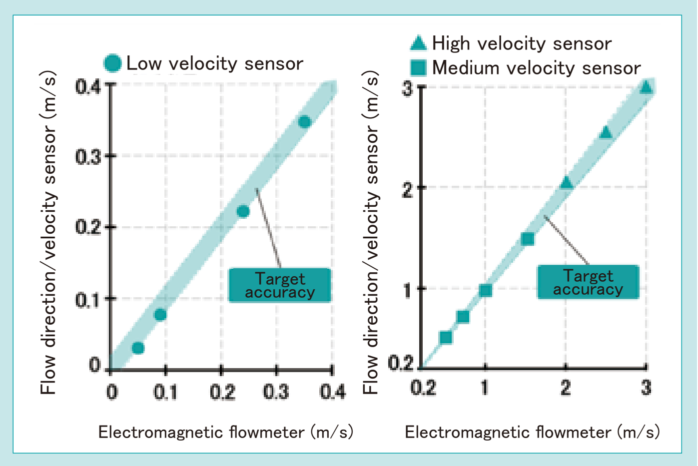


Fig. 7 Flow Velocity Measurement Results

4.2.3 Sensor maintenance methods

We have developed the following methods to perform maintenance promptly under water pressure and from the road surface (Fig. 8).

(1) Mechanism to shut off water pressure in the pipe

A ball valve was adopted as the mechanism to allow communication with a pipe during sensing and to shut off from the pipe during maintenance. Specifically, during sensing, the ball valve is opened to allow the sensor to be inserted into the pipe through the ball valve, and during maintenance, the sensor is raised to the position above the ball valve, which is then closed to shut off the water pressure in the pipe to allow maintenance to be performed.

(2) Mechanism to quickly attach and detach sensors

We have developed a special jig to quickly attach and detach sensors. In the jig structure, jig (A) is installed in the jig mounting section on the body side, and jig (B) is attached to the sensor through jig (A). The screw mechanism on the inner surface of jig (A) enables the sensor to be attached or detached safely and quickly, while receiving the force of the water pressure to pull out the sensor when detaching the sensor and resisting the water pressure when attaching the sensor.

(3) Field test results

To verify the effectiveness of the developed maintenance methods, we conducted a test on an actual pipeline (Fig. 9). Working from the outside of the valve box, we confirmed that maintenance could be performed within the target time of 20 min without external leakage at 0.6 MPa water pressure inside the pipe (Table 5).

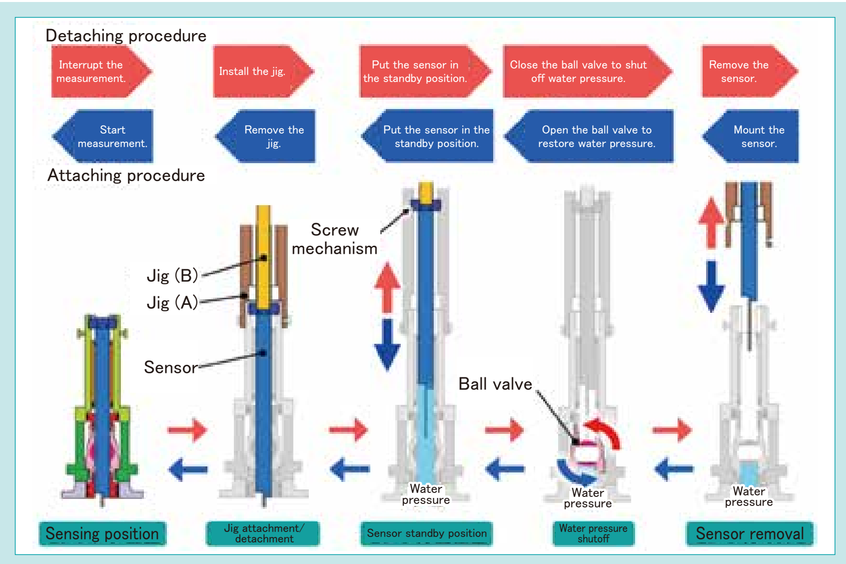


Fig. 8 Sensor Maintenance Procedures

Table 5 Test Result of Sensor Replacement

Test conditions	Target	Result
Water pressure: 0.6 MPa	External leakage 100 mL/min or less	0 mL/min
Working space Diameter: 600 mm/Depth: 860 mm	Working time 20 min or less	19 min

Fig. 9 Sensor Maintenance Test Status

4-3 Wireless communication

4.3.1 Communication device specifications

Table 6 shows the specifications of the communication device.

For wireless communication, we selected the LTE-M and LoRaWAN methods from among the LPWA methods that allow communication over a large area with less power. The LTE-M method was finally selected because of its excellent results in basic communication tests conducted from inside the valve box. In addition, a battery-driven system was adopted for compactness. Assuming a deteriorating communications environment, the communication device was designed to retain data for approximately two weeks (when measured at 10-minute intervals).

Table 6 Specifications of Communication Device

Item	Specifications
Communication system	LTE-M
Size (mm)	W201 × D201 × H161
Power source	Primary battery: thionyl chloride lithium battery (3.6 V × 4 pcs for each of 4 units, 17 Ah)
Protection class	IP65
Measurement and communication mode	1) Fixed time mode 2) Fixed period mode
Measurement period	Measurements at 10 min intervals for 1 year
Amount of data retained when communication environment deteriorates	Capable of retaining data for approx. 2 weeks at 10 min measurement intervals

4.3.2 Communication device installation structure

Communication from inside the valve box varies in radio wave intensity depending on the location of the communication device. Therefore, we investigated the relationship between the location of the communication device in the valve box and radio wave intensity through basic tests and determined the standard location of the communication device (directly under the steel lid hole at a depth of 200 mm). The communication device is mounted on a mechanism (bracket) that allows the depth and circumferential position to be adjusted from the standard installation position according to the local radio wave intensity. This allows the communication device to be installed at the position with the highest radio wave intensity at each installation site (Fig. 10).

4.3.3 Effects of the environment inside the valve box

We investigated the influence of the environment inside the valve box on the communication status. As shown in Fig. 11, the ability to communicate was confirmed for cases where the valve box was filled with sediment and where the top of the steel lid was covered with snow (250 mm deep). On the other hand, communication was not possible when the inside of the valve box was submerged in water, but we confirmed that all data could be recovered after the submersion was removed and data communication resumed.

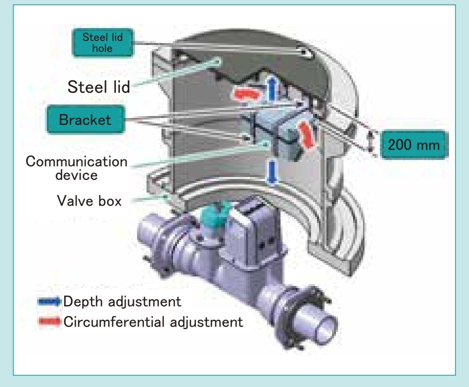


Fig. 10 Installation of Communication Device

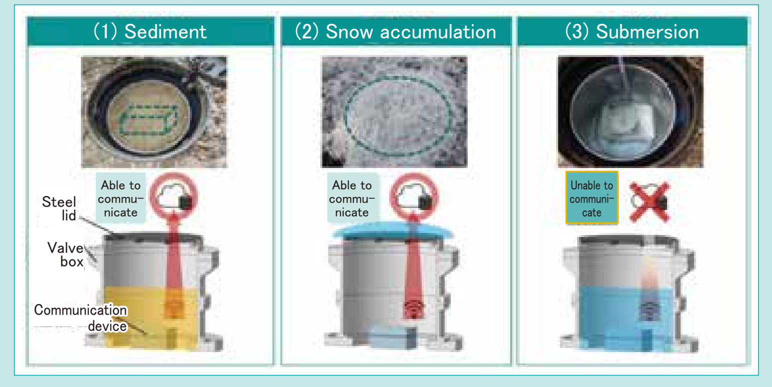


Fig. 11 Communication Environment Test

5. Conclusion

The development was carried out as described above to achieve commercialization of the Water Pipe Com. The features of this product are summarized below.

(1) A sensor mounting section is provided on the existing earthquake-resistant resilient seated gate valve to enable sensing of information inside the pipe.

(2) The flow direction/velocity sensor adopted is a plate strain gauge system that can be supplied at a low cost and is protected by a four-layer waterproof structure. The measurement accuracy of flow velocity satisfied the target values in each target velocity range (±0.02 m/s for less than 0.4 m/s and ±5% for 0.4 m/s or more), and the cost of the sensor also satisfied the development target.

(3) Sensor maintenance can be performed under water pressure and from the road surface by securing a sensing space and developing a dedicated jig. The time required for sensor replacement is less than the target value of 20 min.

(4) The measured data are communicated to the cloud server from a communication device installed in the valve box. The location of the communication device is adjustable on-site to reduce the attenuation of radio wave intensity by the steel lid.

This product was published in the Fiscal 2022 Proceedings of Japan Water Works Association, and many water utilities have shown interest in it.[1)]

As this product becomes more widely used, it will be possible to obtain information about the inside of pipes at multiple points, and combining this information with pipe network analysis is expected to improve the accuracy of real-time condition monitoring. If the accuracy of condition monitoring can be improved, detailed information can be obtained accurately at every point in the pipes, further contributing to improved operational efficiency and labor savings for water utilities.

We will continue to develop products that help visualize the information in pipes and solve the maintenance and management issues that water utilities face.

Contribution to SDG targets

6.1 Increased availability of safe and affordable drinking water
Contribution to providing safe drinking water through early detection of abnormalities through condition monitoring in pipes

9.1 Development of high-quality, sustainable, and resilient infrastructure
Contribution to the realization of meticulous water management through visualization of the inside of pipes

Reference

1) Nishino, M. et al.: "Development of Water Supply Valves Capable of Sensing and Communicating Information in Pipes," Fiscal 2022 Proceedings of Japan Water Works Association, pp. 332-333

Development of Rotating Panel Filter for Membrane Bio-Reactor

Water Circulation Engineering Design Dept. / Membrane Systems Dept.
Water Circulation Engineering Dept.

Membrane Bio-Reactor (MBR) produce high-quality effluent while requiring a relatively small footprint. However, stable operation of MBR depends on effective pretreatment. Although 1-mm spacing bar screens have been widely employed as MBR pretreatment in Japan, their limited debris removal capability can lead to the accumulation of debris on the membrane, compromising its performance. To address this challenge, KUBOTA has developed a novel screening system for MBR that offers superior debris removal, space efficiency, and cost-effectiveness. This innovative system utilizes mesh material as a screening element, achieving both high removal efficiency and high throughput. The combined structure of the mesh and support frame ensures extended screen life, while the integrated high-pressure cleaning system maintains filtration sustainability. By employing this advanced screening system, MBR operations can be stabilized even for sewage treatment plants faced with high debris concentrations in their influent.

【Key Word】
Membrane Bio-Reactor, MBR, Sewage Treatment, Micro Screen, Rotating Panel Filter

Related SDGs

1. Introduction

The membrane bio-reactor (MBR) method, which is a space-saving wastewater treatment method that provides high-quality treated water, has been widely used for industrial wastewater treatment and sewage treatment in Japan and overseas. In the domestic sewage market, a total of 31 sites have installed MBR systems (as of September 2023, including those under construction), and the Kubota Group holds a high share of 19 sites among them, or more than 95% in terms of water volume.

In the MBR, it is important to adequately remove foreign substances such as debris during pretreatment to prevent them from adhering to the membrane unit. In the MBR for sewage in Japan, 1-mm spacing bar screens are commonly used for pretreatment. However, there have been cases where the capacity of the membrane unit is reduced due to the adhesion of debris, leading to the need to develop a pretreatment technology with a high debris removal rate.

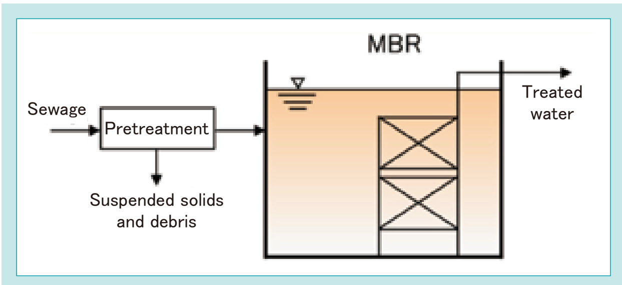


Fig. 1 MBR Process

2. Development concept

2-1 Problems with existing technology

Due to the need for low-cost pretreatment in the MBR, 1-mm spacing bar screens are commonly used. However, such screens have a low removal rate of filamentous debris*1 due to their construction. Although the characteristics and concentrations of sewage vary from region to region, if the sewage contains large amounts of debris that cannot be captured by 1-mm spacing bar screens, such debris will grow into lumps in the biological reactor and adhere to the membrane unit, degrading the membrane filtration performance in rare cases[1] (Fig. 2). Some cases have been reported where debris removal is considered inadequate, leading to the occurrence of membrane damage caused by continuous rubbing of the membrane surface by aggregated debris. Figure 3 shows the measured debris removal rate at a certain sewage treatment plant that has installed 1-mm spacing bar screens (hereafter referred to as "Plant A"), indicating a low average debris removal rate of 43%.

There are already existing pre-screen technologies with higher performance removing debris from sewage water than 1-mm bar screens, such as in-channel type 2-mm perforated pre-screens, but their machine costs are very high and they have a design limitation in that they can only be installed in water channels.

*1 Debris obtained by sieving sewage through a 2-mm aperture sieve.

Fig. 2 Filamentous Debris Attached to the Bottom of a Membrane Block

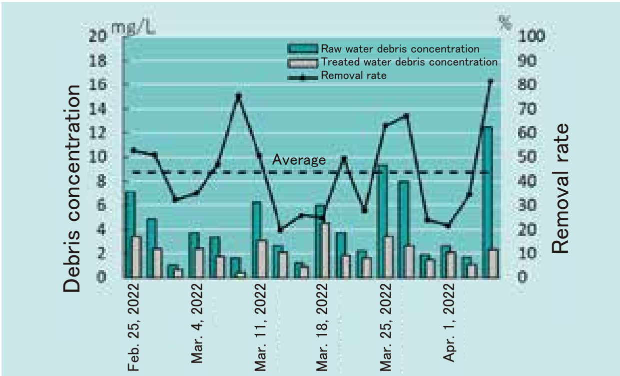


Fig. 3 Debris Removal Rate of 1-mm Spacing Bar Screen

2-2 Concept and overview of equipment

To solve the above problems, we developed the Rotating Panel Filter, which is space-saving, inexpensive, and has a high debris removal rate. The space-saving feature also contributes to cost reductions in civil engineering work when applied to plants. To meet the debris removal requirements of each treatment process, two types of screens with different spacings have been made available: micro screen and ultra-micro screen.

Figures 4 and 5 show schematic and outline views of the newly developed filter model. The developed model is designed to remove debris from sewage while rotating endlessly connected screens. The debris captured by the screens is discharged out of the system together with cleaning water. The treated water is discharged out of the equipment from the inside of the loop formed by the screens.

Table 1 shows the target removal rates. For the ultra-micro screen, which is the finer type of screen, the removal rate of suspended solids, as well as that of debris, was set as an item of concern to reduce the load in the subsequent water treatment process.

Table 1 Target on Removal Rate

Item	Micro screen	Ultra-micro screen
Debris removal rate	Average of 90% or more	Average of 90% or more
Suspended solid removal rate	–	Average of 20% or more

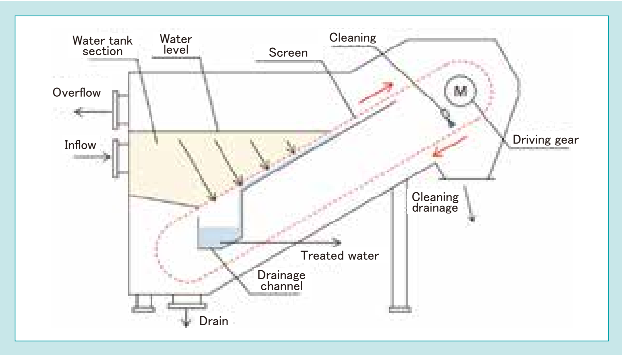


Fig. 4 Rotating Panel Filter (Internal Structure)

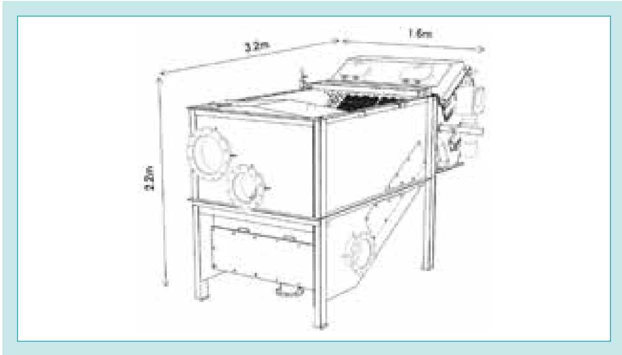


Fig. 5 Rotating Panel Filter (Perspective)

3. Technical issues to be solved

3-1 Screen design

While screens sort inflow material by size, there is a trade-off between passability, or throughput, and impassability, or removal rate. Therefore, it is not easy to achieve our concept of both space saving and high removal rate. Although a smaller spacing in the screen is necessary to achieve a high removal rate, the screen must also be optimized for sewage to ensure throughput.

3-2 Screen speed control

The flow rate and debris concentration of sewage entering a sewage treatment plant fluctuate greatly depending on the time of day. Figure 6 shows the inflow variability of Plant A as a reference, where the inflow was averaged from July 2019 to June 2020, and the suspended solid concentration was measured over a 24-hour period from March 25 to 26, 2020. The hourly inflow rate varied by a factor of 3 or more, and the concentration of suspended solids in the inflow water, an indicator of water quality, varied by a factor of 2 or more.

Because of the large variations in inflow, operating at a constant screen speed in line with the maximum load causes the following issues. One issue is that operating at a constant speed without slowing down at low loads consumes excessive power. The other is that a low inflow of suspended solids and debris results in a thinner layer of these materials trapped on the unit screen area, which means lower removal performance. To address these issues, it is necessary to enable control of the screen speed in response to inflow fluctuations.

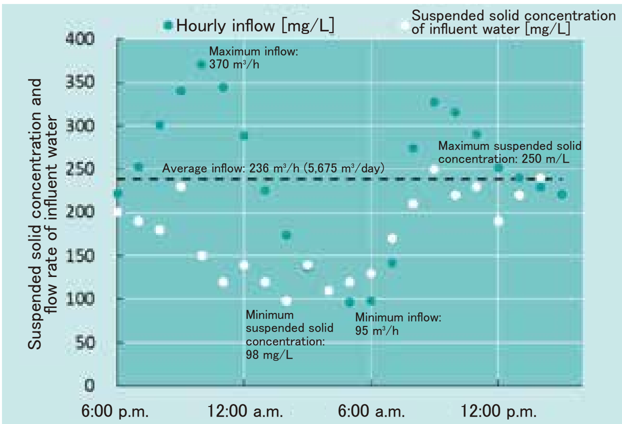


Fig. 6 Pattern of Influent Rate and Quality for One-Day Period

4. Developed technology

4-1 Overview of demonstration test

A basic design was finalized during development through desk studies and bench testing, but some issues, including those mentioned above, could not be verified without using actual sewage. We, therefore, conducted an on-site demonstration test with the cooperation of Plant A. The appearance and procedural flow of the demonstration test are shown in Figs. 7 and 8, respectively. The original flow of the treatment plant was that the sewage from the settling basin was sent to the MBR through a distribution tank and a 1-mm spacing bar screen (dash-dotted line in Fig. 8). For the demonstration test, however, a portion of the sewage from the distribution tank was continuously used for treatment. The flow rate was set to 94 m^3/h (equivalent to 2,256 m^3/day) due to facility constraints.

Fig. 7 Test Plant

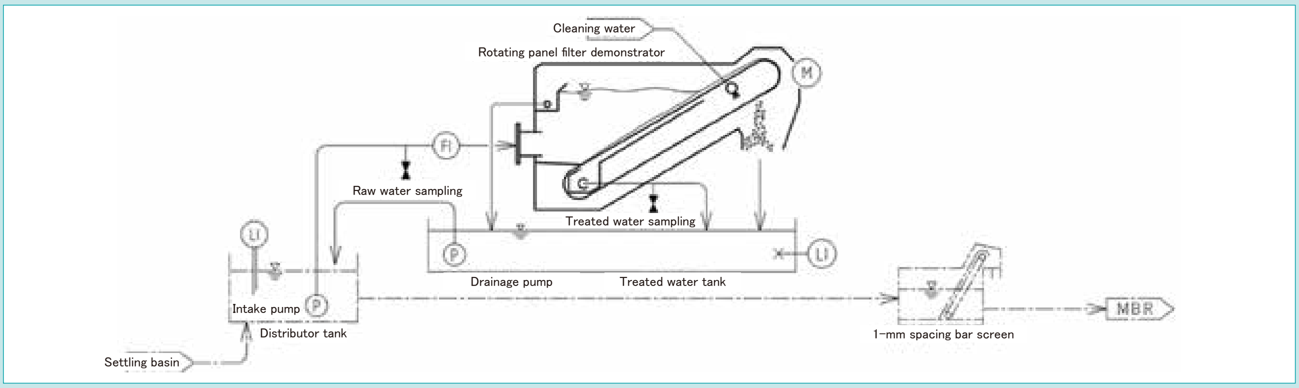


Fig. 8 Test Plant System

4-2 Screen design

4.2.1 Screen material selection

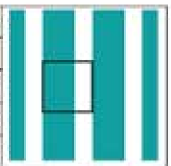
To meet both throughput and removal rate requirements, we focused on aperture ratio in addition to spacing. Table 2 compares a bar screen, perforated metal, and mesh selected as screen material candidates.

Although bar screens can have a small spacing in the bar width direction, the spacing in the length direction is large, allowing filamentous debris to pass through.

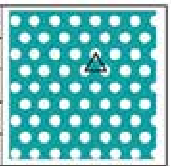
The mesh has a higher aperture ratio than the perforated metal when compared at the same spacing. As an example of a comparison between representative products of similar dimensions, the aperture ratio of a perforated metal with an aperture diameter of 0.63-mm, a pitch of 1.22-mm, and a 60-degree staggered arrangement is 24%, whereas that of a mesh with a spacing of 0.56-mm and a wire diameter of 0.29-mm is 43%. The mesh was selected as the screen material because it allows more water to pass through per unit area, thus saving space and achieving a higher removal rate.

Table 2 Comparison Between Screen Materials

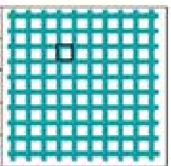
Bar screen

Bar width [mm]	2	
Spacing [mm]	1	
Unit pattern area [mm^2]	9.00	
Aperture area in unit pattern [mm^2]	3.00	
Aperture ratio [%]	33	

Perforated metal

Hole diameter [mm]	0.63	
Hole pitch [mm]	1.22	
Unit pattern area [mm^2]	0.64	
Aperture area in unit pattern [mm^2]	0.16	
Aperture ratio [%]	24	

Mesh

Wire diameter [mm]	0.29	
Spacing [mm]	0.56	
Unit pattern area [mm^2]	0.72	
Aperture area in unit pattern [mm^2]	0.31	
Aperture ratio [%]	43	

4.2.2 Improved durability of screen material

Since meshes are made of small diameter wire, durability testing is more important than with bar screens or perforated metal plates.

In fact, a preliminary investigation of another company's machine manufactured overseas found a case in which a mesh broke, impairing its debris removal function. Although the mesh must maintain its sheet shape under water pressure, the mesh itself is not rigid, so a support frame is needed underneath. In the case where breakage was observed, the support frame was fixed to the main frame, and the mesh was designed to move over the support frame under water pressure of 300 to 700 mmAq. It is likely that the mesh was worn due to sliding over the support frame.

As a countermeasure to avoid sliding and wear between the mesh and the support frame, the newly developed model has a screen configuration where divided meshes and support frames are combined to form mesh panels, which are endlessly arranged (Fig. 9).

While the mesh material used in other companies' models was synthetic fiber, the newly developed model uses stainless steel fiber, which improves durability in terms of material strength.

Fig. 9 Belt-Like Arranged Screens

4.2.3 Improved strength of the support frame

While the mesh was reinforced by combining it with the support frame, the support frame itself must also be strong enough.

The measurement results using the demonstration model showed that, in addition to the water pressure, the frictional force between the support frame and the rail placed underneath was a substantial load on the support frame.

The support frame is connected to the drive chains at both ends, and ribs were provided at the connections to sustain the water pressure and frictional force. Because of the complex loading from the combined hydraulic and frictional forces, a structural analysis was performed at the Analysis Center to confirm that the structure had sufficient strength (Fig. 10).

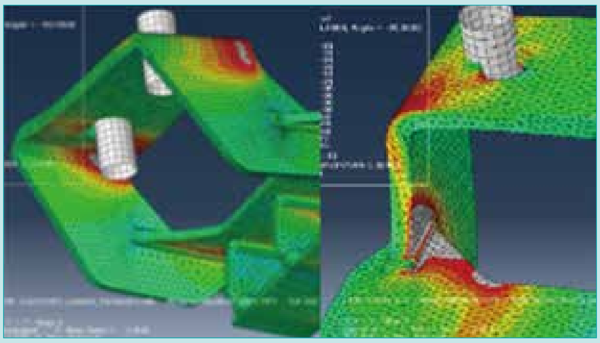


Fig. 10 Structural Analysis of Mesh Support Frame (Analysis Center)

4.2.4 High-pressure cleaning function

Because the mesh is made of fiber, filamentous debris such as hair or the short fibers of toilet paper, etc. easily adhere to the fiber, and once adhered, the fibers are not easily removed. Figure 11 shows how debris adheres to the mesh. Eventually, the mesh becomes clogged with accumulated fibers, preventing further operation. Therefore, it is necessary to take measures to prevent fiber accumulation with a minimum amount of cleaning water.

We, therefore, decided to add a function of intermittent high-pressure cleaning in addition to the normal cleaning as a measure to prevent filamentous debris from adhering to the mesh. Nozzles were selected with an emphasis on cleaning impact force per unit width to enhance removal effectiveness. The cleaning impact force is the force of water hitting the object. Since the width of the water jet is determined by the distance between the nozzle and the object and the spread angle of the water jet, the cleaning impact force per unit width can be calculated from the following equations.

Cleaning impact force [N] =
$0.745 \times$ Flow rate [L/min] $\times \sqrt{\text{Pressure [MPa]}}$

Jet width [mm] = Jet height [mm] $\times$ tan(Jet angle $\div$ 2) $\times$ 2

Cleaning impact force per unit width [N/cm] =
Cleaning impact force [N] / Spray width [cm]

Table 3 compares the nozzles selected as candidates. Compared to the nozzle with a fan-shaped water jet (Plan 1), the nozzle with a straight water jet (Plan 2) has a higher cleaning impact force per unit width (*1). However, because the width of the cleaning water is narrow (*2), numerous nozzles must be installed or a mechanism to move a nozzle is required to clean the entire screen. On the other hand, a straight rotating nozzle (Plan 3), which incorporates a structure that swivels the cleaning direction by water pressure, can expand the cleaning area (*3), thus achieving both high cleaning effectiveness and a large cleaning area without using a complicated structure.

This high-pressure cleaning function was mounted on the demonstration model to check its fiber removal performance. Figure 12 shows the screen surface immediately after high-pressure cleaning, indicating that even fine fibers are removed.

Fig. 11 Sticking Fibril onto Mesh

Table 3 Comparison Between High Pressure Spraying Nozzles

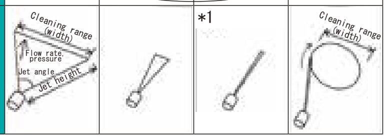
Item		Regular cleaning nozzle	High-pressure cleaning nozzle (intermittent)		
			Plan 1	Plan 2	Plan 3
Jet shape/type		Fan	Fan	Straight	Straight-rotation
Jet pressure		Medium pressure	High pressure	High pressure	High pressure
	MPa	1.5	4.5	4.5	4.5
Jet volume	L/min	5	5	5	5
Jet angle	deg	100	15	8	8
Rotation angle (vertex)	deg	–	–	–	33
Cleaning impact force	N	4.6	7.9	7.9	7.9
Jet height	mm	32	150	150	150
Cleaning water width	mm	76	40	20	20
Cleaning range (width)	mm	76	40	20 *2	110
Cleaning impact force per unit width	N/cm	0.61	1.98	3.95	3.95 *3
Jet shape				*1	

Fig. 12 Surface of Screen after High Pressure

4-3 Screen speed control

4.3.1 Responding to inflow fluctuations

To make the screen speed responsive to inflow fluctuations, a feedback control was incorporated to keep the water level constant in the water tank section as shown in Fig. 4. As the concentration of suspended solids and debris decreases, their layer formed on the screen surface becomes thinner; the volume of permeated sewage increases, and the water level decreases. By monitoring the change in water level, the screen speed can be controlled responsive to inflow fluctuations.

Figure 13 shows a record of screen speed and water level control. When the suspended solid concentration becomes low, the screen speed is slowed to keep the water level constant (black circled area in Fig. 13, with the flow rate kept constant at 65 m^3/h).

4.3.2 Verification of debris removal performance

Using a demonstration model incorporating a constant water level control, the debris removal performance of the micro and ultra-micro screens was verified by replacing one screen with the other. The ability to adapt to inflow fluctuations was confirmed by measuring performance on multiple days and at different times of day.

Figure 14 shows the debris removal rates for the micro screen. Debris concentrations ranged from 1.7 to 11 mg/L in raw water (the anomalous value on September 28 is due to weather conditions) and 0.070 to 0.44 mg/L in treated water. The average removal rate was 95%, achieving the target of 90% or more. As for the ultra-micro screen, the suspended solid removal rate and the debris removal rate are shown in Figs. 15 and 16, respectively. Debris concentrations ranged from 1.2 to 8.3 mg/L in raw water and 0.070 to 0.46 mg/L in treated water, with an average removal rate of 95%; suspended solid concentrations ranged from 84 to 340 mg/L in raw water and 54 to 220 mg/L in treated water, with an average removal rate of 44%. Both met their development goals of at least 90% and 20%, respectively, in removal rate. Although the concentration of inflow sewage varied with the time of measurement, the removal rate was stable, indicating that the system was able to cope with inflow fluctuations.

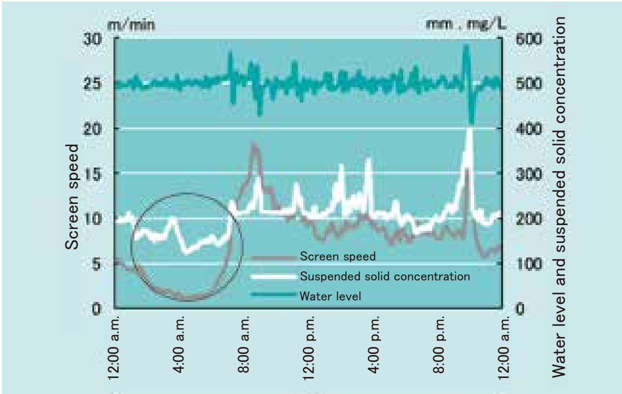


Fig. 13 Trend of Water Level Controlled by Screen Speed

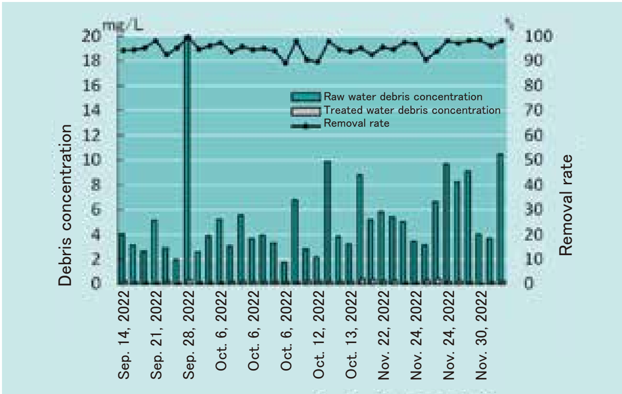


Fig. 14 Debris Removal Rate (With Micro Screen)

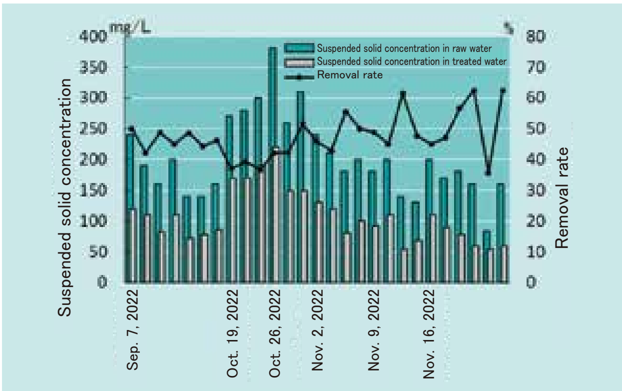


Fig. 15 SS Removal Rate (With Ultra-Micro Screen)

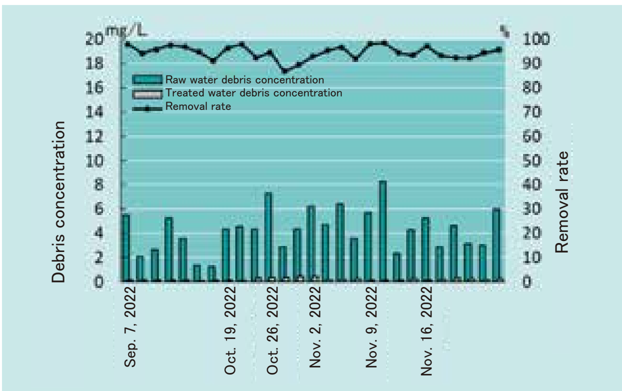


Fig. 16 Debris Removal Rate (With Ultra-Micro Screen)

5. Conclusion

The membrane bio-reactor (MBR) method, which is a conventional activated sludge treatment method that applies a membrane separation process to the gravity-based solid–liquid separation process, has become widely used because it saves space and produces high-quality treated water. In parallel with activities to promote MBRs, Kubota has been developing various ways to add value to MBRs, such as improving the functionality of the membrane separation equipment, reducing initial and operating costs, enhancing operational control, and developing processes that utilize membrane separation equipment.

As part of this effort, we developed a pretreatment system for MBRs. Kubota's membrane unit is flat sheet type membrane equipment, which makes it relatively suitable for operation in treatment plants with large amounts of debris. Depending on inflow conditions, however, there have been cases where conventional pretreatment technology has not been sufficient to remove debris. Against this background, the newly developed model has significantly improved debris removal performance. We believe that a membrane unit that is resistant to debris and a pretreatment system with high debris removal performance can provide excellent added value.

The developed model has obtained a Construction Technology Review and Certification from the Japan Institute of Wastewater Engineering and Technology in FY 2022. We aim to ensure that treatment plants that are planning to install or have already installed MBRs can confidently install and operate MBRs with this model for superior debris removal performance.

We will improve the functions of this model, which is capable of removing both suspended solids and debris, by studying its applicability as an alternative to a primary sedimentation tank.

Contribution to SDG targets

6.2 Increased availability of sewage and sanitation facilities
Contribution to stable sewage treatment

Reference
1) Japan Sewage Works Agency, Third Report on Technical Evaluation of Membrane Bio-Reactors - Energy Saving of MBRs and Response to Flow Fluctuations -
https://www.jswa.go.jp/g/g01/g4g/pdf/gihyo32.pdf (referenced on June 9, 2022)

Development of Flocculation Sensor for Industrial Wastewater Treatment

Water and Environment R&D Dept. Ⅱ
KUBOTA Environmental Engineering Corporation

The flocculation method, a widely employed treatment technology for industrial wastewater purification, poses challenges for customers, including water quality deterioration due to inefficient flocculation, rising costs associated with excessive chemical addition, and the need for maintenance personnel for operational management. To address these issues, we have developed a groundbreaking sensor that utilizes image diagnostics technology to achieve human-like sensing capabilities, setting it apart from conventional aggregation sensors that employ light transmission and scattering techniques. The implementation of this sensor can address customer-facing challenges, foster IoT adoption in the industrial wastewater treatment sector, and contribute to the expansion of Kubota's industrial wastewater treatment business.

【Key Word】
Flocculation, Flocculation Sensor, Image Diagnosis, Operation and Maintenance

Related SDGs

1. Introduction

The declining birthrate and aging population are social issues in Japan; labor shortage has emerged as a major management challenge for approximately 70% of companies, regardless of company size.[1] As a countermeasure, there is a demand for improved operational efficiency through IoT, and the adoption of advanced digital technologies is spreading in some sectors. In the environmental sector, the drive for change is also gaining momentum, with the proliferation of COVID-19 in 2020 prompting the search for ways of working that do not rely on human labor as in the past.

Although efforts are being made in the field of industrial wastewater treatment, it is difficult to say that sufficient measures have been taken to overcome the issues of (1) securing personnel to operate and manage wastewater treatment facilities, (2) increased risk of environmental accidents due to inexperienced operators, and (3) increased operation costs due to excessive chemical injection.

One of the reasons for these issues is that it has become common management practice to determine operating conditions by having operators actually see the wastewater treatment conditions with their eyes and relying on their own experience and intuition to make judgments. Especially in flocculation treatment, which is the most common treatment method, various manufacturers have proposed flocculation sensors to replace operators' eyes to address this issue, but there is still no de facto standard in the market. In response, Kubota has developed a flocculation sensor capable of detecting situations using the image diagnosis method to achieve operation management that does not rely on human experience or intuition.

This paper presents the performance of this sensor and the impact of its implementation.

2. Development concept and target values

2-1 Development concept

The development concept is to provide a sensor that can quantify flocculation condition with the same or greater accuracy as the eyes of experienced operators. Specifically, the sensor should automatically detect poor flocculation by quantifying the characteristics of flocculation condition that are difficult to quantify with conventional techniques. This involves using indicators close to the human visual perception: i.e. (1) the size of flocculated particles (flocs) and (2) supernatant turbidity.

The newly developed machine is based on the image diagnosis method. The most advantageous point of the image diagnosis method is that it enables operators to intuitively recognize flocculation condition, which can be quantified from captured images using indicators close to the human visual perception.

The concept of flocculation sensors based on image diagnosis is not new. It has been around for more than 20 years, but until now, there has been no mainstream product on the market. The reason for this is believed to be as follows: Many of the methods developed in the past either immerse a camera or build an observation window in a tank and take pictures from the outside, but they do not solve the various problems associated with dirt on the observation window.

The system configuration of the newly developed sensor is shown in Fig. 1. The system consists of the main unit of the flocculation sensor, a pump panel, and a control panel. The main unit takes images; the pump panel, which is connected to the main unit, performs automatic cleaning, and the control panel analyzes the captured images and controls the pump panel. The control panel outputs measured values, captured images, and alarms, allowing the monitoring and operational control of the wastewater treatment equipment by "eyes" equivalent to those of experienced operators.

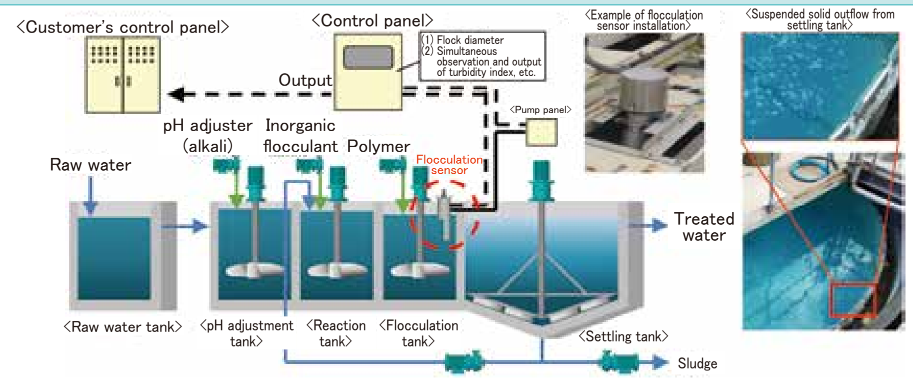


Fig. 1 Flow Diagram of Wastewater Flocculation Treatment

2-2 Development goals

To realize the aforementioned development concept, the following development goals were set.

(1) Establishment of imaging conditions and equipment structure to enable image diagnosis

The accuracy of the information that can be obtained from image analysis is highly dependent on the images captured. In other words, in order to obtain more accurate information on the object to be measured, it is important to establish the conditions for capturing images suitable for analysis. To this end, it is necessary to incorporate the relevant equipment structure into the design, that is, to establish design values.

(2) Quantification of the characteristics of flocculation condition through image diagnosis

In order for operators to judge the flocculation condition, it is desirable to have indicators that allow them to intuitively visualize the condition, rather than indirect indicators such as absorbance and transmittance, which are commonly used as water quality indicators. It is therefore necessary to construct a mechanism and calculation method to quantify floc size and supernatant turbidity as indicators closer to human visual perception.

3. Technical issues to be solved

3-1 Establishment of imaging conditions and equipment structure to enable image diagnosis

The flocculation sensors developed in the past have either a camera immersed in the water or an observation window installed in the water tank to photograph from outside the tank, with the problem that the observation window, which comes into contact with wastewater, always gets dirty. Many patents have proposed solutions to this problem, such as a window cleaning mechanism and a coating agent.[2] However, there are various problems with those proposals. For example, mechanisms have been proposed to periodically clean the window with a brush or by spraying water or air. However, using a brush has a problem with the robustness of the brush drive device in water; spraying water or air does not remove enough dirt, and the remaining dirt hinders stable image capture.

In addition, when actually photographing flocs, it is necessary to adjust the brightness, focus, aperture, etc. each time in natural light, making it difficult to analyze values obtained by image processing on the same basis. Under illumination light, on the other hand, the light reflected from the water surface is reflected in the image, making it impossible to capture images that can be used for image analysis.

3-2 Quantification of characteristics of flocculation condition through image diagnosis

The floc size was defined by the floc diameter, and the degree of supernatant turbidity was defined by the turbidity index to quantify the characteristics of flocculation condition.

As regards the floc diameter, it is difficult to determine individual floc diameters by analyzing raw images taken during the flocculation process because the flocs are distributed in a three-dimensional, overlapping fashion. On the other hand, experienced operators can visually determine the approximate size of flocs and judge whether the flocculation condition is good or poor. The challenge was to establish an imaging and analysis method to fill this gap.

As regards the turbidity index, a conventional indicator is defined as “turbidity” in JIS K 0102.[3] This is obtained by measuring the absorbance or scattered light using a standard turbidity solution to construct a calibration curve and then comparing the measured absorbance or scattered light of the sample water to the calibration curve to calculate numerical values. This measurement method has the following problems, among others. Although a good correlation is obtained when the composition of microparticles, which are the main factor of turbidity, is constant, differences in the measured absorbance or scattered light occur even at the same concentration (weight per volume) depending on the color and size of the particles, and the coloration of the water is also an obstacle to the accurate evaluation of turbidity. On the other hand, experienced operators can comprehensively and visually determine supernatant turbidity and judge the quality of treatment intuitively. As in the case of the floc diameter, the challenge was to establish an imaging and analysis method to fill this gap.

4. Developed technology

4-1 Establishment of imaging conditions and equipment structure to enable image diagnosis

4.1.1 Structure of observation window not exposed to wastewater

To solve the problem of dirt on the observation window, we studied the desirable form of the device in the opposite direction, that is, not allowing the wastewater to come into contact with the observation window.

Since the idea was to avoid contact between the wastewater and the observation window, we first devised a setup in which an inverted cup is partially submerged in water and a camera is used to photograph the water surface from the bottom of the cup. This creates an air gap between the wastewater and the bottom of the cup, which acts as an observation window without the need to construct an observation window.

In addition, the basic shape of the sensor body was determined by calculating the shooting distance (distance between the water surface and the camera) based on the focal length of the lens, the angle of view, and other factors, while preventing the window from being hit by splashes caused by the expected rippling of the water surface.

4.1.2 Design to eliminate the effect of water surface reflection

To eliminate the influence of ambient light, the sensor body is made of a light-impermeable steel plate, and the camera and ring light are mounted outside an observation window that is placed on top of the sensor body. Although it is possible to take pictures with this setup, if the camera is positioned perpendicular to the water surface, light reflected from the water surface will be reflected in the image, making the image unsuitable for analysis. Therefore, the sensor body was tilted so that the reflected light was out of the camera's angle of view.

However, because reflections on the water surface are complicated by wave irregularities, the tilt angle must be sufficiently large to eliminate the influence of reflected light. On the other hand, if the angle is too large, the image will be blurred in the near and far areas, making it difficult to obtain a clear image. Therefore, in order to theoretically clarify the ideal positional relationship of the illumination, camera, and water surface, as well as the tilt angle, a model was created by assuming wave irregularities and finding the intersection of the illumination light reflected from the wavy water surface and the surface of the camera lens. Then, the positional relationship was determined by drawing illumination light paths on CAD based on the calculated coordinate axes (Fig. 2).

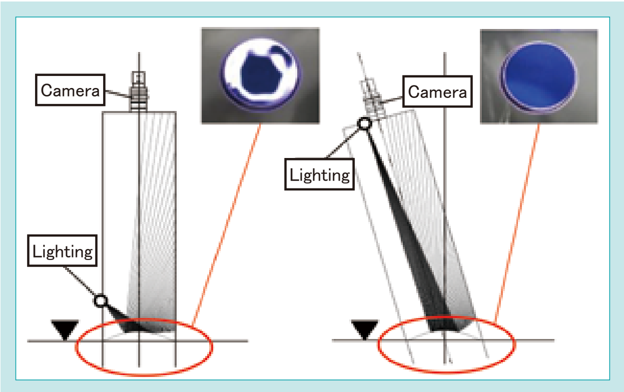


Fig. 2 Positional Relationship Between Lighting, Camera, and Water Surface

As a result of the verification, the minimum tilt angle required was determined, and actual imaging was performed with that angle to confirm the ability to capture images without the influence of reflected light.

4.1.3 Structure to ensure constant shooting distance

To capture clear images, the shooting distance must be constant. In the aforementioned sensor body structure, the volume of the internal air layer changes due to air temperature change or air leakage, causing the water level to fluctuate. If the water level fluctuates, the camera will be out of focus and the captured image will be unclear.

To solve this problem, we submerged the lower part of the sensor body several tens of millimeters under water and adopted a structure where air is constantly supplied to the sensor body and exhausted from a specific position on the lower part of the sensor body to maintain a constant water level (Fig. 3). This structure ensures a constant shooting distance and stable image capture.

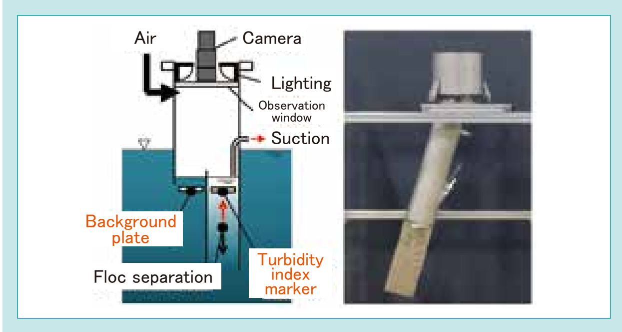


Fig. 3 Structure of Flocculation Sensor

4-2 Quantification of characteristics of flocculation condition through image diagnosis

4.2.1 Floc diameter measurement

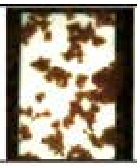
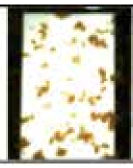
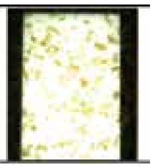
Due to the flocculation condition where flocs are distributed in a three-dimensional overlapping manner, a background plate was used to allow the shape of individual flocs to be determined by image analysis.

The background plate is a resin plate that is submerged so that it is parallel to the water surface when the flocs are photographed, and it is positioned so that there is always 5 to 10 mm of water on top of the plate. The flocs are thinned as they flow over the background plate so that they can be photographed as individual flocs. Table 1 shows captured floc images and measurement examples.

To calculate the floc diameter from a captured flock image, the image is first subjected to binarization. Binarization is a type of image processing that converts a captured image to a 256-level gray-scale image and then converts areas darker and lighter than a specified gray-scale value to black and white areas, respectively. From the binarized image, the total area of flocs and the total number of flocs are calculated to obtain the area per floc and then the floc diameter is calculated by assuming that flocs are circular.

The actual floc diameter calculated by the binarization process was compared with the floc diameter measured by manually tracing the floc edges in the floc images, and the results showed that the two were almost identical, indicating that the sensor output values and the operator's visual perception of size were almost the same (Fig. 4).

Table 1 Floc Images and Measurement Examples Using Flocculation Sensor

Images / Floc diameter [mm]			
Sensor value	4.7	2.6	1.3
Visual measurement	5	3	1.5

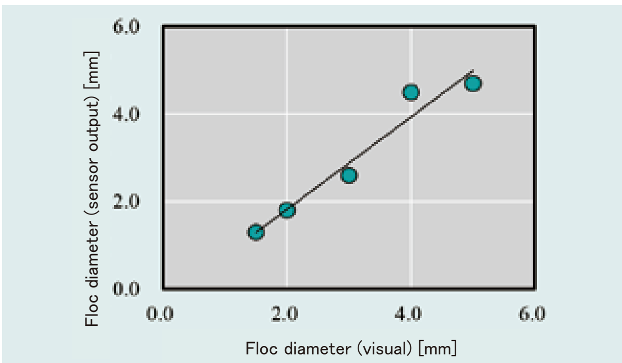


Fig. 4 Correlation Diagram Between Measurement Using Flocculation Sensor and Visually Examine

4.2.2 Turbidity index measurement

As an indicator to quantify supernatant turbidity, we have defined a new turbidity index that can be calculated by image diagnosis. This index quantifies the operator's perception of whether the supernatant is turbid. Although it does not exactly match the JIS-specified turbidity, we believe it will work well as an indicator to determine if the treated water is turbid during normal operation.

When measuring turbidity by image diagnosis, it is impossible to accurately quantify the turbidity of the interstitial water (supernatant) if flocs are still present. Therefore, we extended the lower part of the sensor body to provide a floc separation section with the function of settling and separating flocs. In addition, the supernatant separated in the floc separation section is constantly withdrawn to prevent the treated water from stagnating in the section.

In order to allow a single sensor to simultaneously measure floc diameter and turbidity, the two functions of the sensor body were separated so that half of the angle of view was used for floc diameter measurement and the other half for turbidity measurement.

To calculate turbidity by image diagnosis, a turbidity index marker consisting of two different color regions, white and black, was employed.

The turbidity index marker is a resin plate submerged parallel to the water surface when taking turbidity images and is placed so that there is always 50-70 mm of water above the marker. If the supernatant is turbid, the turbid component in the water above the turbidity index marker will cover the marker, and the thicker the turbid component, the more the shading of the turbidity marker will change.

Table 2 shows turbidity images and measurement examples. To calculate the turbidity index from a turbidity image taken, each of the white and black regions of the turbidity index marker is first converted to 256-level gray-scale values. The difference between the respective shading values is smaller for higher turbidity and larger for lower turbidity. The gray-scale value of the white region with no turbidity is 255. The turbidity index is obtained by subtracting the difference between the gray-scale values of the white and black regions from 255. As a result, the turbidity index approaches 0 as turbidity decreases and approaches 255 as turbidity increases.

In fact, a comparison of the turbidity index determined using the flocculation sensor with the supernatant turbidity measured according to JIS showed a good correlation (Fig. 5). This indicates that the turbidity index is a good measure for quantifying supernatant turbidity.

Table 2 Turbidity Images and Flocculation Sensor Output Value

Images / Turbidity index [−]		
Sensor value	12	51

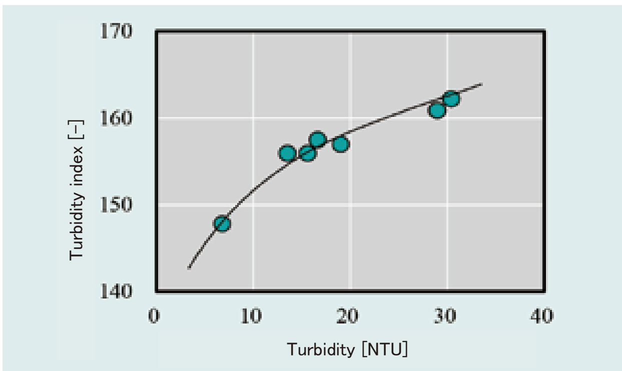


Fig. 5 Correlation Diagram Between Turbidity Index and Turbidity

4-3 Flocculation sensor application examples

4.3.1 Verification method and equipment

Verification was conducted by bringing continuous flocculation treatment test equipment to an actual wastewater treatment plant and running it continuously during the daytime.

The test equipment has the same treatment flow as the real treatment plant, but at about one-twentieth of the real scale of treatment. The target wastewater was inorganic suspended solid wastewater, and polyaluminum chloride (PAC) was used as the inorganic flocculant and an anionic polymeric flocculant was used as the polymeric flocculant. Figure 6 shows an external view and Fig. 7 shows the flow of treatment.

A flocculation sensor was installed in the flocculation tank of the equipment to monitor the flocculation condition and perform feedback control based on the output of the flocculation sensor.

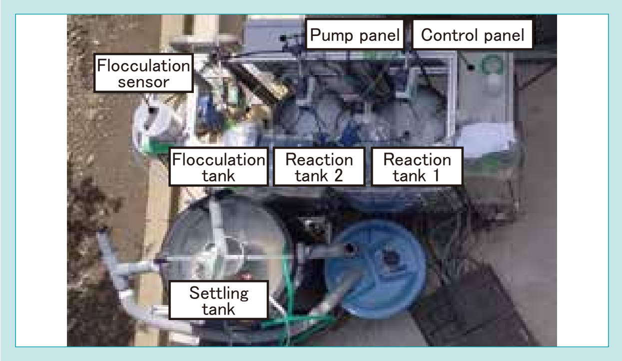


Fig. 6 Testing Equipment

4.3.2 Application of flocculation sensors as monitors

The following is an example of a verification of whether the newly developed flocculation sensor is capable of detecting poor treatment. Figure 8 shows the change in floc diameter and turbidity index when polymer injection was intentionally stopped, postulating a polymer injection pump failure and then resumed. The floc diameter was about 3 mm before the stop, but began to decrease about 3 min after the stop and dropped below 1 mm about 10 min after the stop. The turbidity level was about 50 before the stop, but began to rise about 15 min after the stop, and 20 min after the stop, it rose to 104. Although the polymer flocculant was then injected again, the turbidity index did not immediately decrease but increased to 127. This phenomenon was determined to be caused by the fact that the floc diameter was measured for the wastewater in the flocculation tank with almost no time lag, whereas for the turbidity index measurement, it took about 15 min for the wastewater in the floc separation section to be replaced.

These results confirm that the flocculation sensor readings (floc diameter) respond promptly to changes in water quality during a polymer injection failure. The same behavior was found for PAC injection, confirming that the flocculation sensor can adequately indicate poor treatment in real wastewater.

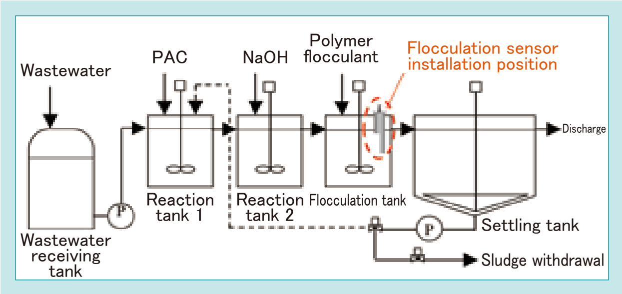


Fig. 7 Wastewater Treatment Flow

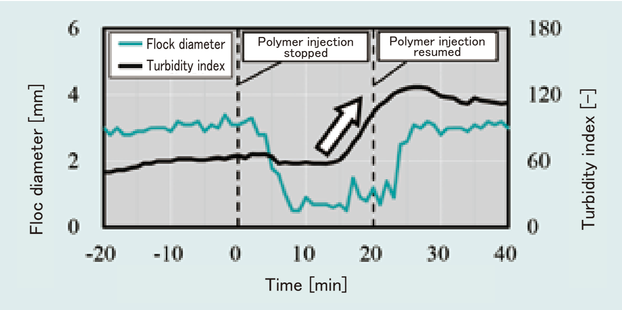


Fig. 8 Time Trend of Floc Diameter and Turbidity Index

4.3.3 Application of the flocculation sensor to automatic control of chemical injection rate

Prior research has shown that floc diameter correlates with polymer injection rate, turbidity index correlates with PAC injection rate, and total floc area correlates with sludge concentration. Therefore, the automatic control of the chemical injection rate was performed by controlling (1) the polymer injection pump by the floc diameter output from the flocculation sensor, (2) the PAC injection pump by the turbidity index, and (3) the sludge circulation pump by the total floc area, each with three to five levels of operating rates.

Figure 9 shows an example of changes over time in flocculation sensor output values and pump operating rates. As shown in the figure, the operating rate of the chemical injection pump varied with the sensor output, confirming that the injection operation was in line with the quality of the treated water. Table 3 shows the effect of implementing operational control on reducing processing costs. When the chemical injection rate and sludge circulation rate were automatically controlled, the amount of PAC and polymer flocculant used was reduced by 75% and 73%, respectively, compared to the conventional operation. In addition, by optimizing the chemical injection rate and promoting floc growth through sludge circulation to achieve stable production of well-compacted sludge, the amount of sludge generated was reduced; sludge disposal costs were reduced by 13%. As a result, the total treatment cost for chemical use and sludge disposal was reduced by 50%. These results confirm that the application of the flocculation sensor to operational control can realize a significant reduction in treatment costs and can be a means to solve the challenges of industrial wastewater treatment.

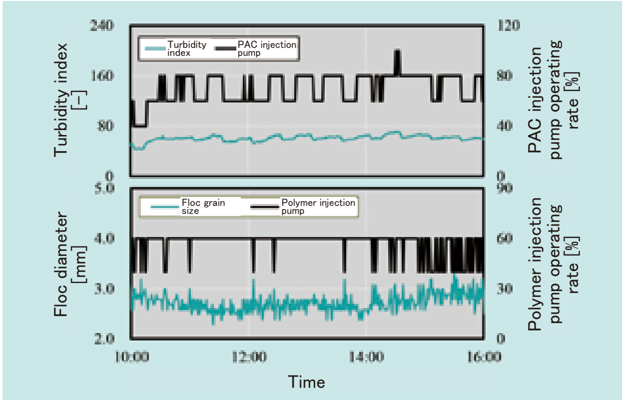


Fig. 9 Time Trend of Flocculation Sensor Output Value and Pump Operating Rate

Table 3 Results of Cost Cuts with and without Operation Control

Item	Unit	Conventional operation	Automatic control	Reduction rate (%)*2
PAC	mg/L	203.3	50.5	–
Polymer	mg/L	13.7	3.6	–
Sludge	kg-wet/m³	3.04	2.6	–
PAC	yen/m³	30.5	7.6	-75
Polymer	yen/m³	16.4	4.4	-73
Sludge*1	yen/m³	30.4	26.3	-13
(Total)	yen/m³	77.3	38.3	-50

*1 The amount of sludge generated is based on 60% moisture content, and the sludge treatment cost is based on 10,000 yen/t-wet.

*2 Reduction rate when conventional operation is set to 100.

5.Conclusion

We have developed a flocculation condition sensing device that uses the image diagnosis method to achieve a performance close to human perception. It has been confirmed that (1) the floc diameter and turbidity index are indicators sufficiently responsive to detect abnormalities in wastewater treatment and (2) the automatic operation stabilizes wastewater treatment and ensures safe operation, thereby reducing operation and management costs and saving manpower. Based on these results, we are confident that this flocculation sensor will support easy maintenance, monitoring, manpower saving, environmental accident prevention, and operation cost reduction in the field of industrial wastewater treatment, thereby contributing to the formation of a sustainable society.

Contribution to SDG targets

3.9 Reduction of deaths and plagues from hazardous chemicals and air, water, and soil pollution
Contribution to the prevention of environmental accidents by improving wastewater treatment monitoring

6.3 Water quality improvement by reduction of untreated wastewater, recycling, etc.
Contribution to the appropriate treatment of industrial wastewater

14.1 Prevention and reduction of marine pollution
Contribution to the prevention of marine pollution by reducing the discharge of contaminated water into the ocean

Reference

1) Ministry of Economy, Trade and Industry: "Policies for Promotion of Basic Manufacturing Technology," 2019 edition, pp. 145
2) Hitachi, Ltd.: "Monitoring and Control Equipment for Flocs in Water Supply," Japanese Patent Application No. Sho-61-82954 (1986)
3) JIS K 0102:2022 Testing Methods for Industrial Wastewater

Development of All-plastic Flange

Kubota ChemiX Co., Ltd.

Steel pipes, commonly employed as piping materials in various industrial settings, are susceptible to corrosion over time. To address this issue, Kubota Chemix (KC) has embarked on an initiative to expand its market presence by proposing plastic pipes as an alternative solution.

However, even with plastic piping, the flanges used to connect valves and other components are typically made of metal, posing challenges in terms of corrosion resistance and processing. In the 2020 technical report, we presented an analysis of the shape of resin flanges. This report focused on the development of a resin flange that exhibits enhanced strength and workability via improvements in product design and mold optimization.

【Key Word】
Pressured Pipeline, Flange, Fiber-Reinforced Resin, Corrosion

Related SDGs

1. Introduction

Since steel pipes used for pressure pipelines in many plants are prone to corrosion as they age, Kubota Chemix has been developing the market for replacing steel pipes with polyethylene and other plastic pipes. However, even with polyethylene piping systems, there have been problems with corrosion resistance and workability (weight) because the flanges that connect pipes to valves and other components are made of metal.

Kubota Chemix, therefore, established the development concept of plastic flanges, as shown in Fig. 1, and compared and studied possible shapes through analysis, etc. As a result, a shape was developed that meets the required product performance,[1] even though the material strength was reduced.

Here, we report the results of performance verification using loose flanges actually molded from fiber-reinforced resin.

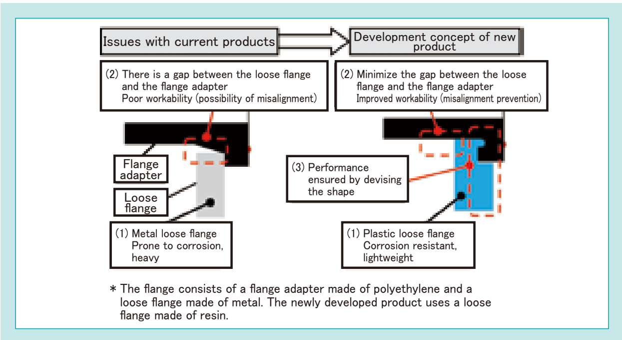


Fig. 1 Development Concept

2. Description of development

2-1 Target performance

The developed product uses a plastic loose flange to improve corrosion resistance and workability, and it has an ingenious shape. In order to verify that it has no problem in practical use, the following two performance requirements were investigated in addition to those of the current products (pressure resistance, etc. according to JWWA K 145).

2-2 Performance verification

2.2.1 Leakage resistance when pipes are bent

One of the features of polyethylene pipelines is that straight pipes can be bent owing to their excellent flexibility. We confirmed that no leakage occurred at the allowable bend radius (Table 1).

2.2.2 Breakage resistance when tightened at low temperatures

Resins, or plastics, generally lose strength at low temperatures, increasing the risk of breakage. Therefore, we conducted tests under the low-temperature environment assumed in actual piping and under severe flange bolt tightening conditions to confirm whether the plastic loose flange was destroyed.

It is generally known that the weld associated with gate selection affects the strength of molded products. Since the initially developed design of the loose flange failed (Fig. 4 left), we modified the gate of the molding die for the loose flange (Fig. 2). The geometries of the corners and ribs were also modified (Fig. 3), resulting in an improvement in breakage resistance (Fig. 4, right).

Table 1 Experimental Results of Bending Water Pressure Test

Nominal diameter	Allowable bend radius (m)	Result	Test situation
50	5.0	No leakage	
75	7.0	No leakage	
100	9.5	No leakage	

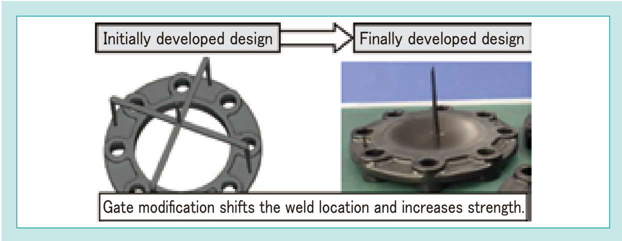


Fig. 2 Change of the Die Gate

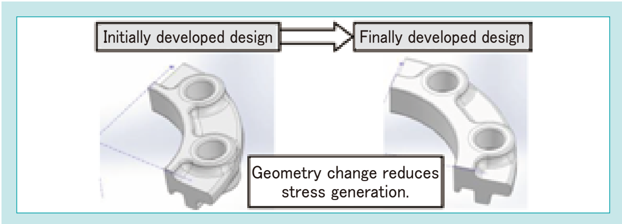


Fig. 3 Change in Shape Dimensions

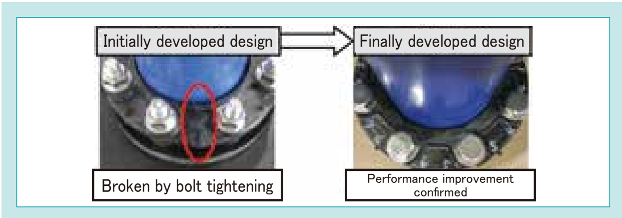


Fig. 4 Experimental Results of Breaking Test

3. Conclusion

Kubota Chemix is Japan's leading manufacturer of synthetic resin pipe materials. In response to declining demand in the infrastructure market, which is a market where Kubota Chemix excels, the company has sought to enter new markets to achieve continued growth.

The product highlighted here, developed for the plant market, is being used in actual pipelines (Fig. 5) and is highly regarded for its corrosion-free nature, lightweight, and ease of alignment.

We will continue to promote the use of resin in piping components to provide high-quality pipelines.

Fig. 5 Plumbing Conditions

Contribution to SDG targets

8.2 Increased productivity through innovation
Introduction of plastic loose flanges that enable lightweight, easy-to-install piping

9.1 Development of high-quality, sustainable, and resilient infrastructure
Contribution to the achievement of leak-proof, resilient pipelines

Reference

1) Hashizu, K., Aoki, K., and Himono, T.: "Development of All-plastic Flange," Kubota Technical Report, No. 53 (2020), pp. 94-95

Introduction of Kubota Research & Development North America (KRDNA)

Kubota Research & Development North America Corporation

Related SDGs

1. Introduction

Kubota established its subsidiary development company, KRDNA (Kubota Research & Development North America Corporation), in 2022 to support its development of Kubota products that are locally produced in GA, USA and consumed by the North American market. KRDNA utilizes local talent (engineers and technicians) to develop product that meets the customer needs and at the same time the expectations that come with the Kubota name. The products that KRDNA develop are riding mowers, utility vehicles, loaders and backhoes for tractors which are manufactured and sold by other local Kubota subsidiaries, KMA (Kubota Manufacturing of America Corporation) and KTC (Kubota Tractor Corporation).

There are 2 effects expected by promoting local development found below.

- Eliminate language barriers between our facilities and our dealers, end users, sales companies, factories, and parts suppliers as it relates to our products. This ultimately allows us to have quicker introduction to market of our products that exceed customers current expectations.
- Creating innovative value by incorporating the ideas of local engineers familiar with the product into Kubota's product development.

Kubota will promote localization of development in North America through KRDNA to realize GMB Kubota.

2. Overview

KRDNA has an office building, a prototype shop, collaboration space for meetings with suppliers or other departments, an indoor test facility (dynos, hydraulic test benches, structural testers and automated test rooms), a low temperature test room that can simulate down to a -40°C condition, an oval course and a trail course for evaluating the running performance of utility vehicles, digging field for tractor's loader and backhoe, and turf fields that have grass native to North America to simulate actual user cutting conditions of riding mowers, in its 297 acres (1.2 million m^2) of total site area.

As for the test facilities, in addition to the test facilities scattered around KMA in Georgia, U.S.A., the test facilities outsourced third company was consolidated in the same site (Fig.1).

Summary of KRDNA

- Name: Kubota Research & Development North America Corporation (KRDNA)
- Establishment: January 2022
- Address: 5855 Whitehall Rd, Gainesville, GA 30507, U.S.A.
- Operation starting: April 2022
- Total site area: 297 acres (1.2 million m^2)
- Total building area: 3.2 acres (13000 m^2)

Fig. 1 Overall View of KRDNA

3. KRDNA Summary of Features

Two features of development at KRDNA, "test facility" and "localization of development" are explained.

3-1 Test facility

KRDNA will significantly improve the development efficiency of each product by consolidating the test facilities to one location and by increasing the overall number of tests that can be performed at the same time with its larger footprint and increased resources now available.

Riding mowers: In turf fields, it is possible to check the performance of mowers against various environments customers are known to use, while using grass grown in North America. In the indoor test facility, endurance and performance tests of various power transmission systems as well as compliance tests are now possible. Structural tests are also now able to be completed onsite that previously required an outside vendor.

Utility vehicle: The extensive proving ground, which includes a variety of paved and rough-road test tracks, is capable of testing both low-speed commercial utility vehicles and gasoline-powered high-speed crossover models.

Loader and backhoe: In a large digging field, multiple large tractors can be used simultaneously. A stable and highly reproducible test can be carried out on a single hydraulic component, all the way up to a fully assembled vehicle.

3-2 Localization of development

Physical proximity to markets, sales companies, factories, and suppliers has enabled better communication and collaboration resulting in quicker turnaround in our product development time.

Regarding market and sales companies, we can perform test validation with the cooperation of dealers, customers and sales companies to ensure new designs meet actual customer use cases. Also, by conducting market surveys, it is possible to quickly grasp customer needs in detail and reflect them in products under development. These activities allow the product to match the way the product is used in the market.

Regarding factories and suppliers, developing the product directly next to the manufacturing facility allows us to work together throughout the design process, making sure the design works within the bounds of our manufacturing capabilities. It also allows for quicker reaction to changes in the design or supplier.

4. Conclusion

With the establishment of KRDNA, Kubota starts digging into product development localization in North America at full scale. Through closer cooperation with North American markets, sales companies, factories and suppliers, and through the use of numbers of test facilities, we will maximize the benefits of local development and promote the realization of GMB Kubota.

Contribution to SDG Targets

8.5 Achieving productive employment, rewarding work
Contribution to the increase in employment of engineering job in U.S.A.

9.5 Promoting scientific research and innovation
Contribution to create engineers who are involved in advanced technologies

17.16 Building Global Partnerships
Contribution to build global partnership through working together with Japanese engineering stakeholders in the area of advanced technologies

Introduction Article

Introduction of Large-Scale MBR Operation Case at Nakahama Sewage Treatment Plant, Osaka City

Water circulation Engineering Dept.

Related SDGs

1. Introduction

At the Nakahama Sewage Treatment Plant (East Line) in Osaka City, sewage treatment (capacity: 32,000 m^3/day) had been carried out using the conventional activated sludge process since the plant was opened in 1960. However, after 50 years the water treatment facilities had deteriorated and were in need of renovation and renewal. In addition, the city had adopted a combined sewer overflow (CSO) system, which collects rainwater and sewage in a single collection system. There was also a need to control the CSO to reduce pollution loads during wet weather, as well as advanced treatment to remove nitrogen and phosphorus to prevent eutrophication in Osaka Bay. To achieve CSO control and advanced treatment with conventional technology, the plant needed to be substantially expanded, which was not possible on the existing site.

The Water treatment facility renewal project at the Nakahama Sewage Treatment Plant (hereinafter referred to as the "Project") was awarded to Kubota in March 2017 as a combined design-build (DB) project. Reconstruction work was performed to combine a membrane bioreactor (MBR), which allows advanced treatment while saving space, with a high-rate filtration system and was completed in October 2021 (Fig. 1). The plant was then operated and managed for a two-year performance evaluation period.

This report provides an overview of the Project and the results of MBR operation over the two years, as well as the results of the energy-saving MBR control technology "SCRUM," which was introduced for the first time.

Fig. 1 Nakahama Sewage Treatment Plant after Reconstruction

2. Overview

2-1 Project overview

Table 1 provides a summary of the Project. The treatment process utilized for the renewal project was a recycled nitrification/denitrification MBR process with coagulant addition. The MBR process is a wastewater treatment method that combines biological treatment using microorganisms (activated sludge) and solid–liquid separation using membranes. Compared to the conventional activated sludge process, the MBR can maintain a three to five times higher concentration of mixed liquor, requires less space, and can produce high-quality treated water due to the use of microfiltration membranes for filtration.

This is the largest MBR in Japan, with a treatment capacity of 40,000 m^3/day during dry weather. During wet weather, the high-rate filtration system treats 576,000 m^3/day, which is 14.4 times the dry weather capacity (40,000 m^3/day), and the MBR treats 96,000 m^3/day, which is 2.4 times the dry weather capacity. The design and construction period began in March 2017, with a one-year design period followed by three-and-a-half years of construction, and the plant began operation in October 2021. During the two-year performance evaluation period, the goal was to optimize operations for energy-efficiency while maintaining the target water quality.

Table 1 Outline of the Project

Project name	Water treatment facility renewal project at Nakahama Sewage Treatment Plant		
Treatment process	Recycled nitrification/denitrification MBR process (with coagulant addition)		
		Dry weather	Wet weather
Treatment capacity	High-rate filtration	40,000 m^3/day	576,000 m^3/day
	MBR	40,000 m^3/day	96,000 m^3/day
Project period	Design	March 3, 2017 to March 31, 2018	
	Construction	April 1, 2018 to October 31, 2021	
	Performance evaluation and verification	October 1, 2021 to September 30, 2023	
Project cost	Approx. 11.2 billion yen (including tax)		
Contractor	Kubota Corporation		

2-2 Facility renovation overview

After modification and repair of the existing civil works and buildings, the existing primary sedimentation tank was converted to a high-rate filtration facility and the existing reaction tank was converted to an MBR facility, thus changing the treatment method from the conventional activated sludge process to the MBR process (Fig. 2). In the MBR, submerged membrane units separate activated sludge and treated water, eliminating the need for a final sedimentation tank, which is a conventional solid–liquid separation process. Furthermore, in the MBR process, filtration is performed using membranes with an average pore size of 0.2 μm, which does not allow coliform bacteria to pass through the membranes, creating treated water free of coliform bacteria (approximately 1-2 μm in size). As a result, the chlorination tank for disinfection is no longer necessary and was converted to a water supply pump facility.

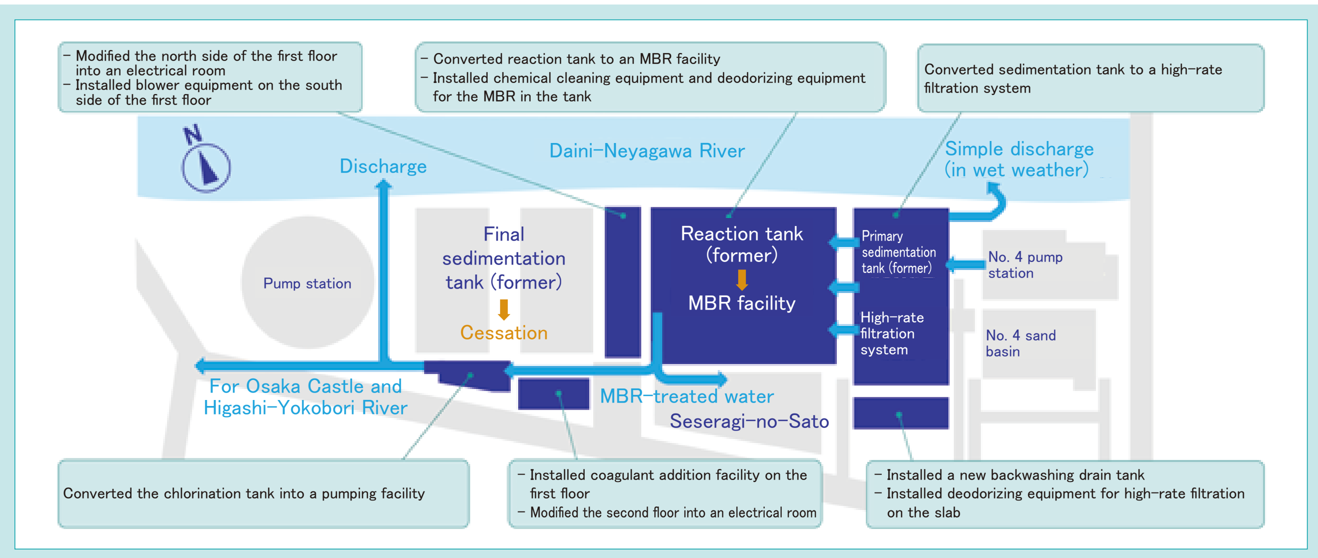


Fig. 2 Overview of Nakahama Sewage Treatment Plant Reconstruction

2-3 Plant processing flow

At the treatment plant, sewage is treated utilizing high-rate filtration and the MBR process. The high-quality effluent is then discharged into rivers in Osaka City by water supply pumps (Fig. 3).

The high-rate filtration system is an upflow filtration technology using floating filter media developed for CSO control and was adopted as an alternative to the conventional primary sedimentation tank. Although more compact than the primary sedimentation tank, this technology can eliminate suspended solids (SS) and biochemical oxygen demand (BOD) (an indicator of organic pollutants in sewage) as effectively as primary sedimentation tanks and can remove at least 99% of debris such as hair. The high-rate filtration system also plays a critical pretreatment role by removing debris to protect membranes from clogging and damage.

The MBR consists of an anoxic tank and an aerobic tank where membrane units are installed. In the aerobic tank, air is discharged into the activated sludge to allow microorganisms to decompose and nitrify organic matter, and the membrane units filter the activated sludge to produce treated water. A portion of the activated sludge is returned by an air lift pump (nitrified liquid circulation pump) to the oxygen-free anoxic tank, and denitrification (nitrogen removal) is performed by microorganisms. Coagulant is injected into the aerobic tank to promote the removal of phosphorus.

A portion of the treated water from the MBR is discharged into the outer moat of Osaka Castle and the Higashi-Yokobori River, which is connected to the Dotonbori River, one of the most popular tourist attractions in Osaka City. The advanced treatment process and high quality effluent has resulted in improved water quality in the latter river, contributing to enhancing the attractiveness of the waterfront and creating a lively atmosphere in Osaka, known as the City of Water.

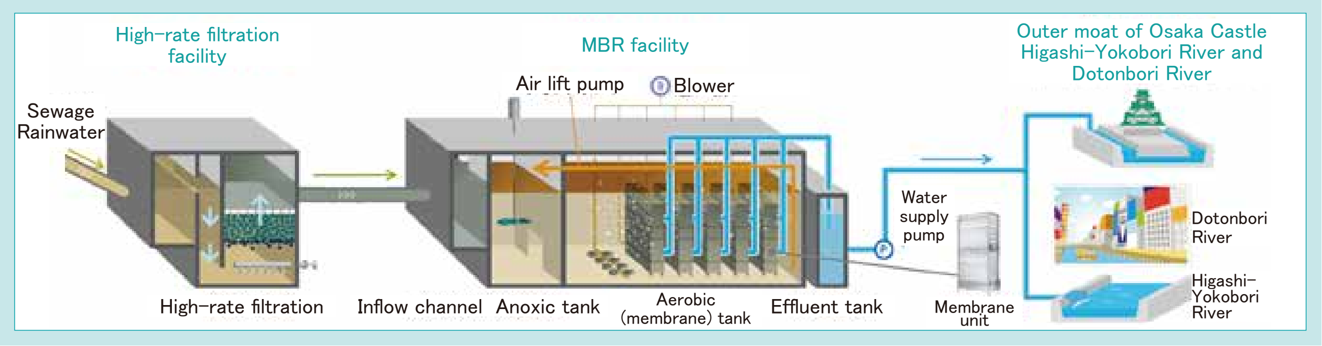


Fig. 3 Processing Flow of Nakahama Sewage Treatment Plant

2-4 Energy-saving operations

The MBR process is a treatment system characterized by its ability to produce high-quality treated water in a very small footprint. However, the high energy consumption of MBR systems compared to conventional wastewater treatment methods has been a drawback and its adoption for medium to large treatment plants has been limited under certain conditions. Therefore, a smart MBR "SCRUM" (Smart Control technology for Reducing energy Use in MBRs) was developed in cooperation with Toshiba Infrastructure Systems & Solutions Corporation for energy-saving operations and was introduced into this treatment plant for the first time.

2.4.1 SCRUM technology

Blower power usage typically accounts for more than 90% of the energy consumption during MBR operations, so reducing the airflow rate is critical to energy savings. The MBR requires two air systems: membrane scouring air to clean the membrane surface and auxiliary air to supplement the oxygen required for biological treatment (Fig. 4). In order to save energy, the SCRUM optimizes the control of these airflow rates based on various sensor information.

Traditionally, scouring airflow has been provided at a fixed rate within a certain margin to prevent membrane clogging, but the SCRUM automatically controls the required airflow rate by predicting the transmembrane pressure (TMP), which is an indicator of membrane fouling. Specifically, after chemical cleaning, a standard target TMP curve is set for the period until the next chemical cleaning. The SCRUM predicts the future TMP and if the predicted TMP is lower than the target TMP curve, then this indicates reduced membrane fouling and the scouring airflow is reduced. If the predicted TMP is higher than the target curve, then this indicates increased membrane fouling and the airflow is increased (Fig. 5).

The auxiliary airflow rate is controlled utilizing ammonia-based aeration control to adjust the dissolved oxygen (DO) concentration in the aerobic tank. The DO set point is calculated from the ammonia nitrogen concentration continuously measured in the effluent tank. This control is made to obtain the airflow rate required to ensure nitrification performance.

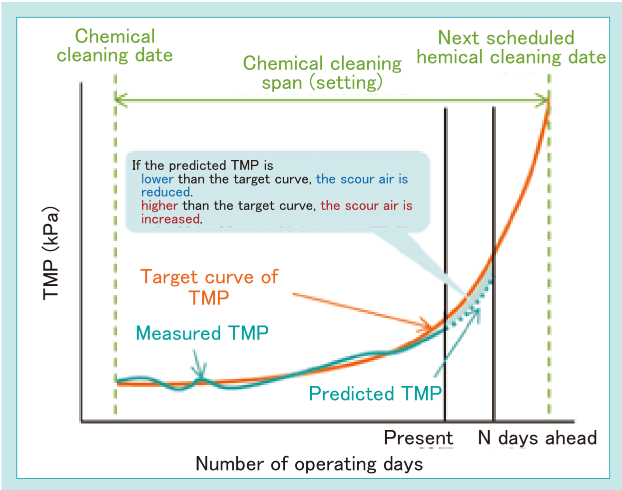


Fig. 5 Airflow Control for Membrane Scouring Utilizing TMP Prediction Model

2.4.2 Siphon filtration and the airlift pump

In addition to the installation of the SCRUM, energy-saving operations with siphon filtration and airlift pumping were adopted.

Siphon filtration is a technology that uses gravity flow based on the difference in water levels between the aerobic tank and the effluent tank to perform filtration, and it can reduce energy consumption by 95% compared to pump filtration.

The airlift pump circulates nitrified liquid (sludge) to the anoxic tank by an airlift effect through aeration with a small amount of air from under an L-shaped duct, reducing energy consumption by 95% compared to pumped circulation.

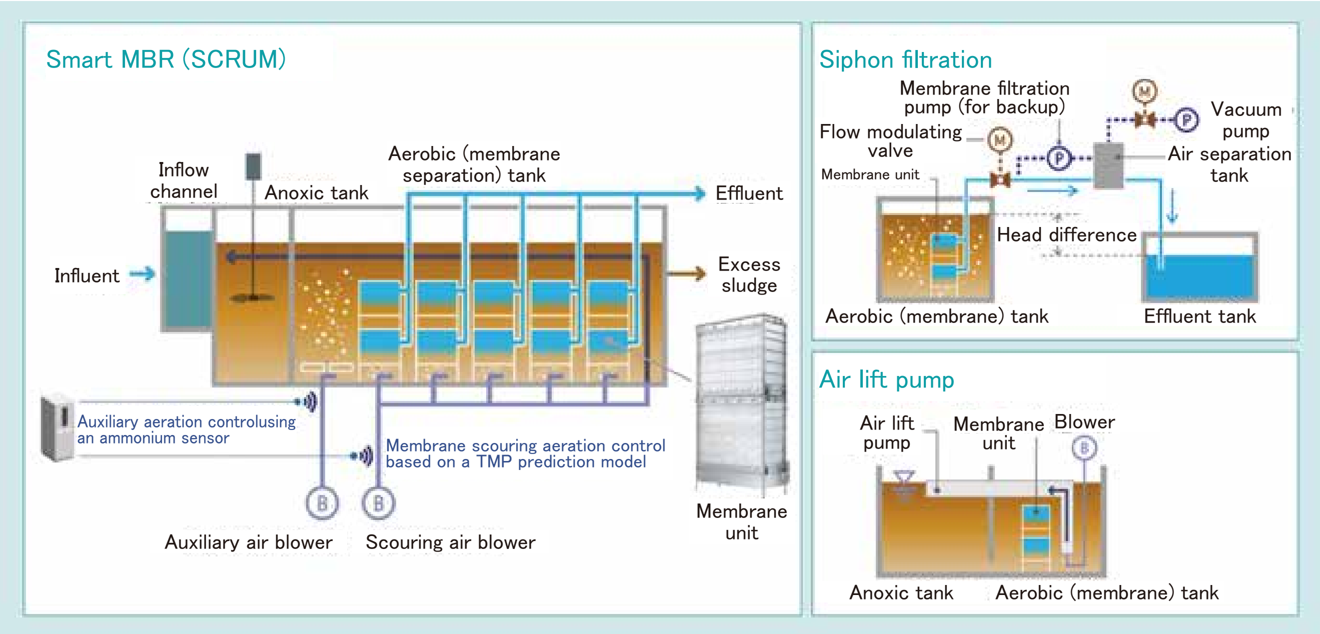


Fig. 4 Overview of Energy-Saving Technology

3. Water quality and energy consumption operating results

3-1 Water quality operating results

The effluent water quality of the MBR has designated target values. These designated values and actual operating results for the two-year performance evaluation period from October 2021 to September 2023 are shown in Table 2.

The average dry weather effluent concentrations were 1.0 mg/L for BOD, 1.0 mg/L for SS, 5.7 mg/L for total nitrogen, and 0.4 mg/L for total phosphorus. All these values met the effluent target values and no coliform groups were detected on any of the test days.

During wet weather, the flux (volume of filtered water per membrane surface area) was increased to 1.21 $m^3/(m^2 \cdot day)$, which was 2.4 times the dry weather flux of 0.51 $m^3/(m^2 \cdot day)$, to manage fluctuations in water volume. The average wet weather effluent had a BOD concentration of 1.5 mg/L and a coliform group of 1/cm^3, indicating that the MBR was operated to meet the designated values. While this was the first attempt to operate the MBR at increased flux during wet weather, successful operations were achieved since the filtration continued at high flux rates and the MBR was able to operate at the target effluent quality.

Table 2 Design Values of MBR and Water Quality Test Results of Treated Water

Item	Inflow water quality (mg/L)		Treated water quality in dry weather (mg/L)		Treated water quality in wet weather (mg/L)	
	Design value	Actual value (average)	Design value	Actual value (average)	Design value	Actual value (average)
BOD	160	117.6	2.0 or less	1.0	2.2 or less	1.5
SS	120	92.2	1.0 or less	1.0	–	–
T-N (total nitrogen)	25	25.4	8.0 or less	5.7	–	–
T-P (total phosphorus)	3.6	3.0	0.8 or less	0.4	–	–
Coliform group	–	–	3,000/cm^3 or less	ND	3,000/cm^3 or less	1/cm^3

3-2 Energy consumption operating results

Operations were conducted using the energy-saving technologies shown in section 2-4. The guaranteed energy consumption per treated water volume for the MBR is 0.28 kWh/m^3 (for treated water volume of 40,000 m^3/day). With the introduction of the SCRUM, operations were carried out with the aim of achieving an energy consumption target of 0.25 kWh/m^3.

During the performance evaluation period, energy consumption for the MBR when SCRUM control was implemented averaged 0.25 kWh/m^3 for a treated water volume of 36,000 to 40,000 m3/day, meeting the target criteria. This is less than or equal to the energy consumption required for conventional advanced treatment using rapid filtration.

While the high energy consumption of MBRs compared to the conventional activated sludge process has been the biggest obstacle to the adoption of MBRs, the successful achievement of the energy consumption target is expected to further promote the widespread use of MBRs.

4. Conclusion

Kubota's MBR system excels in achieving high-quality treated water, space savings, and ease of maintenance. Kubota's MBR system has a market share of more than 90% in terms of the volume of sewage treated by MBRs in Japan. The use of MBRs at the time of reconstruction and renewal of sewage treatment plants can solve challenges related to aging infrastructure and the increasing demand for wastewater treatment in urban areas. Kubota's MBRs offer optimal solutions for the various needs of domestic sewage treatment plants and the continued optimization of operations, and the development of new energy saving technologies and strategies makes the MBRs more attractive for medium and large size wastewater treatment systems.

Contribution to SDG targets

6.3 Water quality improvement by reduction of untreated wastewater, recycling, etc.
Reduction of pollution loads in rivers during wet weather by improving confluence

11.3 Enhancement of inclusive and sustainable settlement planning and management capacity
Improvement of river water quality to enhance the attractiveness of urban waterfront areas

14.1 Prevention and reduction of marine pollution
Advanced MBR treatment of nitrogen and phosphorus, which cause eutrophication

Source

1) Performance Evaluation Report on the Water Treatment Facility Renewal Project at Nakahama Sewage Treatment Plant (2023)

Introduction Article

Introduction of ASB System and Its Effects on Night Soil Treatment

KUBOTA Environmental Engineering Corporation

Related SDGs

1. Introduction

Night soil treatment plants treat night soil and septic tank sludge, which are municipal wastes, to water quality that allows discharge into rivers and other bodies of water. Since around 2000, such plants have evolved into night soil treatment and organic waste recycling centers that comprehensively treat and recycle organic waste.

As efforts to achieve the SDGs gain momentum around the world, the performance requirements for sludge recycling/treatment centers are becoming more advanced and diverse in order to achieve carbon neutrality by 2050.

The ASB (activation of soil bacteria) system is a sewage treatment technology that utilizes the activity of soil microorganisms such as Bacillus bacteria. In 2013, the Kubota Group received accreditation from the Japan Environmental Sanitation Center for its waste treatment technology verification project.

This report provides an overview of the ASB system and its effectiveness.

2. Overview

The ASB system brings activated sludge into contact with ASB pellets (humic substances) and ASB minerals (natural mineral masses) to activate soil microorganisms by creating a growth environment. The contact materials are filled into the ASB reactor. Figure 1 shows the process flow and benefits of the ASB system. The benefits include reduced excess sludge, reduced odor, improved sludge settling, reduced foaming, improved sludge dewatering, and antibacterial effects of Bacillus bacteria. Figure 2 shows the amount of excess sludge in plants that have implemented an ASB system. The amount of excess sludge tends to be low at plants with a high ratio of night soil in the brought-in materials. In addition, an activated sludge return method, where returned sludge is fed into the receiving tank, reduces high concentration odors, such as the original night soil odor.

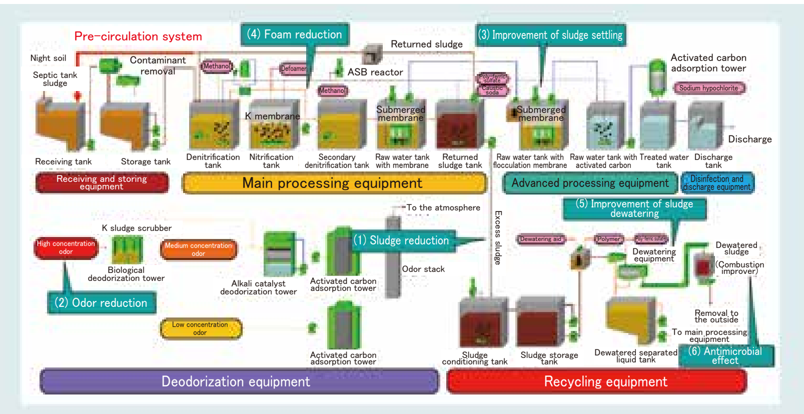


Fig. 1 ASB System Flow and Effects

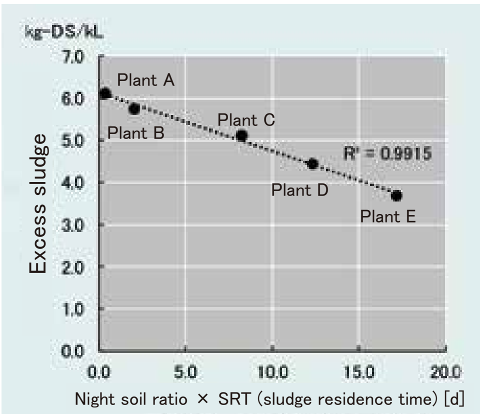


Fig. 2 Excess Sludge Volume with ASB System

3. Detailed explanation

3-1 Bacterial flora analysis of the ASB system and improved sludge reduction efficiency by pre-circulation

A recent next-generation sequencing study to compare and analyze the bacterial flora of plants with and without the ASB system showed that the percentages of phylum Firmicutes, order Bacillus, and order Clostridium were all higher in plants with the ASB system than those without the system (Fig. 3). It has also been confirmed that the use of the aforementioned pre-circulation system in plants with an ASB system improves the excess sludge reduction by 5% to 10% compared to the case without pre-circulation. Because the receiving tank is an anaerobic environment, the action of anaerobic bacteria such as Clostridium bacteria promotes the decomposition of organic matter, which is believed to increase the effectiveness of excess sludge reduction.

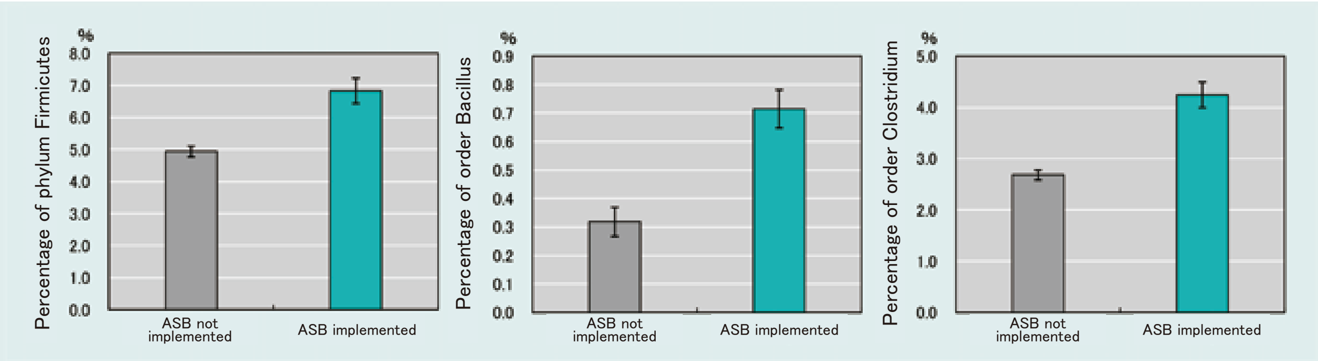


Fig. 3 Comparison of Bacterial Flora Ratios with and without ASB-System (Left: Firmicutes (Phylum), Center: Bacillus (Order), Right: Clostridium (Order))

3-2 CO_2 reduction effect of the ASB system

Table 1 shows the effect of the ASB system on CO_2 reduction. Reducing excess sludge reduces CO_2 emissions associated with sludge incineration and dewatering. In total, 40 t-CO_2 can be reduced annually, which corresponds to about 4.5% of CO_2 emissions (in the case of a plant with a 1:1 composition of night soil and septic tank sludge and a throughput of 50 kL/day).

Table 1 CO_2 Reduction for ASB System (Condition—Night Soil : Septic Tank Sludge = 1:1, 50 kL/day)

Item		Unit	ASB not implemented	ASB implemented	Amount reduced	Reduction rate
Excess sludge	Sludge generated	kg-DS/d	329	254	75	22.8%
	Excess sludge (water content: 70%)	t/year	400	309	91	
CO_2	CO_2 emissions from excess sludge incineration	t-CO_2/year	105	81	24	
	CO_2 emissions from the plant	t-CO_2/year	783	767*	16	2.0%
	Total CO_2 emissions	t-CO_2/year	888	848	40	4.5%

*Reduction of polymers and poly-ferric sulfate used for dewatering

4. Achievements

To date, the Kubota Group has supplied 14 sludge recycling/treatment centers equipped with an ASB system (including those under construction) (Table 2).

Table 2 Installation Record of ASB System Results

Customer	Year completed	Processing scale	Customer	Year completed	Processing scale	Customer	Year completed	Processing scale	Customer	Year completed	Processing scale
	Year	kL/d		Year	kL/d		Year	kL/d		Year	kL/d
Association A, Iwate Prefecture	2006	85	City E, Shimane Prefecture	2016	125	City I, Ibaraki Prefecture	2020	34	Association M, Gunma Prefecture	2023	50
Coalition B, Nagano Prefecture	2012	70	Association F, Chiba Prefecture	2018	97	Association J, Shizuoka Prefecture	2020	210	City N, Chiba Prefecture	2023	67
City C, Ehime Prefecture	2016	45	Association G, Tokyo	2018	24	Town K, Kagoshima Prefecture	2021	223			
City D, Chiba Prefecture	2016	66	City H, Mie Prefecture	2019	170	Town L, Ibaraki Prefecture	2023	26			

5. Conclusion

Sludge recycling/treatment centers are important facilities for the formation of a recycling-oriented society. The reduction in excess sludge and other effects of the ASB system result in reduced CO_2 emissions. The Kubota Group is committed to further technological development of organic waste treatment for the formation of a sustainable society.

Contribution to SDG targets

9.4 Infrastructural and industrial improvement through the introduction of environmentally friendly technologies and industrial processes
Construction of sludge recycling/treatment centers to contribute to waste recycling

12.5 Prevention of waste generation and implementation of reuse
Reduction of 40.0 t-CO_2 per year by reducing excess sludge (in the case of 1:1 composition of night soil and septic tank sludge and a throughput of 50 kL/day)

Ultralight Drainage Pump for Drainage Pump Vehicle

1. Introduction

In recent years, localized heavy rains have become more frequent due to global warming and other effects, causing frequent flood damage throughout Japan. Under these circumstances, there is a growing need for drainage pump vehicles equipped with pumps capable of large-capacity drainage, especially by national and local governments.

Since 2006, Kubota has delivered more than 400 pump vehicles equipped with ultralight drainage pumps that can be installed manually. Recently, there has been a strong demand to reduce the installation workload due to the aging of the personnel who operate pump vehicles. To meet the above needs, we have developed an improved pump.

*Drainage pump vehicles, which are mainly used for emergency drainage purposes in flooded areas, are equipped with a generator, control panel, floats, hoses, and portable pumps on the rear bed (Fig. 1).

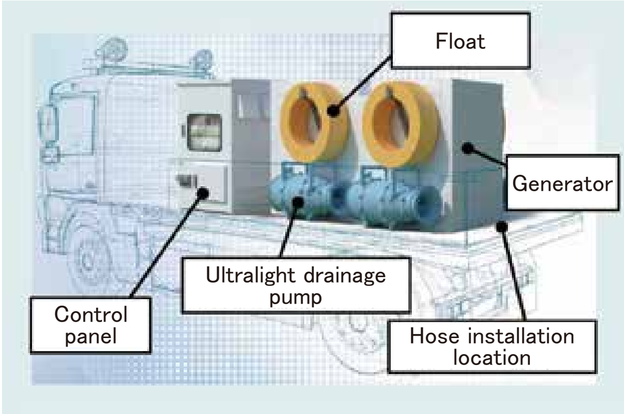


Fig. 1 Drainage Pump Vehicle

2. Product overview

The newly developed pump has the same functionality as the conventional high-head type, that is, the capability to connect two pumps in series (head of up to 20 m) and operate at low water levels; has 1.5 times higher drainage capacity without major changes in dimensions and mass; and has the same discharge rate of 7.5 m^3/min as the conventional large capacity type.

A vehicle with the larger capacity drainage pumps reduces the required number of pumps, hoses, and floats compared to a conventional drainage pump vehicle with similar functionality (Fig. 2), thereby saving space when mounting equipment on the vehicle and during drainage operations, reducing the time required to start drainage. In addition, the shape of the pump handle has been modified for ease of use when loading equipment on the rear bed and when transporting and deploying the equipment.

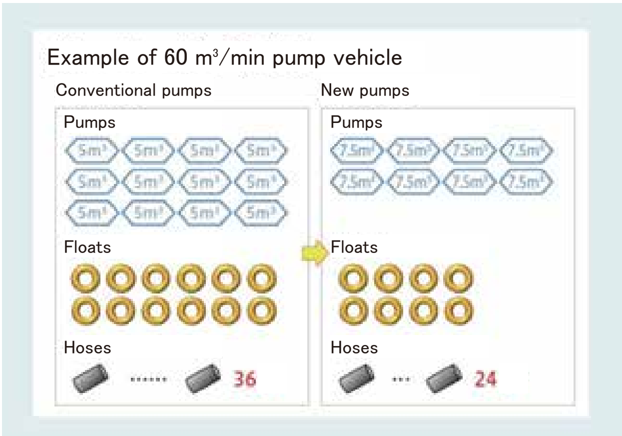


Fig. 2 Quantity Comparison of Installed Items on Drainage Pump Vehicle

3. Conclusion

Drainage pump vehicles are becoming increasingly important in protecting people's lives from heavy rain disasters. As a leading manufacturer of drainage pump vehicles, Kubota will continue to improve the performance, functionality, and operability of its pumps, thereby contributing to the safety and security of citizens.

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