For Earth, For Life
Kubota

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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 Tractor for Domestic Market with a “Keeping Straight Function”
■		Development of Autonomous Driving Assist Combine Harvester WRH1200A
■		Development of Diesel Rice Transplanter NW6S/8S for Domestic Market
■		Development of RTV-XG850 Hi-speed Petrol-powered Model
■		Development of Sugarcane Leaf Remover SLR110H
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	■	Application of Submerged Membrane SP to Industrial Wastewater
	■	Development of All-plastic Flange

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

	SDG goals																
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Kubota's Legacy Creed

Over the 130 years since its foundation in 1890, Kubota has delivered a variety of products that contribute to people's lives and to society in the areas of "food, water and the environment." Throughout that time, we have held firm to the creed of the company's founder, Gonshiro Kubota: "If you try hard, you can get it done," "Do not be afraid to make mistakes," and "Our products should be not only technically excellent but also useful for the good of society."

President and
Representative Director
Yuichi Kitao

[Food] Contributing to increased crop yield through accomplishing an integrated mechanization system

- Since the post-war period when people were still suffering from food shortages, Kubota has developed many types of agricultural machines to realize the stable and plentiful production of food.
- In the 1960s, we successively developed tractors, combine harvesters and rice transplanters, almost accomplishing an integrated mechanization system for rice farming. Those products contributed to a 50% increase in the productivity (normal yield of paddy-field rice per 1000m^2, from 335 kg in 1955 to 501 kg in 1995), helping Japan to resolve the national food shortage problem and boost its GDP.
- In subsequent years, we began exploring overseas markets and developed products to meet the particular needs of different countries and regions. To date, a cumulative total of more than four million Kubota tractors have been used in some 100 countries.

[Water] Developing Japan's first iron water pipes to deliver safe water to people

- During the period in which western technologies and culture were being rapidly introduced into Japan, epidemics of infectious diseases such as cholera, typhoid and smallpox were prevalent. In light of that situation, Kubota developed the first cast iron water pipes to be made in Japan. Since our company supplied 700 tons of water pipes for Tokyo's water system in 1903, through working on development of water distribution around the country, we have made a significant contribution to Japan's water distribution systems, which now serve 98% of the country's population.
- Currently, we contribute to the provision of safe, reliable water as a comprehensive provider of products and technologies relating to water and the environment, including valves, pumps, plastic pipes, and other products for water systems, together with equipment for sewerage infrastructures.

[Environment] Kubota's melting and wastewater treatment technologies contribute to environmental conservation

- In a project to clean up the massive volume of industrial waste illegally dumped in the 1980s on Teshima Island, Kagawa Prefecture, our unique rotating melting furnace was combined with our advanced wastewater treatment technologies to treat toxic such as volatile organic compounds and high-concentration dioxins. In the project, Kubota cleaned up 910,000 tons of waste over the 14-year period starting in 2003, making a major contribution to restoring the environment.
- Utilizing melting technologies and know-how that we gained through this project, we are currently working on reducing the volume of radioactively contaminated waste in Futaba-town, Fukushima Prefecture.

As our society constantly changes, so, too, do the challenges it faces; in recent years, those challenges have been getting increasingly complex and large in scale. Given those circumstances, we aspire to having people say: "We are fortunate to have Kubota." Our aim is to be perceived as such a company for all people at all times.

To that end, we need to revisit the creed of our founder and all of us need to work together to aggressively tackle social challenges.

In this issue, No. 53 of the Kubota Technical Report, readers will find examples of products and services that serve the public in accordance with our founder's creed. It includes articles about the development of products such as tractors, combine harvesters and rice transplanters with automated driving assist functions that contribute to greater efficiency and reduced workloads in farm operations, and to improved productivity through application of ICT; air purifiers to help prevent infectious diseases by sterilizing and humidifying indoor air; earthquake-resistant ductile iron pipes and plastic flanges that contribute to the development of robust water supply and sewerage infrastructures; and new services that utilize cloud computing and AI.

I hope that you will read this report and thereby gain a deeper understanding of Kubota's activities.

Development of Tractor for Domestic Market with a "Keeping Straight Function"

Compact Tractor Engineering Dept.

In Japanese agriculture, against the background of an aging population, the proportion of inexperienced workers is increasing and the consequent shortage of skilled human resources is becoming a serious problem. As one of the solutions to this problem, in 2016, Kubota released onto the market a rice transplanter with a "Keeping Straight Function" for use in rice paddy cultivation. Similarly, field cultivation with a compact tractor requiring skilled and experienced operators has the same problem. To address this problem, Kubota has developed a compact tractor with "Keeping Straight Function" to save labor and improve efficiency (Fig.1). This paper describes the efforts made in the development process and defines the characteristics of working with a compact tractor.

【Key Word】
Robot, Automatic Steering, GNSS, GPS(Global Positioning System), Sloping Ground

Related SDGs

1. Introduction

In agriculture in Japan, the consolidation of farmland is increasing due to the labor shortage caused by the aging of the population, and the management of agriculture by professional farmers is increasing. Those professional farmers are required to make a good profit, so efficiency improvements and labor-saving are necessary. Measures taken by national and local governments in response to labor shortages have meant that the number of newly employed agricultural workers is increasing, but a lack of skills limits the work that can be entrusted to them. From such a background, there are requirements for efficiency improvement using agricultural machinery and for it to be possible for people with no agricultural experience to become able to conduct the same work as a skilled operator in a short period of time.

In addition, there has been an increase in the number of cases where professional farmers shift their crops from rice to vegetables in order to improve their profitability. In dry field farming with compact tractors, there is a high demand for work in straight lines, such as to make ridges and conduct the seed sewing or transplanting at narrow intervals to increase the yield per area.

If the accuracy of the movement straight-ahead is poor, then this can lead to a decrease in yield, variation in growth and an increase in effort due to reworks. In addition, the work requires the operator to have a high level of skill to operate the steering wheel and adjust the implement while checking the tracks of the work and the condition of the work. This means that it is not currently possible to entrust this work to unskilled workers and a large mental and physical burden is concentrated on a limited number of people.

Fig. 1 Compact Tractor "NB21GS" with Automatic Steering

In 2016, Kubota responded to the problem of the shortage of workers with advanced skills in rice

transplanting with the development of a function using the Global Navigation Satellite System (GNSS) for automatic straight-forward steering on rice transplanters (the Keeping Straight Function). In this development, that Keeping Straight Function was utilized to develop the first compact tractor with automatic straight-forward steering in the industry, as an initiative to solve the problems in dry-field farming work. This report describes the technology that was newly developed to adapt the rice transplanter Keeping Straight Function for use on tractors. (Hereinafter, the automatic straight-forward steering function for tractors is called the "Keeping Straight Function".)

2. Development concept and goals

The attractiveness of compact tractors is their low price, small turning radius (adjacent work in a narrow interval is possible), and easy handling (operating them is simple). To develop a tractor that can be widely used and takes advantage of this attractiveness, the concept of the development was "A tractor that is inexpensive and can be used easily and with no anxiety by anyone to perform work that is equivalent to that of an expert."

In order to satisfy this concept, this development was carried out with the following three points set as the goals for dry-field tractor work.

[1] To realize high straight-line accuracy that is adapted to the features of tractor work that are different from rice transplanter work, at a reasonable sales price.
[2] To realize easy operability so that the Keeping Straight Function can be started smoothly while traveling.
[3] To install a function to be a countermeasure to inattention and misoperation and perform functional design so that anyone can use it without anxiety while working.

3. Technical issues to be solved

3-1 Realization of high straight-line accuracy

As tractor work has different features from rice transplanter work, it was not possible with the existing control to secure the accuracy of straight line movement in the following situations. Being able to achieve the target accuracy in working conditions specific to tractors became an issue.

[1] Working in a tilted state
When a tractor is always in a tilted state, such as on sloping land or in adjacent work, the conventional control produces meandering work paths because it does not take into account the effect of the inclination. It was necessary to have control technology that achieves high straight line accuracy even when in a tilted state.

[2] Work using a variety of implements
Various different implements are used in dry-field farming. Depending on the type of the implement, the burden on the steering will vary and also the distance between the antenna position and the work position will vary, so the work traces can meander if the same control is used. In addition, there are also effects due to the condition of the fields, so the appropriate control will vary depending on the location and on the timing of the work. Some of the automatic steering devices currently available for retrofitting can be adjusted to suit the work and the field conditions, but that adjustment is complicated and the responses and changes are often difficult for the user. It was therefore necessary to design a system that can cover a large number of work tasks and has control that can be easily used by anybody to obtain a satisfactory final result.

[3] Long work time
In order to reduce the product price, it was decided that DGNSS (Differential GNSS) positioning would be used as the location information positioning system. This has moderate accuracy and is relatively inexpensive. However, DGNSS positioning has the characteristic that location information errors occur after the passage of time. There is a high possibility that significant errors may appear after approximately two minutes. As the work on compact tractors is performed at a relatively low speed, the working time for one journey across a field may be five minutes or more, and there is a possibility that errors in the DGNSS location information may cause a deterioration of the straight-line accuracy. It was necessary to develop a system which could carry out the automatic steering with the straight line accuracy maintained to the end point of the work, even if location information errors occur.

3-2 Realization of an operational interface that is easy to use while working

The Keeping Straight Function only conducts automatic steering when moving forward in a straight line, so it is necessary to perform manual steering when turning. It is necessary to operate a switch to change from manual steering to automatic steering. However, if the position of the tractor work must be adjusted precisely after turning to achieve the predetermined width between adjacent paths, then it is necessary to perform the work carefully with both hands on the steering wheel at all times, so as not to lose control of the steering over the unevenness of the field.

For this reason, another issue was the construction of an interface that can be easily used by anybody to perform the operation for the switching to automatic steering without taking a hand off the steering wheel. In addition, as this means adding even more operations that are not found on conventional tractors, it is necessary for even first-time users to be able to perform the operation without hesitation.

3-3 Realization of support functions that operators can use with confidence

The function developed eliminates the need to operate the steering wheel while going straight forward. It is therefore conceivable that the attention of the operator may shift away from the traveling operation to concentrate on matters such as checking the working conditions. As a result, there is a possibility that the operator may not notice the end position of the work, or may not notice that the surrounding situation has changed and the state of the location information reception has changed. It was necessary to develop a function that could cope with such inattention by the operator, or misoperation outside the field, so that anybody can feel reassured when performing the work.

4. Developed technology

4-1 Development of control technology for straight forward movement

4.1.1 Controlling straight forward movement in a tilted state

If we examine how a skilled operator steers with the steering wheel on sloped land, even if the movement is straight forward, the work is always performed with the steering wheel turned towards the higher part of the slope. In other words, the steering wheel is operated according to the amount of displacement and the inclination.

We therefore added the information on the inclination from the IMU (Inertial Measurement Units) to the control when the correction direction is determined in the steering control (Fig. 2). When inclined land results in a lateral shift or inclination of the machine, the front wheels are turned to point more towards the top of the slope than when moving in a normal straight line. This made it possible to maintain the target accuracy with smooth steering control.

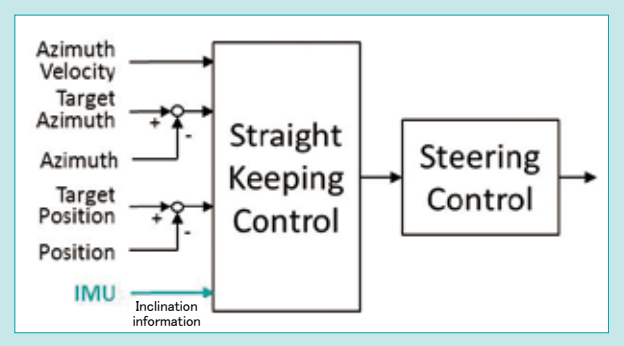

Fig. 2 Block Diagram of Controller

4.1.2 Controlling straight forward movement according to the characteristics of the work

In order to satisfy the target accuracy under various conditions, it is necessary to change the control for each different implement and field. As a simple and easy method to control the steering wheel appropriately, we classified the contents of the work according to differences in the implement position, resistance and steering wheel load, and then gathered these into three modes to develop a mechanism that can cope with different conditions. In addition, we prepared three levels of sensitivity setting for each work task in order to respond precisely to differences in the field conditions. Table 1 and Table 2 show the differences for the work and sensitivity settings. The combination of these two settings means that a total of nine patterns of control can be selected, which enables a detailed response to the work. A simple method of operation was realized as the setting is completed by selecting the work with the closest conditions from three different work tasks on a color LCD monitor and then adjusting the sensitivity to suit the field conditions.

Table 1 Characteristics of Control in Each Work Setting

Item	Adapted work	Effect on steering	Characteristics of the work	Control gain
Ridge making	Ridge making, simultaneous ridge making and mulching/sowing	Large	Compared to tilling, there is more resistance from the implement, so the effect of the ground surface is less. However, if it starts to deviate, then it deviates greatly.	▲ Large
Tilling	Tilling, simultaneous tilling and sowing/fertilization	Medium	There is resistance on the steering from the implement, but the response to steering is also good	
3P lifting	Fertilization, sowing	Small	There is less resistance from the implement than when tilling, and the vehicle body direction can be changed smoothly by the steering	▼ Small

Table 2 Characteristics of Control on Sensitivity Setting

Item	Field conditions assumed	Characteristics during manual steering	GS travel condition before setting
Sensitive	Large resistance from the ground (heavy, clay)	A large force is required	Set if the work trace meanders greatly
Normal	Moderate resistance from the ground	–	–
Not sensitive	Low resistance from the ground (Light, smooth and dry)	Steering is possible with a small force	Set if the front wheel shakes minutely

4.1.3 Adaptation to work where one journey across a field takes a long time

In this development, the problems were solved by the following methods in order to achieve the appropriate cost and performance (straightness).

[1] Algorithm change for machinery body orientation calculation

We focused on improving the control accuracy during low-speed operation by making the orientation of the machinery body that is calculated from location information closer to the actual orientation. The method used for this was to improve the algorithm in the machinery body orientation calculation. In previous control, the location information used was from a distance further away, but the improvement made it possible to make judgments using finer intervals. As a result, an azimuth angle that is closer to the actual angle can be calculated, so the control accuracy is improved and straight line accuracy suitable for tractor work was realized with an inexpensive GNSS unit (Fig.3).

[2] Correction by the operator

In order to maintain the accuracy during work that takes a long time while also suppressing the cost, we devised a method for the operator to correct the traveling direction during the use of the Keeping Straight Function. In this method, a correction switch was newly introduced and the operator presses the switch if he/she recognizes any deviation from the target line. This moves the target line by a predetermined distance in the direction that was pushed.

We used smooth control for when correcting the position with the switch operation, so that the work trace is not made chaotic by sudden steering control. Furthermore, the correction switch can also be used for fine adjustment of the adjacent distance after starting the travel using the Keeping Straight Function, so it is also possible to improve the finished quality of the adjacent work. We selected a seesaw type switch that can be operated intuitively for the switch. The path resulting from the correction switch use is shown in Fig. 4.

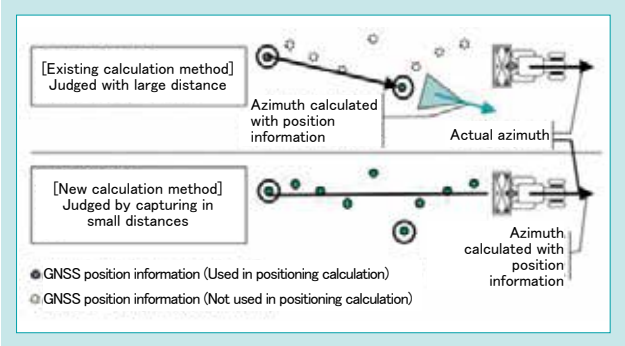

Fig. 3 Method Used to Calculate GNSS Azimuth

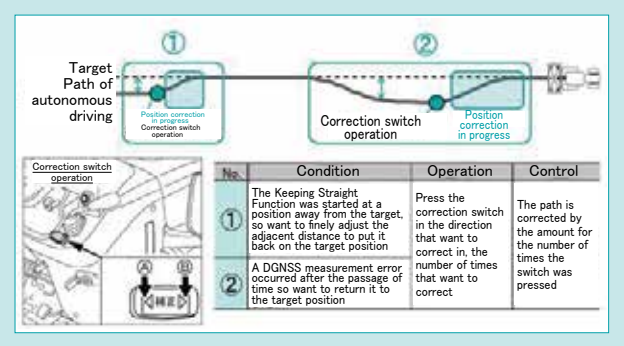

Fig. 4 Orbit Pushing Assist Switch

4-2 Development of the operational interface

4.2.1 Easy-to-operate layout

As the steering wheel is operated manually during the time after turning until the operation is switched to automatic steering, the switches necessary for the Keeping Straight Function were mounted near to the steering wheel so that they can be operated while operating the steering wheel. The layout takes into consideration the selection and operability of the types of switches, with the following quality objectives: [1] The normal operation of the steering wheel and the operation of the implement lifting/lowering switch can be performed without any problem; [2] The widening of the operation area must not affect the operator getting on/off the vehicle; and [3] The operability of the other operation levers and the visibility of labels must be secured. We arranged the new switches as shown in Fig. 5, in a simple mechanism that has the switches for the basic operation of the Keeping Straight Function all integrated into a single switch (Fig. 6). This switch is a four-way lever switch that moves up, down, left and right. It can be used to register the reference line with movement front and back, and to turn the Keeping Straight Function ON/OFF with movement up and down. Through the use of this switch, the space used was minimized, the conventional functions were maintained, and the operation can be performed with just a finger, without taking the hand off the steering wheel. It was also possible to be intuitively the same as the implement lifting/lowering lever ("Pompa" lever) which has already spread on the market. The integration of all the basic operations into one switch realized a mechanism that is easy to understand and can be used easily by anyone.

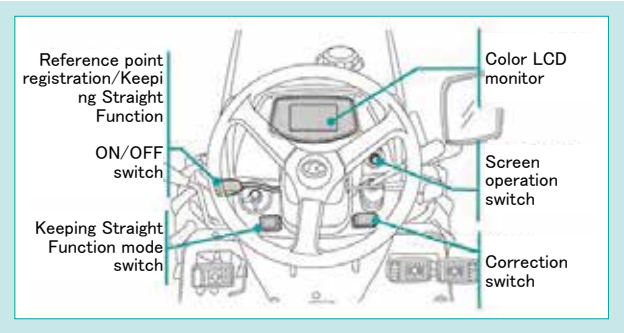

Fig. 5 Interface of the Developed System

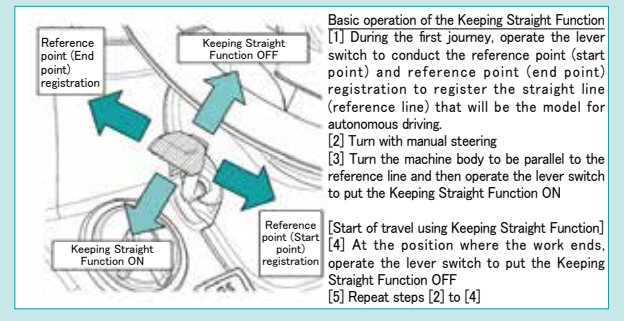

Fig. 6 Basic Operation of the Keeping Straight Function

4.2.2 Guidance on color LCD monitor

A color LCD monitor was used to display the guidance for the operation of the Keeping Straight Function. The development was conducted with the following objectives: [1] Even first-time users will know when and what to operate and in what direction; [2] The control status of the Keeping Straight Function can be seen at a glance; and [3] To display guidance that supports the adjustment of the machine body direction at the start of the work, which is particularly difficult. The display selected uses pictures and short phrases and is easy to understand intuitively (Fig. 7).

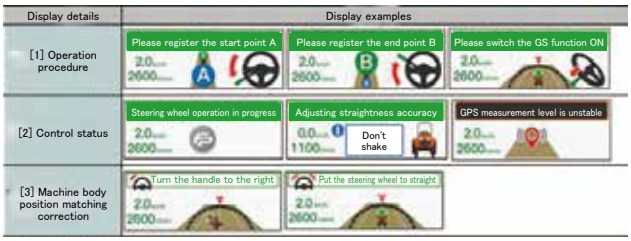

Fig. 7 Monitor Display

4-3 Expansion of reassuring support functions

4.3.1 Function to prevent mistaken use outside the field

In addition to the work in fields, tractors also carry out loading work and are driven on public roads.

If the Keeping Straight Function were to be accidentally activated during loading work or when driving on public roads, then it could affect the steering and cause tipping, etc. It is therefore necessary to prevent the use of the Keeping Straight Function outside of fields.

To solve this problem, we devised a mechanism for the turning ON/OFF of the power supply to devices such as the motors and motor drivers that control the steering operation related to automatic steering. The turning ON/OFF is performed using the Keeping Straight Function switch and the function can only be activated when the Keeping Straight Function switch is turned on.

The specification is such that the mode is always turned off when the engine is started. Before using the Keeping Straight Function, it is necessary to intentionally put the switch to ON, so this made it possible to prevent any unintended activation of the Keeping Straight Function. In addition, the specification is to display the ON/OFF state on the color LCD monitor, so that it can be easily checked by the operator.

4.3.2 Notification of the machinery body status

[1] Work end position notification function

If the attentiveness of the operator declines during work using the Keeping Straight Function, then there is a risk of going through the edge of the field. It was therefore necessary to detect the work end position and prevent the vehicle from traveling past the end position.

A similar notification function exists for the Keeping Straight Function for rice transplanters. This records the position where the Keeping Straight Function was turned on in the previous journey across the field and then after turning, a buzzer sound and an indication on the monitor are used to give notification of the position recorded as the end point for the current journey.

On the other hand, there is some dry-field work using tractors where there are no turns performed, as the work is performed in one direction and then when moving to the next journey, the tractor returns to the work start position by reversing. At this time, the work start position of the previous journey and the work end position are not the same, so the notification function cannot be used.

Therefore, in this development, a new algorithm for detecting the work end position was developed. The position where the Keeping Straight Function was turned off in the journey before last is registered as the virtual work end position to realize appropriate notifications for the tractor. We selected the same notification method as that on the rice transplanters, with a buzzer sound and monitor indication used to notify the operator when the vehicle approaches the work end position during work using the Keeping Straight Function (Fig. 8).

[2] Inclination notification function

There is a risk that as the Keeping Straight Function is possible, the operator may concentrate on checking the work and accidently go up on an uneven part that puts the vehicle at a steep tilt. It is therefore necessary to encourage the operator to check the surroundings.

We therefore developed a mechanism that uses an inclination sensor on the main machinery and warns the operator when the inclination angle is greater than or equal to a threshold value. The threshold value was set to 10 degrees, which is considered to be the angle where normal operation is possible on a compact tractor. When the inclination exceeds 10 degrees, a buzzer sound and a monitor indication are used to warn the operator. This mechanism therefore makes it possible to be aware of the condition of the machinery even as the operation is ongoing, so the work can be performed with peace of mind.

[3] Location information positioning level reduction notification function

As the work is being carried out, the GNSS location information positioning level may deteriorate if the surrounding situation changes, so the straight line accuracy may temporarily deteriorate. There is a notification function that uses a buzzer sound and a monitor indication if this occurs, so this mechanism makes it possible for the operator to know the reception status while performing the work.

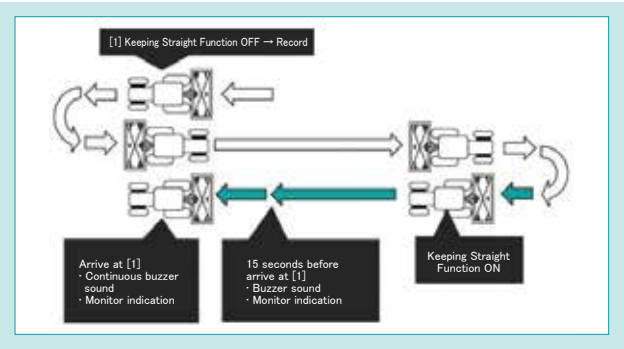

Fig. 8 Approach Finish Point Function

5. Market evaluation of developed technology

5-1 Evaluation under various field conditions

5.1.1 Straightness

After performing the technology development described in the preceding paragraphs, we then conducted testing in various locations around Japan with various different conditions and work tasks. In the results, the control was possible with high precision, and the required accuracy for each task was achieved (Fig. 9).

5.1.2 Operability

For the evaluation of the operability, we had a person who was driving a tractor for the first time perform a test drive.In the results, the handling was possible immediately, even for a beginner, and the work moving straight forward was conducted easily (Fig. 10). One of the test drivers said that, "In the case of manual operation, when I was operating the implement, my hands were full with that and I curved. When I was just traveling straight, I was always concentrating so as not to look away from the front, so it was a tense situation. With the Keeping Straight Function, I had the spare capacity to look behind and check the work condition." The function therefore reduced the burden of the labor.

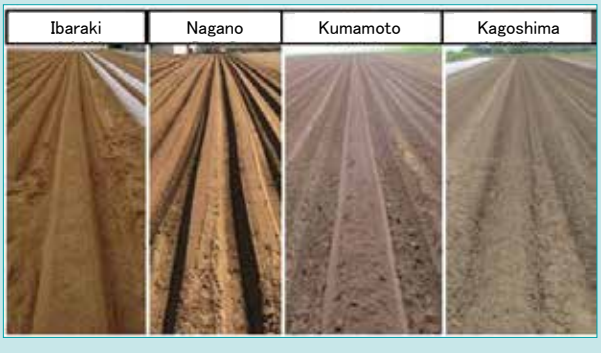

Fig. 9 Result of Test (Pictures)

Fig. 10 Comparison of Straight Furrows by Beginner

5-2 User evaluations

We conducted interviews with customers who had purchased the function. Table 3 shows some of those evaluations. The users were generally satisfied overall as the operation was easy and the straightness and labor-saving effects of the function were strongly felt. The price was also accepted as being appropriate for the functions. Also, in addition to the labor-saving and higher accuracy that we had originally assumed, another favorable evaluation was that there was an improvement to efficiency and it created spare time for other work. This was because it had become easier to check the work, so it was possible to increase the vehicle speed during the work.

Table 3 User Evaluation

Item	Evaluation
Labor reduction	I was able to perform the work with spare capacity, even while checking how much of the chemicals remained.
	Previously, the longer the distance was, the more it strained my nerves, but this burden was gone.
	Previously, it was tiring to have to sit in a difficult position to look at the tracks of the work while also holding the steering wheel. That has now gone and it is easy to ride it all day long.
Higher efficiency	It became easier to check the condition of the work, so the speed of the vehicle could be increased and it was possible to do about 1.5 times as much as before.
	It was possible to increase the vehicle speed, so there was spare time to do other work.
Precision	I am very satisfied.
	I used to curve every time I looked back behind me, so it is good that it becomes possible to go straight.
Cost	I think that the price is appropriate for the performance.
	Two-person work became possible by one person (cost reduction).
Skill	I think it will be a shortcut for new farmers to become professionals.

6. Conclusion

This newly developed machinery was launched in 2019 as tractor with a Keeping Straight Function. It was the first automated tractor in the compact tractor class in the industry. The development of control technology suited to the characteristics of the work enabled the realization of highly accurate tractor work that is not influenced by the skill of the operator. In addition, in comparison with the expensive automated farm machinery, it was possible to offer the function at a price that is also affordable for users of compact tractors (at an increase of 500,000 yen from the standard model). As a result, it is a product that increases the number of customers who can feel the effects of automation.

We believe that this product can make a significant contribution to the solution of the problem of the labor shortage in the market and the realization of efficient agricultural management.

In the future, we will use the evaluations and requests from customers to promote automation that is even more adapted to the actual work. We will also promote technology development to realize high-efficiency and high-quality crop production through cooperation with KSAS (the "Kubota Smart Agri System" agriculture business and service support system) and other models.

Contribution to SDG targets

8.2 Improvement in productivity through innovation Contribution to more efficient agricultural work through ICT
9.5 Promotion of scientific research and innovation Contribution to the promotion of agricultural automation

Development of Autonomous Driving Assist Combine Harvester WRH1200A

Combine Harvester Engineering Dept.

Japanese agriculture is accelerating the consolidation and expansion of farmland to principal farmers due to the decrease in the number of farmers as a consequence of those abandoning farming and aging. However, principal farmers are confronted with various problems such as labor shortages and the need to reduce labor costs. In order to solve these problems, Kubota has commercialized rice transplanters with a straight-ahead function and autonomous driving tractors using the Global Navigation Satellite System (GNSS). Even in the combine, at the time of harvesting, it was still necessary to reduce the burden on the workers who had to work continuously from harvesting → drying and winnowing → shipping and faced long hard days as a consequence. In response to these demands, we have also launched WRH1200A, an autonomous driving assist combine harvester that uses GNSS, and is based on the concept of "a combine harvester that makes it possible anyone to perform optimal harvesting easily and without waste".

【Key Word】
Combine Harvester, Autonomous Driving, GNSS, Driving Control, Assist

Related SDGs

1. Introduction

In recent years, the declining size and increasing average age of the working population in Japanese agriculture has led to an acceleration of the consolidation of farmland under the management of professional farmers and the expansion of the scale of their farming. However, there are also many professional farmer businesses where the number of operators is not keeping pace with expansion of scale, so there are demands for the securing of operators and for labor-saving.

In response to such demands, Kubota developed the “WRH1200A” Autonomous Driving Assist Combine Harvester (Fig. 1). This machine uses RTK-GNSS (Real Time Kinematic - GNSS), which is capable of high-precision positioning. It realizes a contribution for operator shortages and the reduction of work load by harvesting rice and wheat automatically.

Fig. 1 Autonomous Driving Assist Combine Harvester "WRH1200A"

2. Development concept and goals

2-1 Development concept

In harvesting work using a combine harvester, in order to conduct the work without leaving any uncut, it is necessary to constantly operate multiple levers, etc., to adjust the traveling direction and speed, and the height of the reaping part. At the same time, it is also necessary to check the safety around the combine harvester, to decide the work route for efficient work, and to decide the timing of grain discharge that will not lead to wasteful travel. This work is therefore said to require an extremely high level of skill and experience.

In addition, there is a great burden placed on the operator during the period of harvesting as it is necessary to perform the harvesting, grain transportation, drying and shipping work every day.

The development concept selected was therefore "A combine harvester that anyone can use with simple operations and with ease to achieve the optimal harvesting (artisan cutting) without waste."

2-2 Development goals

In order to realize a combine harvester to fit the concept, the development goals were set as follows.

(1) Easy operation

To make the operations performed before the start of autonomous driving, such as map creation and setting, as simple as possible.

(2) With ease

No operation is required during the harvesting operation, and the operator can concentrate on the monitoring of safety and the working conditions.

(3) Optimal harvesting

To travel on an efficient route and automatically move to the position for grain discharge at the optimal timing.

3. Technical issues to be solved

(1) Simple autonomous driving

If the operations for autonomous driving and the map creation procedures performed as preparations are complicated, then the product ceases to be a practical product that is acceptable to everyone.

Also, the case of combine harvesters differs from that for tractors and rice transplanters in the fact that there are crops in the fields to be worked in, so it is not possible to set the map points by running the vehicle in the field in advance.

It was necessary to construct the map creation algorithm and operation specification with as little additional work as possible compared with the normal work of manual cutting.

(2) Autonomous travel technology for combine harvesters

With a combine harvester, it is not practical to simply control the vehicle to travel accurately with respect to a target travel line. This is because any sudden steering change during harvesting work can lead to crops being knocked down by the reaping part, which will leave some crops uncut.

In addition, various conditions such as the hardness of the field and the depth of sinking will differ depending on factors such as the region, the weather and the season. Even in the same field, the field condition may completely change when rain falls.

It was necessary to develop control technology that enables travel in any field conditions without leaving crops uncut.

(3) Optimal travel route

During combine harvesting operations, the harvested grain is accumulated in the grain tank of the combine harvester. When the tank becomes full, the combine harvester is moved to the position of the grain transportation vehicle and the discharge operation is carried out.

In a manual cutting operation, the tank may become full at a place far from the grain transportation vehicle, so wasteful travel may occur.

It was necessary to construct technology to create travel routes that do not cause unnecessary travel.

4. Developed technology

4-1 Simple autonomaous driving

4.1.1 Development of map creation technology

For the map creation method, repeated consideration was given to making the operations and work as simple as possible. The method chosen is a highly practical one that is completed simply by performing a few cycles of normal cutting around the outside.

During the creation of the map, the harvesting work is performed from the outermost periphery of the field with manual operation, in the same way as in normal operations. At this time, when the width of the reaped area (generally the distance from the ridge between fields to the crop) becomes 6 m or more around the whole circumference, the map is created on the basis of the location information obtained from the RTKGNSS on the combine harvester that performed the work. The reason why the distance is set to 6 m or more is to secure the area required for turning in the first round of autonomous driving. After the map is created, the remaining uncut areas are harvested automatically (Fig. 2).

In the calculation method for the map area, the outermost locus points and the innermost locus points are obtained from the locus points when the perimeter cutting is performed two or three times manually. After that, linear approximation is performed for each locus point of the outermost circumference and the innermost circumference to obtain the field outline and the uncut area (Fig. 3).

The map creation is completed when the shortest distances between each side of the uncut area and the field outline are all 6 m or more.

With a calculation method such as this, it is possible to create the map simply by performing normal cutting work around the perimeter.

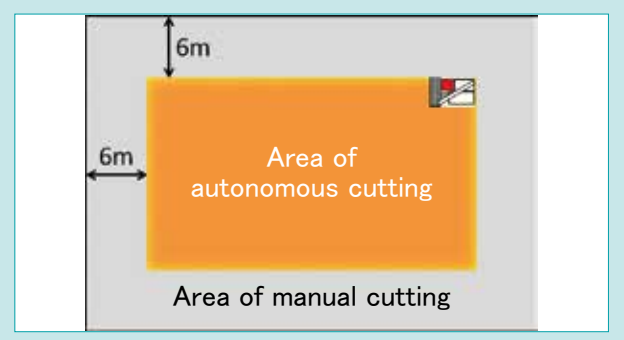

Fig. 2 Work Area of Autonomous Operation

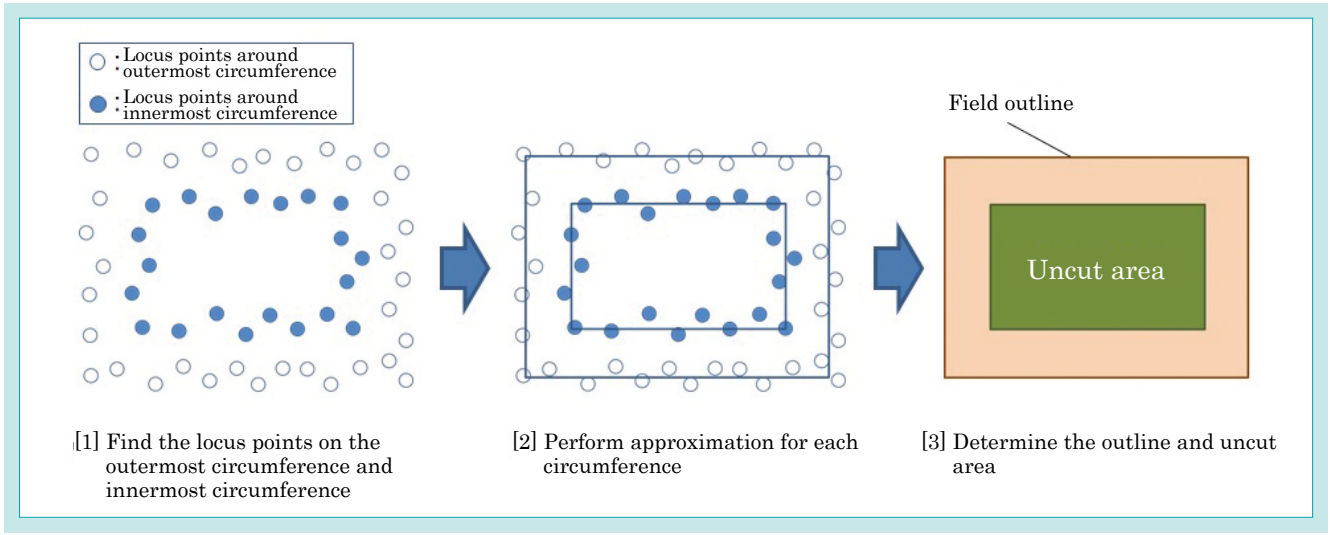

Fig. 3 Schematic Representation of Map Making

4.1.2 Simple setting

After the map has been created, the terminal monitor (Fig. 4) installed to the upper left of the driver's seat is used to set the turning method and the grain discharge position (Fig. 5). Normally these two items are the only settings to be performed, so the autonomous driving can be started immediately after the map creation is completed.

The turning method is selected from either α-turns (Swivel 90° with forward/backward movement) or U-turns (180° turn in forward movement), as shown in Figure 6. When α-turns are selected, the travel performed is the general method of harvesting in a spiral in the counterclockwise direction.

On the other hand, with U-turns, the vehicle is driven in a manner unique to autonomous driving, with the routes with the shortest travel distance being calculated one by one during the harvesting.

The grain discharge position is set to near the grain transportation vehicle and the combine harvester moves automatically to that position and stops there when the grain tank on the combine harvester is nearly full and when the work is completed.

Fig. 4 Terminal Monitor

Fig. 5 Setting of Turn and Discharge Position

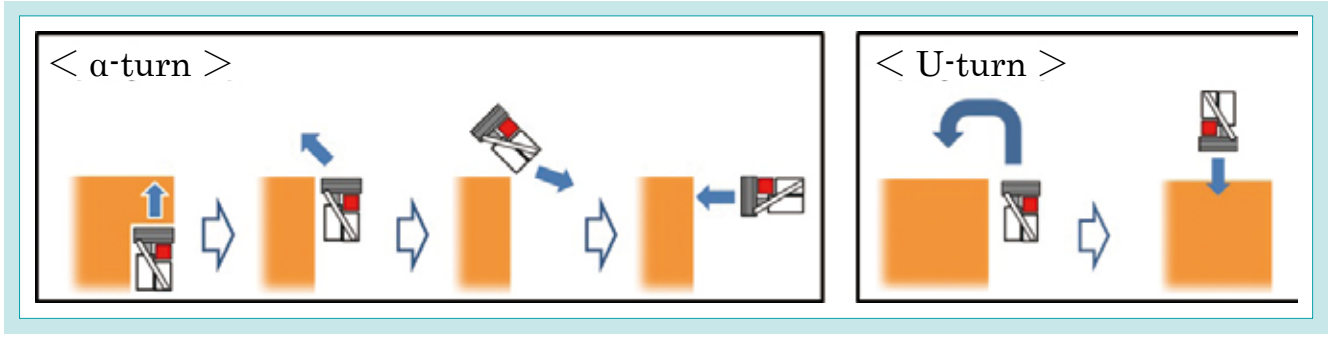

Fig. 6 α-turn and U-turn

4.1.3 Autonomous driving

When the map creation and setting are complete, the travel route is generated automatically. After that, the autonomous driving is started by simply pressing the two driving assist start switches simultaneously and putting the main shift lever to the forward side (Fig. 7).

After the autonomous driving has started, the speed adjustment, left/right steering, turning, and adjustment of the reaping part height are performed automatically. This makes it possible for the operator to concentrate on safety and monitoring the working conditions. (The speed and reaping part height can also be adjusted manually.)

Thus, the autonomous driving can be started by a simple operation, and the harvesting operation can be performed with ease.

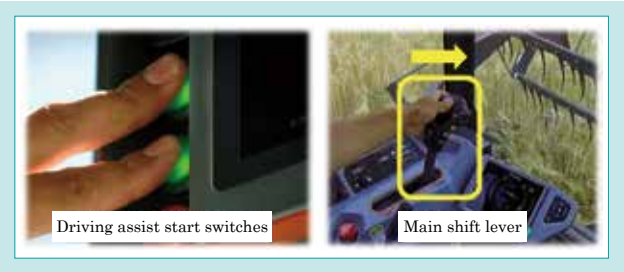

Fig. 7 Start Operation of Autonomous Driving

4-2 Autonomous travel control

4.2.1 Travel control

The travel control during autonomous driving is performed based on the location information from the RTK-GNSS. The RTK-GNSS unit (Fig. 8) mounted on this product is made by Kubota and is also used on products such as the AgriRobo Tractor. It also has an IMU (Inertial Measurement Unit) built in, so it can also obtain posture information for the combine harvester. The information output from the IMU and RTK-GNSS is combined to obtain high-precision (±2 cm to 3 cm) and high-rate location/direction information for the travel control.

During the autonomous driving, the position deviation and the azimuth deviation with respect to the target route are calculated from the current position and current azimuth of the combine harvester that are obtained (Fig. 9). The steering control is then performed so as to minimize those deviations.

If the direction of combine harvesters is corrected suddenly, then the crops will be pushed down by the side face of the reaping section and the fallen crops will remain uncut. We therefore installed control that performs automatic adjustment so that the steering command amount will not result in the crops being pushed down.

Fig. 8 RTK-GNSS Unit

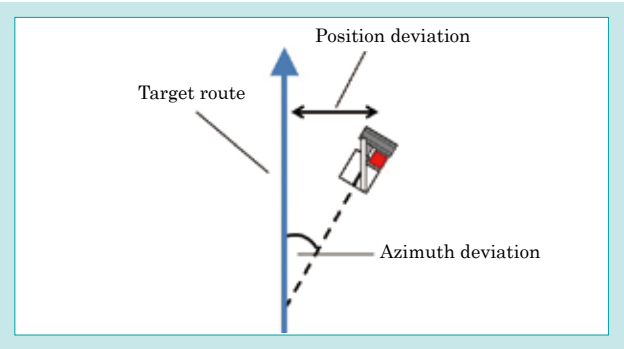

Fig. 9 Position Deviation and Azimuth Deviation

4.2.2 Turning stability

There are a wide variety of conditions such as the hardness of the field and the depth of sinking that affect the turning performance and these vary depending on the region, weather and season. Also, even within the same field, the weight of the grain tank changes depending on the cutting situation, so deviations occur in the weight balance of the combine harvester and this causes a difference in the right and left turning forces.

Therefore, even if the same travel control program is used, the vehicle may not travel accurately.

To make it possible for the turning to be performed with stable accuracy under different field conditions, we repeated actual travel tests with various field conditions and optimized the amount of the steering control for the deviation.

4-3 Optimal route

4.3.1 Travel route for each turning method

The operator selects in advance whether the turning during the autonomous driving will be α-turns or U-turns. When U-turns are selected, calculations are performed as the vehicle travels, to determine the route that will have the shortest travel distance during turning according to the area still uncut and the minimum turning radius of the combine harvester. This makes it possible to reduce the idle travel distance and perform the optimal harvesting with no waste.

Figure 10 shows a comparison of the number of turns performed when working with α-turns and with U-turns in the same field. When U-turns are used, the number of turns is half that when using α-turns, so the working time can be shortened. When we performed a comparison for a field of about 5,000 m², we confirmed that the use of U-turns could shorten the work time by about 10%.

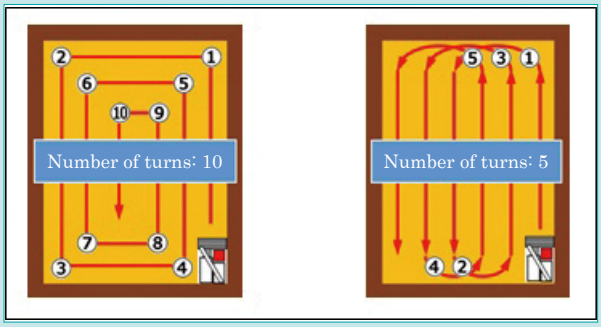

Fig. 10 Comparison of the Number of Turns

4.3.2 Automatic movement to the discharge position using yield prediction

If the tank becomes full at a place far from the grain transportation vehicle, then this causes wastefulness as the vehicle travels without performing cutting work. In order to prevent this, the weight of the tank is constantly measured by a yield sensor (Fig. 11) installed under the grain tank and the point where the tank will become full is predicted.

With the grain discharge position that was set used as the reference point, the vehicle automatically moves to the discharge position when it is judged that the tank will become full part-way around the next lap (Fig. 12).

Fig. 11 Yield Sensor

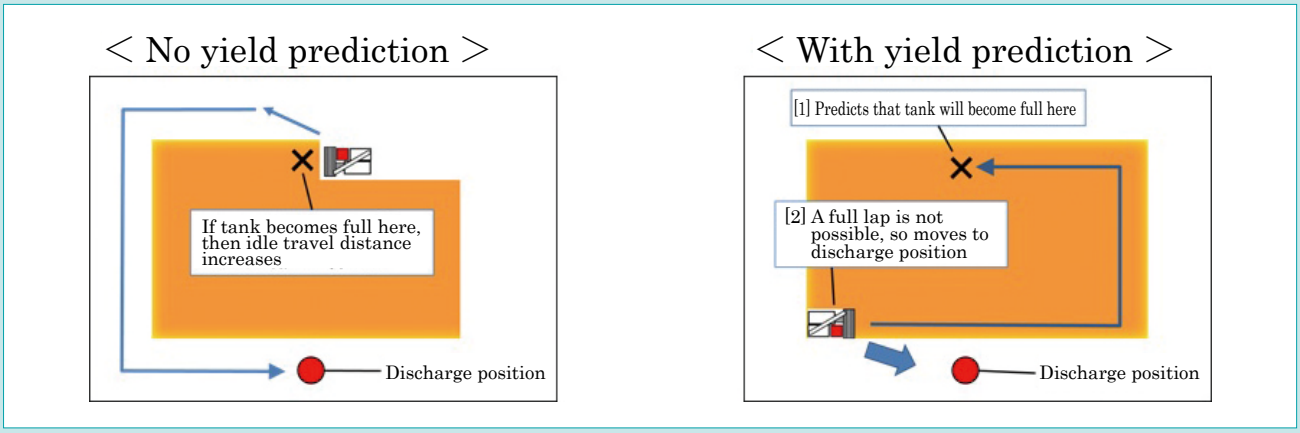

Fig. 12 Autonomous Movement to Discharge Point

5. Conclusion

We worked on this development with the concept that even if the operator was not skilled, it would be "A combine harvester that anyone can use with simple operations and with ease to achieve the optimal harvesting (artisan cutting) without waste." We have been told by users that "The work became easier." We hope that this product will contribute to the solution of the shortage of skilled workers, the reduction of the burden of harvesting work, and the expansion of the scale of operations.

On this product, the user mounts the vehicle and monitors the surrounding safety and working conditions. However, the ultimate goal is unmanned operation.

In order to ensure safety when using unmanned operation, the vehicle must stop immediately if there are any people or obstacles around the combine harvester. To achieve this, sensors to detect obstacles must be installed on the combine harvester. However, unlike a tractor or a rice transplanter, a combine harvester is a machine that performs the work in a situation where it has crops around it, so it is necessary to develop low-cost sensors that can distinguish between obstacles and crops.

In addition, the opinions of users regarding harvesting work by a combine harvester include that they want to be watching the working conditions, or that they feel uneasy if they are not watching it. There is a lot of recognition that combine harvester work may involve clogging and changes in the state of the crops to be harvested. In order to achieve unmanned operation, it will also be essential to improve the basic performance of the combine harvesters so that they can perform the harvesting work more stably.

In addition to the above, there are also various other hurdles to achieving unmanned operation. However, we will continue to work towards the practical application of unmanned combine harvesters in order to solve the major problems facing Japanese agriculture such as the drastic decrease in the number of farmers.

Contribution to SDG targets

8.2 Improvement in productivity through innovation	Contribution to the reduction of farmer labor with the first autonomous driving combine harvester in the industry
9.2 Strengthening inclusive and sustainable industrial infrastructure	Contribution to the solution of labor shortages in Japanese agriculture

Development of Diesel Rice Transplanter NW6S/8S for Domestic Market

Transplanter Engineering Dept.

In domestic agriculture, there is an ongoing process whereby farmland is being consolidated and taken over by large-scale farmers, and it is important to develop products that meet the needs of these leading farmers. Based on the concept of creating a "high-performance and high-precision rice transplanter that solves the management issues faced by farmers in charge", we have developed a product that features two major selling points: improvement in basic performance and reducing the consumption of materials. This paper describes, among the development technologies, efforts to improve Fukada's running ability, which is one of the basic requirements of a rice transplanter, and the development of the functions to “Maintain an even distance between rows” and “Maintain even fertilizer application” have been created as new selling points that lead to material savings.

【Key Word】
Ability to Run in Deep Rice Fields, Weight Saving, Material Saving, High Accuracy, Slip Compensation, Hydrostatic Transmission

Related SDGs

1. Introduction

In Japan, the consolidation of farmland under the management of professional farmers is accelerating and the development of products that meet the needs of those professional farmers is becoming more important.

The needs (management issues) of professional farmers can be roughly divided into “increasing revenue” and “reducing expenses.” The basic method to increase revenue is to expand in scale, so efforts have been made to increase the working speed and to enlarge (use multiple rows).

On the other hand, for cost reduction, there have been many approaches from the aspect of cultivation, such as sparse planting and dense seeding, but none of the manufacturers has implemented measures from the aspect of the machinery.

In response to the above, in this development we addressed the “improvement of basic performance,” which is the thing most requested by professional farmers, and also the development of a rice transplanter that contributes to “cost reduction.”

2. Development concept and goals

2-1 Development concept

The concept for this development was "A high-performance, high-precision rice transplanter to solve the management issues for professional farmers."

Based on this concept, the development focused on the improvement of basic performance and also on the reduction of expenses, which is something that has not yet attracted much attention.

2.1.1 Improvement of basic performance

In this development, we made an effort to improve the "running," "planting" and "fertilizer scattering" of rice transplanters, which are the basic aspects of their performance.

For example, for the "planting" performance, we improved the planting posture by changing the path of the planting claw and improving the sharpness of the seedling scraping part.

Also, for the "fertilizer scattering" performance, we fully reconsidered the structure of the fertilizer distributor and improved the feeding accuracy, maintainability and operability.

Efforts such as these were made to improve various aspects of the basic performance. In particular, for the "running" performance, we focused on the ability to travel through muddy rice fields and worked to reduce the weight and improve the weight balance.

2.1.2 Reduction of material costs

To create a new sales promotion point, the development also focused on materials costs (seedlings and fertilizer), which farmers have not really been aware of. We worked to reduce the number of seedlings and volume of fertilizer, which are normally prepared in quantities and amounts 10% more than in the plan.

If a farmer with an area of 20 ha could reduce the excess seedlings and fertilizer prepared from 10% to 5%, then this would save about 150,000 yen (Table 1).

The main reason for preparing extra materials is that slipping during the work causes the seedling and fertilizer consumption to vary.

In this development, we worked on the development of a "planting distance keep" function and a "fertilizer application keep" function. These functions maintain the distance between seedlings (the distance between seedlings in the direction of forward movement) and the amount of fertilizer application with high precision, even when slipping occurs.

Table 1 Material Cost Saving Effect

		Seedlings	Fertilizer	
		500 yen/tray	¥125/kg	
Planned amount		4,000 trays	800kg	Spare materials costs
Spare amount	With no Keep function <10% of planned amount>	400 trays	800kg	¥300,000
	With Keep function <5% of planned amount>	200 trays	400kg	¥150,000 (150,000 yen reduction)

2-2 Target values

To improve the running performance in muddy rice fields, the target values were set as follows.

(1) Machine body weight -50 kg
(2) Front wheel load +5%

The development targets for the reduction of materials costs were set as follows.

(1) Distance between seedlings Control so that is near to the set value
(2) Amount of fertilizer applied Control so that is near to the set value

3. Technical issues to be solved

3-1 Issues for the improvement of the running performance in muddy rice fields

In recent years, rice transplanters have been made larger, so their weight has increased.

In addition, implements that can simultaneously conduct operations such as fertilizer application, chemical application and weeding at the same time as rice transplanting have been attached on the transplanting part at the rear of the machinery. In addition to increasing the weight, this also means that the center of gravity of the machine moves towards the rear, so the weight balance has also deteriorated (Fig. 1).

In addition to causing a decrease in vehicle speed due to the increase in load torque, these changes also lead to the rear wheels sinking deeply and the machinery becoming unable to move, which causes a large work loss (Fig. 2). To improve the running performance in muddy rice fields, it is essential to reduce the weight and to improve the weight balance.

In addition, although increasing the axle output is effective for improving the running performance in muddy rice fields, there is the disadvantage that when the engine is enlarged to increase the output, the weight of the vehicle body is increased.

In this development, while increasing the size of the engine, we also made a thorough effort to reduce the weight and to improve the weight balance, to improve the running performance.

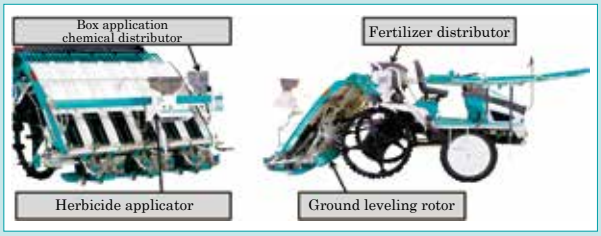

Fig. 1 Multiple Functions of Rice Transplanter

Fig. 2 Rice Transplanter that has Become Bogged Down

3-2 Issues for the reduction of materials costs

Figure 3 shows a conventional gear train. There is an input from the engine through the main HST (Hydraulic Static Transmission) to the transmission (hereinafter called the "T/M"), and then there is branching to the planting drive and the traveling drive. The vehicle speed is changed by operating the main HST with the main shift lever.

The transplanting drive is linked to the traveling drive, and it is possible to set it to different planting distances in the T/M by using the multi-stage speed change of the transplanting transmission gear. Similarly, the driving of the fertilizer distributor is also linked to the traveling drive.

In a field, the wheels of a rice transplanter slip as it moves forward. The ratio of the loss caused by slipping to the theoretical vehicle speed is called the slip ratio. The values set for the distance between the seedlings and the amount of fertilizer are designed with the slip ratio assumed to be 10%.

The slip ratio will vary depending on the soil quality and the field depth, and will also vary from place to place within the same field. When, for example, the slip ratio exceeds 10%, the distance between the planted seedlings becomes smaller than the value set. This increases the consumption of seedlings and fertilizer per unit of area. In this way, the actual amount of fertilizer applied and the distance between the planted seedlings will always vary from the set values, so farmers need to prepare extra seedlings and fertilizers compared to the plan.

In order to reduce these spare materials, we developed a technology to detect the constantly changing slip ratio and correct the reduction ratio of the transplanting and fertilizer distributor in real time.

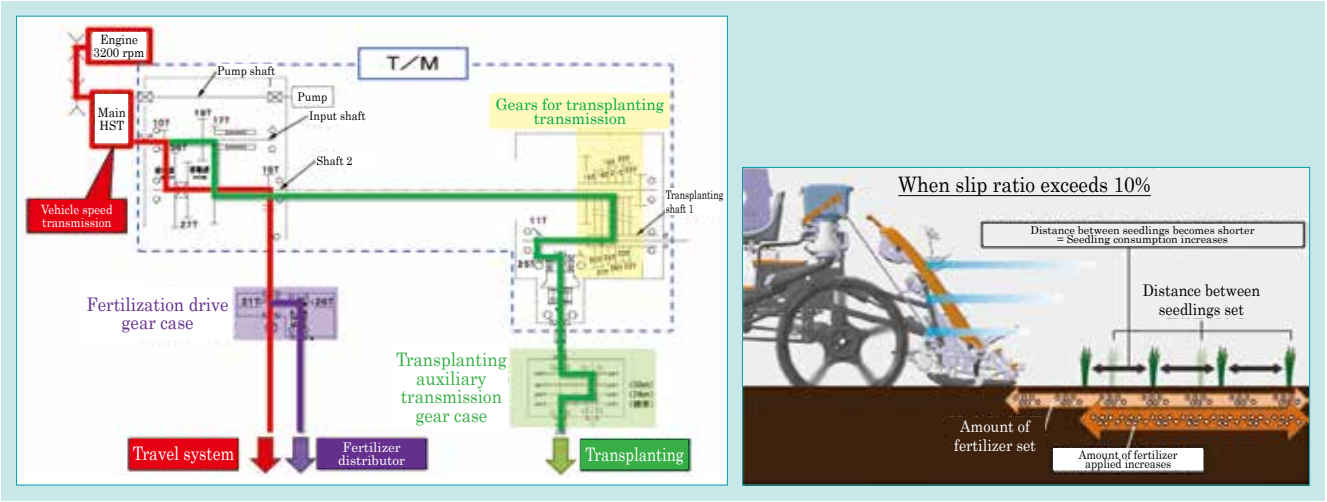

Fig. 3 Power Transmission and Issues of Conventional Machines

4. Developed technology

4-1 Weight reduction and weight balance improvement

4.1.1 Solutions

In this development, we conducted thorough weight reduction for the design of every part. The most effective of those reductions were as follows.

First, we designed a new main frame and integrated the conventional split type into one to reduce the materials required for connections. We also changed the step material from sheet metal to resin, which reduced the weight by about 20 kg (Fig. 4).

Next, for the ground leveling rotor of the transplanting part, we reconsidered the structure supporting the mud cover and achieved weight reduction by changing the material from the conventional sheet metal to resin. In addition, we changed the power take out from the conventional method of a chain case from the transplanting claw, to a take out structure using a propeller shaft from the rear axle case. This reduced the weight and also helped improve the weight balance (Fig. 5).

Also, in the development of the transmission case described later, we put the transplanting auxiliary transmission gears inside the transmission case. This eliminated the external gear case and reduced the weight.

Furthermore, the weight was also reduced by the development of the motor-driven fertilizer distributor described later, which meant that the conventional transmission system that had the power taken out from the T/M was eliminated.

These weight reductions made it possible to increase the size of the engine on the newly developed NW8S and the increased output torque made it possible to improve the running performance in muddy rice fields.

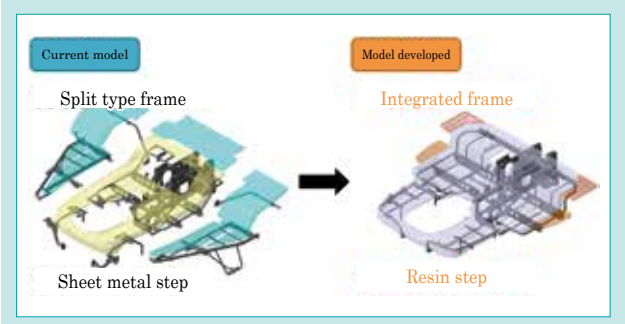

Fig. 4 Weight Saving of Main Frame and Step

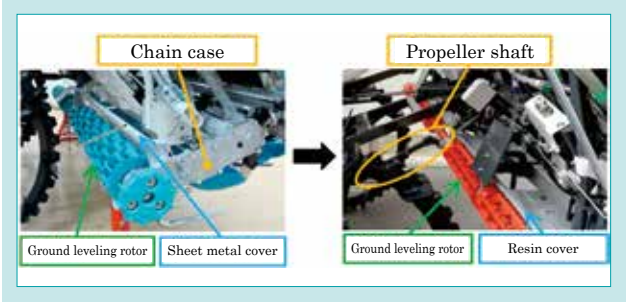

Fig. 5 Weight Saving of Planting Mechanism

4.1.2 Results

As a result of these efforts, the weight of the main machine body was reduced by approximately 50 kg from the conventional machine. Also, the improvement to the weight balance made it possible to raise the front wheel load by approximately 6%. The development targets were therefore achieved (Fig. 6).

To verify the effects, we performed tests to compare the running in actual fields. Figure 7 shows the engine speed while driving in a muddy rice field. The black line indicates the engine speed set.

The points where the rotational speed decreases during the running are where the front of the machine rises up and the load increases, so the vehicle speed decreases. It can be seen from this graph that the machine developed has improved running performance in muddy rice fields.

In the monitor tests, many users in areas with particularly wet paddy fields said that they could work without stress because there was no longer a fear of the engine stalling.

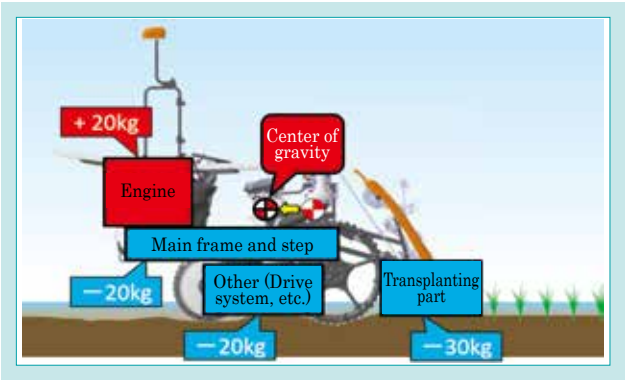

Fig. 6 Improved Weight Balance

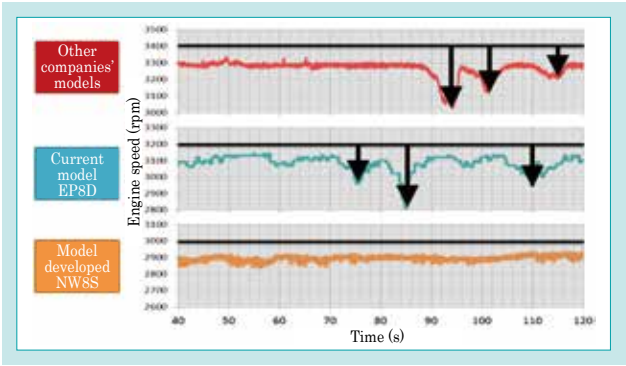

Fig. 7 Engine Speed while Driving in Deep Rice Fields

4-2 New transmission supporting slip compensation

4.2.1 Issues

(1) To enable stepless speed control of the transplanting drive with respect to the traveling system
(2) Obtaining the slip ratio
(3) Configuration in the limited space around the T/M
(4) Consideration for weight reduction

4.2.2 Solutions

(1) We abolished the multistage gears for the transplanting transmission from the T/M. As a replacement, we newly provided a dedicated HST for transplanting, positioned it on the opposite side to the main HST, and connected the output shaft of the main HST directly to the input shaft. For the speed change operation for the dedicated HST for transplanting, we created a simple structure with a motor unit that directly operates the HST (Fig. 8). With these mechanisms, a configuration was created where the transplanting drive can be controlled with continuous variable speed with respect to the traveling system.

(2) To obtain the slip ratio, we calculated the actual slip ratio from the data of the theoretical vehicle speed obtained using the axle rotation sensor provided on the rear axle and the data of the actual vehicle speed obtained using the GPS unit (Fig. 9).

(3) For the charge oil supply to the dedicated transplanting HST, we simplified the hydraulic circuit by using the return oil of the main HST, and also achieved space saving by installing an oil passage in the case, without piping (Fig. 10).

(4) In the space created by the elimination of multistage gears, we built the transplanting auxiliary transmission gears, which were previously mounted separately outside the T/M case, inside.

The result of the above was the realization of a configuration where the transplanting HST is controlled according to the slip ratio and the variation in the distance between seedlings due to slip can be corrected.

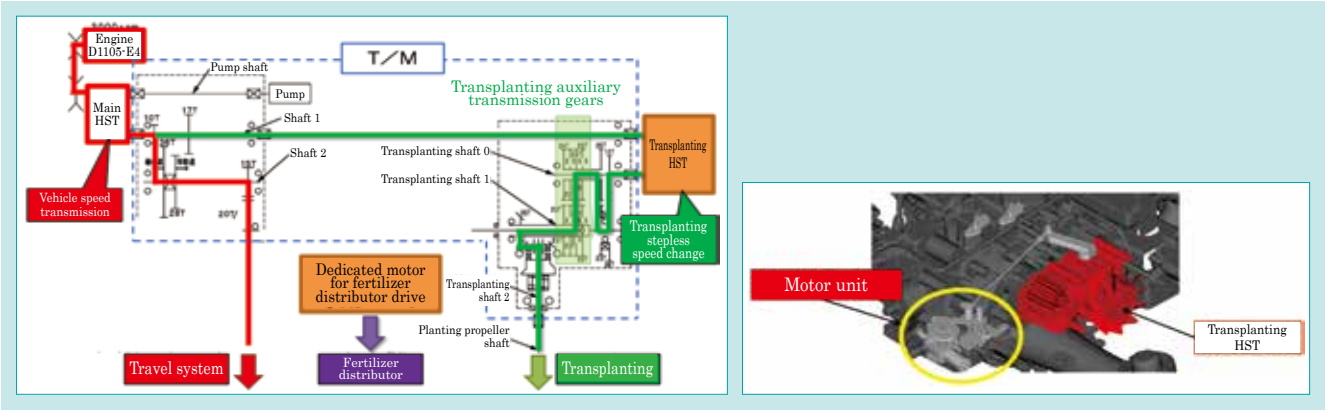

Fig. 8 Power Transmission and Planting HST Operation Unit of Developed Machine

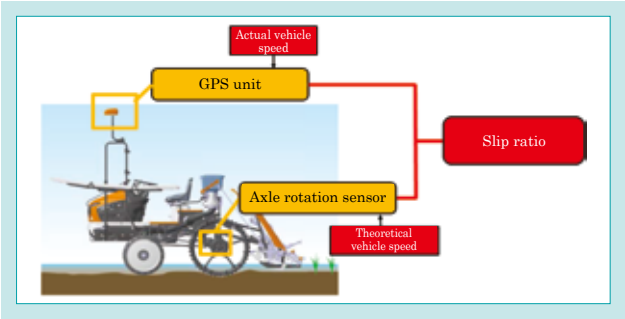

Fig. 9 Obtaining Slip Rate

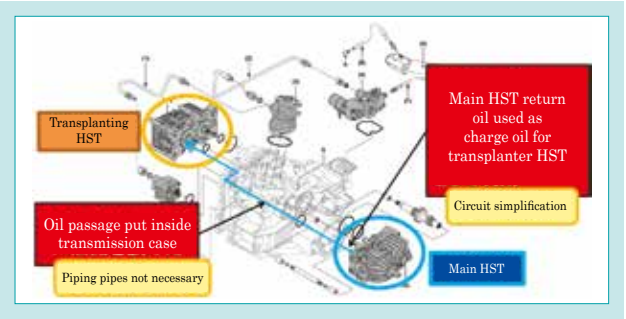

Fig. 10 Supply of Planting HST Charge Oil

4.2.3 Results

In order to verify the effects of the slip correction, we conducted transplanting tests in fields in various areas. Table 2 shows the results.

Even though the slip ratio and the distance between seedlings set varied between the regions, the results were all close to the distance between seedlings that had been set. The development targets were achieved and the new sales promotion point of the “planting distance keep” function was completed.

Table 2 Interval Measurement Results Obtained in an Actual Field

	Akita	South Korea	Hokkaido	Niigata
Soil quality	Volcanic ash	Sandy soil	Peat	Loam and clay
Depth of cultivation	12 – 17 cm	12 – 15 cm	10 – 16cm	32 – 38 cm
Slip ratio	6.9 – 14.6%	8.1 – 12.4%	4.7 – 7.9%	14.2 – 20.6%
Distance between seedlings set	21cm	18 cm	11 cm	21 cm
Distance between seedlings measured	20.4 cm	17.8 cm	11 cm	20.7 cm
Precision	2.9%	1.1%	0.9%	1.4%

4-3 New fertilizer distributor supporting slip compensation

4.3.1 Issues

(1) In addition to the slip correction, there is also the phenomenon that when the vehicle speed is increased and the rotational speed of the fertilizer distributor is increased, the rate of fertilizer filling to the feed roll groove declines and the actual amount of fertilizer applied is decreased. It is therefore necessary to correct this (Fig. 11). In other words, it is necessary to make the fertilizer distributor drive independent of the running system.

(2) If the vehicle travels while fully loaded with fertilizer, the fertilizer in the hopper is compressed and a large starting torque is required when starting feeding immediately afterwards (Fig. 12).

(3) Consideration for weight reduction

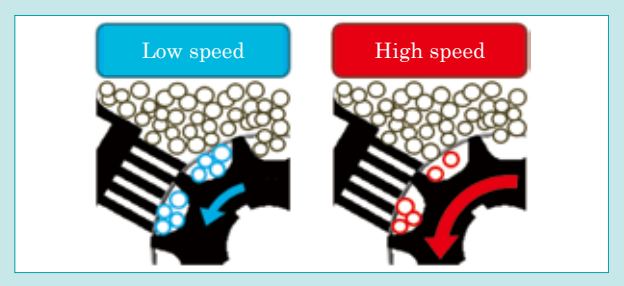

Fig. 11 Decrease in Fertilizer Filling Rate in Feeding Roll Groove

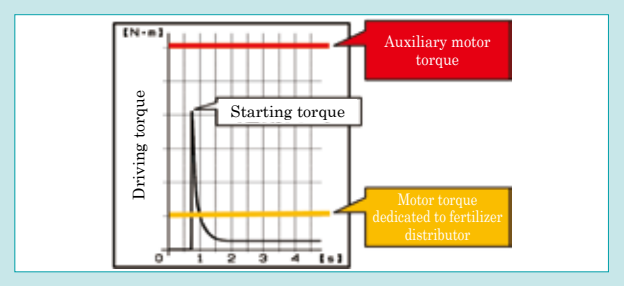

Fig. 12 Starting Torque of Fertilizer Applicator

4.3.2 Solutions

(1) We adopted a dedicated motor for the fertilizer distributor driving, to enable the correction of the slip effects and correction of the variation of the filling rate to the feed roll groove.

(2) We considered increasing the size of the motor to ensure a large starting torque, but this was difficult due to space constraints. We solved this problem by installing a separate unit on the opposite side. The unit consists of a small auxiliary motor that operates only at startup, a reduction gear and a one-way clutch (Fig. 13).

(3) By using a motor drive system, it was possible to eliminate the conventional structure of the drive system, in which power was taken out from the traveling system. This led to a reduction in weight and decreased costs.

As a result of the above, we completed a fertilizer distributor system that can adapt to changes in the slip ratio and in the vehicle speed.

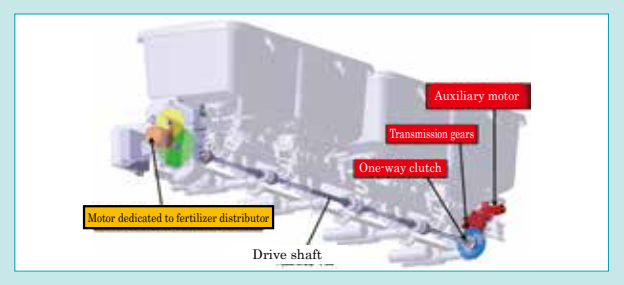

Fig. 13 Auxiliary Motor

4.3.3 Results

In order to verify the effects of the correction, we conducted transplanting tests in actual fields. The fertilizer used was a local one. Table 3 shows the results.

Even though the slip ratio, the amount of fertilizer set and the vehicle speed varied between the fields, the results were all close to the values that had been set. The development targets were achieved and the new sales promotion point of the "fertilizer application keep" function was completed.

Table 3 Measurement Results of Fertilizer Application in an Actual Field

Field	A	B	C	D	E	F	G	H	I	J	K
Fertilizer amount set [kg/10 a]	20	20	40	40	40	40	40	40	40	40	40
Actual fertilizer amount [kg/10 a]	20.5	20.2	40.2	39.9	40.1	39.5	40.2	40.7	40.0	39.2	39.6
Precision	2.4%	0.8%	0.6%	−0.3%	0.3%	−1.2%	0.4%	1.8%	0.0%	−2.0%	−0.9%

5. Conclusion

In this development, we did not simply improve the basic performance to respond to the demands of professional farmers, we also created entirely new technology that contributes to cost reduction.

From now on, we will use this technology as a base to work on themes such as smart agriculture and unmanned vehicles. We will also promote integration with ICT technologies such as KSAS to create new added value.

Contribution to SDG targets

2.3 Increasing agricultural productivity and income	Contribution to higher income for farmers with technology to reduce materials costs for seedlings and fertilizer
2.4 Realization of sustainable and robust agriculture	Contribution to improved rice transplanting efficiency by improving the running performance in muddy rice fields
8.2 Improvement in productivity through innovation	Contribution to increased productivity by establishing technology for more precise seedling and fertilizer consumption

Development of RTV-XG850 Hi-speed Petrol-powered Model

Utility Vehicle Engineering Dept.

The market volume in North America for utility vehicles has doubled from about 240 000 units in 2010 to about 490 000 units in 2018. The utility vehicle market is dominated by high-speed petrol-powered vehicles that are used not only on work sites but also for leisure activities. To expand its business, a decision was made for Kubota to enter the high-speed utility vehicle market. Therefore, in 2018, we released the RTV-XG850 into the high-speed petrol-powered utility vehicle market. This paper describes the following three technical development features of the RTV-XG850. 1) Emission certification with the vehicle (CARB/EPA, FTP-75(b) MODE) that was first trialled for KBT. 2) Electric power steering system for safer handling and good maneuverability. 3) Disk brake system with a strong braking force and high durability.

【Key Word】
Utility Vehicle, High-speed Petrol-powered Market, Electric Power Steering System, Disk Brake System, Emission Certification with the Vehicle, CARB/EPA FTP 75(b)MODE

Related SDGs

1. Introduction

Utility vehicles (hereinafter called “UV”) are multipurpose transportation vehicles that are used as a means of getting around and transporting goods for farmers, for patrols of factories and construction sites, and for leisure activities (Fig. 1). The main market for UV is the North American market. The scale of that market grew from approximately 240,000 vehicles to 490,000 vehicles between 2010 and 20181). The driver of that growth is the market for high-speed gasoline UV, which have a maximum speed that exceeds 40 km/h. These are the main vehicle used for both work and leisure applications.

Since the launch of the RTV900 in 2004, Kubota's UV business has maintained about a 40% share in the market for work sites, with what are called Pure Utility Vehicles (hereinafter called “PUV”). These have a maximum speed of 40 km/h or less and are mainly used for work. All of the products in the current lineup from Kubota are classified into the PUV category. Roughly 80% of the vehicles sold are models equipped with a diesel engine and Variable Hydraulic Transmission (hereinafter called “VHT”).

Fig. 1 Utility Vehicle

From 2013 to 2015, Kubota launched four models in the RTV-X Series, which are a full model change with the diesel and VHT specifications. These are maintaining the market share in the PUV market. However, although the UV market is continuing to grow, the growth of the PUV market has been small. This meant that full-scale entry into the high-speed gasoline UV market was necessary in order to expand the UV business.

2. Development concept and goals

2-1 Development concept

We developed the RTV-XG850 vehicle as the fastest of the Kubota products, in order to expand the Kubota UV business with a product for the high-speed gasoline UV market where we have not entered yet (Fig. 2). Kubota worked on product development in accordance with the laws, regulations and standards for high-speed gasoline UVs and with the concept of ensuring the "reliability and durability" that the customers expect of Kubota products.

Fig. 2 RTV-XG850

2-2 Target values

1) Acquisition of vehicle exhaust gas certification in compliance with U.S. exhaust gas regulations (CARB/EPA, FTP-75(b) MODE certification)
2) Securing of excellent steering stability at high speeds
3) A braking device that can be used safely in any environment

We set the three points above as the development targets and aimed to achieve the development concept described above.

3. Technical issues to be solved

1) Acquisition of vehicle exhaust gas certification

As the maximum vehicle speed is 40 km/h or more, the U.S. exhaust emission regulations mean that the certification to be obtained is not for the engine alone. It is necessary to obtain vehicle exhaust gas certification (CARB/EPA, FTP-75(b) MODE certification) for the entire vehicle (Fig. 3). This was the first time that Kubota was attempting to acquire this vehicle exhaust gas certification. In addition, it was also necessary to optimize the layout of the exhaust system on the vehicle body for the compliance. This was different from the conventional gasoline engine models which had certification for the engine alone.

2) Securing of excellent steering stability at high speeds

With the "fully hydraulic power steering system" used in the RTV-X Series and the "manual steering system" used in the RTV400 and 500 series, there are cases when steering force is determined irrespective of the vehicle speed, and cases where the steering force may become excessive under certain conditions. As a result, these would display unstable steering stability performance during high-speed driving. It was therefore necessary to adopt a new steering system in order to secure excellent steering stability at high speeds to satisfy the market demands.

3) A braking device that can be used safely in any environment

As a UV is not only used on asphalt paved roads, but also on unpaved and rough areas such as farms and pastures,there are demands for high durability performance for the whole vehicle. For brake pads, which are generally handled as consumable parts, the demands in recent years have been for durability equivalent to that on automobiles. The improvement of durability performance was therefore an important technical issue. However, early wear of the brake pads occurred when we checked the pad durability when driving on unpaved, uneven ground with brake pads for which the durability performance had been secured on asphalt paved roads. It was therefore necessary to solve this issue.

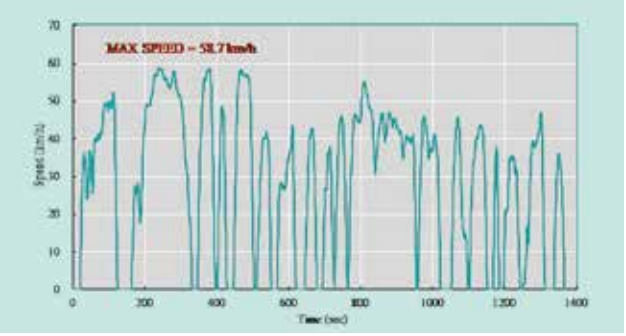

Fig. 3 FTP-75(b)MODE

4. Developed technology

4-1 Optimization of the exhaust system layout on the vehicle body

In order to comply with vehicle exhaust gas certification, parts such as a three-way catalyst and an O2 sensor were newly adopted on the exhaust path. We implemented the following measures to make these new parts function effectively and obtained the certification.

[1] Optimization of the exhaust pipe length
[2] Three-way catalyst placement to suppress cost increases
[3] A design that considers heat shielding and heat insulation to suppress costs

In [1], we adopted a layout with an 800 mm independent section from the exhaust port to the point where the exhaust pipe converges (Fig. 4). This was in order to avoid a lowering of the exhaust efficiency due to exhaust interference and to increase the torque in the low engine speed range.

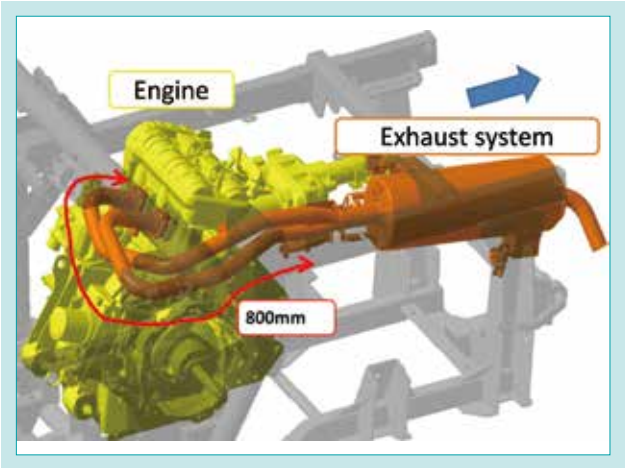

Fig. 4 Exhaust Pipe Layout

In [2], we placed the three-way catalyst in the muffler after the exhaust pipe merging and therefore avoided the cost increase that would result for the separate mounting of the catalyst and the muffler (Fig. 5).

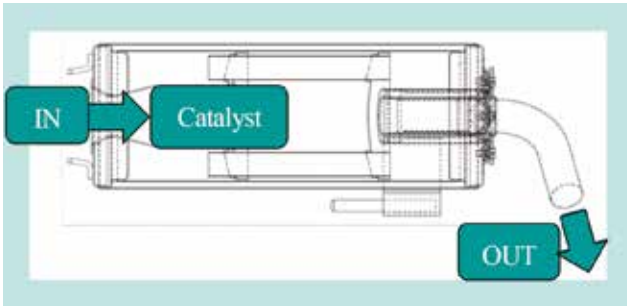

Fig. 5 Three-way Catalyst Layout

In [3], in order for the three-way catalyst to decompose the harmful components in the exhaust gas in a catalytic reaction, it is necessary to keep the catalyst surface at 300°C or higher. For this reason, it is necessary to have a heat shielding structure to prevent a drop in temperature along the path from the engine exhaust port to the three-way catalyst inside the muffler.

In order to secure the length of the independent section of the exhaust pipe as described above, it becomes necessary for the exhaust pipe section to have a complicated shape with three-dimensional bending. A heat shielding cover mounted directly on the exhaust pipe would therefore have a complicated shape, which would result in high costs.

Instead of attaching the heat shield plate directly to the exhaust path, we used the method of attaching the heat shield plate to the vehicle body frame, with a clearance to the exhaust pipe (Fig. 6). This avoided the cost increase and secured the temperature for catalytic activity. In addition, to maintain the temperature for catalytic activity, we built glass wool into the muffler barrel to enhance the heat shielding and heat insulation effects (Fig. 7).

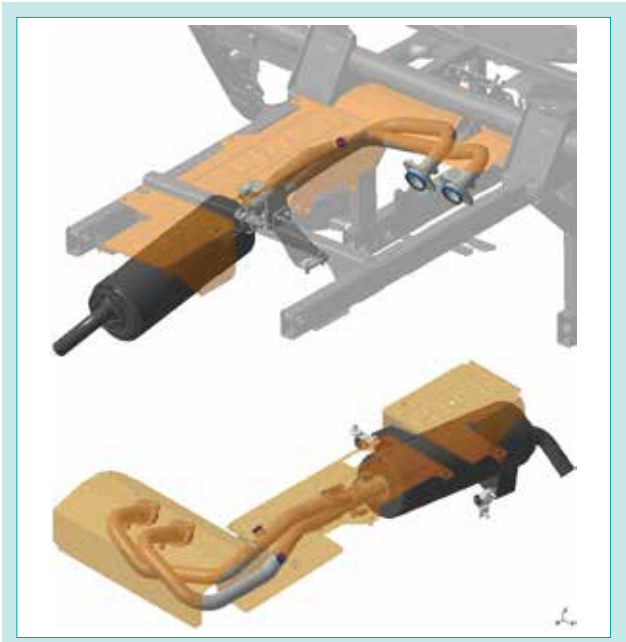

Fig. 6 Heat Shield Layout

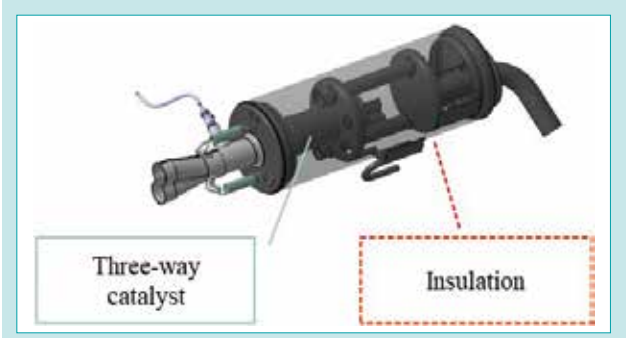

Fig. 7 Insulation Layout Inside the Muffler

4-2 Adoption and optimization of electric power steering system

4.2.1 The current system and its issues

The "fully hydraulic power steering system" used in the RTV-X Series and other products is a hydraulic assist system in which oil at a constant pressure is constantly supplied to the steering unit by a gear pump attached to the engine. In this system, when the steering is operated, oil corresponding to the amount of rotation is sent to the steering cylinder to move the tires rotationally.

The "manual steering system" adopted in RTV400 and 500 is a system in which the steering is mechanically connected via a shaft to a gearbox on which a rack and pinion is mounted. In this system, the tires are moved rotationally according to the steering amount.

The "fully hydraulic power steering system" makes light steering possible due to the strong assistance from the hydraulic pressure. This means that the vehicle can be easily operated, even if it is heavily loaded. However, as the force pushing the steering cylinder is caused by the pump pressure, it is not easy to adjust the steering torque to suit the vehicle speed. Even when traveling at a high speed, the steering force is the same as that in low-speed travel, which makes fine adjustment difficult.

In the "manual steering system," the tires and the steering are connected mechanically, so the condition of the road surface is transmitted well to the driver and the driver gets the feeling that he/she is performing the steering.

4.2.2 Optimization of an electric power steering system

We newly selected a "vehicle speed sensitive type electric power steering system" that has an assist mechanism installed on a manual steering system and electronic control to change the assist amount according to the vehicle speed (Fig. 9). We then optimized the assist amount control map to improve the steering stability performance to deal with the higher speed.

For the assist amount control map, the following two types of control map adaptations were performed.

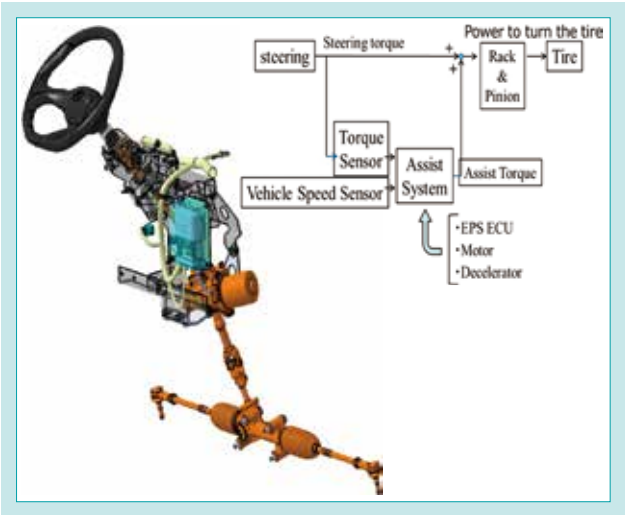

Fig. 9 Electric Power Steering System

However, the absence of the assist mechanism means that the steering torque easily increases and the steering becomes extremely heavy at a very low speed. As a result of the above, neither steering system meets the requirements for the high-speed type UV market. In order to realize steering stability performance that would be trusted by users as a Kubota product, it was necessary to use a new steering system that includes the advantages of both a "fully hydraulic power steering system" and a "manual steering system."

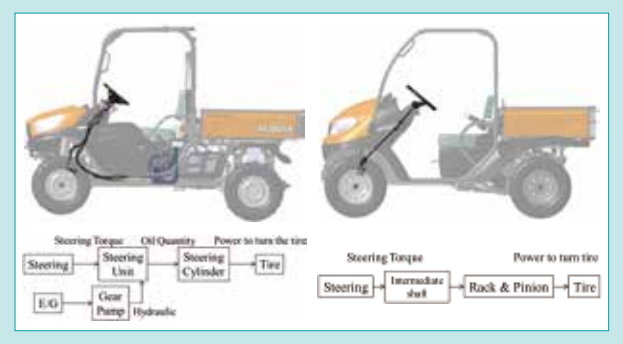

Fig. 8 Current System

[1] Base assist map: Control map adaptation that determines the motor basic assist current according to the vehicle speed and input torque

[2] Damping control map: Control map adaptation that divides the steering speed into the three levels of low speed, medium speed and high speed, and reduces the assist current according to the level

As a result of the adaptation in [1] and [2], the relationship of the steering torque for each vehicle speed and steering speed became as shown in Figure 10. The steering torque increases as the vehicle speed and the steering speed increase, so this realized steering stability performance that can suppress sudden steering and can support higher speed travel.

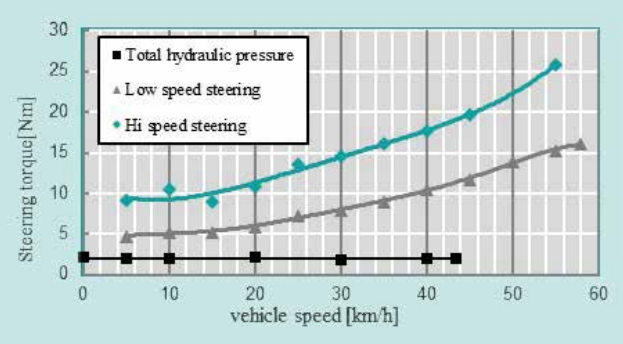

Fig. 10 Steering Torque Result for Each Vehicle Speed and Steering Speed

4-3 Dry disk brake performance development

4.3.1 Premature pad wear when traveling on rough ground

Problem analysis

As the problem did not occur when traveling on paved roads and only occurred when traveling on rough ground, it was presumed that the cause was something peculiar to rough ground. When brake pads that had early wear were checked, the following characteristics were confirmed (Fig. 11).

- A large amount of earth and sand had accumulated between the pad materials
- Scratches on the pad surface

Fig. 11 Mud Sediment Pad

From these characteristics, we assumed that muddy water and soil had been scattered on the brake disk during travel on a muddy wet road, which is a condition peculiar to travel on rough ground, and that this muddy water and soil had then penetrated between the brake disks and the pads and accelerated the wear. We therefore performed a visual check of the flow of muddy water around the disks and calipers on an actual vehicle during travel on a muddy wet road. As a result, it was found that muddy water was scraped up by the wheel and scattered onto the disks and calipers, and that this led to soil and sand infiltration (Fig. 12).

Fig. 12 Muddy Water Flow

4.3.2 Countermeasure [1]:

New installation of a watertight disk cover

We believed that the problem would be improved by preventing the mud and soil that infiltrates inside during travel on a muddy wet road, so we newly installed a cover inside the brake disk that was shaped so as to cover the disk. As a result, it was possible to reduce the infiltration of the mud and soil scraped up during travel on muddy wet ground, and the amount of brake pad wear was improved by 8.3% (Fig. 13).

Fig. 13 Disk Cover Layout

4.3.3 Countermeasure [2]:

Development of new brake pad material resistant to soil and sand wear

We conducted evaluations on several kinds of brake pads and it became clear that differences in the brake pad materials affect the amount of wear. We surmised that the cause of this was the differences in the types and amounts of the component ingredients of the pad materials. We therefore used energy dispersive X-ray analysis to investigate the relationship between the types and amounts of the component ingredients of the pad materials and the resistance to wear from mud and soil.

As a result, Cu was found to be the effective ingredient against wear from mud and soil and by optimizing the content of that ingredient, it was possible to achieve a 32.9% improvement in the resistance of the brake pads to wear from mud and soil.

5. Conclusion

In order to obtain vehicle exhaust gas certification (CARB/EPA, FTP-75(b) MODE certification) for the first time for Kubota, we worked to optimize the exhaust system layout on the vehicle body, which is different from that on conventional gasoline models, and obtained the certification. We succeeded in the development of the RTVXG850 high-speed gasoline UV as the fastest model among the Kubota products and achieved entry into the high-speed gasoline UV market in 2018.

The concept stated for this development was to secure the "reliability and durability" that the customers expect of Kubota products. For the steering stability aspect of this, we newly adopted a vehicle speed sensitive type electric power steering system which includes the advantages of both a fully hydraulic power steering system and a manual steering system. The steering stability performance necessary to support higher speeds was realized through the adaptation of the assist amount control map.

For the braking performance aspect, the target was to be able to control the vehicle safely and securely in all operating conditions and to have durability performance that allows continuing use in any environment. This target performance was achieved by installing a new waterproofing disk cover and optimizing the brake pad material component content.

The RTV-XG850 developed this time was based on the RTV-X Series and only a two-seat vehicle was launched on the market. However, in addition to two-seat vehicles, there have been many different models developed for the high-speed gasoline UV market, such as ones with three seats and ones with two rows of seats. There are also many models in the higher speed range. As product development becomes necessary in the future, we will use the technology developed this time as a foundation for further technology development, to contribute to global agriculture with the aim of becoming the global major brand Kubota.

Contribution to SDG targets

2.3 Increasing agricultural productivity and income	Productivity is improved with a 60% faster top speed than on conventional models
11.3 Strengthening of inclusive and sustainable housing planning and management capabilities	Contribution to the development of the agricultural and livestock industries in more than 50 regions of North America and Oceania

Reference

1) Power Products Marketing UV 2017

Development of Sugarcane Leaf Remover SLR110H

KUBOTA Research & Development Asia Co.,Ltd.

Sugarcane is one of the major crops in Asian countries. The sugarcane harvesters currently being used in the agricultural sector are imported from Europe; however, they are not popular because of high yield loss and a high degree of leaf contamination. Moreover, these machines are also expensive. Therefore, most harvesting (around 83%) is still done by hand and before harvesting the sugarcane leaves are removed by burning. But burning not only affects the farmer's income from yield loss and reductions in the selling price, but it also causes the problem of air pollution (PM2.5). This has become such a serious problem in Thailand that the government has announced a "zero burn" policy to combat pollution.

Therefore, Kubota Research and Development Asia (KRDA) has developed SLR110H to support the "zero burn" policy and help save the environment. Now, the sales volume of SLR110H is increasing steadily and we expect to export to every country throughout Asia.

【Keyword】
Sugarcane Leaf Remover, Roller, Trimmer

Related SDGs

1. Introduction

World sugarcane production has been rising continuously from 1796 to 1919 million tons and estimated to reach 2034 million tons in 2023. Thailand sugarcane production has also been rising from 101 to 111 million tons repeatedly and expected to be reach 120 million tons in 2023 (Fig.1).

Currently, sugarcane harvesting in Thailand mostly harvested by human labor that is a very hard work. To reduce harvesting difficulty, the most popular process is burning sugarcane to remove leaves before harvesting.

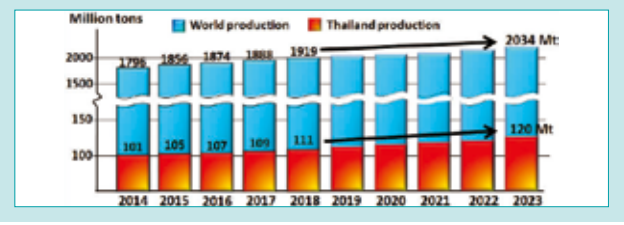

Fig. 1 Global and Thailand Sugarcane Production

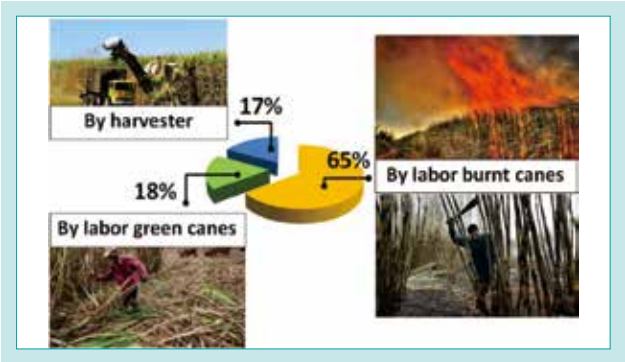

Fig. 2 Sugarcane Harvesting Process

The impacts of each method of harvesting in Thailand are as follows (Fig. 2);

1) Harvesting the burnt sugarcane by human labor 65%
   - Hard work, air pollution, high contamination of leaves, yield loss and selling price deducted.
2) Harvesting the fresh sugarcane by human labor 18%
   - Hard work, unable to be finished in season due to low working capacity
3) Harvesting by harvester machine 17%
   - High yield loss, high contamination of leaves, high machine price (unaffordable)

In conclusion, each of the sugarcane harvesting processes should considered about how to “Save Environment”, “Maintain Sugarcane Yield and Quality" and “increasing Working Capacity” respectively.

To Save Environment, maintain Sugarcane Yield and Quality, we aim to terminate harvesting method both 'harvesting the burnt sugarcane by human labor' and 'harvesting by machine'. To achieve these target, harvesting the fresh sugarcane by human labor is the best solution. Therefore we have to develop sugarcane leaf removing machine to change hard work into light work, to increase working capacity. Then finally, the overall concerning difficulties can be resolved.

2. Development Concept and Target Value

2-1 Development Concept

SLR110H was developed by KRDA to match with B-series tractor which is the only series that can be used as an inter-row maintenance work in the sugarcane field.

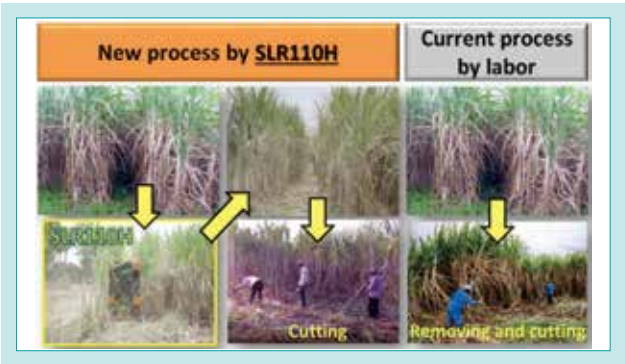

Fig. 3 Development Concept

Main objective of SLR110H is to be used instead of manual leaves removing by labor in pre-harvesting process in Fig.3.

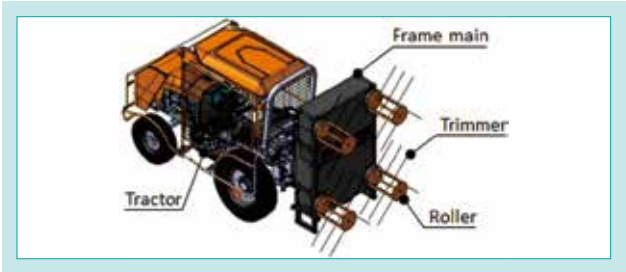

Fig. 4 Overall Structure of SLR110H

Overall structure of SLR110H as shown in Fig. 4 by main structure of SLR110H consist of main Frame, Roller and Trimmer. Breaking leaves by use rotating trimmer.

2-2 Target Value

KRDA have developed SLR110H for Kubota tractor with 3 target values as below.

2.2.1) Must be able to remove leaves to create enough labor’s working area to cut sugarcane. Design Target : achieve required working area ≥ 100%.

2.2.2) Must be able to breaking leaves by rotating trimmer. Design Target : trimmer's impulse force > required breaking leaves force.

2.2.3) Must be able to complete sugarcane leaves removing along the row by rotating trimmer.

SLR110H works inter rows of sugarcanes to remove leaves as shown in Fig. 5.

Fig. 5 Typical Working View of SLR110H

3. Technical challenge to be solved

In order to achieve high quality leaves removing target. First, create layout of Roller and Trimmer to get leaves removing area more than labor's working area when harvest green sugarcanes. (Fig.6)

Fig. 6 Adequate Removing Area

Second, to find breaking leaves force at each sugarcane height, and then select Roller and Trimmer specification.

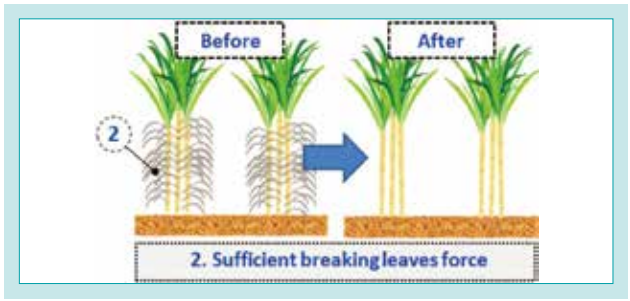

Fig. 7 Sufficient Breaking Leaves

Target is SLR110H must be able to generate impulse force more than maximum breaking leaves force. (Fig.7)

Third, the big challenge is SLR100H must be able to completely remove leaves along the sugarcane row. So, we consider kinematic models of trimmer. Key factors to achieve zero gaps are tractor velocity, trimmer revolution, trimmer width, number of trimmer in each section and number of trimmers' section. (Fig.8)

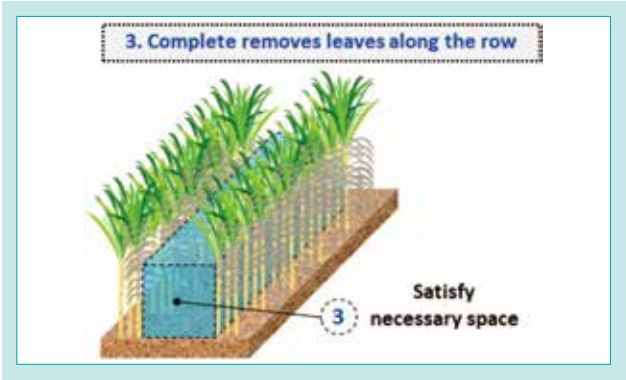

Fig. 8 Completely Removes Leaves Along the Row

4. Developed Technology

4-1 Adequate removing area development

The first technology, Leaf removing structures are consisting of Roller and Trimmer. Its removes leaves from sugarcane by using rotating roller with trimmer to hit the leaves. Then, removing area is the sweeping area of trimmers. (Fig.9)

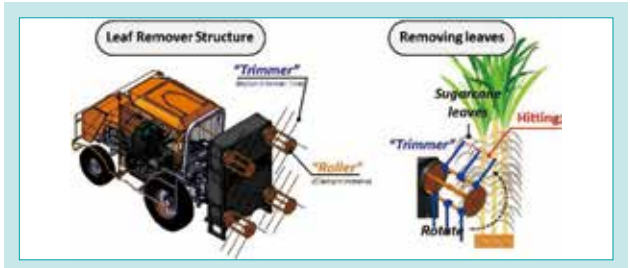

Fig. 9 Diagram Showing Leaf Removal

Next, design the roller diameter to prevent sugarcane leaves wrap around the roller by using Eq. [1]

Roller circumference = $2\P(D/2) > L_{max}$ Eq.[1]

From research, we can find maximum sugarcane leaf length L_{max}. So, we will know minimum roller diameter.

From maximum width of B-series tractor, If we create 4 rollers at minimum diameter. Removing area of trimmer are incomplete removing area and can't be achieved the target. because of the limitation of trimmer hitting together.

To solve this problem, we create new technology called "Zig-Zag" design by arranging 'overlap trimmer line' at the intersection of diagonal to Maximize extension length. Finally, we can increase leaves removing area and achieve customer requirement as shown in Fig.10.

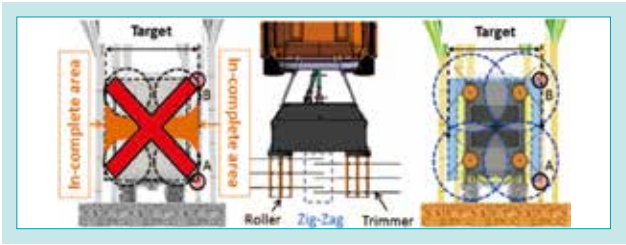

Fig. 10 Layout of Zig-zag Trimmer Design

4-2 Sufficient breaking leaves revolution

From model: Impulse force (F) > Breaking leaf force (f)
Impulse force (F) was generated by trimmer and Breaking leaf force (f) is the force that can separate leaf from sugarcane. We calculate impulse force (F) from Eq. [2].

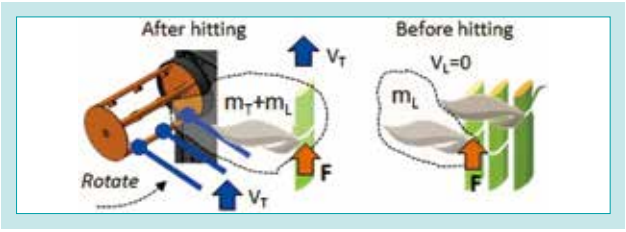

Fig. 11 Free Body Diagram of Force Required

$$F = (m_T + m_L) V_T - (m_L) V_L / \Delta t \quad \text{... Eq.[2]}$$

F = impulse force from trimmer
m_T = trimmer mass , m_L = leaf mass , Δt = time
V_T = trimmer velocity, V_L = initial leaf velocity
From Free body diagram of trimmer (Fig.11, 12).
We can find V_T trimmer velocity from Eq. [3].

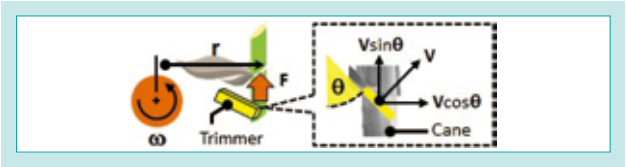

Fig. 12 Free Body Diagram of Trimmer Velocity

$$V_T = V \sin\theta = \omega \cdot r \cdot \sin\theta \quad \text{... Eq. [3]}$$

ω = roller revolution, r = hitting radius, θ = hitting angle
Compound Eq. [2] with Eq. [3]. We can find the minimum roller revolution as Eq. [4]

$$\omega = (F \Delta t) / \{ (m_T + m_L) r \cdot \sin\theta \} \quad \text{...Eq.[4]}$$

The model: Impulse force (F) > Breaking leaves force (f)
From Thai Agricultural Research Journal 2016, breaking leaves force at each sugarcane height is shown on Fig.13.

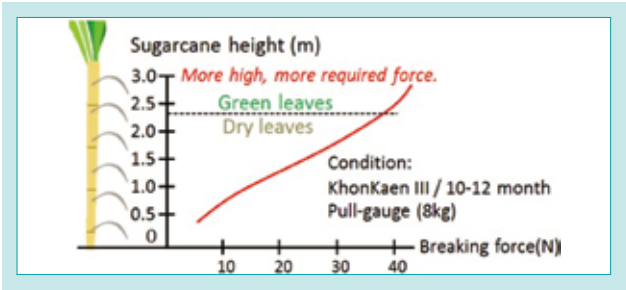

Fig. 13 Relationship Between Breaking Force and Sugarcane Height

Then, apply breaking leaf force (f) into (F) in Eq. [4]. We can find the minimum roller revolution at the upper roller as shown on Fig.14.

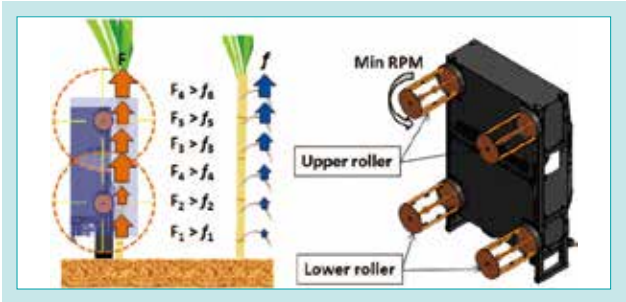

Fig. 14 Free Body Diagram & Roller Revolution Table

Finally, we design transmission system (Fig. 15) by using the suitable size of pulley. It can generate force which more than target and sufficient for breaking leaves all of sugarcane height.

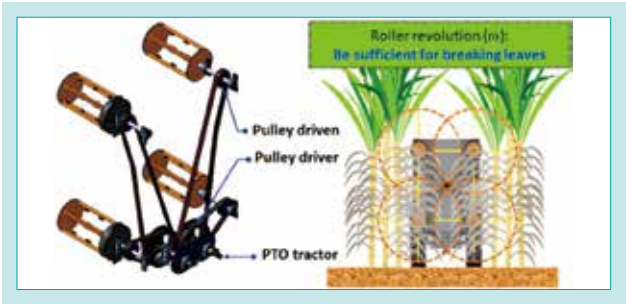

Fig. 15 Transmission with Sufficient Breaking Force

4-3 Complete removing leaves along the row

Consider kinematics model of leaves removing by using one trimmer. Then, we found tip gap as shown in Fig.16

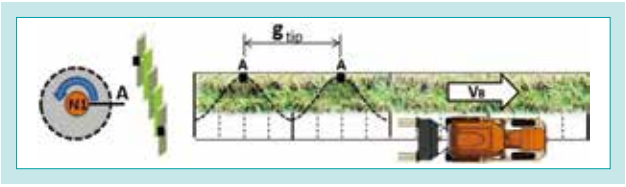

Fig. 16 Kinematics Model of 1 Trimmer

We calculate tip gap from Eq. [5]

$$g_{tip} = \text{Tip gap (mm/turn)} = V_B(1/\omega) \quad \text{...Eq. [5]}$$

g_{tip} = Tip gap, V_B = tractor velocity, ω = roller revolution
Then consider kinematics model of leaves removing by using four trimmers. Tip gap are as shown in Fig.17.

Fig. 17 Kinematics Model of 4 Trimmers

By using four trimmers, we still cannot fulfill tip gap. So, we also consider number of roller section. Hitting position of each trimmer is depending on pitch between sections (P) as shown in Fig. 18.

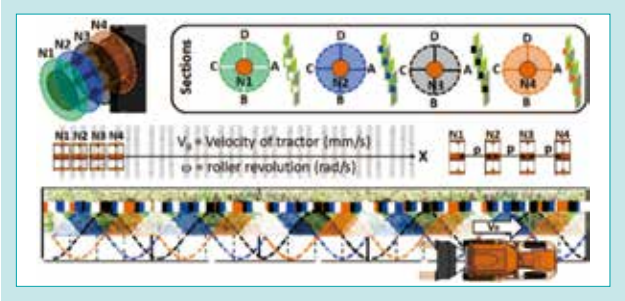

Fig. 18 Kinematics Model of 4 Trimmers & 4 Sections

$X_{N1} = VB(1/\omega) \cdot turn$ …Eq. [6]
$X_{N2} = VB(1/\omega) \cdot turn+p$ …Eq. [7]
$X_{N3} = VB(1/\omega) \cdot turn+2p$ …Eq. [8]
$X_{N4} = VB(1/\omega) \cdot turn+3p$ …Eq. [9]

Gap fulfillment model:

$Gap(g) = V_B(1/\omega) - \{W_{N1}\}\text{-}\{W_{N2}\}\text{-}\{W_{N3}\}\text{-}\ldots$ Eq. [10]

V_B = tractor velocity

W_N = removing width per turn

Consider sizes of trimmer and clamp trimmer in Fig. 19.

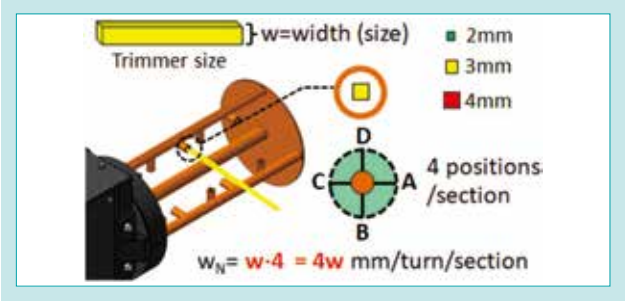

Fig. 19 Trimmer Layout

Next, we find perfect pitch between sections (P) that fill more gap and do not duplicated by use equation Eq. [11].

If pitch design is bad, trimmer will repeat at the same point of others.

$P = \{(1/(4N)) + (I/4)\} \cdot g_{tip}$ …Eq. [11]

The result of gap percentage is shown in Fig. 20. We selected roller 3 and 4 sections which can make zero gap with trimmer all sizes.

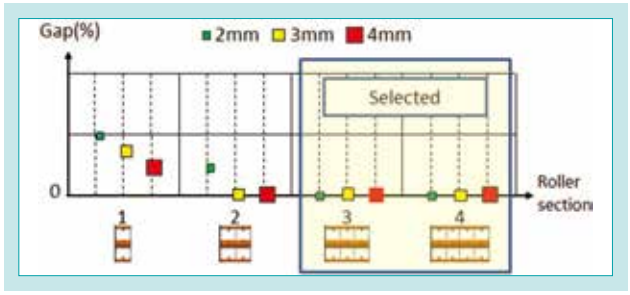

Fig. 20 Gap Results

Moreover, we consider belt slip and trimmer damage. Found roller 3 sections with trimmer 2 mm don't pass target of gap overlap.

We choose the best design by compare total power consumption from removing power consumption and Drag power consumption in Eq. [12], Eq. [13] & Eq. [14]

$Power_R = \int F\, dR \cdot \omega \cdot k_1 k_2$ … Eq. [12]
$Power_D = (1/2)\rho \cdot V^3 \cdot A \cdot C_d$ … Eq. [13]
$Power_{Total} = Power_R + Power_D$ … Eq. [14]

F = breaking leaves force, ω = roller revolution
k_1 = leaves quantity factor
k_2 = hitting sugarcane factor
ρ = air density, V = trimmer velocity
A = total area of trimmer, C_d = drag coefficient

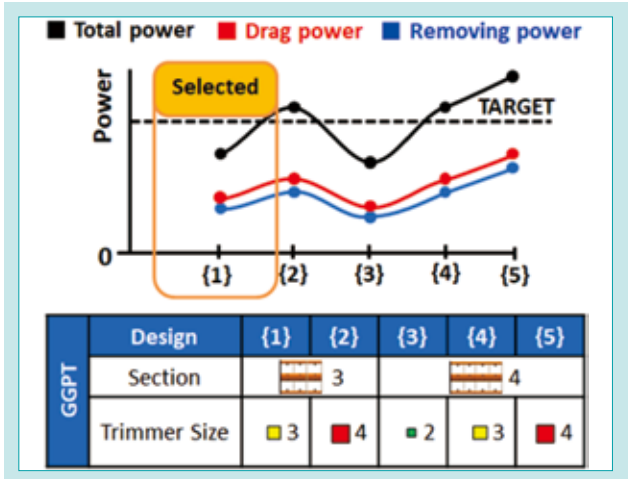

Fig. 21 Comparison of Total Operating Power and Roller Design

By these equations, we can find total power consumption of each design {1} – {5}. And compare results with our target as shown in Fig. 21. Finally, we select design {1} that are 3 sections, trimmer width 3 mm because of less consumption and less cost.

5. Conclusion

5-1 Evaluation of product

5.1.1) Adequate removing area development: from designed layout of roller and trimmer line by use zig-zag type.

5.1.2) Sufficient breaking leaves revolution: from designed minimum revolution must be enough to break leaves.

5.1.3) Complete removing along the row: consider kinematics model of removing, gap fulfillment and design the best trimmer size and number of roller section.

From this product evaluation, SLR110H achieved all targets as shown in Table 1.

Table 1 Product Evaluation

Items	Result	Evaluate (Target > 100%)
Adequate removing area development	162%	●
Sufficient breaking leaves revolution	105%	●
Complete removing along the row	149%	●

5-2 Effect to business

SLR110H start sale on Dec 2018. The achievement of this development will contribute the expansion of Siam Kubota Corporation Co., Ltd. (SKC) implement and tractor business in sugarcane crop as show on Fig. 22.

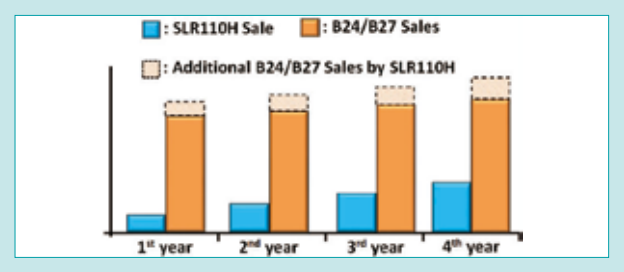

Fig. 22 Sales Volume of SLR110H and Tractor

5-3 Next activity

To study the benefit of SLR110H used in maintenance phase with the sugarcane aged around 7-8 months by 10 field experiment test compared the yield with no use of SLR110H. It is found that the productivity was increased in all fields as shown on Fig. 23. This is because there are better air flow between leaves and sun light intensive on to the sugarcane. Moreover some of insects between leaves and sugarcane could be reduced.

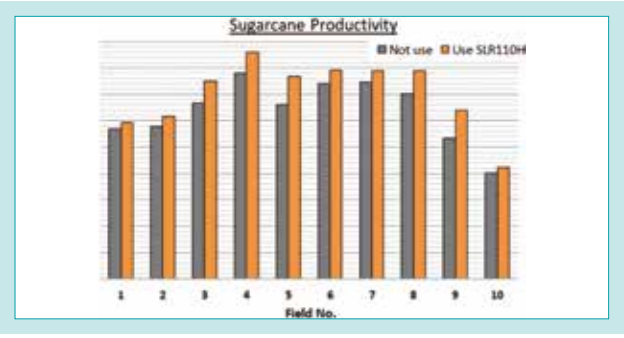

Fig. 23 Sugarcane Productivity After Use in Maintenance Phase

Contribution to SDG Targets

2.3 Increasing agricultural productivity and income	Removing leaves instead of burning increases yields more than 10% and makes better sugarcane price for Thai's farmer.
8.8 Promote safe and secure working environments	Contribution to reduce burning in sugarcane industry that one of major cause PM2.5 air-pollution in Thailand

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Development of High Capacity Pneumatic Seed Delivery System

Great Plains Manufacturing, GP Engineering

The mechanization of global agriculture has increased competition in the marketplace, and as a result more efficient and productive technologies are needed. Higher planting speeds improve efficiency but require more capacity from pneumatic seed delivery systems. Planting while the planter is turning using conventional drive technologies causes incorrect plant spacing as the outside rows of the planter travel a larger distance than the inside rows. The Great Plains PL5000 series of planters incorporate numerous developments that improve user efficiency and yields. The pneumatic seed delivery system was designed to increase the maximum planting speeds and crop types that it will support. The seed meter drive controller provides turn compensation with automatic adjustments across the planter width to maintain correct plant spacing whether near the center or outside of the turning radius.

【Keyword】
Pneumatic Seed Delivery, Turn Compensation, Planter, Precision Drill, Computational Fluid Dynamics

Related SDGs

1. Introduction

Commodity grain farming is a very competitive business requiring high efficiency and economically productive yields. Farmers have used larger equipment to increase efficiency, and manufacturers have offered planters (precision drills) up to 37m in size. Limitations in cost, weight, horsepower requirements, field efficiency and transport requirements have more recently caused engineers to design equipment to operate faster in smaller sizes as an alternative method to gain efficiency. This requires seed meters, seed delivery and seed placement mechanisms to operate at higher outputs to support the raised speeds. Additionally, the accuracy of metering seeds has been improved with enhanced mechanical designs. Adding electronic controls and drive motors has allowed additional improvements in accuracy by allowing individual row meters to be regulated rather than having all rows operating at the same RPM as happens with linked mechanical or wide section electric drives. Figures 1 and 2 below show two examples of the new PL5000 series planters with new seed delivery and meter drive controls.

Fig. 1 PL5500 Planter 6 m Wide

Fig. 2 PL5700 Planter 12 m Wide

2. R&D Concept and Target Value

2-1 R&D Concept

The new PL5000 series planters have many areas of technical focus in their developments including improved seed meters, new electronic controls software and user interface, variable rate fertilizer with section control, pneumatic seed delivery system, seed meter drive system, multi-function hydraulic circuits, transport dimensions and more. Two areas are being separated here for this report due to space restrictions, the pneumatic seed delivery system and the seed meter drive and control system. The pneumatic seed delivery system improvement concept was to increase the overall capacity of the system for higher planting speeds and to increase the robustness of the system in difficult conditions and with difficult crops. The seed meter drive and control concept was to provide a robust, high torque capacity electric drive with a standardized commonly understood control protocol. It also includes operational features including turn compensation to maintain correct plant spacing while planting in curves or following contours along with advanced onboard diagnostics to aid support technicians. The concept supplies a scalable solution applicable from the smallest to the largest planter models in the product family, able to operate with as few as 4 rows and as many as 48 rows while maintain the full set of operating functions.

2-2 Target Value

The objective for the pneumatic seed delivery system was to deliver core crops of corn, soybeans and sunflowers along with additional more difficult crops including edible beans, canola, sweet corn, cotton and others at rates and speeds exceeding current requirements. The target for soybeans was a rate of 450,000 seeds per hectare at 17 kph during continuous operation at 100% duty cycle. Corn for grain and sweet corn had targets of 75,000 seeds per hectare at 16 kph, while crops such as sunflowers, grain sorghum, cotton and other crops had similar target rates established for them. The objective for the meter drive and control system was to support a wide variety of seeds and rates, deliver accuracy equal to or better than current systems, and deliver accurate rates while planting contours and curves. In additional it needed to have a robust drive motor able to operate with a variety of seeds in difficult conditions reliably for 10 years or more of use. The control system needed a simple interface to exchange information easily between suppliers and also be scalable to cover the wide range of planter offerings without loss of performance.

3. Technical Challenge to be Solved

Technical challenges to be solved included effectively doubling the capacity of the pneumatic seed delivery system without significantly increasing the input hydraulic power requirements. Tractors used on these systems produce hydraulic oil flows up to 225 lpm (liters per minute) and pressures of 20.7 Mpa. This oil serves multiple functions with a maximum of 98 lpm at 19.7 Mpa designated to operate the pneumatic delivery system. The seed delivery system has to supply seed ranging in size from canola to large corn/maize and edible beans, and at rates from 1.7 – 90 kg/Ha at planting speeds up to 17 kph.

The seed meter drive system must drive the meters accurately without affecting the seed singulation performance which is required to be 99 % accurate or better in maize, usually performing at 99.5 % accuracy. The seed spacing needs to be kept consistent whether planting in straight lines or in curves. Motor power consumption has to be kept to a minimum in order to expand the system to operate at least 48 seed meters independently to achieve the desired level of control. The large number of motors possible combined with the amount of data in use requires a control system that is able to operate efficiently in order to be compatible and interface with ISO11783 standardized virtual terminals across multiple types of tractors.

4. Developed Technology

4-1 Pneumatic Seed Delivery

4.1.1 Technical Challenge

The pneumatic seed delivery system operates as an on-demand airflow operated self-regulating system which supplies seed from one central hopper to meters across the planter as needed. It does this using air only without the use of additional meters or mechanisms to regulate seed flow from the storage hopper. Older model planters had a similar system that was designed for rates that were 50 – 60 % of what was needed for the new models. In order to achieve the new target rates of seed supply with the seed delivery system, the efficiency of all sub segments of the system was addressed. The air supply to the system, the seed hopper, the seed pickup aerator, the delivery conduits and the seed receptacle inlets at the meters were all studied for improvements.

4.1.2 Solution of Challenge

The seed delivery system was modelled in CFD (Computational Fluid Dynamics) software to examine overall effectiveness. For example, Figure 3 is a plot of the air velocity within the seed aerator assembly CFD model. Figure 6 shows a top view of an air velocity plot of the entire system. The seed aerator is at the center, top of the image and the discharge conduits that deliver seed to each separate meter are below. The results of CFD study showed that decreasing the primary delivery conduit from 38 mm to 32 mm would decrease the amount of seed in transit between the storage hopper and the meters at the planting units. This decreased the air required to deliver the seed while making the system more responsive to seed requirements. The conduit routing away from the seed aerator was changed to eliminate 35 cm of vertical climb for the seed.

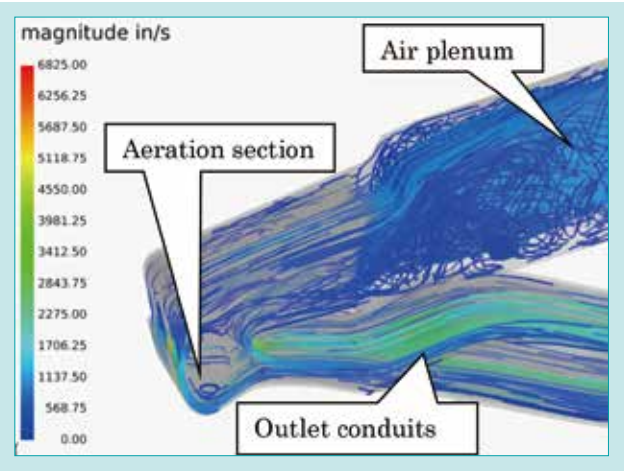

Fig. 3 Air Velocity Seed Aerator CFD Model

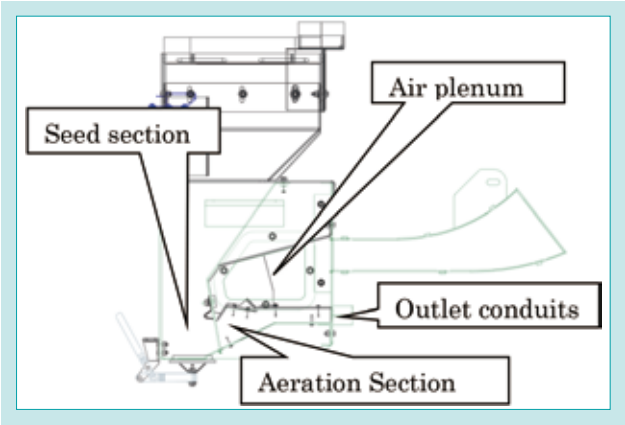

Fig. 4 Cross Section of Previous Aerator

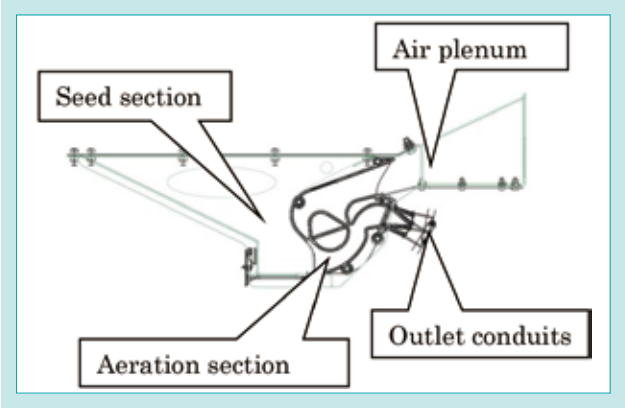

Fig. 5 Cross Section of Improved Aerator

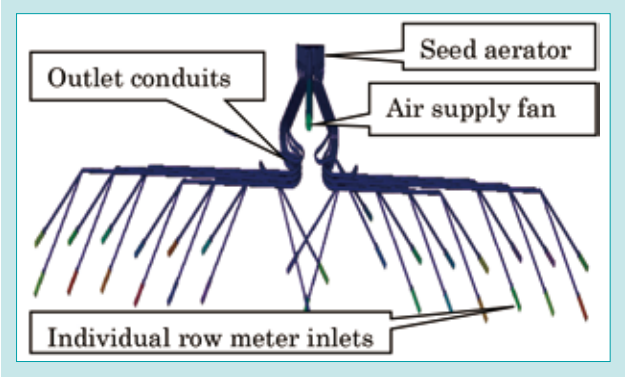

Fig. 6 Air Velocity Seed Delivery System

After some effort, we were unable to achieve accurate modelling of the seed aerator device with entrained individual seeds using CFD software. We resorted to visual analysis and physical measurements to develop improved solutions. A lab model utilizing a clear support structure was then created to simulate field operation of the system. The model included full scale components for seed conduits and operating meters at the discharge outlet. The system output was measured by A) Seed delivery rate, B: Failures to start seed delivery, C: Total amount of seed in transit between hopper and meter, D: Uniformity of seed flow over time, E: Air consumption. The system was also video recorded to allow slow motion analysis to aid development. Figure 7 shows portions of the aerator segment with red colored corn seed to the left and the aeration section to the right of the seed. Shape optimization of the aeration section was conducted and 3-D printed pieces were placed in the simulator and evaluated. The object was to maximize A and D while minimizing B, C and E. The lab results of the best versions were validated using full scale testing and were proved to correlate accurately. Figures 4 (before) and 5 (after) show the changes developed in the aerator.

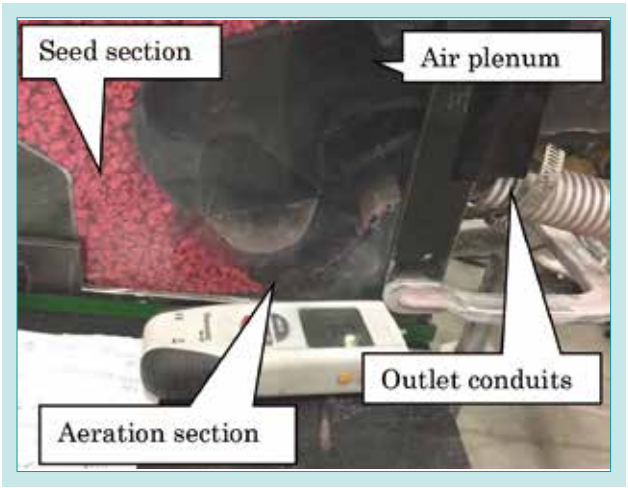

Fig. 7 Actual Lab Prototype of Seed Aerator

4-2 Seed Meter Drive System

4.2.1 Technical Challenge

The seed meter drive system must be accurate, provide uniform spacing in curves as well as straight lines, be robust and be scalable to fit many different size models. Standard communication protocol and ease of service features were also required.

4.2.2 Solution of Challenge

Accuracy of the seed meter is a critical performance parameter, measured in seed singulation and in seed spacing. In corn, the 5000 series seed meters deliver singulation of 99.5 % and places 85 % of seeds within 5 % of target spacing location. The electric meter drive and control system had to maintain that

level of accuracy during startup or high and low speed operation and whether operating in a straight line or in curves. Traditional drive systems operate multiple meters at one common speed, either by mechanical linkage or by control systems that operate based on one speed signal across a broad section of the planter. When planting on curves this results in the rows near the center of the arc planting too many seeds, and the rows away from the center of the arc planting too few seeds. In the sharpest expected turns (defined as mid-frame turn radius = 100% of planter width) the inner rows will overplant 100% and the outer rows will underplant by 50%. To overcome this problem the 5000 series planter control each meter independently and use curve compensation algorithms. The planter is equipped with one RADAR or Hall Effect speed sensor near each end of the planter (Figure 8). The location of the sensor is a parameter recorded in the software during assembly of the planter and can vary based on the planter configuration. The location of each meter on the planter frame is calculated based on the row spacing, quantity of rows and row number parameters. The speed signal from each sensor compared to its location on the planter swath is then used to compute a local, Curve Compensated forward speed for each meter based on its location on the frame. This compensated local forward speed is used in combination with the planter target population, seed disc seeds/revolution and row spacing for that meter location to compute a desired meter RPM for each meter. The control system then regulates each motor independently to achieve the desired RPM to maintain the correct spacing. Figure 9 shows the effect on individual seed spacing with and without curve compensated metering.

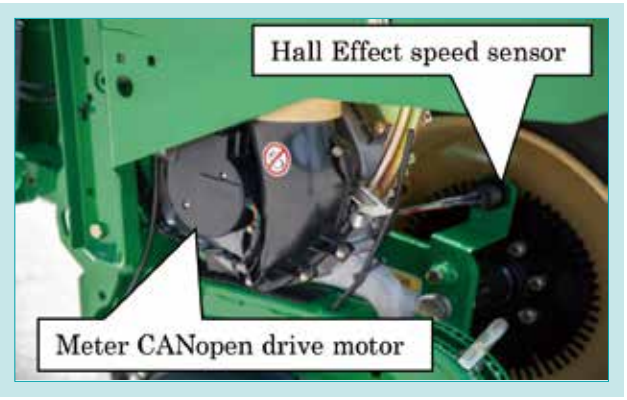

Fig. 8 Electronic Drive and Speed Sensor

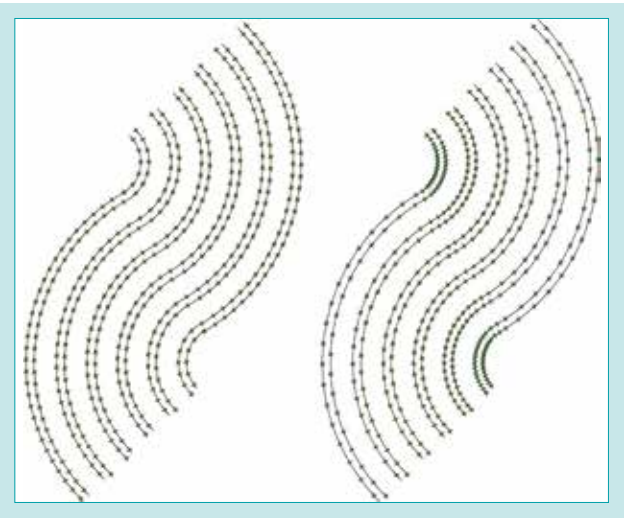

Fig. 9 Seed Spacing in Curves With and Without Curve Compensation

4-3 Motor Control Scaling and Power

4.3.1 Technical Challenge

The Great Plains planters range in size from 4 rows with 4 meters up to 48 rows with 48 meters. They utilize data intensive features including row by row RPM and population control, swath mapping and overplant avoidance, mapping of the material (seed and fertilizer) as applied to the field, meter seed singulation, seed spacing and quality index monitoring, motor voltage, temperature, RPM and other parameter monitoring. Due to the amount of data traditional ISO11783 networks were unable to support the larger sizes. In addition, the power requirements to operate the larger sizes are higher than the ISO standard cables were able to carry.

4.3.2 Solution to Challenge

The solution was to add a secondary slave CAN (Controller Area Network) system and power supply to the controls system. The second network uses CANopen protocol to control the motors, monitors meter performance and supports the ground speed sensors used for curve compensation calculations. The secondary CAN features modular controls that operate and monitor two rows each with a slave ECU (Electronic Control Unit) based on instructions from the central main ECU. Slave ECUs can be added as needed to operate smaller or larger planters.

Seed will occasionally have foreign material and broken pieces of seed in it. This material can get between the seed disc and the meter housing or get stuck in the seed disc air holes that hold the seed in

place for metering. When it sticks in the air holes the meter can skip a seed at that location every time the disc rotates. If it gets between the disc and the housing it can generate friction and increase the torque required from the drive motor. Competitive drive systems sense the increased torque requirement at a low level and react by stopping the disc and reversing it slightly, attempting to dislodge the foreign material. This cycle is repeated a few times until the material is discharged or the motor enters overload. While this is happening, the farmer is continuing to travel forward and thus will have a skip in the planted field with no seeds in that row. The solution came in three parts. Figures 10 and 11 shows the design incorporates a cleaning edge along the outer periphery of the seed disk. This edge intercepts foreign material between the outside of the seed disc and the housing and has a geometry that guides material away from the disc and discharges it into the seed delivery tube and to the soil. The second part of the solution is cleaning brush that rubs the seed disc air holes to dislodge material that is stuck in the holes. This brush clears debris from the air holes and discharges it to the ground. The final part of the solution is a CANopen drive motor (Figure 8) with torque capacity sufficient to keep turning when any remaining foreign material is passing through the meter up to a non-damaging threshold value. To determine the desired torque specification a test apparatus was built to measure meter loads. The measurement was done with a strain gauge on a torque arm holding a drive motor operating the meter, as well as by measuring the current, voltage and RPM of the drive motor. The meter was then operated with clean seed to determine the basic operating load and progressively more contaminated seed until component damage would occur. It was found that normal operating loads were approximately 1.69 Nm while damaging loads did not occur until 33.0 Nm. Motor specification was set at nominal operating torque requirement of 3.4 Nm at 99.9% cycles and 20 Nm at 0.01% cycles.

Fig. 10 Seed Meter with Improved Cleanout

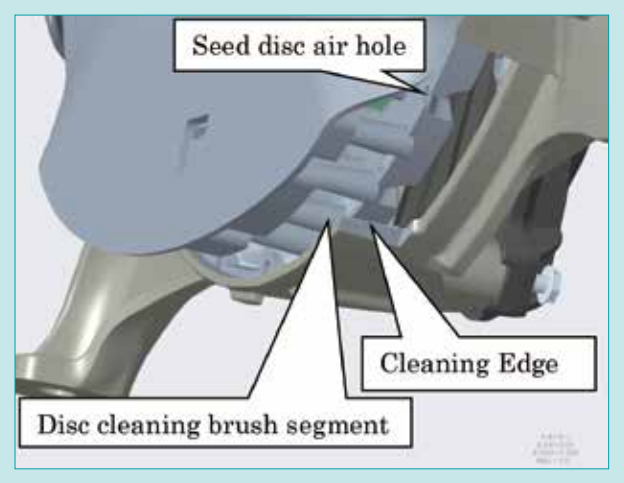

Fig. 11 Detail of Self Cleaning Area

5. Conclusion

Adding curve compensation adjustment to the seed meters drive increases accuracy of meeting desired population and plant spacing. The effect varies by the amount of curves the farmer has in their field and by the sharpness of the curves. It can range from correcting a 100 % error to zero effect in completely straight rows.

The seed delivery system changes met 100% of target objectives. In field testing growers were able to increase field speeds by 45% in soybeans. Sweet corn growers were able to increase speeds by 80% and plant some varieties that could not be delivered with pneumatic seed delivery systems in the past.

Contribution to SDG Targets

2.3 Increasing agricultural productivity and income	Contribution to increased productivity through increased speed and allowing more crop to be planted during optimum days.
8.2 improvement in productivity through innovation	Contribution to improving crop quality by improving planting accuracy through turning correction.

Development of CRS-ECU

Engine Engineering Dept.

Recently, industrial diesel engines are required not only to deliver lower fuel consumption, but also to meet emission regulations and a range of customer demands. CRS-ECUs have become a more important factor to increase the value of the engine itself because applying advanced electronic control techniques with CRS has almost become indispensable for meeting these requirements. However, conventional development of CRS-ECUs is too costly because there are some issues with their hardware and software architectures. Hence, we have to establish a more efficient process to maintain our market competitiveness. In order to resolve these problems, we developed new CRS-ECUs.

【Key Word】
ECU, Common Rail System, Model-based Development, AUTOSAR

Related SDGs

1. Introduction

In recent years, the exhaust emission regulations for industrial diesel engines have been rapidly strengthened. For example, Figure 1 shows the exhaust emission regulations for industrial diesel engines (56 kW - 75 kW) set by the EPA (U.S. Environmental Protection Agency)[1]. In the Final Tier 4 (regulations enforced in 2015), the emissions of nitrogen oxides and hydrocarbons are limited to about 1/8 those in the Tier 3 (regulations enforced in 2007) and emissions of PM (fine particulate matter), which causes black smoke, are limited to about 1/20. In addition to these United States regulations given as an example, other countries around the world have also strengthened their regulations, particularly the developed countries, and this trend is expected to continue. In particular, as diesel engines in the high-power range place a larger burden on the environment, there are stricter regulation values set for them and more advanced technical measures are required to comply with the regulations. As a result, it is effectively impossible to use the conventional mechanical control methods to comply with the exhaust emission regulations in developed countries for the high-power range.

Therefore, in order to clear the strict exhaust emission regulations in developed countries, it is essential to apply electronic control technology. Of the technology available, the main technology installed on diesel engines is the CRS (Common Rail System). CRS is one of the electronically controlled fuel injection control mechanisms for diesel engines. It enables the precise control of the fuel injection timing and injection pressure, and of the fuel injection frequency per cylinder. This control makes it possible to greatly improve the fuel consumption and exhaust gas performance. Furthermore, a CRS not only includes the fuel injection control mechanisms such as fuel injectors and fuel pumps, but also electronic control devices such as DPF (Diesel Particulate Filter) and urea SCR (Selective Catalytic Reduction) systems have been newly added in connection with the tightening of exhaust emission regulations, so this is making the systems more complex. These changes have meant that the control software for diesel engines has become increasingly large-scale and complex, and the electronic control unit for the CRS, the CRS-ECU (Electronic Control Unit), has become an important factor in the raising of the commercial value of engines.

In addition to the use of Kubota diesel engines on in-house agricultural machinery and construction machinery, they are also used on an OEM (Original Equipment Manufacturing) basis by various manufacturers of industrial machinery all around the world (Fig. 2). The way that the engine is used and the environment of use differ greatly between applications, so after meeting the various requirements of the customers, it is also necessary to satisfy the exhaust emission regulations of the various countries and regions of use. To respond to this, Kubota releases individual software for each of the installed applications and tunes the control parameters for each destination. Control logic is also added or changed as necessary. Kubota has led the market for industrial diesel engines by providing a detailed response to such customer demands. However, on the other hand, a vast number of varieties of the CRS-ECU control software have been created. As of October 2019, Kubota had released more than 1,000 types of CRS-ECU software. The number of newly released control software types is increasing year by year and the construction of an efficient control software development system is strongly required in engine development.

As described above, there has been a rapid increase in the CRS-ECU development load in the development of diesel engines. If the conventional development environment is used, then it is expected that it will become difficult to respond to the various customer demands and to keep up with the increasingly sophisticated electronic control technology. The preparation of a quicker and more flexible CRS-ECU development system will be essential if we are to maintain the competitiveness of Kubota engines in the market from now on. We therefore developed a new CRS-ECU in order to reform the development environment for electronically controlled engines.

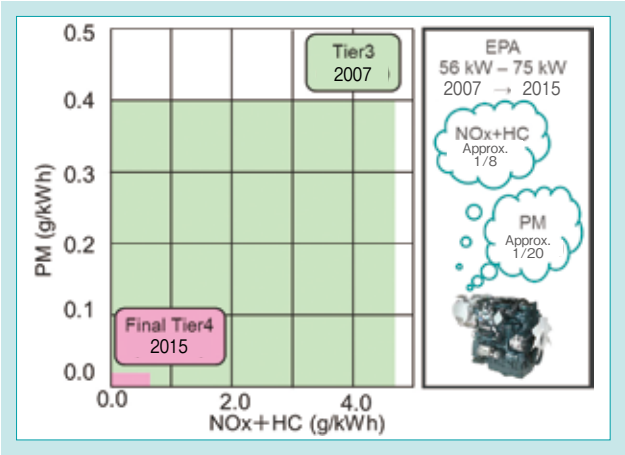

Fig. 1 Exhaust Gas Restriction for Non-Road Engine in the U.S.

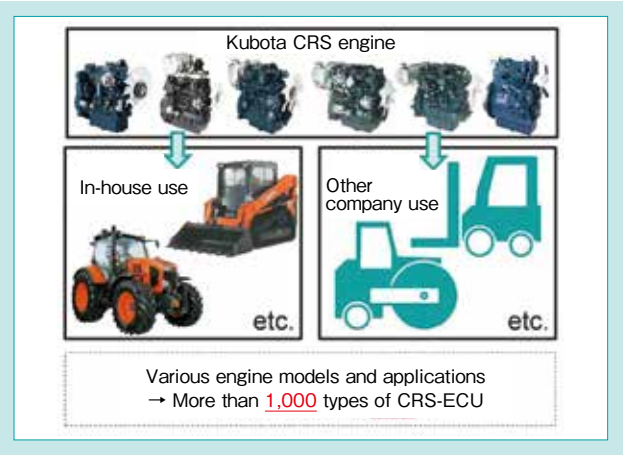

Fig. 2 Kubota Engine Application

2. Development concept

The new CRS-ECU development was based on the following two concepts.

(1) Strengthening the ability to respond to customer demands by strengthening hardware specifications

(2) Increasing the speed of development by improving the efficiency of software creation and verification

The goal of this development was to raise the engine product value by realizing a CRS-ECU that achieves the above, in order to improve the competitiveness of Kubota engines in the market. Furthermore, in order to respond to more customer demands and expand the range of the engine business, the engine series targeted in this development were the V3 and 07 series (Fig. 3). Among the lineup of Kubota engines, these series have a particularly wide variety of customers.

Fig. 3 Target Engine for Newly Developed CRS-ECU (L.: V3, R.: 07)

3. Technical issues to be solved

The following issues existed for the development concepts described in the previous chapter.

3-1 Technical issues: Hardware

1) Resistance to the environment

Unlike passenger vehicle engines, industrial diesel engines are required to continue operating under severe conditions for long periods of time and various environmental performance tests are conducted during their development (Fig. 4). In particular, Kubota engines are not only used in-house, but also in industrial machinery for a wide range of applications all over the world, so it is necessary to consider their use under various conditions. The newly developed CRS-ECU was therefore also required to have environmental durability performance equivalent to or greater than that of the conventional products.

2) Extensibility

As mentioned above, Kubota engines are used in a wide range of applications and there are also a great variety of customer demands. However, with the conventional CRS-ECUs, it was sometimes not possible to meet those demands due the limitations of the hardware specifications such as the number of input/output ports and the memory size.

For this reason, the hardware in this CRS-ECU development was required to have high extensibility to be able to meet a wider variety of customer demands than the conventional products could.

Fig. 4 Environment Resistance Test

3-2 Technical issues: Software

1) Efficiency

It is known that the work hours required for software development increase geometrically with respect to the development scale. This is mainly because as the size of the software increases, the complexity increases dramatically and the work-hours required for programming and debugging increase. In addition, with large-scale software development, more people are involved in the project and there is a risk of bugs due to miscommunication. Unlike programming work performed by a single person, when programming is performed by a team, there is a risk that defects may be introduced due to small differences in the understanding of the members. This risk increases as the scale of the development increases[2].

With the increasing scale of engine control software, the conventional software development environment would limit our ability to continue to supply electronically controlled engines that meet the market needs in a timely manner. For this reason, it is necessary for us to create a software development environment in which software can be created more efficiently than before and information can be effectively shared among the personnel in charge.

2) Reusability and portability

It is desirable that the software design assets that can be obtained with this development can also be utilized in the next development. In addition to diesel engines, the lineup of Kubota engines also contains a large number of other models, including gasoline engines. Only the V3 and 07 series were targeted in this development, but the new development of other series of engine ECUs in the future is also being considered.

However, as described above, a large number of work-hours are required to create engine control software. It would be inefficient to start from the beginning of the software development each time a new engine ECU is developed. It is therefore desirable that the design assets obtained from existing software development can be actively utilized in the next development. For similar software functions, it is desirable that assets can also be used in other software (reusability). It is also desirable that software can be used with an ECU that uses a different microcomputer (portability).

3) Verifiability

In order to confirm the operation of the software, it was previously necessary to operate an actual engine each time. In order to operate an actual engine, a large number of work-hours were required for the test preparation, such as for the setting of the engine operation bench. However, on the other side, the size of engine control software is increasing year by year, so the number of verification items is also increasing. For these reasons, it is becoming impossible to conduct all the necessary verification within the specified development period.

In addition, there are other problems such as tests that require conditions that are difficult to reproduce with an actual engine, tests involving hazards such as engine breakage, and variations in the verification accuracy and efficiency depending on the level of knowledge of the operator. It is therefore necessary to fundamentally reconsider the software verification method

4. Developed technology

4-1 Developed technology: Hardware

1) Resistance to the environment: Aluminum die cast ECU case

The electronic governor diesel engine ECU already manufactured by Kubota used a case in which resin potting was applied to a plastic container. With the resin potting, as the electronic substrate is entirely covered with resin, it is an excellent technique for aspects such as waterproofing, dustproofing and vibration resistance, but it had a problem with heat dissipation. In the case of a CRS-ECU, there are circuit elements on the electronic substrate that have a high heating value, such as the constituent elements of the injector driving circuit, and the substrate temperature rises up to a maximum of about 130°C. It was therefore not possible to apply the conventional resin potting technology to the CRS-ECU.

For that reason, in this development, an ECU case using aluminum die casting was selected for the first time for Kubota (Fig. 5). In order to determine the optimal ECU case shape and electronic substrate component layout, we repeatedly conducted simulation-based design and evaluations using prototypes (Fig. 6: Heat radiation performance testing, etc.). This realized environmental durability performance at the required level.

Furthermore, to achieve compatibility with the conventional product, the CRS-ECU in this development was designed to have approximately the same dimensions as the conventional product, and mounting hole positions that are exactly the same as the conventional product. The connector types and pin arrangement were also designed to be the same as those of the conventional product, and the mounting location and wire harness are compatible with those of the conventional product. This makes it possible to easily switch from the conventional CRS-ECU to the CRS-ECU in this development.

Compared with the conventional product, the developed product also realizes equivalent or superior environmental durability performance related to heat and vibration resistance.

This made it possible to realize ECU hardware that can be used in a wide variety of applications in a wider range of environments.

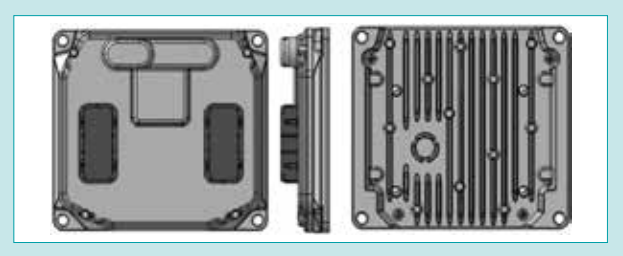

Fig. 5 Appearance of newly developed CRS-EC

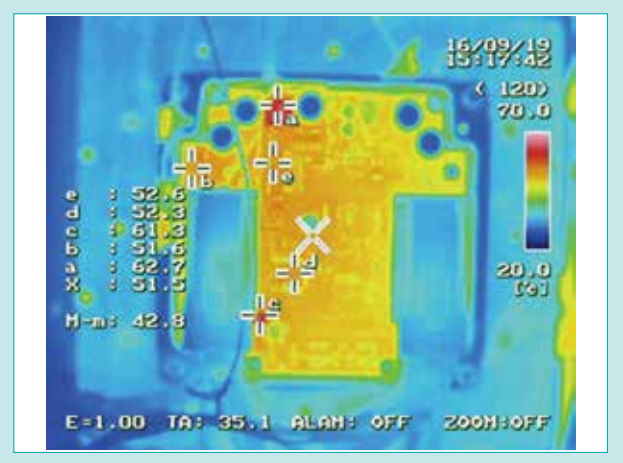

Fig. 6 Heat Radiation Performance Test

2) Extensibility: Hardware specifications

The requirements of a wide range of customers were assumed and the hardware specifications for the newly developed CRS-ECU were substantially strengthened.

For the memory, the capacity of the ROM (Read Only Memory), which is the program area, was increased to twice that on the conventional product. On the conventional product, the ROM capacity had almost reached its limit, making it difficult to implement additional software on a large scale. The ROM capacity was increased in the CRS-ECU in this development to solve this problem. The size of the EEPROM (Electrically Erasable Programmable Read-Only Memory) nonvolatile memory, which is the memory area for the operation status and the engine settings, was also drastically increased to 96 times that of the conventional product. As a result, new functions have been realized that could not be implemented before. This includes the addition of a function so that the engine operating status (speed, cooling water temperature, etc.) before and after the occurrence of a failure is stored in the CRS-ECU.

More input/output ports were also added to increase the number of electronic control devices (sensors, actuators, etc.) that can be connected to the CRS-ECU.

As a result, we realized hardware that was a CRS-ECU for industrial engines that can respond more flexibly to the requests of the customers than conventional products (Fig. 7).

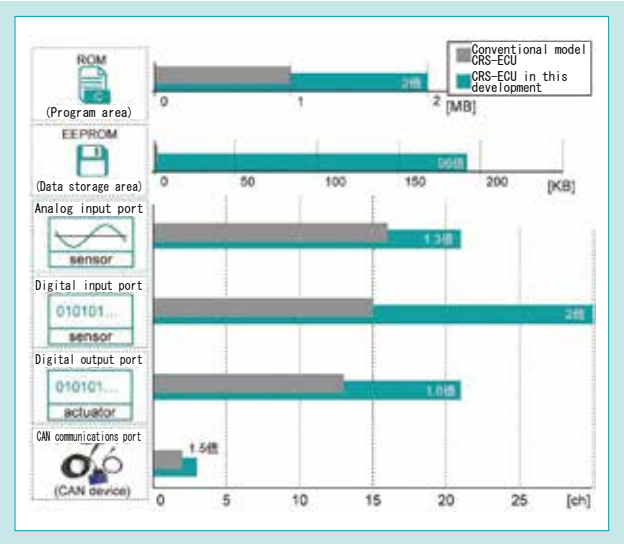

Fig. 7 Hardware Specification Comparison

4-2 Developed technology: Software

1) Efficiency: Model-based development

In this development, a development technique called “model-based development” was introduced to improve the efficiency of the software creation.

In conventional programming work, software was handled as strings of characters (C Source Code). In such text-based programming, it is difficult to grasp the contents by simply looking at the source code, so there was a problem with the readability of the program. On the other hand, in model-based development, a dedicated development tool is used and it is possible to represent the software graphically with flowcharts and block diagrams called “models.” The graphical representation of the software using models makes it possible to more intuitively understand the action of the software compared with conventional text-based programming, so it is possible to greatly improve the readability of the program (Fig. 8). The improvement of the readability greatly contributed to more efficient software development, because it is possible to avoid the inclusion of bugs arising due to inconsistencies in the understanding of software operations among the persons in charge, and it is possible to improve the accuracy of reviews.

Other advantages include that the models created in model-based development can be extended as the control specifications for the software as they are, and the single-unit verification can be easily executed by simulation.

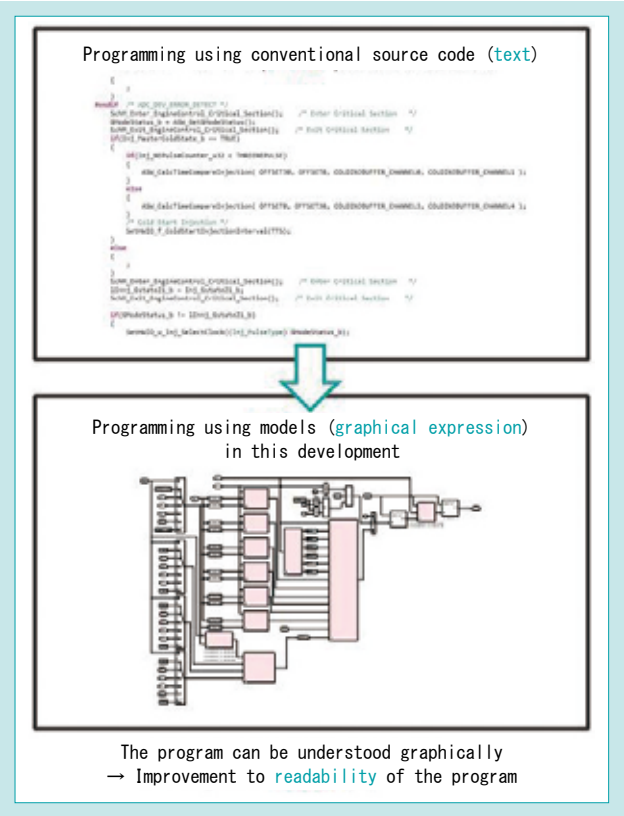

Fig. 8 Model-based Development

2) Reusability and portability: AUTOSAR

In this development, the software was created based on AUTOSAR (Automotive Open System Architecture), which is the world standard for automotive software.

In AUTOSAR, each functional unit of control software is managed as an independent module called an SW-C (Software Component). The SW-C can be added and removed through an interface called RTE (Real Time Environment) as if they were a standard part. This therefore makes it easy to reuse past design assets. Also, it is possible to incorporate any SW-C as long as it complies with AUTOSAR, so in addition to reusing in-house design assets, it is also an effective method for exchanging SW-C with other companies.

Furthermore, the influence of changes to the hardware, such as the microcomputer, is localized to the MCAL (Micro-controller Abstraction Layer), which is a part of the BSW (Basic Software) that constitutes the base of the software. Therefore, the impact that a hardware change has on the software can be almost completely absorbed by just modifying the MCAL, so it is possible to improve the portability (Fig. 9).

Kubota joined as an AUTOSAR Associate Partner in 2018, at the timing of the sales of engines with the CRS-ECU developed this time.

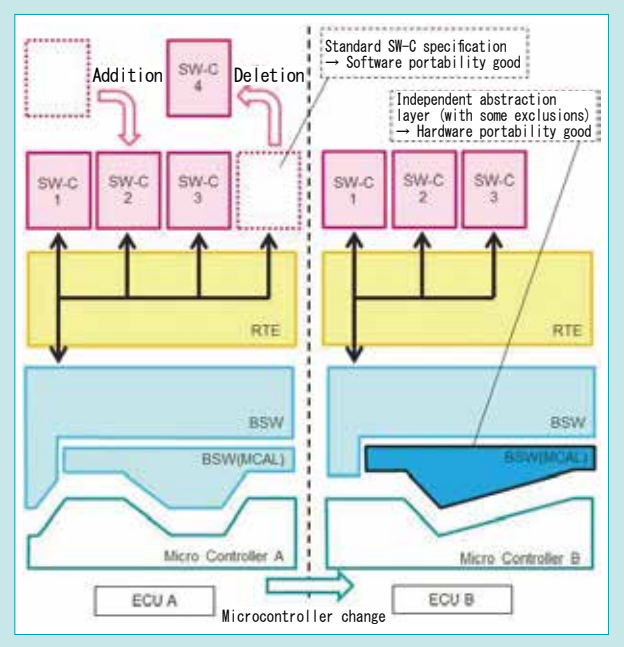

Fig. 9 AUTOSAR Benefits

3) Verifiability: HILS

We introduced HILS (Hardware In the Loop Simulation) to build a verification environment for the engine control software.

HILS is a simulator which simulates an actual machine for the ECU testing. A plant model of the engine was created based on the operation data obtained from the actual diesel engines of Kubota. This realized a simulation environment equivalent to the state where the CRS-ECU is connected to an actual engine. This makes it possible to verify the software without operating an actual engine. The introduction of HILS made it possible to greatly reduce the work-hours required for software verification, which conventionally required a great deal of time, so this contributed to the improvement of development efficiency.

Furthermore, in the HILS environment, the state of the engine can be easily controlled with the settings of the simulation, so tests that are difficult to realize in an actual machine can also be performed easily. There are tests that may involve danger or engine and test facility damage if actual machinery is used, but these tests can be carried out easily in a simulation.

Furthermore, by automating a series of test environments, it became possible to automatically perform software operation checks that were conventionally done manually. As a result, the series of control software verification steps (Test execution → Data collection → Report creation) can now be executed without a human being, so this greatly contributed to a more efficient development speed (Fig. 10).

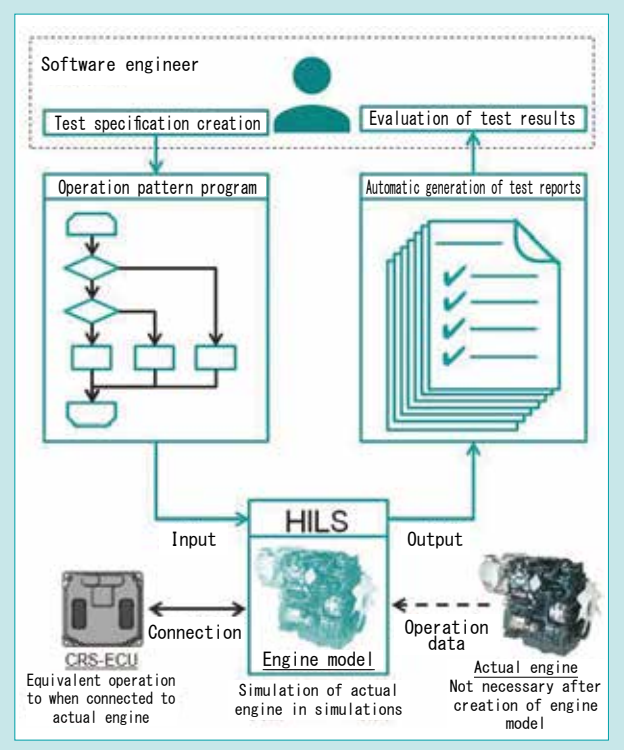

Fig. 10 HILS System

5. Conclusion

The following two points were realized by this development.

(1) Strengthening the ability to respond to customer demands by strengthening hardware specifications

(2) Increasing the speed of development by improving the efficiency of software creation and verification

This has made it possible to respond quickly to a variety of customer demands, which was not possible with the conventional CRS-ECUs. Furthermore, in addition to the performance improvements achieved for the hardware and software, it was also possible to reduce costs, so the competitiveness of the product was also increased in terms of price.

Future prospects include the horizontal deployment of the know-how accumulated in this development to ECU development for other engine series and to the development of low-cost CRS-ECUs for emerging countries. Also, in order to further improve the software verification environment in preparation for this, we are working to improve the verification environment with SILS (Software In the Loop Simulation) in addition to HILS, and to expand and improve the autonomous operation patterns in the verification programs.

Contribution to SDG targets

9.2 Strengthening inclusive and sustainable industrial infrastructure	Contribution to the strengthening of the industrial base by supplying industrial engines that satisfy customer need

Reference

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https://www.epa.gov/emission-standards-reference-guide/epa-emission-standards-nonroad-engines-and-vehicles
(Reference date 2019-08-22)

2) By Steve, McConnell: CODE COMPLETE, (2005), pp. 229, Nikkei BP

Development of V2403-M-DI-TI Diesel Engine (KET) for PRO758 General Purpose Combine Harvester for Chinese Market

Engine Engineering Dept.

The V2403-M-DI-T (68PS) diesel engine installed in a KAMS (Kubota Agricultural Machinery SUZHOU) main combine harvester PRO688 has been mass-produced by KET (Kubota Engine Thailand) since 2015. This is the first 4-valve 03 series engine E-CDIS (Environment, Earth, Ecology-Center Direct Injection System) system, and it meets the need for low fuel consumption. In order to meet the market requirements for even lower fuel consumption and higher output, we developed the intercooled turbo engine V2403-M-DI-TI(75PS) installed in a KAMS new model combine harvester PRO758. In this paper, we describe the approach we adopted to improve reliability, which is the most important task when attempting to achieve high output and low fuel consumption.

【Key Word】
KET, V2403-M-DI-TI, Low Fuel Consumption, Higher Output, High Durability

Related SDGs

1. Introduction

KET started operations in 2012 and produces the 03 Series for OEM and in-house use for the emerging countries. In addition, the company has been working to expand its lineup of models that comply with the increasingly stringent emissions regulations in emerging countries. In November 2015, it also started production of the V2403-M-DI-T mounted on the PRO688 for KAMS in China, as a flagship model that meets the market needs for improved fuel efficiency. In the Chinese combine harvester market, due to the background of environmental problems such as air pollution, the burning of the straw that is discharged after the rice is harvested is prohibited by law. As a result, there is increasing demand for the mounting of a unit called a chopper, which cuts the straw into small pieces. Furthermore, the increase in workload due to an increase in field area has also had an effect and there have been calls for “further output increases.” In addition, rival companies have been introducing high-horsepower models and promoting them. On top of this, there has also been a particularly strong increase in the “fuel cost reduction needs,” as these account for most of the running costs for a contracted harvesting business, where the product is used for a long time. At the same time, the size of the main machinery body must be kept the same as it is currently due to restrictions in the loading width of the transportation trucks owned by the users. We were therefore required to increase the output and reduce fuel consumption while maintaining the compatibility with the conventional 03 Series machinery, which has a maximum output of 49.2 kW.

2. Outline of the development

2-1 Development concept

The conventional model V2403 already has the highest output of the 03 series, at 49.2 kW. The higher horsepower range models are the high end 07 and V3 series. However, the engine body of the high end models is too large to maintain the installation compatibility. Therefore, the aim was to increase the output while maintaining the installation compatibility by using an intercooler on the conventional model, so we established the following two development concepts.

[1] Develop a model with a high power density that is in the top class globally as the top-of-the-line model in the 03 Series, in order to differentiate from the competition in terms of power density for body size.

[2] Realize fuel efficiency that is in the top class globally, to meet the need for fuel cost savings and to increase added value for the customers.

2-2 Target values

Table 1 shows the main specifications of the engine developed and Figure 1 shows its external view.

We set the following two development goals.

[1] Mount an intercooler on the conventional V2403-M-DI-T model to raise the rated output by about 13% and develop the top-of-the-line model in the 03 Series made by KET.

[2] Reduce the specific fuel consumption by 7% or more from the current level to achieve low fuel consumption that is in the top class globally for an industrial diesel engine.

Table 1 Engine Specifications

Model	New Model V2403-M-DI-TI	Current Model V2403-M-DI-T
Combustion System	Direct Injection (DI) system	
No. of Cylinders	4	
Bore×Stroke [mm]	φ87×102.4	φ87×102.4
Displacement [L]	2.434	2.434
Brake Horsepower Gross intermittent [kW/rpm]	55.4/2600	49.2/2700
Maximum torque Gross intermittent [N•m/rpm]	255.2/1500	218.2/1500
Rated fuel consumption [g/kWh]	217	233
Maximum torque fuel consumption [g/kWh]	198	218
Dimensions [mm] (Length×Wide×Height)	683×504×713	683×504×698
Weight [kg]	202	200

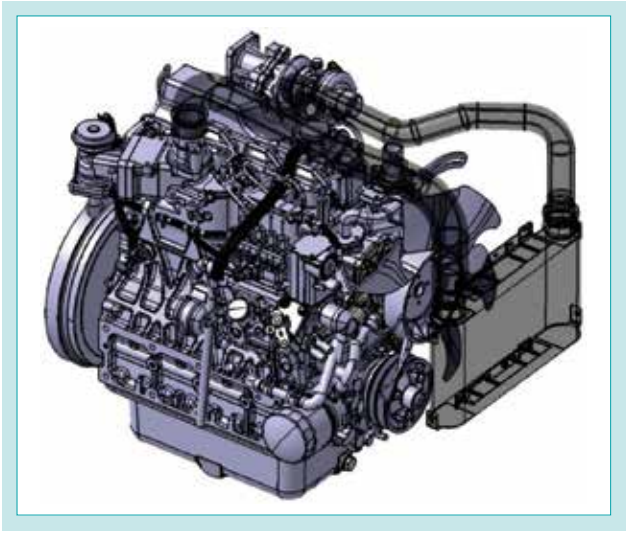

Fig. 1 Engine External View

3. Technical issues to be solved

We set the following three points as the important technical issues in order to achieve the development goals.

[1] Technical issues related to installation compatibility

While increasing the output, it was also necessary to minimize any size increase on the engine overall in order to keep the basic structure and appearance layout as close the conventional model as possible to maintain the installation compatibility.

[2] Technical issues related to the reduction of fuel consumption

Achieve the maximum injection pressure of a mechanical engine to improve the combustion.

[3] Technical issues related to the improvement of durability and reliability

As the output is increased, the burden on the components increases because of the increase in the maximum combustion pressure (Pmax) in the cylinder, so secure the durability and reliability.

4. Developed technology

4-1 Achieving both installation compatibility and a higher output

In order to increase the output, an intercooler was installed to cool the temperature of the air heated by turbo supercharging, to increase its density.

As shown in Figure 2, the increase in the engine size was minimized to just a 2.7% increase by just making the minimum necessary change of raising the intake hose mounting position by 15 mm in the height direction.

As a result, the power density (Note 1) per body size unit was increased by 10.2% compared with the current machine, achieving the highest output for body size in the series (Fig. 3). In addition, a large decrease in NOx was realized by lowering the supercharge temperature, so it also complies with the Tier 3 Chinese emission standards. This achieved an increase in output while maintaining installation compatibility.

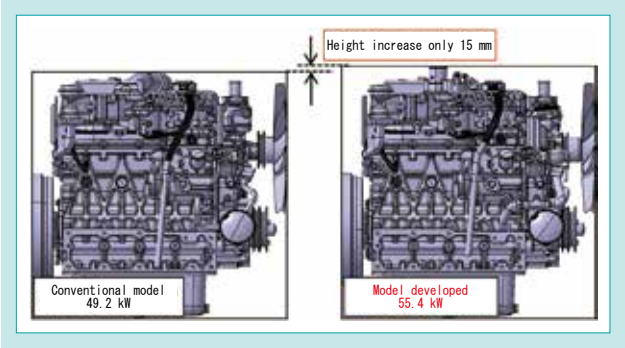

Fig. 2 Comparison of External Dimensions

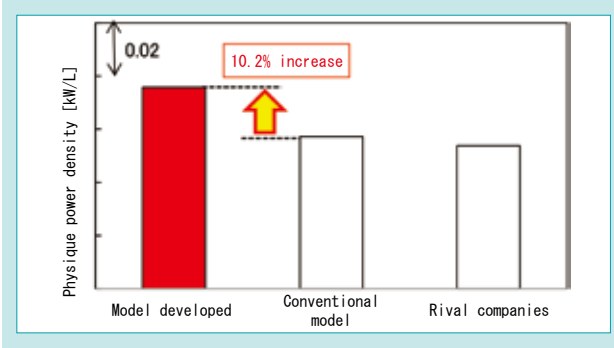

Fig. 3 Physique Power Density

注1 体格出力密度[kW/L]=定格出力[kW]/エンジン体格[L]
（幅L[mm]×長さW[mm]×高さH[mm]）

4-2 Realization of maximum injection pressure for mechanical engines

4.2.1 High-pressure fuel injection on mechanical engines

In order to realize lower fuel consumption, it is important to improve the combustion efficiency by injecting the fuel at a higher pressure to atomize the fuel and promote the mixing of the air and fuel. In a mechanical injection system, in order to increase the fuel pressure, it is important to increase the pumping speed of the fuel cam to feed the fuel in the injection pump more quickly. In order to increase the pumping speed of the fuel cam, it is necessary to decrease the radius of curvature of the concave surface of the cam profile and increase the lift per cam rotation angle. Therefore, as shown in Figure 4, we reduced the radius of curvature of the fuel cam concave shape to 15% less than that on the conventional model. This was a reduction to the limit possible for the grinding stone diameter on the machining equipment. As a result, in comparison with the conventional model, the pumping speed was increased by 13% and the injection pressure was increased by 18%, thereby achieving the maximum injection pressure of a mechanical injection system (Fig. 5, Fig. 6). Initially, it was thought that mass production would not be possible due to vibration and workpiece shaking during cam polishing. However, the mass production was realized by working together with the supplier to optimize the machining conditions such as the machining run-in amount, grinding speed and lubrication quantity.

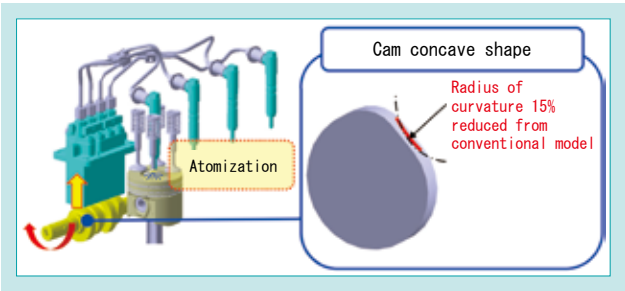

Fig. 4 Configuration of Fuel Camshaft

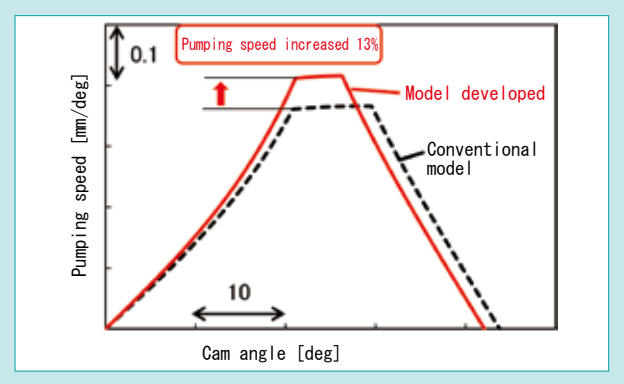

Fig. 5 Pumping Rate of Fuel Camshaft

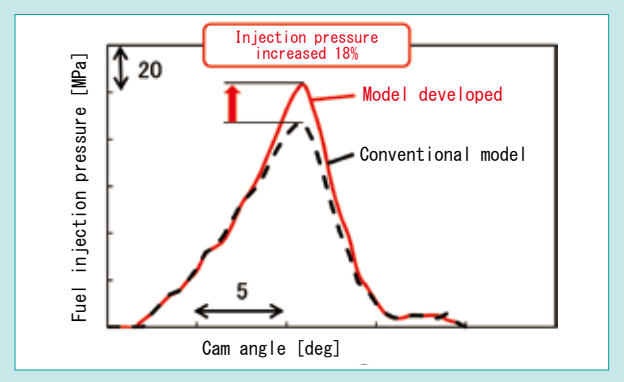

Fig. 6 Fuel Injection Pressure

4.2.2 Fuel efficiency improvement by higher pressure fuel injection

As a result of the efforts to improve the combustion by realizing the maximum injection pressure of a mechanical injection system, the fuel consumption was drastically reduced compared to the conventional model. The reduction was -7% at the rated point and -9% at the maximum torque point, so the target performance was achieved (Fig. 7).

(Reference: For an assumed annual product operating time of 1,000 hours, work load factor of 70% and fuel cost of 100 yen per liter, the annual fuel cost can be reduced by around 70,000 yen.)

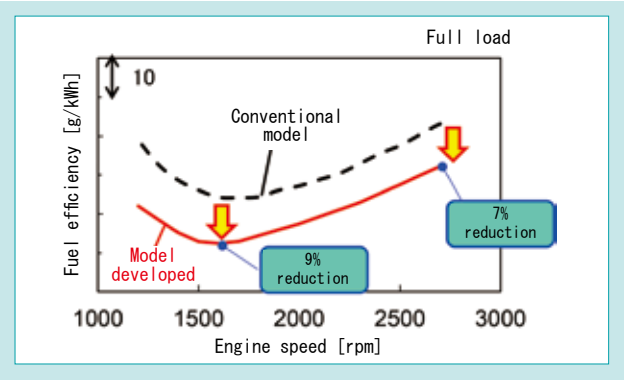

Fig. 7 Effect of Improved Fuel Efficiency

4-3 Improvement of durability and reliability

An unwanted effect of the realization of higher output and lower fuel consumption is that the load on the parts increases due to the increase in the maximum combustion pressure Pmax in the cylinder during combustion. Securing durability and reliability therefore becomes an important issue. To address this, the design was considered through DR (Design Reviews) and analysis to investigate a countermeasure. As a result, it was found that it was necessary to increase the strength of the piston and the fuel camshaft. The piston is a major component of the power transmission, and the fuel camshaft is the component that is the key to low fuel consumption. Securing the durability and reliability of these two parts was therefore considered to be the most important issue and efforts were made to address this.

4.3.1 Securing piston durability and reliability

In both stress analysis and single unit tests performed for the piston, it was found that there was insufficient strength in the pin hole part which transmits the explosion pressure to the connecting rod. We therefore comprehensively considered the QCD and worked on the following two measures as methods to address the problem with the minimum cost: [1] Improvement of the thermal fatigue strength by improving the cooling performance of the piston, and [2] Optimization of the shape of the pin part to relax the stress.

For the first countermeasure, the piston cooling is performed with a structure that has holes drilled in the engine oil path to spray an oil jet for cooling. On the conventional model, there was one hole drilled for a single jet. In the development, the drilled hole diameter was increased by 50%, two holes were opened for a double jet, and the flow rate of the oil jet was increased to about four times that before. This reduced the heated temperature of the pin hole part by about 9°C (4%) (Fig. 8).

For the second countermeasure, we considered the relaxation of the stress by optimizing the profile. The explosion load received at the piston top surface is transmitted to the connecting rod via a piston pin positioned in the pin hole. The pin holes are tapered by conical machining to release the deformation of the piston pin under stress. We therefore made changes so that the pin hole length was extended by 10%, the pressure-receiving area was increased by 10% and the taper angle of the pin hole was changed to 20%, to set the optimum amount of stress relief at the time of piston pin deformation to alleviate the stress concentration (Fig. 9). In order to confirm the effects of these two measures, we used accelerated testing on single units to shorten the evaluation period to about 1/5 and we confirmed that the fatigue strength could be ensured. From the above, we decided the specifications to ensure durability and reliability at the minimum cost.

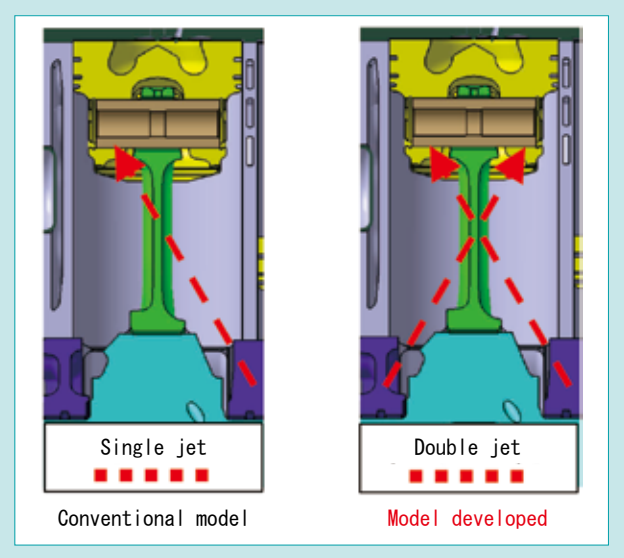

Fig. 8 Improved Piston Cooling Performance by Double Oil Jet

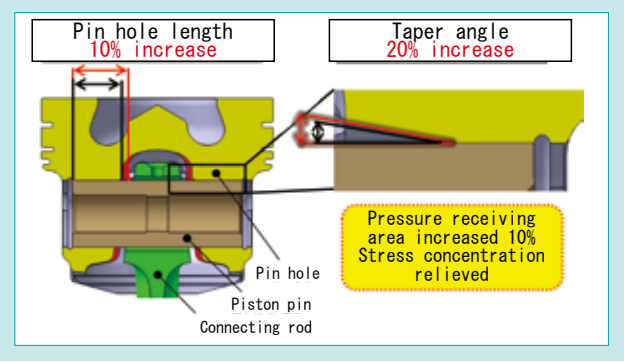

Fig. 9 Optimization of Piston Shape

4.3.2 Securing fuel camshaft durability and reliability

On the conventional model, the optimal heat treatment and surface treatment have been conducted as appropriate for the increase in Hertzian stress caused by the high-pressure injection (Fig. 10).

However, as we had drawn out the performance limit of the maximum injection pressure of a mechanical engine, the Hertzian stress of the fuel

cam was increased by 11%, and we found that new fatigue strength improvement technology would be required. As the shape of the fuel cam affects the performance, a change of shape like that done on the piston was not possible. Therefore, as a countermeasure that is possible with the current equipment, we worked in cooperation with the camshaft manufacturer to develop the first fine particle shot peening for an engine part, with a smaller particle size than the conventional method.

Fine grain shot peening is a technology where small steel balls called media are thrown against a workpiece at high speed to impart residual compressive stress to improve the fatigue strength (Fig. 11). As the Hertzian stress on the fuel cam is the largest near the surface, it is necessary to reduce the particle size of the shot so that the maximum value of the residual compressive stress is near the surface. For this reason, the conventional impeller type of shot machine was changed to an air nozzle type with greater projection energy. As a result, the residual compressive stress at the outermost surface was increased to roughly double the stress with the conventional impeller type (Fig. 12).

There are many parameters for the shot, such as the type of media and the nozzle specifications, so a roller pitching tester simulating an actual machine was used. After repeated discussions with the supplier, the shot conditions were determined in a short period roughly 1/4 the length of evaluations on an actual machine. As a result, we succeeded in improving the fatigue strength to about three times the conventional figure and the durability and reliability were secured without making any large structural changes.

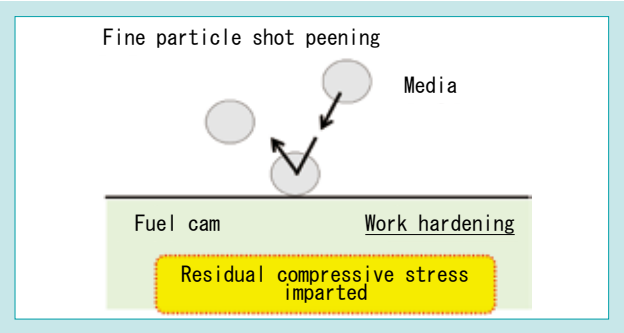

Fig. 11 Outline Fine Grain Shot Peening

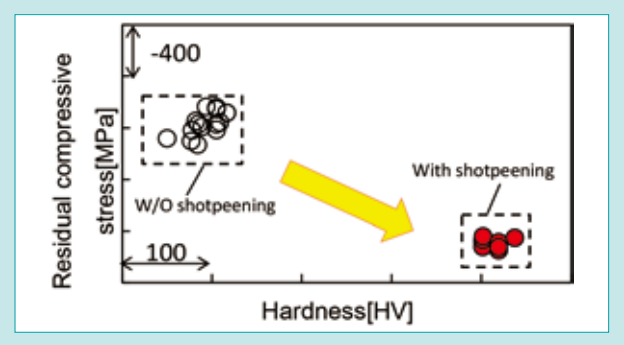

Fig. 12 Shot Peening Quality Hardness, Residual Compressive Stress

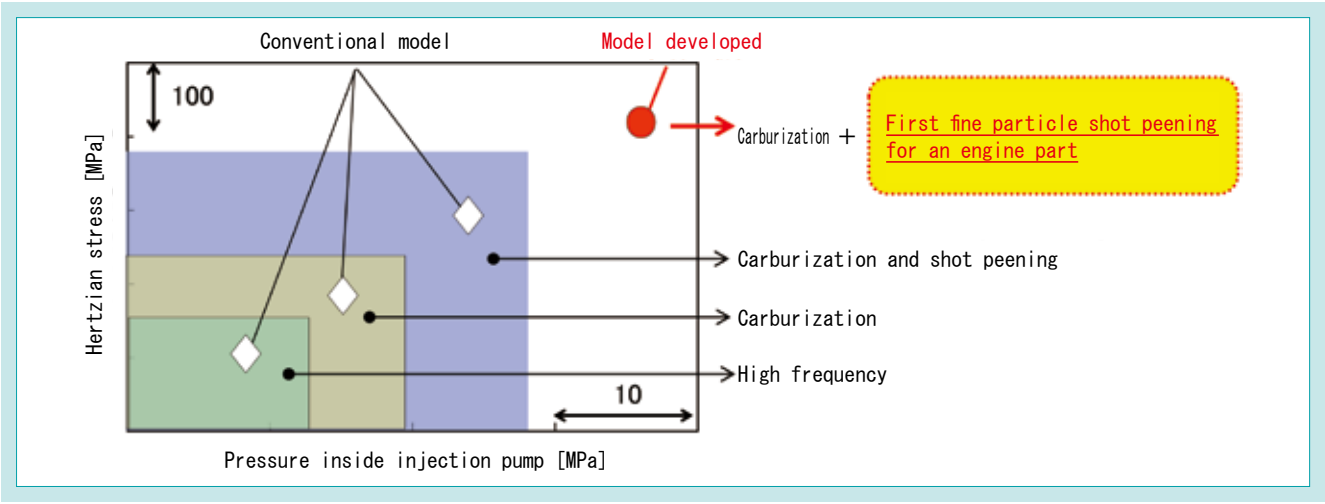

Fig. 10 Hertzian Contact Stress of Fuel Camshaft

4.3.3 Mass production quality control for fine particle shot peening

In preparation for the start of mass production using fine particle shot peening, there was an issue of the mass production quality control at the local supplier in Thailand. The measurement of residual compressive stress requires the use of expensive X-ray instruments, so it would be necessary for large capital expenditure by both the KET inspection department and the suppliers responsible for the post-processing. We therefore devised an alternative method to use existing facilities to perform the control for the residual compressive stress, by using surface hardness and the metal structure. First of all, when the shot processing has been performed normally, the surface hardness is greatly increased and the retained austenite is transformed into martensite.

However, if the shot processing is excessive, in what is called overpeening, then the surface hardness largely decreases. We therefore decided on a method for determining whether or not the shot has been properly performed by setting a threshold value for the hardness (Fig. 13). Next, when the shot processing is insufficient, there is less transformation of the structure, so there is more precipitation of retained austenite near the surface layer. We therefore decided a method for judging whether there was. Insufficient shot processing by observing the structure to check the retained austenite precipitation in the surface layer from the above, we established a control method that makes it possible to check the quality of mass production without any expensive capital investment by utilizing the correlation between the hardness and the structure. This method was exchanged with suppliers as the specification and has been in operation since the mass production start in 2017.

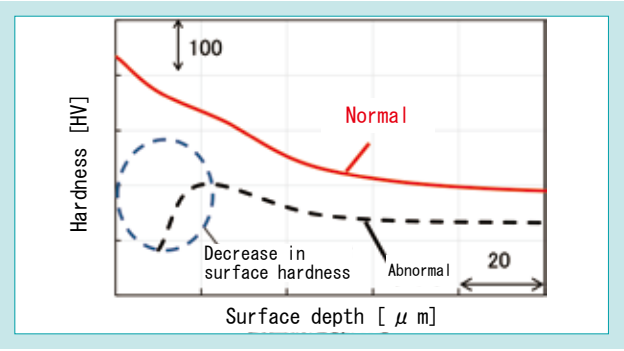

Fig. 13 Image of Reduced Hardness From Overshot Peening

4-4 Fuel efficiency improvement results

Combustion was improved by solving the problems of durability and reliability that occur when higher power is used, and realizing the maximum injection pressure in a mechanical injection system. In addition, we also worked on the reduction of fuel costs through the optimization of high boosting, EGR, the combustion system and the piston ring tension[1),2),3)]. Figure 14 shows the sampling data of the rated fuel efficiency of the models from various companies that meet the Tier 3 Chinese emission standards. The model in this development, the intercooler specification V2403-M-DI-TI manufactured by KET, reduces the fuel efficiency at the rated point by more than 7% compared with the conventional model. As a result, it achieves the highest fuel efficiency in the world and has helped enhance the competitiveness of the models it is mounted on.

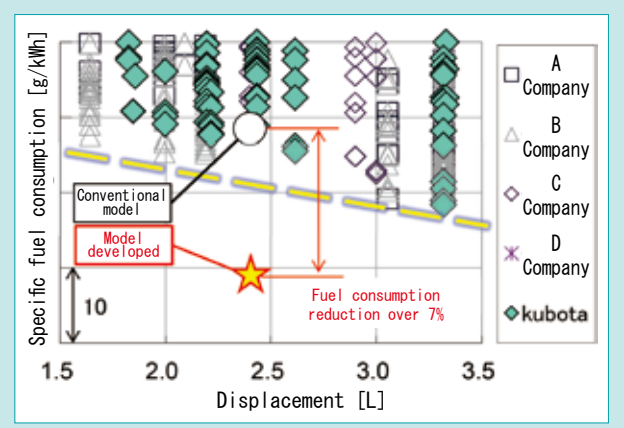

Fig. 14 Sampling Data on Fuel Efficiency

5. Conclusion

We simultaneously achieved both lower fuel consumption and also improved workability due to an increased output, which responds to the long hours of operation and heavy work load in the rented use peculiar to the Chinese market. This market-in oriented development that satisfies the market requirements has therefore helped strengthen the competitiveness of the machinery it is mounted on.

1) We developed the top-of-the-line model in the 03 Series with a 55.4 kW specification, while at the same time also achieving low fuel consumption in the top class globally (with a reduction of 7% compared with the conventional model).
2) While maintaining the installation compatibility, we also responded to the market needs by simultaneously balancing a high output power, low fuel consumption, and durability and reliability at a high level.
3) We devised a method for mass production quality control for fine particle shot peening.

In the future, we will extend the fuel-efficient technology adopted in this development to the V2403-M-DINA models and will also make efforts to reduce material costs. We will work to strengthen the product competitiveness of the models produced by KET, which simultaneously satisfy both performance and cost requirements at a high level, and will strive to expand their sales in emerging countries.

Contribution to SDG targets

2.3 Increasing agricultural productivity and income	Contribution to increased agricultural productivity with increased rated output
7.3 Improvement in energy efficiency	Compared with the conventional model, fuel consumption was reduced by 7% at the rated point and by 9% at the maximum torque point
17.16 Building global partnerships	Development of new technologies in cooperation with the overseas production base KET and local suppliers

Literature

1) Introduction of SKYACTIV-D Engine 2013 Society of Automotive Engineers of Japan
2) Newly Developed SKYACTIV-D 1.5 2015 Mazda Technical Review
3) Newly Developed Diesel Engine SKYACTIV-D 2.2 2017 Mazda Technical Review

Development of the Mini Excavator KX027-4 for European Market

Construction Machinery Engineering Dept. for Excavator

In Europe's mini backhoe market, there is a high demand for machines in the 2-3 ton range with 10 000 units sold per year. In 2014, Kubota acquired a high share of this market segment with its 2.6 ton minimum tail swing excavator. To increase market share, we developed a 2.6 ton conventional tail swing compact excavator. Because of the physical size of European operators, there is a need in the European market to expand the 'living" space around the driver's seat. Accordingly, in the development of the KX027 we decided to increase the cabin size to enhance safety and provide a secure working environment. Because there are limitations on the weight of the KX027-4 for shipping, it is difficult to increase cabin size without increasing the cabin weight. In this paper, we explain the development of the KX027-4 aluminium cabin that allows the cabin size to be increased to better accommodate the operator comfortably while saving weight at the same time.

【Key Word】
Mini Backhoe, Cabin, Aluminium Alloy, Increased "Living" Space, Weight Saving

Related SDGs

1. Introduction

In the European market, 2 to 3 ton class mini excavators are mostly transported on 3.5 ton trailers (the top class of trailer that can be driven with a license that is easy to obtain). To be transported by a 3.5 ton trailer, it is necessary for the machinery mass to be 2.6 ton or less (Fig. 1). The KX61-3 standard 2.6 ton mini excavator that was introduced for Europe in 2004 clears these weight restrictions and has also been well received by customers for its good basic performance and durability, so it has achieved an increase in market share.

In recent years, however, as the market has matured and the lineup from competitors has expanded, the following four requirements have emerged from the market.

[1] Improvement of comfort
[2] Improvement of price competitiveness
[3] Addition of advanced functions such as manual operation of AUX (Hydraulic source that moves the additional attachment)
[4] Compliance with law and regulation revisions

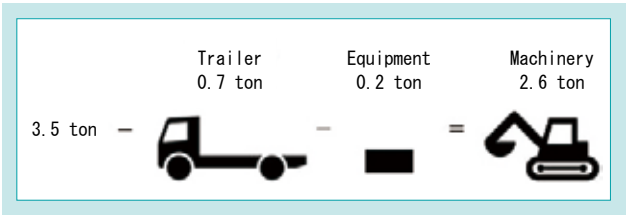

Fig. 1 Explanation of Weight Limitation

We therefore developed the KX027-4 as a full model change that satisfies the requests above while also keeping the machinery mass, basic performance and high durability of the conventional model (Fig. 2).

The improvements in the development of this new KX027-4 model were as follows. [1] For the improvement of comfort, the space occupied by the operator was enlarged by enlarging the cabin. [2] The price competitiveness was improved. [3] For the addition of advanced functions, a basic model that prioritizes price and a high-spec model with additional advanced functions were developed simultaneously. [4] For the compliance with law and regulation revisions, the compliance with the European Stage V emission regulations was ensured. Of these improvements, this report describes the development of a larger cabin.

Fig. 2 External View of KX027-4

2. Development concept and goals

2-1 Development concept

The cabin on the conventional model was made of steel. Increasing the size of the cabin with the same structure would increase the weight of the cabin due to the increased materials. However, as described in the first chapter, it was not possible to increase the machinery mass of the KX027-4 due to the restrictions during transportation. Therefore, in order to increase the size of the cabin, it was also necessary to make an effort to reduce the weight of the cabin. Possible methods to reduce the weight of the cabin include to reduce the sheet thickness of the materials or to make the support columns thinner. However, the cabins of Kubota mini excavators are a ROPS (Roll-Over Protective Structure), to protect the operator if the machine overturns, so it is not possible to reduce the rigidity of the frame compared with the conventional cabins. It was therefore difficult to incorporate the weight reduction methods above into the KX027-4 cabin design, so it was difficult to achieve both a larger cabin and a lighter cabin while still using steel as the material. To solve this problem, we performed the development with the use of aluminum alloy for the cabin materials. This material has a high specific strength (Tensile strength/density) and can be expected to significantly reduce the weight (Fig. 3).

The development was conducted with the following two concepts.

[1] Improvement of comfort by increasing the size of the cabin

[2] Achievement of the target machinery mass by reducing the cabin weight

Fig. 3 External View of Cabin

2-2 Development goals

(1) Cabin volume

Set the target for the cabin volume as that of the 3 to 4 ton class mini excavators, which have been highly rated in the European market, and achieve a 10% increase in cabin volume from the conventional cabin.

(2) Cabin weight

There are changes in the development of the KX027-4 that cause a weight increase, such as the addition of advanced functions. Take that into consideration and achieve a 25% weight reduction compared to conventional cabins.

3. Technical issues to be solved

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

(1) Setting of allowable stress values for aluminum welded structures

There are no past results from the use of welded parts made from aluminum alloy as a strength part on a mini excavator from Kubota. Also, the following features of aluminum alloy differ from those of steel, which has been used in the past. [1] The heat affected zone (hereafter called the "HAZ part") close to the welded surface becomes softer. [2] There is no fatigue limit. Due to [1] and [2], it is necessary to set an allowable stress value unique to the aluminum alloy and different from that of steel.

(2) Securing the rigidity required for ROPS strength

The cabin of a Kubota mini excavator is a ROPS, so it is necessary to secure a protective space so that an operator wearing a seat belt will not be crushed if the machine rolls over. However, aluminum alloy is not as strong as steel and it is easily deformed. Therefore, it would not be possible to secure the necessary rigidity by simply changing the material of the cabin to aluminum alloy while maintaining the same shape as the conventional cabin.

(3) Evaluation of resistance to brittle fracture at low temperatures

ISO 3471 (ROPS Laboratory tests and performance requirements) requires that ROPS structures be evaluated for resistance to brittle fracture at low temperatures if the material used is anything other than steel, which is the material specified for the structural elements of a ROPS. However, only the specified steel has been used for the structural elements of the ROPS on Kubota mini excavators so far, so no evaluation method has been established. Therefore, it is necessary to consider and establish an evaluation method for the resistance of aluminum alloys to brittle fracture at low temperatures.

4. Developed technology

4-1 Setting of allowable stress values for aluminum welded structures

The following is a description of the difference between steel, which has proven results so far, and aluminum alloy. Figure 4 shows the hardness distribution in the vicinity of the welded surfaces on steel and aluminum alloy[1), 2)]. It can be seen from Figure 4 that the hardness of the HAZ part of the steel is higher than the hardness of the base material. As the tensile strength of steel is proportional to its hardness, the tensile strength of the HAZ part of steel is higher than the tensile strength of the base material. As a result of this, evaluations have been conducted with the assumption that the HAZ part tensile strength is equivalent to the base material tensile strength. On

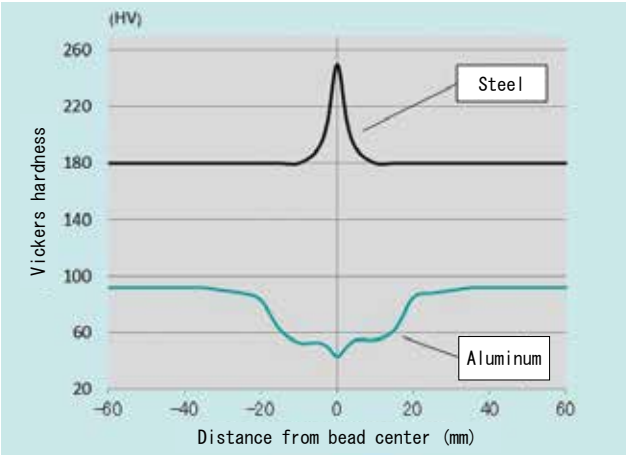

Fig. 4 Hardness Distribution Near Weld Surface (A6063)

the other hand, Figure 4 shows that in the case of aluminum alloy, the HAZ part has been softened.

In the same way as for steel, the tensile strength of aluminum alloy is also proportional to its hardness. Therefore, the HAZ part tensile strength of the aluminum alloy is lower than the base material tensile strength.

Next, the S-N diagram for steel and aluminum alloy is shown in Figure 5[3].

It can be seen from Figure 5 that in the case of steel, the graph becomes horizontal after 107 repetitions. This suggests that steel has a fatigue limit. On the other hand, in the case of aluminum alloy, it can be seen that the repeated stress continues to decrease as the number of repetitions increases. From this, it can be said that aluminum alloy does not have a fatigue limit.

As described above, in the case of steel, the tensile strength of the base material and the tensile strength of the HAZ part are equal and there is a fatigue limit. Therefore, the fatigue limit of the base material has previously been used as the allowable stress value for both the base material and the HAZ part.

However, in the case of aluminum alloy, the HAZ part tensile strength is lower than the base material tensile strength and also there is no fatigue limit. It is therefore not possible to set the allowable stress value in the same way as it is set for steel. As a result, we decided to find the tensile strength of the base metal and the HAZ part and to set the number of repetitions to fit the method of use of the machinery, so that an allowable stress value is set for both the base metal and the HAZ parts.

First we will describe the results found for the strength. The cabin material for the KX027-4 is the aluminum alloy A6063. Figure 6 shows the hardness distribution of the HAZ part of A6063. It can be seen from Figure 6 that the HAZ part has softened to about 70% of the hardness of the base material. As the hardness and the tensile strength are proportional to each other, the tensile strength of the HAZ part is 70% of the tensile strength of the base material. On an S-N diagram, if the material is the same, then it is a fair approximation to assume that the line is parallel to the tensile strength as a proportion of it.

Therefore, from the proportion of the tensile strength and the S-N diagram for the A6063 base material, the S-N diagram for the A6063 HAZ parts was presumed to be as shown in Figure 7.

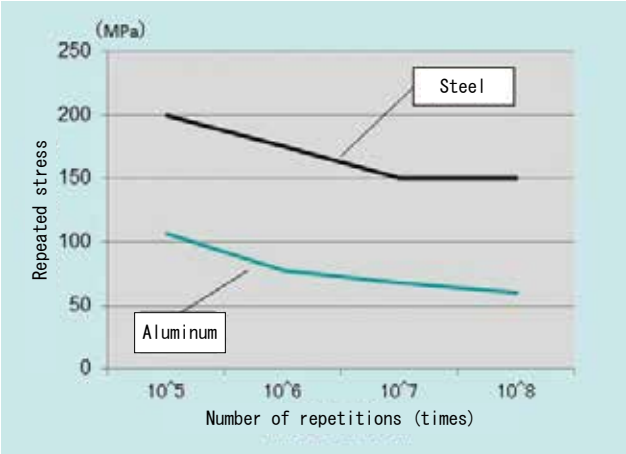

Fig. 5 S-N Diagram

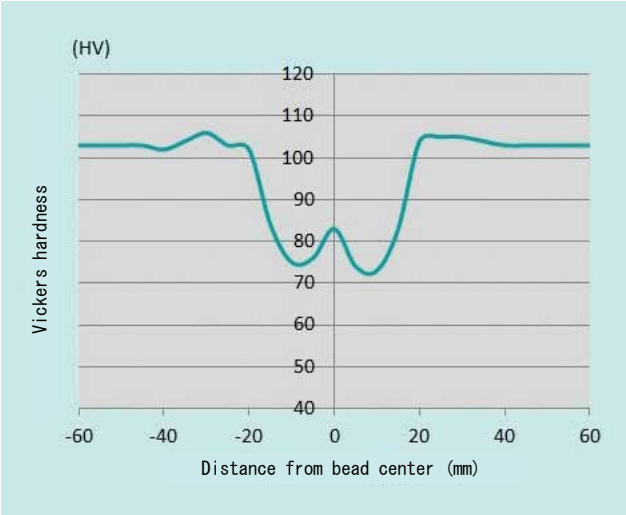

Fig. 6 Hardness of Weld Neighborhood (A6063)

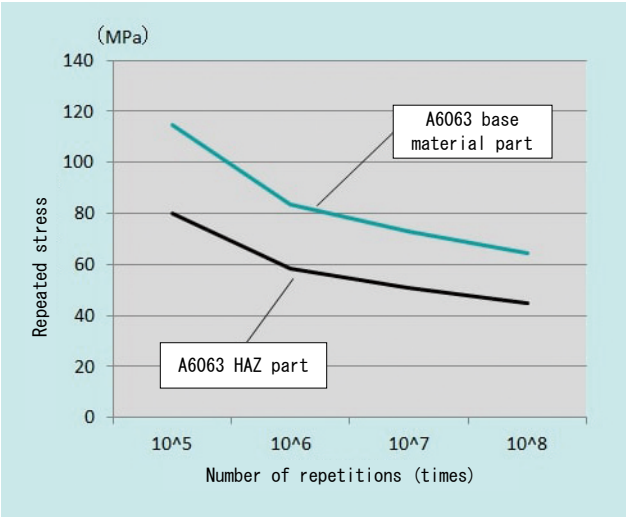

Fig. 7 S-N Diagram of A6063

The next section describes how the number of repetitions was set to fit the method of use of the machinery. It was assumed that setting the number of repetitions to the number of loads applied to the cabin during the total operating time of the machinery would mean that a cabin would not suffer fatigue failure in the market. Figure 8 shows the representative operation modes of the machinery. We counted the stress amplitude from the stress waveform of the actual machinery during the excavation and running operations shown in Figure 8, which are the representative operation modes for the machine. The number counted was then converted using the total operating time assumed for the machinery to estimate the number of loads added to the cabin during the total operating time. This was then used as the repetition number.

The number of repetitions derived as above and the S-N diagram in Figure 7 were then used to set the allowable stress values for the A6063 base material parts and HAZ parts. The allowable stress values that were set were then used in repeated evaluations and improvements to create a cabin that was below the allowable stress values set.

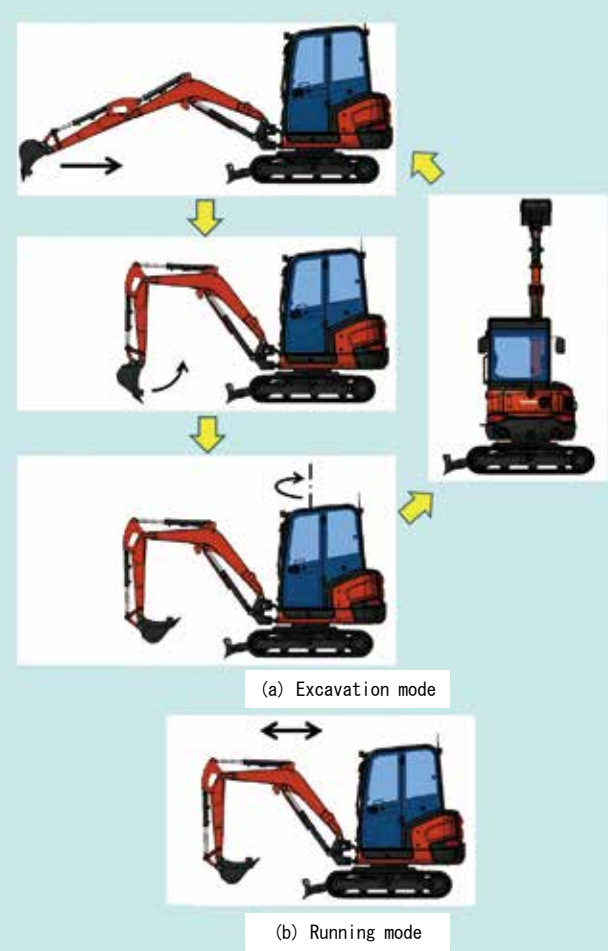

Fig. 8 Explanation of Work Mode

4-2 Securing the rigidity required for a ROPS

Figure 9(a) shows the cross-sectional profile of the support columns of a conventional steel cabin and Figure 9(b) shows the cross-sectional profile of the support columns of the KX027-4 aluminum alloy cabin. The Young's modulus of aluminum alloy A6063 is about 30% that of steel, and it is easily deformed. Therefore, it would be difficult to secure a protective space for the operator by simply changing the material of the cabin while maintaining the same cross-sectional profile of the support columns as on a conventional cabin. This is because if the machinery overturned, then the cabin frame would be greatly deformed by the force applied to the cabin from the ground. For this reason, for the KX027-4 cabin, we took advantage of the excellent formability and easy plastic deformation of aluminum alloy and adopted an extruded material in which ribs are formed in the interior of the support columns. The rigidity was increased by using an extruded material with the cross-sectional profile shown in Figure 9(b), which increased the section modulus of the support columns without enlarging their external shape. The section modulus for (b) is 230% that for (a). Also, the weight of the support column in (b) is 60% of the weight of the support column using (a). This is because of the lower specific gravity of the aluminum alloy, which is 1/3 the specific gravity of the steel. From this

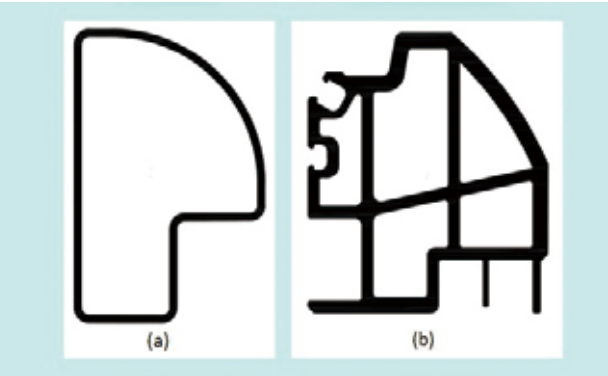

Fig. 9 Cross Section Surface of Cabin's Prop

viewpoint, it can be said that the application of the extruded material is effective in reducing the cabin weight.

Next, the cross-sectional profiles of each part of the cabin frame are shown in Figure 10. In addition to forming a rib in the interior, the functions necessary for the cabin were also formed in the extruded shape, such as a rain gutter (Fig. 10-a), a window rail (Fig. 10-b), and a speaker fitting part (Fig. 10-c).

The use of the cabin frame with these cross-sectional profiles ensured the rigidity necessary for a ROPS and also reduced costs.

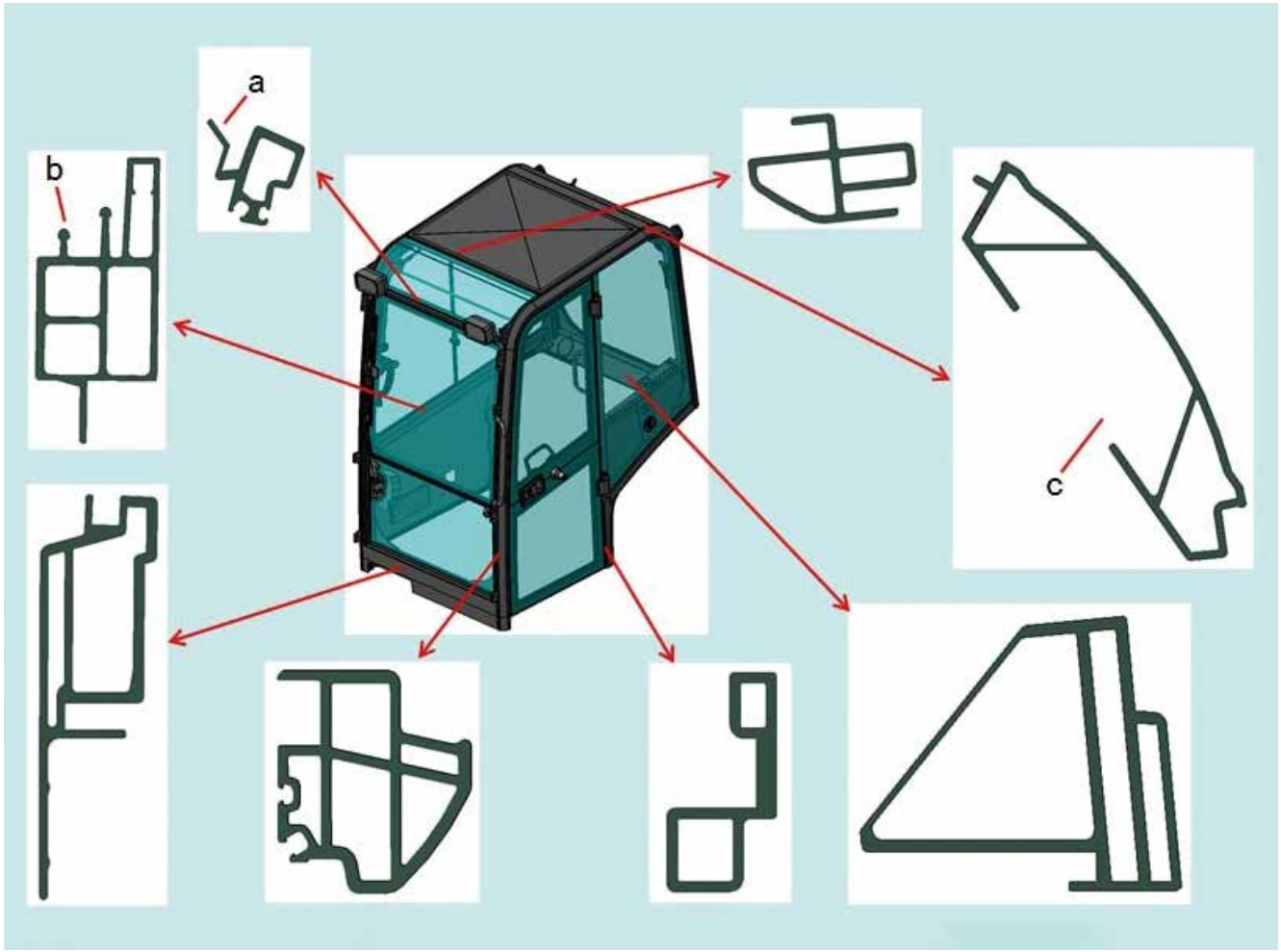

Fig. 10 Cross Section of Cabin's Frame

4-3 Evaluation of resistance to brittle fracture at low temperatures

ISO 3471 stipulates that if the structural elements of the ROPS are made of steel that meets the Charpy impact test standards, then the evaluation of the resistance of the structural elements of the ROPS to brittle fracture at low temperatures can be replaced by an evaluation by ROPS tests at room temperature. On the other hand, in the case of other materials, it is necessary to perform ROPS testing at a temperature of -18°C or below to evaluate the resistance of the structural elements of the ROPS to brittle fracture at low temperatures.

Aluminum alloy is used for the structural elements of the ROPS on the KX027-4 cabin, so the latter method applies. However, Kubota does not have facilities to conduct ROPS testing at a temperature of -18°C or below. Therefore, it was decided to evaluate the resistance to brittle fracture at a low temperature by cooling the cabin frame so that the cabin frame itself is at -18°C or below while performing the ROPS testing.

The details of the test method (Fig. 11) are as follows.

[1] Cover the cabin frame with thermal insulation material and cool the cabin frame to -18°C or below

[2] Remove the cooled cabin frame from the thermal insulation material

[3] Use the cabin frame from [2] and perform the testing while confirming that the cabin frame is at -18°C or below

It was confirmed by the method above that the KX027-4 cabin has the resistance to brittle fracture at low temperatures that is required for a ROPS, so it was possible to make an aluminum alloy cabin with ROPS performance.

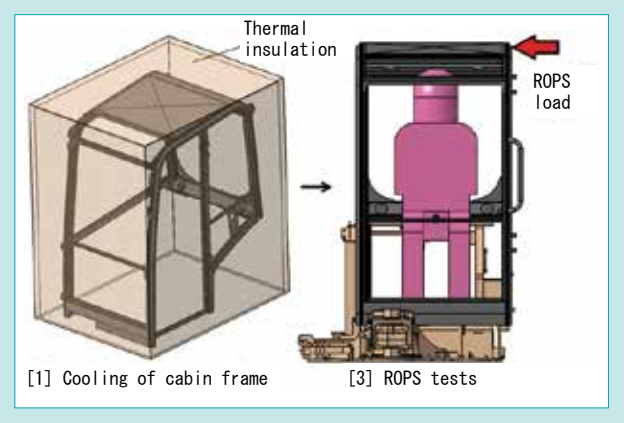

Fig. 11 ROPS Test Method at Low Temperature

5. Conclusion

We were able to achieve the initial product concept for the KX027-4 cabin. The volume of the cabin was increased by 13% compared with the conventional cabin. As a result, it was rated highly in the market because the operator can operate the machine comfortably, and we were able to contribute to the "Promotion of a safe and secure working environment." With regards to the cabin weight, the creation of a cabin that takes advantage of the characteristics of aluminum alloy made it possible to achieve our target cabin weight reduction.

The cabin size is not the same as a part that doubles in size when the machinery doubles in size. Therefore, for the same cabin weight reduction, the effect of the weight reduction is greater with smaller machinery. From this viewpoint, we believe that the extension to even smaller machinery would be beneficial. We will continue to contribute to the development of infrastructure and urban development in Europe and the rest of the world through the production of products that are suitable for the market.

Contribution to SDG targets

8.8	Promotion of a safe and secure working environment	The increased cabin size expands the space occupied by the operator
9.2	Strengthening inclusive and sustainable industrial infrastructure	Contribution to easier machinery transportation by reducing the weight of the cabin
11.a	Support for connections between urban and rural areas	Contribution to infrastructure development in Europe

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Development of Commercial Humidified Air Purifier "Purewasher"

Precision Equipment Engineering Dept.

The demand for air purifiers to improve room air quality has increased. To enter the market for commercial humidified air purifiers, for which growth can be expected in the future, we developed the commercial humidified air purifier "Purewasher". We applied technology for spraying water actually used for air conditioning in clean rooms, and we downsized the air washer. We utilized slightly acidic electrolyzed water to eliminate bacteria. We consider these to be the core technologies of Purewasher. We proceeded with development emphasizing the above technologies, maintainability, and design. A performance evaluation of the product yielded the following results: bacterial eradication rate: 99%; gas odor reduction: over 90%; and humidification capacity: 2.7kg/h(20ºCDB・30%RH). This product successfully completed the development process and we entered the market for commercial humidified air purifiers.

【Key Word】
Air Purifier, Air Washer, Slightly Acidic Electrolyzed Water, Humidification, Bacteria Elimination, Deodorization

Related SDGs

1. Introduction

In recent years, there has been a growing interest in air cleaning technology due to the increasing awareness of the prevention of hay fever, influenza and air pollution due to yellow Asian dust and PM2.5. In around 2000, household air purifiers were launched by several Japanese manufacturers. They spread in ordinary households and became widely recognized. As part of this background, there is also growing interest in commercial air purifiers for larger spaces. It is thought that the requirements for these will slowly spread as part of efforts for preventive medical care, to prevent in advance the spread of hay fever and influenza in public spaces where many people gather, such as hospitals, nursing facilities for the elderly and offices.

As a result of these increasing requirements, and because it is a sector that rival companies have not yet entered, we believed that growth could be expected as a new business and developed the "Purewasher" humidifying air purifier with the aim of entering the commercial humidifying air purifier market.

2. Development concept and goals

2-1 Development concept

The goal was to enter the commercial humidifying air purifier market with an original product to establish a business base and the following items were selected as the concepts for the development.

(1) A single air cleaner can be used to humidify, sterilize, remove dust and deodorize in a large public space
(2) Air cleaning using the power of water, by applying the air washers used in cleanrooms, etc.
(3) Differentiation from the products of other companies that use electrolyzed water (Electrolyzed water take-out function, sterilization in the machine)
(4) Specifications that are close to end user specifications, without going through a design office, general contractor or sub-contractor (Standalone type instead of build-in duct or machine room type)
(5) Design and high operability suitable for public spaces such as offices, hospital waiting rooms and stores

2-2 Target values

The following technological development targets were established based on the needs of target markets such as hospitals and nursing care facilities for the elderly, and on surveys of products from other companies.

(1) Applicable floor area ··· 150 - 200 m^2 (In-house standards for air cleaning)
(2) Humidification performance ··· 2.7 kg/h (At 20°CDB and 30% RH)
(3) Sterilization performance ··· 99% removal of airborne bacteria and airborne viruses (JEM 1467)
(4) Deodorizing performance ··· 90% or more decrease in ammonia concentration within 30 minutes (compared with natural attenuation ratio)
(5) Electrolyzed water take-out function
(6) Design suitable for a public space

3. Technical issues to be solved

The following four items were the technical issues that became particularly important in the development of the new Purewasher product.

(1) Making an air washer more compact and securing performance
An air washer is incorporated into an AHU type air conditioner for a cleanroom. It sprays atomized water against the airflow. In order to install this equipment in a humidifying air purifier for public spaces, it is necessary to reduce the size of the equipment and also to secure the humidification, sterilization, dust removal and deodorization performance.
(2) Securing sanitary conditions inside the Purewasher
The use of water inside equipment can be a factor of bacteria propagation.

In order to make it possible to use the product for a long time, it is essential to have a means of preventing bacterial propagation inside the equipment. It is also necessary to have a structure that makes maintenance easy, especially around the wet area.

(3) Addition of electrolyzed water take-out function
It is necessary to add a function utilizing electrolyzed water to promote the sterilization performance of electrolyzed water and to enhance the added value of the product, to differentiate it from the products of other companies.
(4) Design and high operability suitable for a public space
As a humidifying air purifier for public spaces, it is necessary to have a design that promotes the air cleaning function and also has a sense of presence and high quality, as well as high operability so that it can be operated intuitively.

4. Developed technology

4-1 Making an air washer more compact and securing performance

4.1.1 Making an air washer more compact

As the Purewasher is for installation indoors, the development was conducted with a target main body height of 1,900 mm or less, so that it can be carried into a room via an elevator. For this purpose, it was necessary to reduce the size of the air washer and to make the maximum use of the space available to secure the performance.

If the size of an air washer is kept the same, then in order to improve the performance, it is important to increase the gas-liquid contact efficiency and to suppress the pressure loss in the air flow path to secure the flow rate. Therefore, jet nozzles and gas-liquid contact media that satisfy the following conditions were set as the candidates for selection.

(1) Spray nozzle

The candidates were set as spray nozzles that have a small nozzle hole and large jet angle, in order to increase the gas-liquid contact efficiency, and a low spray pressure, in order to reduce the pump power.

(2) Gas-liquid contact media

The candidates were set as media with a structure and material capable of both water retention and low pressure loss while also being easy to clean and making it difficult for bacteria to propagate.

We selected nozzles and media of several different types based on (1) and (2) and conducted performance tests.

The specification chosen for the spray direction from the nozzle was for the spray to be the direction along the media as shown in the figure. The aims were both the wetting of the media and the humidifying effect of spatial spraying. In addition, by placing the media obliquely, we reduced the overall size and created a structure in which water does not easily accumulate when the operation is stopped. The nozzle adopted was one that sprays in a fan shape, and the media selected was a SUS material mesh with a wave-fold structure. After deciding the specification, we conducted the performance evaluations below and confirmed that the target performance had been satisfied.

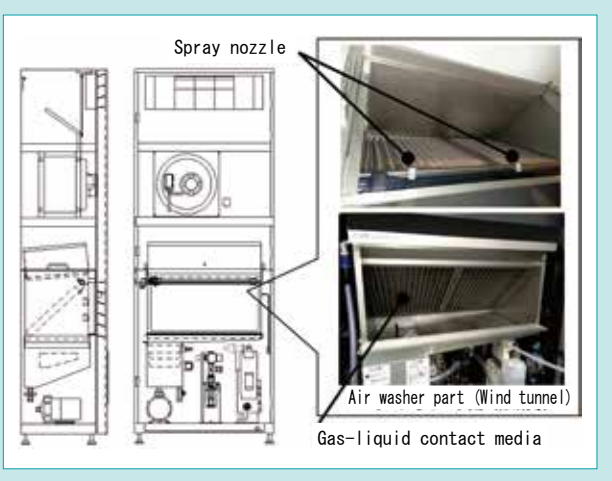


Fig. 1 Construction of Air Washer

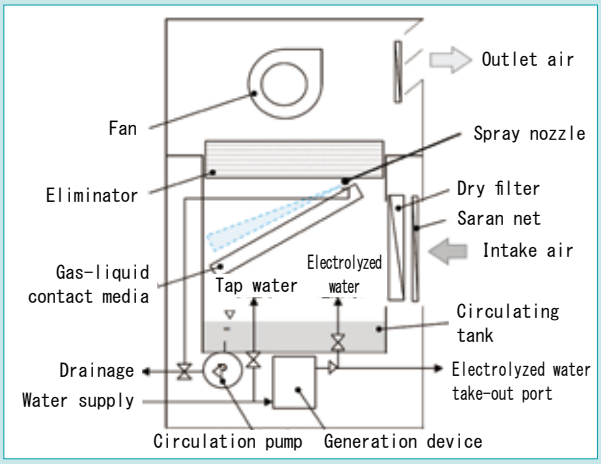


Fig. 2 Flow Diagram of Purewasher

4.1.2 Performance evaluation [1]: Sterilization performance

The sterilization testing was conducted by an external organization in accordance with the Japan Electrical Manufacturers' Association standard JEM 1467 "Household air cleaner."

(1) Airborne bacteria and airborne viruses

After using a nebulizer to spray microorganisms (bacteria and viruses) in a test space of 25 m^3, we captured the airborne microorganisms with an impinger and checked the changes in the airborne microorganism concentration over time (Fig. 3). The reduction rate compared to the natural attenuation was more than 99% at 10 minutes. Also, the effect of the air washer on the removal of airborne microorganisms was recognized from the difference in effect to that when operating with the dry filter (colorimetric method 65%) only.

(2) Attached viruses

A Petri dish onto which a virus (coliphage) was dropped was placed in a test space of 25 m^3 and the Purewasher was operated. The Petri dish was then removed every predetermined time and the number of viruses attached to the Petri dish was measured (Fig. 4). The reduction rate in the number of viruses compared with the natural attenuation was more than 99% at 60 minutes. In addition to the ability to take in and eliminate pollutants inside the machine, the effect in suppressing attached viruses in the room was also recognized.

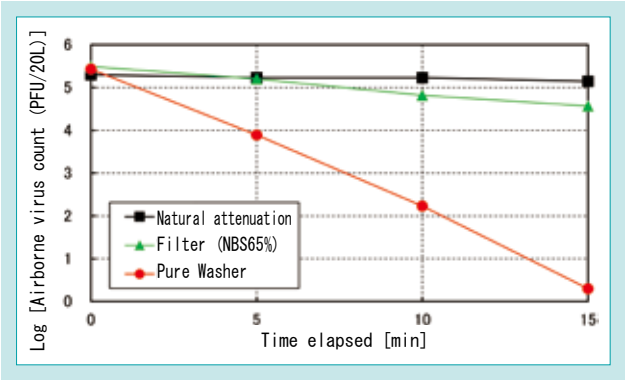


Fig. 3 Evaluation Test Result of Airborne Virus Elimination

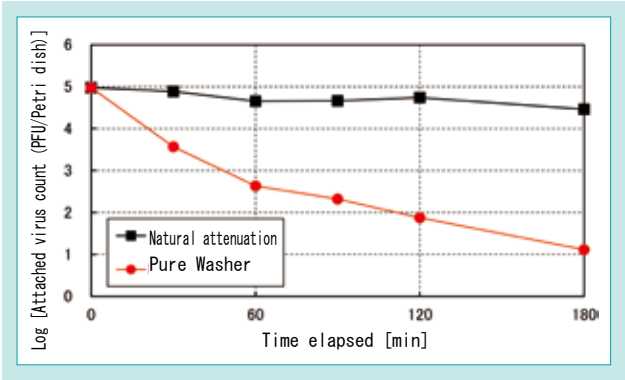


Fig. 4 Evaluation Test Result of Attached Virus Elimination

4.1.3 Performance evaluation [2]: Deodorizing performance

The 25 m^3 test space was filled with an initial concentration of 8.7 ppm of ammonia (odor intensity 3.5 to 4) and then the Purewasher was operated. We then used a chemiluminescence method three-state nitrogen gas analyzer to check the change in the ammonia concentration over time (Fig. 5). Tests using a dry filter (colorimetric method 65%) were also conducted for comparison.

The reduction rate of the ammonia 30 minutes after starting the operation of the Purewasher was 92% (compared with natural attenuation ratio), so the deodorizing effect of the air washer on the water-soluble odor components was recognized. Based on these results, we set the cycle in which all of the circulating water is replaced as variable in the range of 20 to 60 minutes and made it possible to set the deodorizing force arbitrarily.

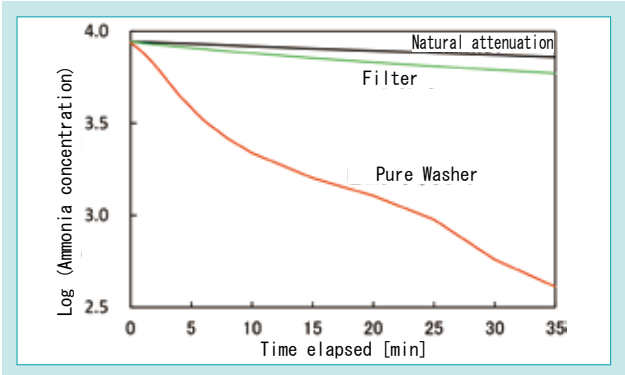


Fig. 5 Change Over Time in NH_3 Concentration

4.1.4 Performance evaluation [3]: Humidification performance

In order to demonstrate humidification performance in a large space, two Purewashers were installed in the factory canteen (Floor area: 350 m^2) of a food manufacturer. They were operated and stopped repeatedly every other week for about two months from January to March. Figure 6 shows the test results. The relative humidity during the period when the Purewasher was not operated was in the 20-30% range, but 42-54% (average 50%) was maintained during the operation.

In order to inactivate the influenza virus, it is thought desirable to maintain the humidity at 40% or higher. In this factory, the Purewasher was installed in the canteen, where the employees gather, and the objective was to prevent the spread of influenza, especially during the dry winter season. This verification test confirmed the expected effects.

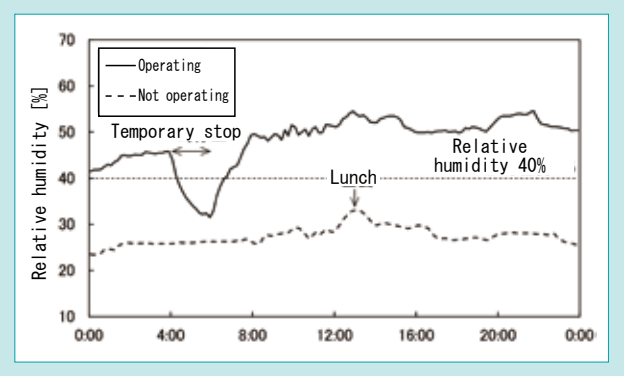


Fig. 6 Indoor Relative Humidity of Factory Canteen

4-2 Securing sanitary conditions inside the Purewasher

4.2.1 Selection of disinfectant

We selected slightly acidic electrolyzed water as the disinfectant to ensure that sanitary conditions are maintained inside the Purewasher. The reasons for this include: [1] It has been designated as a food additive and a specific control material; [2] It is safe for anyone to use because it has sufficient sterilizing ability even at low concentrations (Effective chlorine concentration of approximately 30 mg/L), compared to other hypo disinfectants; [3] It has a broad bactericidal spectrum and is highly effective against norovirus, fungi and spores; and [4] It does not precipitate salts because it is made from hydrochloric acid. It is effective as a disinfectant and also satisfies the various other conditions such as safety performance suitable for use in residential spaces and low corrosiveness.

4.2.2 Implementation of a cleaning operation mode

In order to effectively disinfect the inside of the machine with slightly acidic electrolyzed water, we considered a cleaning operation mode in which the effective chlorine concentration would be increased (to about 30 mg/L) compared with the normal operation mode. Figure 7 shows the results of the measurement of the number of bacteria in the water in the circulating tank after repeated times in the cleaning operation for five minutes per time. With washing using tap water, the number of bacteria in the water did not become less than 300 cfu/mL. However, we confirmed that with washing using electrolyzed water, the number of bacteria in the water decreased as the number of washes increased, and approached 0 cfu/mL after about four times (a cumulative total of 20 min).

(cfu: Colony forming unit. An index indicating the number of living cells.)

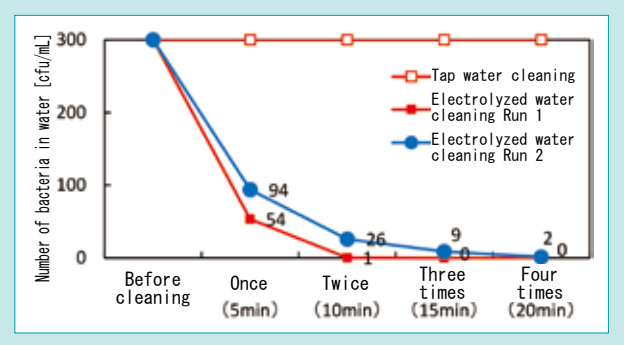


Fig. 7 Relationship Between Number of Times Electrolyzed Water Cleaning is Performed and Number of Water-borne Bacteria

In order to check the source of bacteria after the resumption of operations, we measured the number of bacteria in the circulating water after washing with electrolyzed water for the case when a new eliminator is used and the case when a used eliminator is used (Fig. 8). With a used eliminator, the count exceeded 300 cfu/mL in three minutes after the start of the operation. With a new eliminator, the count reached 258 cfu/mL in 30 minutes, but did not exceed 300 cfu/mL. Therefore, the eliminator is considered to be one of the main sources of the bacteria in the water that increase after the start of the operation. From these results, we selected a specification in which the fan is operated during the cleaning operation, so that the eliminator can also be cleaned during the cleaning operation, ensured that the electrolyzed water can reach the eliminator, and also decided that the eliminator should be replaced during periodic maintenance.

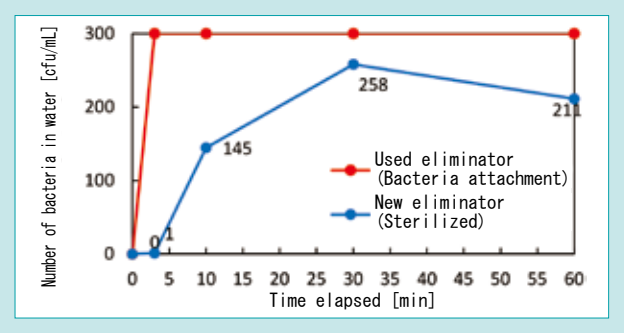


Fig. 8 Change Over Time in the Number of Water-borne Bacteria After Electrolyzed Water Cleaning

4.2.3 Verification of the suppression effect for the bacteria and slime in the circulation tank and wind tunnels

During the monitor testing, there was a case in which a slime (a biological slime or biofilm formed by bacteria) was generated around the wet parts in the machine due to the installation environment. In order to suppress slime and ensure that there are sanitary conditions inside the machine, we implemented a cleaning operation mode with specifications decided from the tests above, a drying operation mode to dry the inside of the machine by blowing air, and an electrolyzed water storage mode in which electrolyzed water is stored in the circulation tank while the operation is stopped. We checked the effects of these operation modes in field tests and confirmed that the slime suppression effect was greatly improved (Fig. 9).

Fig. 9 Confirmation of Slime Elimination Effect During Field Tests

4.2.4 A structure that makes maintenance easy

A periodic inspection of the wet areas is indispensable in order to ensure that there are sanitary conditions inside the machine. In order to reduce the maintenance load, the ease of inspection was prioritized in the design, especially regarding the wet area structures. For the wind tunnels, the structure designed makes it possible to separate the side part and the bottom part, to make it easy to clean the dirt that accumulates in the bottom part. Also, for the eliminator, a unit was created by putting a resin eliminator for high-speed air and a SUS eliminator for low-speed air together in one SUS frame. The structure was then designed so that it is only necessary to place that unit at the outlet of the wind tunnel section, so this makes installation and removal easy (Fig. 10).

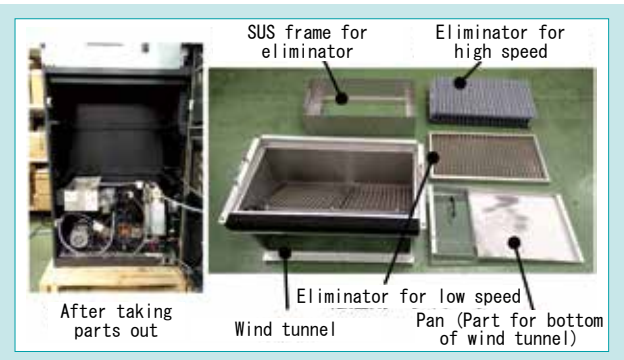


Fig. 10 Plumbing Component Parts

4-3 Addition of electrolyzed water take-out function

When slightly acidic electrolyzed water is produced from hydrochloric acid, which is its raw ingredient, the running costs are less than 10 yen per liter (Raw material chemicals + Electricity + Water). As the market price for slightly acidic electrolyzed water varies from several hundred yen to a thousand yen per liter (according to our own company survey), the cost benefits for producing it increase the greater the volume used. Therefore, a function that makes it possible to take out electrolyzed water was added as a function for differentiation from the products of other companies. By switching the flow path of the electrolyzed water generation line, electrolyzed water can be taken out from the machine via a small door on the lower part of the machine body (Fig. 11). The following issues became especially important during the development.

Fig. 11 Produce of Slightly Acidic Electrolyzed Water

4.3.1 A structure allowing variable take-out nozzle height

In order to cope with containers of various heights when taking the electrolyzed water out, the take-out door was made into a hinged structure so that the height of the nozzle can be changed. The hinges used were torque hinges to make it possible to secure the nozzle at any height (Fig. 11).

4.3.2 Prevention of water dripping from the take-out nozzle

During the development, there was an occasion when the electrolyzed water in the hose after the take out dripped and wet the inside of the machine. As a solution, we changed the hose inner diameter on the take-out path from 6 mm to 8 mm. We increased the inner diameter of the hose to make it easier for air to flow back after the take out, and this reduced the amount of electrolyzed water that accumulates in the hose. We also installed an evaporation sheet below the take-out nozzle (Fig. 12). Any electrolyzed water that drips from the nozzle is absorbed by the evaporation sheet and evaporated.

4.3.3 Intuitive operation panel

In order for the users to use the product without stress, we made it possible to operate the taking out of sterilized water intuitively on a touch panel. We also mounted a video explaining the take-out operation procedure and made it possible to refer to it during the take out (Fig. 11 right).

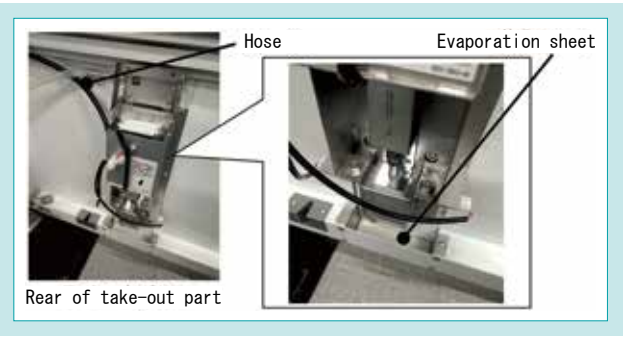


Fig. 12 Rear View of Produce Part

4-4 Design and high operability suitable for a public space

Another important element to raise the added value of the product was to design it to be appropriate for various installation environments as a humidifying air purifier for public spaces. In addition to increasing the efficiency of the air washer to reduce the main body size, we also improved the design. The concept selected was "A sense of presence and luxury for use in public spaces, in a unique design unlike the products of other companies."

To prioritize the appearance and the operability, the specification chosen was to install a 9-inch wide viewing angle touch panel on the front of the main body. High operability is realized by intuitive operation using a touch panel. At the same time, a high-class feeling is created with graphics, such as by displaying an animation publicizing the cleaning of the air using water during operation. In addition, blue LEDs were installed on the air outlet to publicize the air cleaning function. At the 47th Machinery Industrial Design Awards sponsored by the Nikkan Kogyo Shimbun, the Purewasher received the Japan Society of Industrial Machinery Manufacturers Award.

It has been highly rated by end users and stores as a design that has a high-class feeling that matches use indoors.

Fig. 13 External Appearance of Purewasher

5. Conclusion

We developed a commercial humidifying air purifier for public spaces which had the core technologies of the water spraying technology of air washers for cleanrooms, and the bacteria elimination technology using slightly acidic electrolyzed water. As the product was to be for indoor installation, we reduced the size of the air washer from the size used for cleanrooms. At the same time, for its performance, we achieved the targets for humidification, sterilization and deodorizing performance. By using slightly acidic electrolyzed water as the disinfectant, we achieved both safety and the maintenance of sanitary conditions inside the Purewasher. Also, the addition of a function to take out slightly acidic electrolyzed water differentiates the product from those of other companies and increased the added value of the product. In the future, we will continue to improve quality and reduce costs, and we will aim for further business expansion through the development of a series of products based around the core technologies of this product.

Contribution to SDG targets

3.3 Eradication of communicable diseases and response to infectious diseases	Contribution to the prevention of infectious diseases that are transmitted through the air

Development of New Earthquake-Resistant Ductile Iron Pipe US-R Type for Piping in Shield Tunnel

Pipe Systems Networks R&D Dept.

Recently, many large-diameter water pipeline renewal projects are being planned for large-scale water supply utilities. Construction of a large-diameter pipeline is often performed in a shield tunnel constructed under the road, and earthquake-resistant ductile iron pipes US type, which have a proven record, have been adopted to date. However, as competition in the steel pipe sector intensified, we got some hints from customers about improving the US type, such as shortening the construction period and reducing the installation cost at the curved sections of the shield tunnel. In order to respond to their demands, we developed a new earthquake-resistant ductile iron pipe, the "US-R type".

【Key Word】
New Rubber Gasket, Lock Ring Supporter, Angled Straight Pipe, Shortening the Construction Period, Reduction of Pipeline Laying Cost

Related SDGs

1. Introduction

Large-scale disasters have occurred frequently in recent times and it is said that the water supply facilities in Japan must be strengthened in order to provide a stable water supply. However, many of the main pipelines that were constructed during the period of high economic growth have aged and it has been a long time since they became due for renewal. Under such circumstances, large-scale enterprises such as the Tokyo Metropolitan Government and Yokohama City have started to actively plan the renewal of the large-diameter main pipelines.

Large-diameter pipe construction is often carried out in a shield tunnel constructed under roads, due to the large space occupied and the traffic conditions (Fig. 1). In this construction work, the main type used so far has been US type ductile iron pipes (hereinafter called "US type"), which have proven past results.

However, in recent years, the situation of underground usage has meant that the shield tunnels constructed are often curved.

As a result, the long periods required for pipe construction in curved sections and the increases in pipe material costs have been considered to be problems. On the other hand, competition with steel pipes has intensified in the large-diameter market. There are demands for products which are superior in terms of ease of construction and costs, while also ensuring the same level of earthquake resistance and durability as conventional products. We therefore developed a new US-R type large-diameter earthquake resistant pipe (for target nominal diameters of 1500 to 2600) for piping in shields.

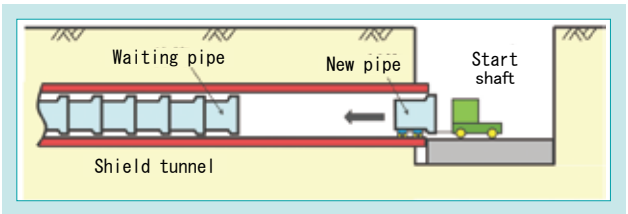


Fig. 1 Image of Water Pipe Construction in Shield Tunnel

2. Development concept

Figure 2 shows the development concept for the US-R type.

- We decided to develop a new joint which can solve the issues for the installation of the US type joints.
- To reduce the pipeline installation costs to the same level as or less than that of competing steel pipes, we decided to develop a straight pipe with an angled joint that would be capable of reducing the cost of curved sections.
- Ductile iron pipes have the advantage that the construction period for them is short. In order to make that superiority even more certain, we decided to develop a method for the simultaneous transportation of multiple pipes.

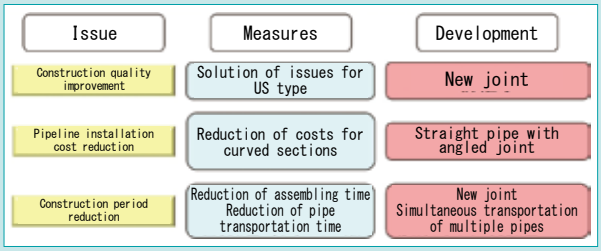


Fig. 2 Development Concepts of US-R Type

3. Issues to be solved

The problems to be solved in the development of new joints, straight pipes with angled joints and a method for the simultaneous transportation of multiple pipes are described below.

(1) New joints

[1] Realization of a watertight mechanism with clear construction management

With the US type, the spigot is inserted into the socket and then a pressing ring and bolt are used to insert a rubber gasket between the spigot and socket to ensure watertightness. In the tightening work for this bolt, it was previously necessary to use two different methods of construction management, namely, the amount of screw out of the bolt and the tightening torque value. This construction management was entrusted to the worker (Fig. 3 top). In order to clarify the construction management method regardless of the worker, there were demands for the realization of a new watertight mechanism that does not use bolts.

[2] Abolition of complicated mortar filling work

In the joining of the US type joints (Fig. 3 bottom), there is a process step for filling with mortar to prevent the rusting of the joining part (bolts and joining rods). The work for this filling with mortar is complicated and requires a high level of skill, so there were many requests for its improvement, including by its abolition.

[3] Realization of a disengagement prevention mechanism capable of shortening the joining time

In order to produce disengagement prevention performance on a large-diameter pipe, it is necessary to have a part to ensure that the lock ring is adhered to the outer surface of the spigot. On the US type, rubber to squeeze the lock ring is used as this part. However, as it is necessary to pass the spigot through it during the joining, it is necessary to first increase the diameter of the lock ring, and this work took time (Fig. 4). There were demands for a new disengagement prevention mechanism that can shorten the joining time by facilitating the work to increase the diameter of the lock ring, while also maintaining the disengagement prevention performance.

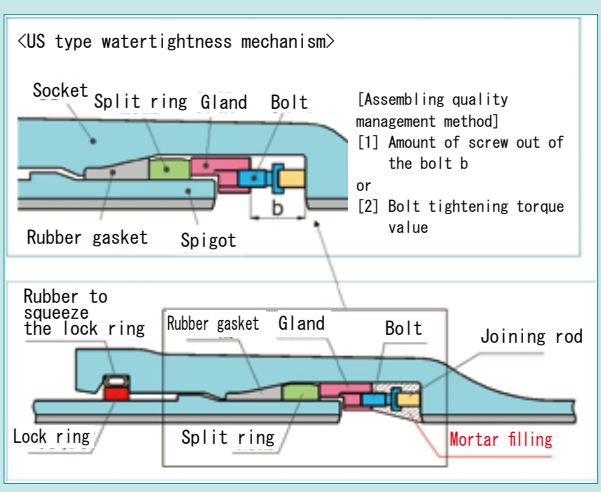


Fig. 3 Structure of US Type Joint

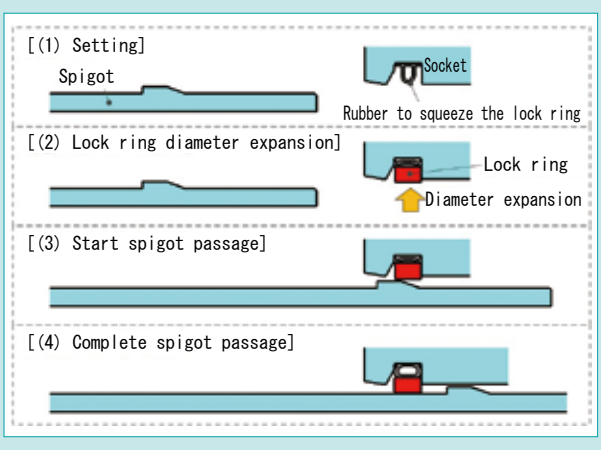


Fig. 4 Assembling Process of US Type Joint

(2) Straight pipes with angled joints

In the curved sections of piping in a tunnel, the piping is often formed with a combination of curved pipes and straight pipes (Fig. 5). The cost of curved sections is higher than the cost of straight sections, because the manufacturing methods for curved pipes make them more expensive and also their pipe length is shorter.

The frequency of these curved sections has increased and it has become impossible to ignore the high cost of curved sections, so there have been increasing calls for cost reduction.

(3) Method for simultaneous transportation of multiple pipes

In piping in a tunnel, the distance from the departure shaft to the piping position in the tunnel can be several kilometers. The pipes are carried one by one on a bogie (Fig. 6), so the further the construction extends, the longer the time required for the pipe transportation becomes. It has been pointed out that this can cause a loss of construction time, such as when having to wait before conducting joining work.

There were demands for a method which can eliminate this loss of construction time.

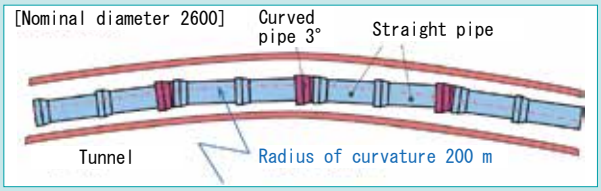


Fig. 5 Example of Piping in Curved Sections

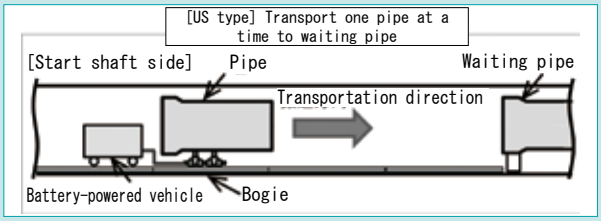


Fig. 6 Pipe Transport in the Shield Tunnel

4. Developed technology

4-1 New joints

4.1.1 US-R type joint structure

Figure 7 shows the joint structure for the US-R type.

The structure has the joint parts covered at the spigot to eliminate the mortar filling work, which is complicated and difficult. In addition, cost reduction was achieved by reducing the weight of the pipe, such as by shortening the socket, and by reducing the number of joint parts (from 7 to 5 parts).

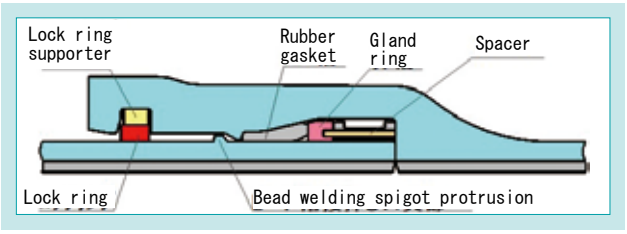


Fig. 7 Joint Structure of US-R Type

The basic performance (watertightness and earthquake resistance) of the joint was made equivalent to that of the US type (Table 1).

Table 1 Performance Target of Earthquake Resistant Joint

Item	Performance target
Joint expansion/ contraction	+1% of the pipe length
Disengagement prevention force	3 DkN (D: Nominal diameter [mm])
Allowable bending angle	Equivalent to the US type
Maximum bending angle that can be bent during an earthquake	Equivalent to the US type
Watertightness	Equivalent to the US type

4.1.2 Watertight mechanism

(1) New profile rubber gasket

In order to clarify the construction management, we devised a new rubber gasket profile which can absorb the tolerance of the pipe. The current rubber gasket is composed of a round bulb portion and an angled wedge portion. The bulb part is compressed between the socket and the spigot for watertightness. On the new rubber gasket profile, the bulb part is the same as that of the US type, but a clearance was provided on the wedge part (Fig. 8).

When the part accommodating the rubber gasket is large, the rubber gasket is pushed in as it is. When the part accommodating the rubber gasket is small, the wedge part is compressed and it deforms to fill the clearance (Fig. 9). As a result, the tolerance of the pipe can be absorbed without using bolts, so the watertightness can be secured by just installing a spacer of a certain length. This made it possible for the construction management to become just a check that a spacer is installed normally.

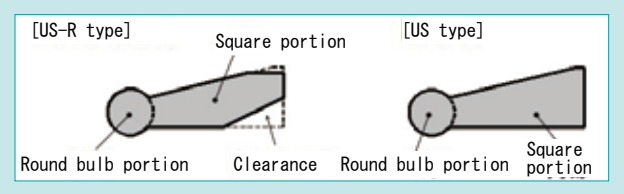


Fig. 8 Rubber Gasket Sectional View

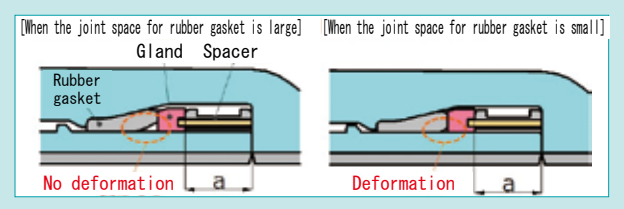


Fig. 9 Deformation of Rubber Gasket due to Clearance Between Socket and Spigot

(2) Investigation of rubber gasket behavior

In order to investigate the behavior of the rubber gasket with the new profile at the time of joining, we implemented FEM analysis and an investigation of the cross sections of actual items.

[1] FEM analysis

In the results of FEM analysis to check the behavior of the rubber gasket at the time of joining, it was confirmed that the bulb part of the rubber gasket with the new profile fits in the prescribed position in the same way as the current rubber gasket (US type). In addition, the stress distribution in the bulb part of the rubber gasket after joining was equivalent to that of the current rubber gasket (US type) (Fig. 10).

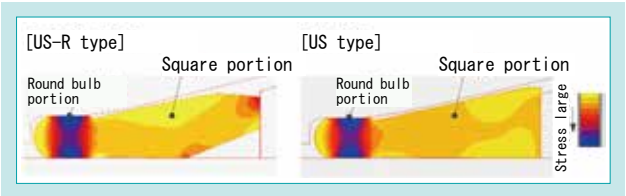


Fig. 10 Result of FEM Analysis of Rubber Gasket

[2] Cross-sectional investigation of actual items

We used an actual joint cross section and rubber gasket piece and investigated the cross section of the rubber gasket at the time of joining. In the results, it was confirmed that the wedge part was compressed and deformed into the clearance according to the size of the socket-spigot gap, and that the rubber gasket was fitted in the predetermined position as designed (Fig. 11).

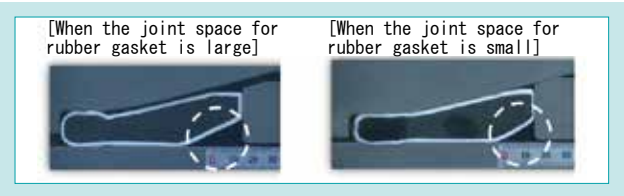


Fig. 11 Result of Section Survey of Rubber Gasket

(3) Measurement of the surface pressure of the rubber gasket

We measured the surface pressure after the rubber gasket was joined by using a cross section investigation using the test piece and the joining of actual pipes. As a result, it was confirmed in both investigations that the surface pressure after joining was the same as that of the current product, and that the value was sufficient to ensure watertightness (Table 2).

Table 2 Face Pressure Measurement Result for Rubber Gasket

Condition			Face pressure measurement results	
Nominal diameter	Investigation method	Socket–spigot gap	US–R type	US type
2600	Cross–sectional investigation	Standard	1.1MPa	—
		Maximum	0.8MPa	0.7MPa
	Actual pipe investigation	Maximum	0.6MPa	0.6MPa

4.1.3 Disengagement prevention mechanism

To facilitate the work to increase the diameter of the lock ring to allow the spigot to pass through it during joining, we devised a lock ring supporter which is assembled by alternately connecting support pieces (stainless steel plate) and resin pieces (Fig. 12). The support pieces press the lock ring against the spigot, and the resin pieces are parts to evenly arrange the support pieces circumferentially. As the support pieces are arranged intermittently rather than around the entire circumference, the force when increasing the diameter of the lock ring can be greatly reduced compared with the US type using rubber to squeeze the lock ring. As a result, for a nominal diameter of 2600, we were able to shorten the setting time by 35%. In addition, it was confirmed that the state of adhesion of the lock ring after joining was equivalent to that of the US type.

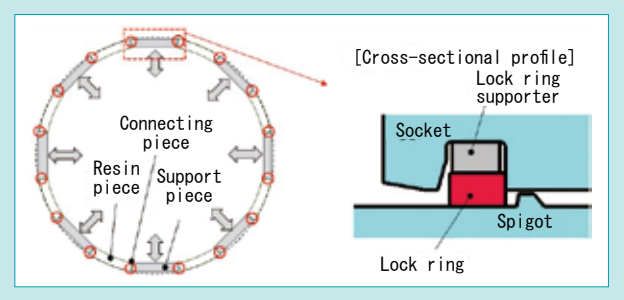


Fig. 12 Lock Ring Supporter

4.1.4 Performance evaluation (For nominal diameter 2600)

In order to evaluate the performance of the new joint, we performed a joint test, a separation prevention performance test and a watertightness test on a straight pipe with a nominal diameter of 2600.

(1) Joint test results

Through the development of the rubber gasket with a new profile and the lock ring supporter, the work time was reduced by 43% from the 99 minutes for the US type to 56.5 minutes (Fig. 13).

(2) Separation prevention test results

After the joint was extended by 1% or more of the pipe length as a result of a tensile force to the joint, it was confirmed that the joint could withstand a tensile force of 3 DkN (D: Nominal diameter mm) and that the joint did not pull out (Fig. 14).

(3) Watertightness test results

It was confirmed that there was no water leakage even when 2.0 MPa of water pressure was applied under the conditions of being completely straight, being bent and being flexed repeatedly in the conditions assumed for earthquakes (Table 3).

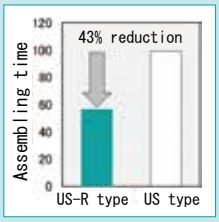


Fig. 13 Comparison of Assembling Time

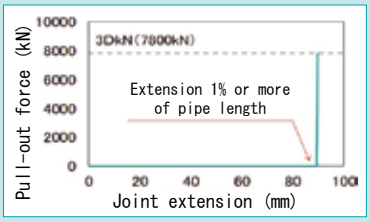


Fig. 14 Result of Pull-Out Resistance Performance of Joint

Table 3 Result of Water-Tightness Test

Test conditions					Test results
Nominal diameter	Joint condition	Bending angle	Load water pressure	Retention time	
2600	Straight state	0°	2.0MPa	5 minutes	No leakage
	Deflected state	1° 50'	2.0MPa	5 minutes	No leakage
	Repeated Deflecting 20 times	1° 50'	2.0MPa	5 minutes	No leakage

4-2 Straight pipes with angled joints

4.2.1 Straight pipes with angled joints

Straight pipes with angled joints are straight pipes that have the inner surface of the socket formed at an angle. They can be produced with the same centrifugal casting as straight pipes, so they are cheaper than curved pipes.

The joint structure is the same as that on a straight pipe, and the assembling method is also completely the same (Fig. 15).

As is shown in the upper part of Figure 16, with the US type, in most of the curved sections of piping in a tunnel, the curved piping route is formed from a combination of straight pipes and curved pipes. On the other hand, with the US-R type, curved piping can be formed by connecting a straight pipe to a straight pipe with an angled joint (Fig. 16 lower part). It is therefore possible to form a curved piping route by using a straight pipe with an angled joint instead of a curved pipe. As a straight pipe with an angled joint has a long pipe length, the number of pipes can also be reduced. A pipeline constructed by the US-R type can greatly reduce the pipeline installation cost in curved sections.

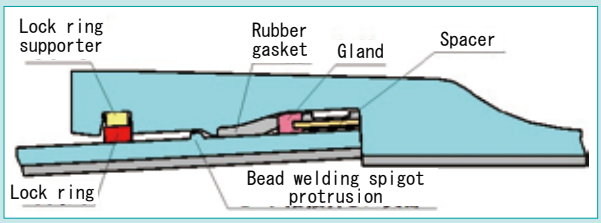


Fig. 15 Joint Structure of with angled joint Straight Pipe

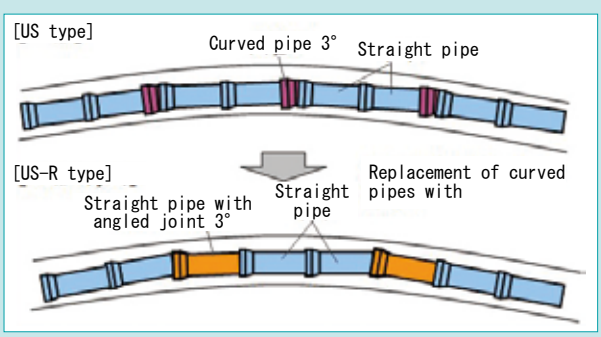


Fig. 16 Comparison of Piping in Curved Sections

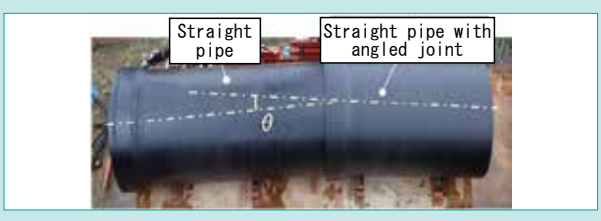


Fig. 17 Example Piping Using with angled joint Straight Pipe

4.2.2 Performance evaluation (For nominal diameter 2600)

In order to evaluate the performance of the straight pipe with an angled joint, we performed a joint test, a separation prevention test and a watertightness test on a straight pipe with an angled joint with a nominal diameter of 2600, in the same way as for the straight pipe. As a result, it was confirmed in all the tests that it had performance equivalent to that of the straight pipe, and that it can be used as a substitute for a curved pipe without any problem.

4-3 Method for simultaneous transportation of multiple pipes

4.3.1 Method for simultaneous transportation of multiple pipes

For pipe transportation for piping in a tunnel, instead of the conventional method of transporting one pipe at a time, we developed a method for the transportation of multiple pipes simultaneously. If multiple pipes can be transported simultaneously, then in cases where the construction extends a long distance, the daily progress (the length of construction extension per day) can be increased and the construction period can be shortened.

The two-pipe simultaneous transportation method is described below as an example.

When two pipes are transported at the same time, a problem arises as shown in Figure 18.

After joining the front pipe, the empty front bogie and the connecting rod between the bogies (Part A) become an obstacle, and the rear bogie and the rear pipe cannot be moved to the piping position.

We therefore developed a mechanism for the disconnection of the bogies so that the rear pipe can be transported to the piping position. As shown in Figure 19, the connecting rod between the bogies is removed and the front bogie is stored under the rear pipe.

Figure 20 shows the disconnection mechanism. When releasing the connection, the operator pulls the operation lever and the support plate comes off. The operator can remove the bogie connecting rod without entering under the pipe.

4.3.2 Performance evaluation (For nominal diameter 2600)

In order to evaluate the ease of operation of the two-pipe simultaneous transportation method, we measured the work time in the simulated tunnel shown in Figure 21. Table 4 shows the results of the work time measurement.

As a result, it was found that the work time was shorter than the target work time (the time required for joining one joint) and that the ease of operation was good.

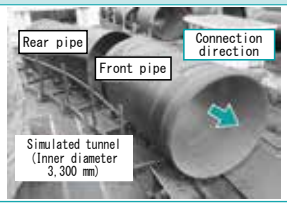


Fig. 21 Test Status

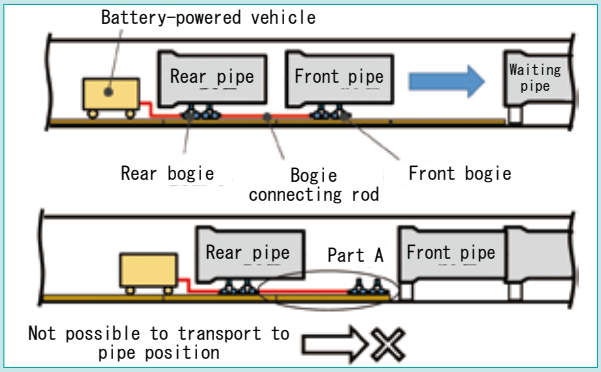


Fig. 18 Problem When Transporting Two Pipes

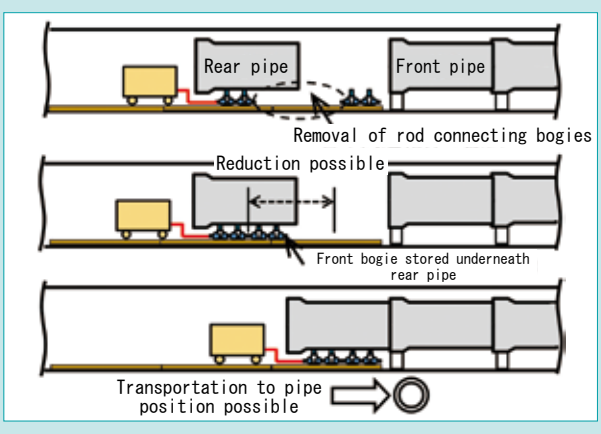


Fig. 19 System that Can Shorten the Space between Bogies

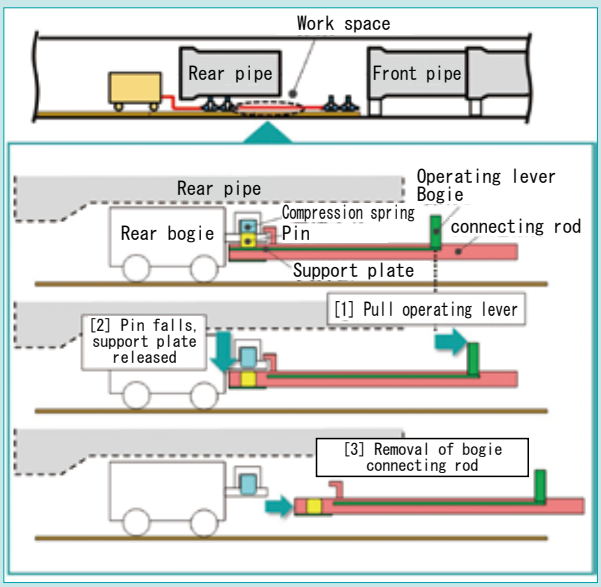


Fig. 20 Uncoupling System

Table 4 Result of the Operation Time

Test details		Work hours	Test results
Nominal diameter	Main work		
2600	Release of bogie connecting rod	7 minutes 29 seconds	○
	Storage of front bogie under rear pipe		
	Reconnection		

5. Effects of the development

Table 5 shows an example of the design results for a 3.5 km model pipeline with a nominal diameter of 2600 constructed with the US-R type.

Although 148 curved pipes are necessary when using the US type, it is possible to replace these with 137 straight pipes with angled joints, and the number of joints can be reduced from 861 to 824.

As a result, the pipeline installation cost could be reduced by 29% from the US type, and the cost could be reduced to a level equivalent to that of steel pipes (Fig. 22).

Table 5 Design Example of Model Pipeline (Nominal Diameter2600×3.5km)

Joints	Straight pipes (No. of pipes)	Fittngs (No. of pipes)	Straight pipes with angled joints (No. of pipes)	Number of joints (Joints)
US type	712	148	—	861
US-R type	676	10	137	824

With the inclusion of the effects of the faster joining speed for the joints and the method for the simultaneous transportation of multiple pipes, the construction period could be shortened by 26% from that for the US type and it was possible to further expand the difference to steel pipes (Fig. 23).

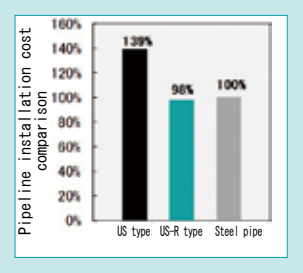


Fig. 22 Comparison of Pipeline Installation Cost

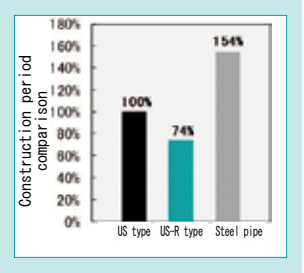


Fig. 23 Comparison of Construction Period

6. Conclusion

We developed a new US-R type for earthquake-resistant ductile iron pipes with improved product competitiveness for the large diameter market.

Through the development of (1) New joints, (2) Straight pipes with angled joints and (3) A method for the simultaneous transportation of multiple pipes, the US-R type was able to realize “Improved construction quality,” “Reduced pipeline installation costs” and a “Shortening of the construction period.”

We are currently developing activities for the adoption of the technology and adoption is advancing at large enterprises such as the Tokyo Metropolitan Government. The first construction of the technology is scheduled to start from March 2020 in Tokyo, on a pipeline with a nominal diameter of 2600. We expect that full-scale adoption will accelerate further in the future.

We will continue to develop products and construction methods that can contribute to the seismic reinforcement and renewal of main pipelines.

Contribution to SDG targets

6.1 Strengthening access to safe and affordable drinking water	Contribution to water supply and sewerage infrastructure development by providing water pipe materials with reduced pipe laying costs
9.1 Development of high-quality, sustainable and resilient infrastructure	Contribution to the development of sustainable and resilient infrastructure by providing long-life earthquake-resistant pipes that are resistant to natural disasters

Development of AFTALLOY+MERT as a Cracking Tube for Ethylene Production

Steel Castings Technology Dept.

Cracking tubes are a key part of an ethylene plant in the petrochemical industry. Recently, there has been an increase in the number of plants, especially ethane cracking furnaces, adopting alumina forming tubes because highly efficient production can be expected due to their coking- and carburizing-resistant properties. On the other hand, Kubota's proprietary technology, MERT (Mixing Element Radiant Tube), has been adopted in over 600 furnaces, mainly naphtha furnaces, since MERT was developed about 20 years ago. Therefore we have developed a top level functional product "AFTALLOY+MERT" which is a combination of AFTALLOY (Kubota's alumina forming tubes) and MERT technology. It has been installed in a commercial ethane cracking furnace of a major ethylene producer for performance evaluation. The results of the evaluation verified the excellent properties of the new product compared with the original MERT.

In this paper, we report on our development activities and the results.

【Key Word】
Cracking Tube, Coking, Mixing Element, Plasma Powder Arc Welding, Alumina Forming

Related SDGs

1. Introduction

1-1 Background of the development

Cracking tubes for ethylene production (hereinafter, called "cracking tubes") are a core component in production plants producing ethylene, etc., (hereinafter, called "ethylene plants") in the petrochemicals industry. They are heated to about 1,000 to 1,100°C by a heat source on the outside of the tubes. This thermally decomposes the ethane, naphtha and the like, which flows down the tubes and produces ethylene and the like (Fig. 1)[1]. At this time, the carbon generated (hereinafter called "coke")[2] adheres to the inner surface of the tube. This coke, which has low thermal conductivity, accumulates in the tube (hereinafter called "coking": Fig. 2), and the resulting drop in thermal conductivity causes an increase in the tube temperature and an increase in the pressure drop. Therefore, when the tube temperature reaches the allowable material temperature, or when the pressure drop reaches the allowable upper limit, the operations must be stopped for the coke removal operation (hereinafter called "decoking"). This reduces the utilization rate of the ethylene plant and the ethylene productivity.

Kubota has supplied its original MERT[*1] technology as one solution to this problem that is experienced by customers. This technology was developed over 20 years ago. The development of the technology has been continued since, such as to reduce the increase in pressure drop by improving the design of the mixing elements, which can be a factor increasing the pressure drop (Fig. 4). As a result, by May 2019, MERT had been supplied to more than 600 furnaces in 21 countries and regions around the world, mainly for cracking furnaces for naphtha raw materials (hereinafter called "naphtha furnaces") (Fig. 5). Our competitors do not have similar products that can rival this MERT technology and it is making a contribution as a core product in Kubota's roughly 50% share of the cracking tube market (2019 Kubota survey).

On the other hand, in recent years, there has been an increase in the number of customers selecting cracking tubes in which an alumina layer can be formed[4], particularly for cracking furnaces using ethane, propane or the like as a raw material (hereinafter called "gas furnaces"). These cracking tubes can be expected to lead

to highly efficient production, as they have excellent coking resistance and carburizing resistance (because carburization limits the life of the materials). In 2012, Kubota started sales of the AFTALLOY[5] cracking tube with an alumina layer formed inside (Fig. 6). These built up proven results such as achieving two to four times more days of continuous operation (meaning days between decoking) than with conventional tubes that do not have alumina inside. These tubes are contributing to the improvement of the utilization rate, ethylene productivity and energy efficiency of customer ethylene plants.

*1 Mixing Element Radiant Tube: A technology in which helical protrusions (hereinafter called "mixing elements") are formed on the inner surface of the cracking tube and have a fluid stirring effect. These elements increase the efficiency of the heat transfer from the heat source on the outer surface of the tube to the fluid raw material flowing inside the tube, which reduces the tube temperature: Fig. 3[3]

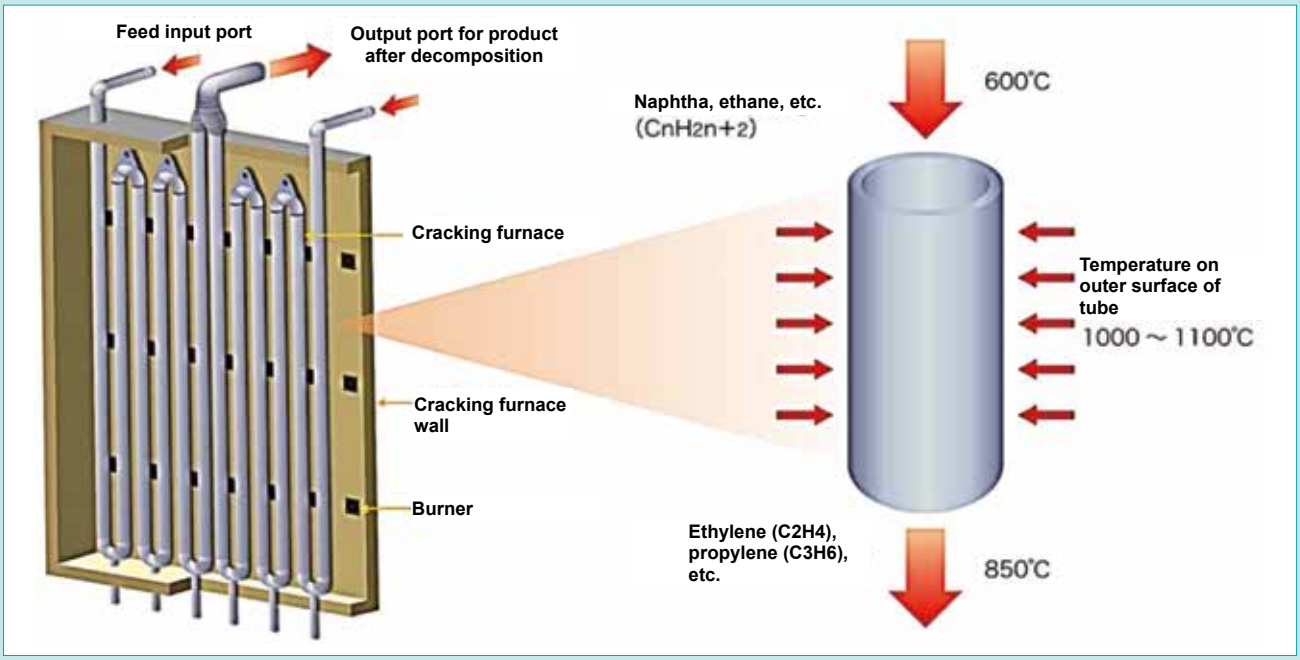


Fig. 1 Cracking Tube in Cracking Furnace for Ethylene Production[1]

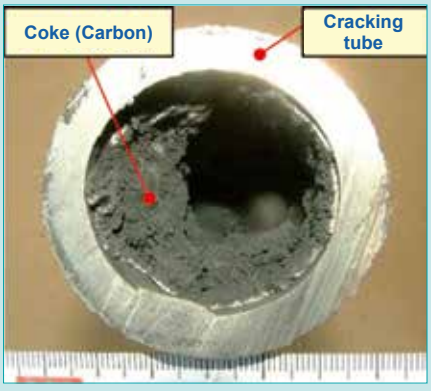


Fig. 2 Coking in Cracking Tube

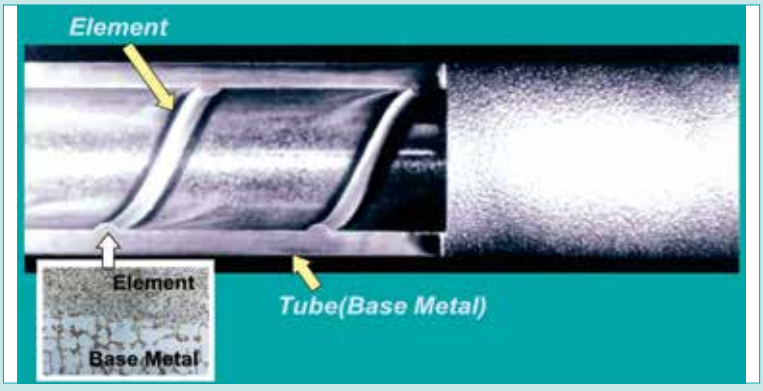


Fig. 3 Overview of MERT Cut Sample and the Microstructure

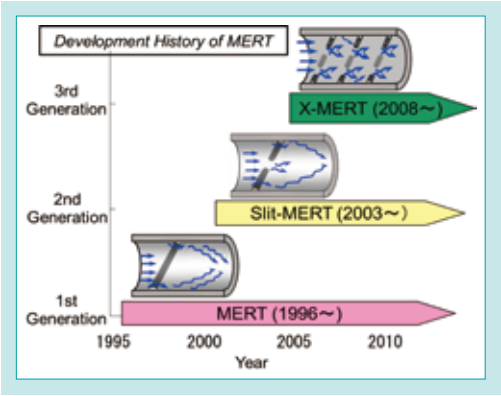


Fig. 4 Development History of MERT

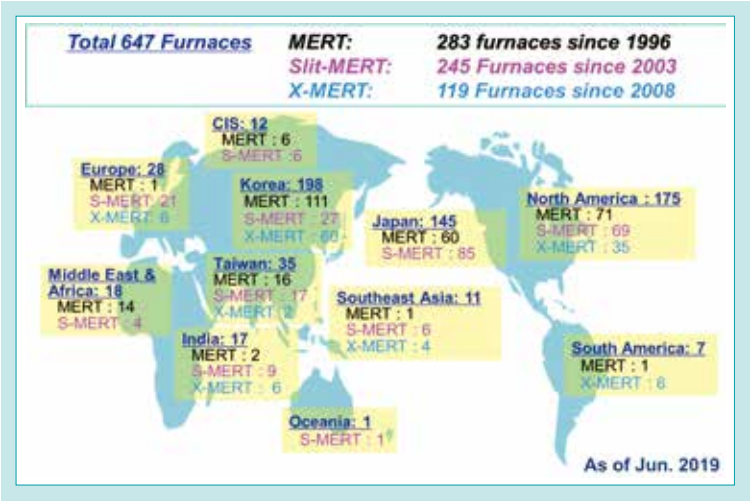


Fig. 5 Number of Commercial Furnaces that have Installed MERT as of Jun, 2019

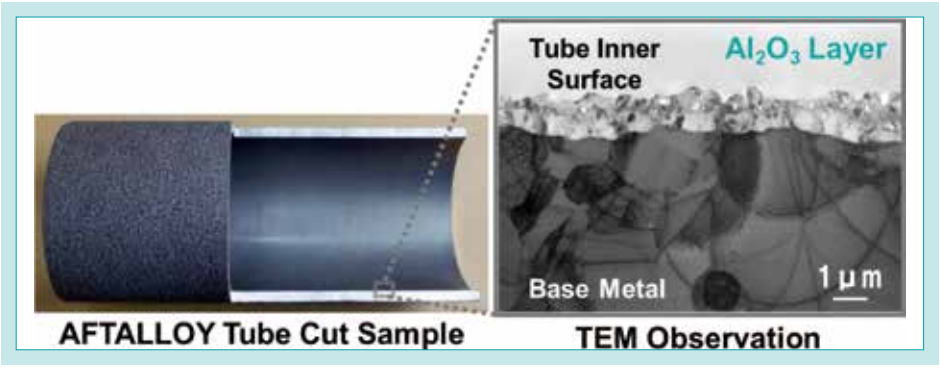


Fig. 6 Overview of AFTALLOY Cut Sample and Cross Section View of Alumina Layer[5]

1-2 Purpose of the development

In this development, we combined the MERT and AFTALLOY technologies described above to develop "AFTALLOY+MERT" (Fig. 7)[3), 5)].

At first, the main target for the developed product was customers who had adopted MERT (hereinafter called "MERT users") but wanted further improvement of production efficiency in gas furnaces. However, in recent years, the market price for the raw materials for ethylene plants has fluctuated due to the shale gas revolution and other factors, and the needs of MERT users who have begun to use gas raw materials such as ethane and propane in conventional naphtha furnaces have become increasingly apparent.

The purpose was therefore to contribute to a further increase in the number of days of continuous operation when gas raw materials are used, by either type of user, in order to contribute to the further improvement of the utilization rate and the productivity of ethylene and the like in ethylene plants, including those of MERT users.

Fig. 7 Concept of AFTALLOY+MERT [3,5)]

2. Development concept and goals

2-1 Development concept

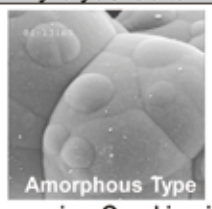
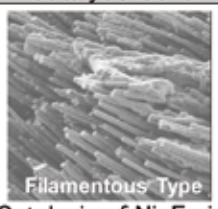
With the AFTALLOY+MERT, in addition to the tube temperature reduction effect obtained from the MERT technology as described above, each of the AFTALLOY and MERT technologies also suppress the occurrence of different types of coke (Table 1).

With MERT, the mixing elements on the inner surface of the tube agitate the fluid raw materials and break up the boundary layer on the inner surface. This increases the heat transfer efficiency and therefore suppresses any excessive temperature rise on the tube due to the heating from the outer surface of the tube. This also makes the temperature distribution on the inner surface of the tube more uniform and this suppresses the generation of coke, mainly pyrolytic coke.

On the other hand, with AFTALLOY, the coating of the inner surface of the tube with an alumina layer mainly suppresses the generation of the catalytic coke that is caused by the catalytic action of the Fe, Ni and the like that are the main constituent elements of the tube material.

With the tube temperature reduction effect and coke generation suppression effects describe above, when compared with either technology alone, the AFTALLOY+MERT further reduces the increase in tube temperature and increase in pressure drop that are the two main factors limiting the utilization rate of ethylene plants. It is therefore possible to expect further improvement of the utilization rate and the productivity of ethylene and the like in ethylene plants. There are also expectations for it as a technology supporting the diversification of raw materials in ethylene plants.

Table 1 Two Kinds of Coke and Anti-coking Mechanism in Cracking Furnace

Item	Pyrolytic Coke	Catalytic Coke
Main Coking Mechanism	 Excessive Cracking in Over Heated Zone	 Catalysis of Ni, Fe in Cracking Tube Material
Technology for Anti-coking	MERT by Mixing Elements	AFTALLOY by Alumina Film
Ethane Furnace	Approx. 20%	Approx. 80%
Naphtha Furnace	Approx. 70%	Approx. 30%

2-2 Target values

The development target value for AFTALLOY+MERT was set at more than twice the number of days of continuous operation of conventional MERT. However, the raw materials at that time were limited to the gas materials such as ethane and propane for which the effect of AFTALLOY has been recognized. This is because, as described above, the coke mainly generated with naphtha raw materials is pyrolytic coke, which is considered to be sufficiently suppressed with the effects of MERT.

3. Technical issues to be solved

The development of AFTALLOY+MERT was not a simple combination of the existing technologies. It was mainly necessary to solve the following two problems.

1) Development of powder materials

The mixing elements on the inner surface of the tube are formed by plasma powder welding (hereinafter called "PPW") (Fig. 8). Therefore, it was necessary to develop a powder material that has both weldability and the ability to form an alumina layer on the mixing elements (hereinafter called "alumina layer formability").

2) Development of processing technology for the inner surface of the tube

The alumina layer must be formed over the entire surface inside the tube, which includes on the mixing elements in addition to on the base material. It was therefore necessary to develop a manufacturing technology to efficiently and uniformly process the inner surface of the tube after the formation of the mixing elements, so that it has the surface properties suitable for alumina layer formation.

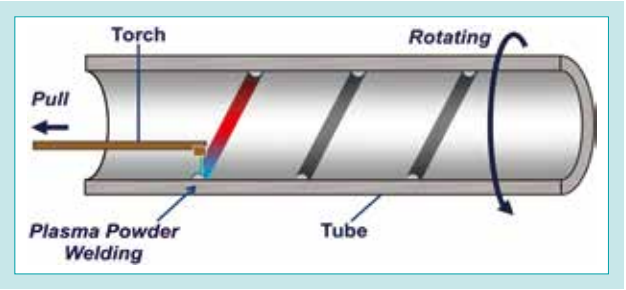


Fig. 8 PPW Method for Building MERT Elements

4. Developed technology

4-1 Powder material technology

4.1.1 Issues for the powder material technology

The weldability of the materials is decreased when there is an increase in the amount of the aluminum (Al), which is the alloying element that secures the alumina layer formability of the mixing elements.

There was therefore the issue that the alloy design must consider not only the alumina layer formability, but also the weldability.

4.1.2 Solutions for the powder material technology

In response to the above, we added alloying elements such as niobium (Nb) to improve the weldability by strengthening the grain boundary by carbide precipitation. This secured the ability to form the mixing elements by PPW. We also reduced the silicon (Si) from that in the conventional powder material to suppress the formation of Si oxide. This ensured the alumina layer formability (Table 2).

When designing the alloy, the number of prototypes necessary was reduced by using Thermo-Calc[*2] (software for equilibrium diagram calculations using thermodynamic databases) to evaluate the appropriate range of Si and Nb concentrations in advance. However, it could be said that the factor that most facilitated the alloy design was the accumulated knowledge on the conventional powder materials and the base material AFTALLOY.

*2 A trademark of Thermo-Calc Software AB

Table 2 Main Chemical Composition of Base Metal & MERT Powder

wt%	C	Si	Cr	Ni	Al	Nb	Other	Fe
Base metal AFTALLOY	0.4/0.6	<1.0	20/30	25/40	2.0/4.0	<1.0	add.	bal.
Original MERT Powder	0.1/0.6	<4.0	20/50	30/50	<4.0	<4.0	add.	bal.
AFTALLOY+MERT Powder	0.1/0.6	<1.0	20/50	30/50	2.0/6.0	0.5/2.0	add.	bal.

* Numerical indications according to the descriptions in the patent publication information

4-1 Processing technology for the inner surface of the tube

4.2.1 Issues for the processing technology for the inner surface of the tube

The cracking tube dimensions (inner diameter, outer diameter, wall thickness, etc.) are determined by the specifications required by the customer. The dimensions (height, width, number of divisions, etc.) and helix angle of the mixing elements formed by PPW are determined based on the operating conditions of the customer by using an original Kubota analysis method. The mixing elements are formed by PPW, so they do not have a regular shape like that obtained from mechanical machining. This makes it possible to execute a wide variety of arrangement designs such as MERT, Slit-MERT and X-MERT (Fig. 9).

On the other hand, in order to impart the surface properties suitable for the formation of an alumina layer, it was necessary to efficiently and uniformly process the inner surface of a tube that has that wide variety of stirring elements. However, we did not possess such a technology.

Fig. 9 Design of Several MERT Elements

4.2.2 Solutions for the processing technology for the inner surface of the tube

As a result of searching for technologies both inside and outside of the company, we were able to find appropriate processing technology and were able to develop and practically apply processing equipment for AFTALLOY+MERT.

We were able to standardize this processing technology based on a large amount of experimental data accumulated over a long time. Unfortunately, the details of that are manufacturing know-how, so they will be omitted here.

4-3 Evaluation of the developed product

As a result of the development described above, it was possible to efficiently and uniformly process the inner surface of the tube, including for mixing elements that had the ability to form an alumina layer. We were then able to use the same layer oxidation treatment as that of the conventional AFTALLOY to stably form an alumina layer on the entire surface inside the tube, including on the mixing elements (Fig. 10). The product developed was actually used in a commercial furnace of an important customer that uses ethane raw material. The coke deposition rate (rate of increase in pressure in the tube as an alternative indicator) of AFTALLOY+MERT was very low compared with that on conventional MERT under the same conditions. This was therefore the good result expected. From the results obtained, it is estimated that the number of days of continuous operation will reach at least twice that of the conventional MERT.

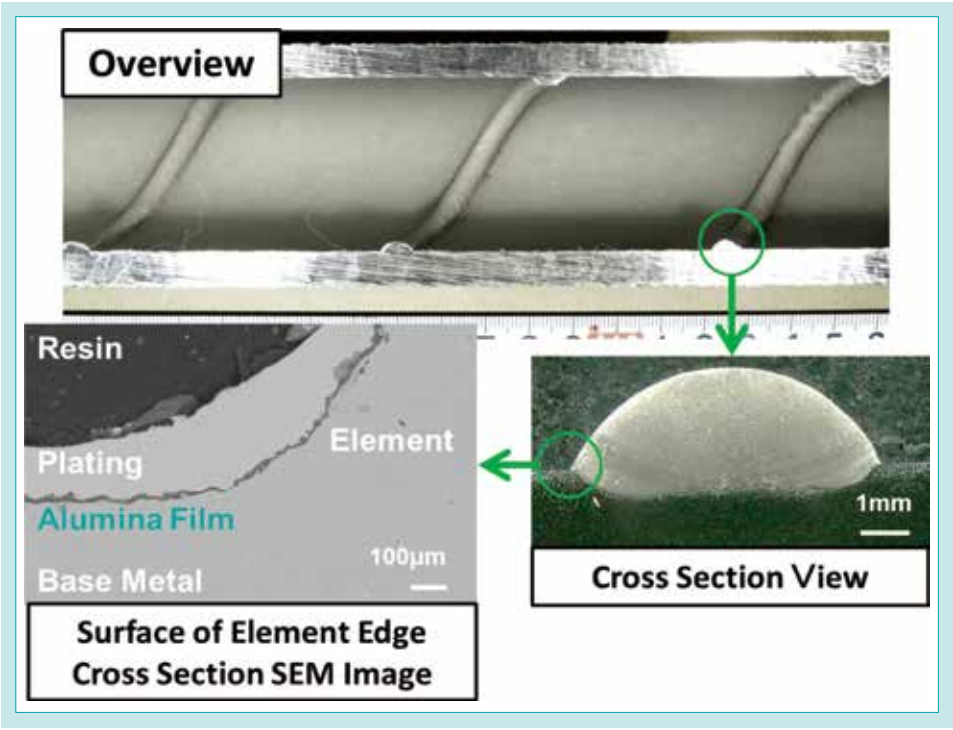


Fig. 10 Overview of AFTALLOY+MERT Inner Tube and Detailed Cross-section View of an Element

5. Conclusion

We developed a powder material for AFTALLOY+MERT which had both the ability to form alumina layers and the ability to form mixing elements. We also developed processing technology to impart surface properties suitable for alumina layer formation on the inner surface of tubes containing mixing elements. As a result, we succeeded in the development of the new AFTALLOY+MERT product that combines the conventional MERT and AFTALLOY technologies.

From the results obtained in demonstration testing in a commercial furnace of an important customer, it was estimated that the number of days of continuous operation with AFTALLOY+MERT would reach more than twice that with the conventional MERT. This customer rated the technology very highly as "the ultimate cracking tube." In addition to placing a repeat order, the customer also suggested that AFTALLOY+MERT may be applied in the long-term renewal and establishment plan. This meant that AFTALLOY+MERT will be expected to satisfy many customers in the world.

Contribution to SDG targets

7.3	Improvement in energy efficiency	Contribution to more than twice the number of days of continuous operation than with the conventional MERT in the case of ethane raw material
9.4	Industry improvement through the introduction of environment-friendly technologies	Reduction of CO_2 emissions due to fuel consumption by improving ethylene production efficiency
12.2	Sustainable management and efficient use of natural resources	Contribution to the efficient use of mineral resource raw materials by extending the life of cracking tubes made of high-nickel, high-chromium stainless steel

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Development of the Energy-saving Cylindrical Dewatering Centrifuge

Environmental Engineering Dept.

In recent years, initiatives to save energy have become an urgent issue in the sewerage business, and sewage treatment facilities needs to reduce energy consumption more than ever. Dewatering centrifuges, used in the treatment sewage sludge, are widely used because they have such features as being resistant to fluctuations in sludge properties, are highly suitable for treating difficult-to-dewater sludge, capable of large-scale treatment, and are characterized by their high processing stability. However, on the other hand, compared with other dehydration methods, power consumption is high, and further reduction in power consumption is an issue. Kubota' cylindrical dewatering centrifuge has become a major player in the environmental plant business, and has been highly evaluated for its dewatering performance. In this paper, we report the development of an energy-saving cylindrical dewatering centrifuge which has the lowest power consumption in the industry.

【Key Word】
Sewer, Centrifugal Force, Dewatering Machine, Moisture Content, Energy-saving

Related SDGs

1. Introduction

1-1 Background to the cylindrical dewatering centrifuge development

In recent years, there have also been calls to reduce the volume of greenhouse gases generated by sewage treatment facilities and efforts to reduce the energy used by sewage treatment facilities have become an urgent issue. The spread of sewage treatment facilities has now reached 79.3%[1)], as they are essential social capital for national life, including for the improvement of the water quality in rivers and oceans. On the other hand, sewage now accounts for about 0.7%[2)] of the annual electricity consumption in Japan (with an annual power consumption equivalent to a million kW class nuclear power plant). There are therefore demands for further energy-saving in sewage treatment facilities.

The sludge treatment process in a sewage treatment plant is indispensable to reduce the volume of sludge and to detoxify it. Sludge is first reduced in volume by concentration and dehydration processes. Then, for further volume reduction and effective utilization, it is either sent to a later stage facility such as for incineration, or it is disposed of outside the plant. The sludge dehydrators used in the dewatering process are important treatment equipment because the low moisture content performance (hereinafter called the “dewatering performance”) of the dewatered cake (hereinafter called the “cake”) affects the construction and operation costs of the later stage equipment and the off-site disposal costs.

Dewatering centrifuges have been widely used because of their advantages such as being able to cope with variations in sludge properties, being highly applicable to sludge that is difficult to dehydrate, being capable of large-scale treatment and having high treatment stability. On the other hand, their spread has been limited by the fact that they have higher power consumption than other dehydrating methods because they are high-speed rotating equipment. In addition, when dehydrator facilities have been rebuilt or renewed in recent years, there have been demands for space-saving compact dehydrators, so that a wide maintenance and management flow line can be installed around the dehydrator.

In 2000, Kubota developed and launched a cylindrical dewatering centrifuge for the purpose of improving the dehydrating performance compared with the conventional decanter type high efficiency dewatering centrifuges. As a result, the cylindrical dewatering centrifuges were highly rated for their dehydrating performance and orders have been received for 77 units (Throughput: 3 m3/h to

60 m3/h) as of 2019, making them a main model in the environmental plant business.

However, in recent years, energy-saving and space-saving dewatering centrifuges have been introduced from overseas and it became necessary for Kubota to perform development for improvement. To respond to the recent demands for energy-saving, it was necessary to reduce the electricity consumption on the cylindrical dewatering centrifuges with the aim of becoming the No. 1 equipment, not only in terms of dewatering performance but also in energy saving performance. The details of that development are described below (Fig. 1).

Fig. 1 Energy-saving Cylindrical Dewatering Centrifuge

1-2 Outline of cylindrical dewatering centrifuges

A dewatering centrifuge is a machine that uses the differences in the specific gravity of substances to separate solids and liquids by centrifugal force. Sludge and a polymer coagulant are put into a bowl that can be rotated at high speeds and this forms a coagulated sludge that makes it easier to remove the moisture. The sludge is then separated into solids and liquid by a centrifugal force several thousand times the force of gravity. Just the solids are then continuously transported and discharged by a screw.

In a dewatering centrifuge, the size of the centrifugal force and the dewatering time (Machine capacity/Sludge input) are the main design factors determining the dewatering performance. The larger these factors are, the lower the cake moisture content becomes. Cylindrical dewatering centrifuges have the following excellent advantages.

[1] Cylindrical bowl

As the bowl is cylindrical, the maximum centrifugal force acts for a longer time than on the general

decanter type (with a structure that combines cylindrical and conical sections). Also, as the sludge layer in the bowl is thick, it is possible to increase the compacting force applied to the sludge.

[2] Tapered screw conveyor

The adoption of a tapered screw conveyor shape makes it possible to apply a strong squeezing force due to the volume decrease.

[3] Gap structure

Making the cake discharge portion into a gap structure makes it possible to increase the cake squeezing force at the discharge part. It is also possible to only discharge the cake that is on the bowl walls, which has been subjected to the maximum centrifugal effect and has the lowest moisture content (See Fig. 2).

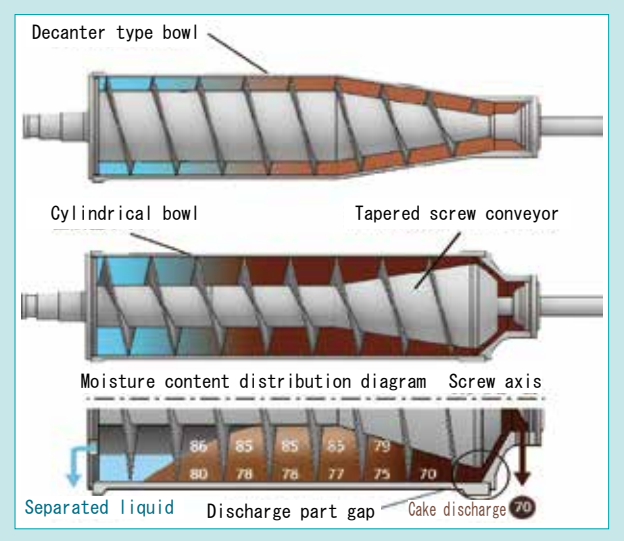


Fig. 2 Cylindrical Dewatering Centrifuge

2. Development concept and goals

2-1 Development concept

The development concept selected was to make a compact cylindrical dewatering centrifuge which has advanced to have low power consumption at the highest level in the industry while still maintaining the dewatering performance of the current machine.

Also, the basic policy was to reduce the bowl diameter while maintaining the original structure of the cylindrical dewatering centrifuge and also to change the differential device from the hydraulic type to the gear type and to reconsider the installation position for the motor. Also, the lineup was to consist of ten models with a standard throughput of 3 m^3/h to 60 m^3/h, and the throughput was to be about 0.7 to 1.5 times the standard throughput.

2-2 Target values

The target value for the development was a power consumption of 0.9 kWh/m^3 or less, with the dewatering performance kept equivalent to that of the current machine. Also, the installation area was to be reduced by 30% from the current machine.

3. Technical issues to be solved

3-1 Issues for the simultaneous achievement of energy saving performance and dewatering performance

The power consumed by a dewatering centrifuge can be classified into the following three categories:

[1] No-load electric power: The electric power required to maintain high-speed rotation, even without sludge

[2] Separated liquid and solids discharge power: The electric power required to supply rotational acceleration energy to the separated liquid and solids

[3] Conveyance power: The power required for the screw conveyor to convey the sludge layer formed in the rotating bowl.

Figure 3 shows the breakdown of the power consumption on the current machine.

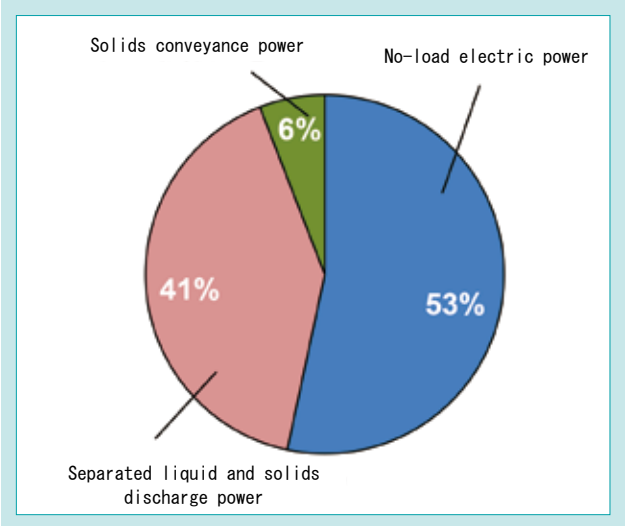


Fig. 3 Power Breakdown of Dewatering Centrifuge

As shown in the figure, the no-load electric power and the separated liquid and solids discharge power account for 94% of the total electric power consumption. For this reason, it was necessary to reduce the power consumption for mainly the no-load electric power and the separated liquid and solids discharge power. It was also necessary to simultaneously achieve both energy saving performance and dewatering performance, so it was necessary to maintain the centrifugal force and dewatering time (Machine capacity/Sludge input) from the current machine, as these are the main design factors determining the dewatering performance.

The no-load electric power accounts for 53% of the electric power consumed. This is mainly caused by windage loss (the air friction resistance due to the high-speed rotation of the bowl) and reducing the bowl diameter contributes to a reduction of the electric power.

However, simply reducing the bowl diameter reduces the internal volume, so this leads to a reduction in the dewatering time. In other words, this lowers the dewatering performance. In order to reduce the bowl diameter while maintaining the internal capacity, it is necessary to reduce the screw hub diameter. However, in the structure of the current machine, bearings are arranged in the screw journal that is part of the screw, so there was the problem that the screw hub diameter could not be reduced further if the screw rigidity was to be maintained.

On the other hand, the separated liquid and solids discharge power accounts for 41% of the electric power consumed. This power is the energy to apply a centrifugal force to the sludge that is put inside to

accelerate it. It is equivalent to the kinetic energy of the separated liquid and solid matter that is discharged at high speed, so it depends on the bowl rotation speed and the discharge diameter. Of these, it is difficult to change the rotation speed because it affects the centrifugal force, so in order to reduce the separated liquid and solids discharge power it was necessary to reduce the discharge diameter.

However, because of the layout of the bearings installed on the bowl shaft, the diameter of the bowl shaft becomes an obstacle making it difficult to reduce the diameter of the separated liquid discharge any further. There was therefore the issue that it was difficult to reduce the diameter while maintaining the screw rigidity.

Also, up until now, it was not possible to utilize the energy lost when the separated liquid is discharged at high speed in the radial direction.

3-2 Issues for the reduction of dewatering equipment size

When working to make the dehydrator more compact, no great size reduction could be expected from simply reconsidering the structure around the bowl and screw, which are the main parts of the rotating body. It was therefore necessary to optimize the layout, including the auxiliary equipment.

On the current machine, the main motor for driving the rotating body is installed on the base of the main

body, so the base width is wide and an obstacle to the size reduction.

Also, the differential speed device is a hydraulic type, so it is necessary to install a differential speed hydraulic unit separate to the dehydrator to drive the hydraulic motor. This was a factor enlarging the installation area.

4. Developed technology

4-1 Technology to simultaneously achieve energy saving performance and dewatering performance

In order to reduce the screw hub diameter and the separated liquid discharge diameter, we adopted a new design (see Fig. 4) in which a bearing is placed inside the screw but the screw diameter is reduced. This eliminated the need for a screw journal and it was also possible to reduce the bearing space in the bowl shaft, so it was possible to reduce the diameter of the bowl shaft and to also reduce the diameter of the separated liquid discharge port. As a result, we achieved a significant reduction in the no-load electric power and the separated liquid discharge power, while still maintaining the centrifugal force and the internal capacity (dewatering time).

In addition, in order to effectively use the separated liquid discharge energy, we changed the separated liquid discharge direction from the radial direction to the tangential direction and newly installed a separated liquid overflow plate e-booster (see Fig. 5) with a function to assist the bowl rotation force by changing the jet reaction force of the separation liquid into rotational force. This further reduced the separated liquid discharge power (see Fig. 6).

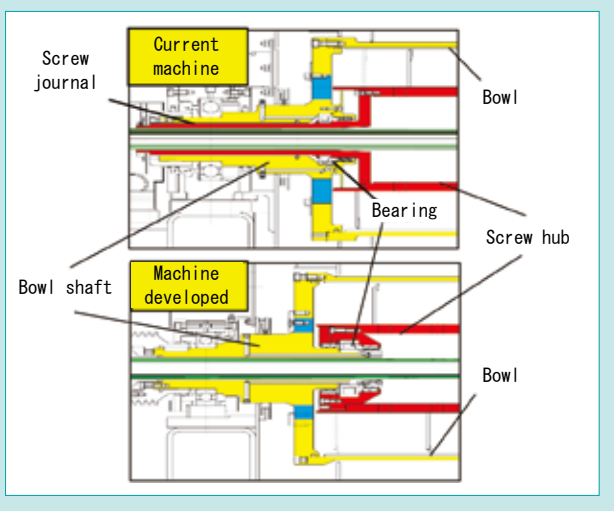


Fig. 4 New Design Around Screw

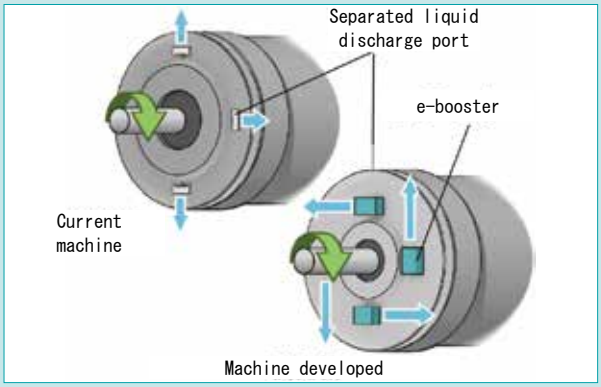


Fig. 5 Design Change Around the Separation Liquid Outlet

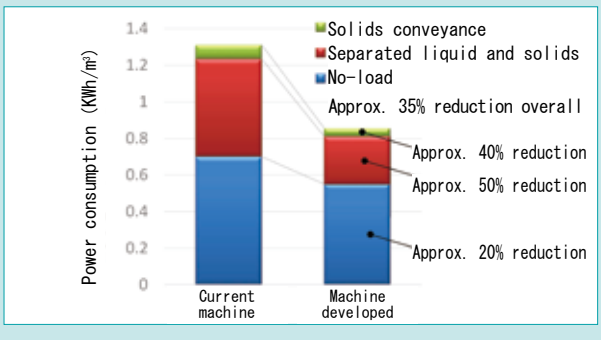


Fig. 6 Result of Power Consumption Reduction

4-2 The reduction of the dewatering equipment size

We moved the motor which had been installed in the base of the main body of the dehydrator to a position below the rotating body. This made it possible to reduce the width of the base and make the equipment more compact. Furthermore, for small and medium sized machines, we changed the differential device from a hydraulic motor to a planetary gear speed reducer.

This eliminated the need for a hydraulic unit and reduced the installation area by 30 to 40%, so the development target was achieved (see Fig. 7). We performed differential stability and vibration measurements on a prototype to check that there was no effect on the durability from the changes to the motor position and differential device and it was confirmed that there was no problem.

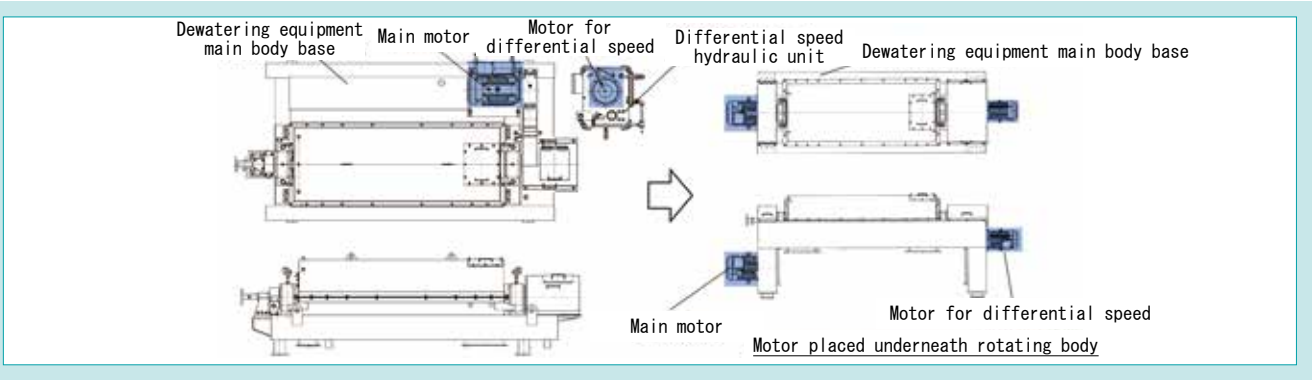


Fig. 7 Compact Dewatering Centrifuge

5. Demonstration tests using the technology developed

5-1 Tester specifications and test fields

We conducted tests at three sewage treatment plants to compare the performance of the machine developed and the current machine. Table 1 shows the specifications of the tester used for the demonstration tests.

The test fields were either digested sludge (sludge from the anaerobic digestion of sewage sludge), which is difficult to dewater and can easily generate a difference in the dewatering performance, or mixed raw sludge (sludge that is primary sedimentation tank sludge mixed with excess sludge), which is easy to dewater and can be used to evaluate the effect of a difference in the amount treated on the power saving performance.

The equipment to be compared with was the current test equipment at A treatment plant and the existing current machine at B and C treatment plants (current machines already installed at the test facility). Table 2 shows the outline of the test facilities and Table 3 shows the sludge properties.

The sludge properties of A and B treatment plants are that the VTS (organic matter concentration) is extremely high compared with general digested sludge, and the sludge is difficult to dewater. On the other hand, at C treatment plant, the sludge has more fibrous substances than general mixed raw sludge and is easily dewatered.

Table 1 Test Machine Specification

	Cylindrical dewatering centrifuge
Rated throughput	7 – 20 m^3/h machines
Rated centrifugal effect	2500G
Motor output	Main motor: 22 kW Motor for differential speed: 7.5 kW

Table 2 Test Facility Overview

	A treatment plant	B treatment plant	C treatment plant
Sewage system	Separated system	Separated system	Separated system
Water treatment system	Standard activated sludge process	Standard activated sludge process	Standard activated sludge process
Target sludge	Digested sludge (Separation and concentration)	Digested sludge (Separation and concentration)	Digested sludge (Separation and concentration)

Table 3 Sludge Properties

			A treatment plant	B treatment plant	C treatment plant
Analysis item		Units	Digested sludge	Digested sludge	Mixed raw sludge
TS		%	1.22	1.7	1.3
SS		%	0.97	1.48	1
VTS		%/TS	75.1	72.5	80.2
Fibrous substances	100mesh	%/SS	3.94	2.38	22

5-2 Test results

1)A treatment plant

Figure 8 shows the relationship between the polymer dosing rate and the cake moisture content. The higher the polymer dosing rate is, the lower the cake moisture content becomes. With a dosage of 1.5%, a cake moisture content of about 78% was obtained. On the other hand, the power consumption was 0.90 kWh/m^3, which is about 25% less than the 1.2 kWh/m^3 for the current machine, so the development target was achieved. The SS recovery rates were all over 95%.

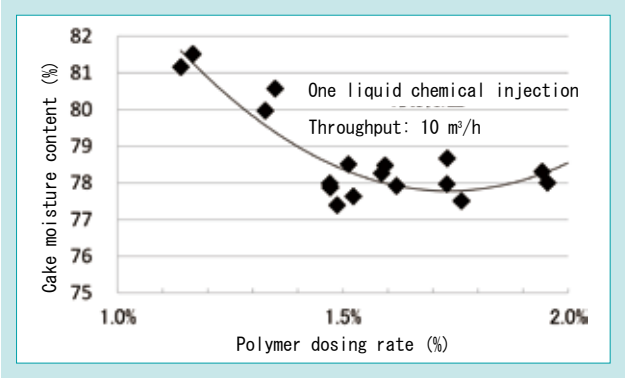


Fig. 8 Result of Changes in Polymer Dosing Rate (A Treatment Plant)

2)B treatment plant

1)Figure 9 shows the relationship between the polymer dosing rate and the cake moisture content.

In one liquid polymer injection, a cake moisture content of about 81% was obtained with a polymer coagulant dosing rate of 1.5%. On the other hand, the power consumption was 0.85 kWh/m^3 compared with the 1.7 kWh/m^3 for the current machine, so an energy saving of 50% was achieved. The SS recovery rates were all over 97%.

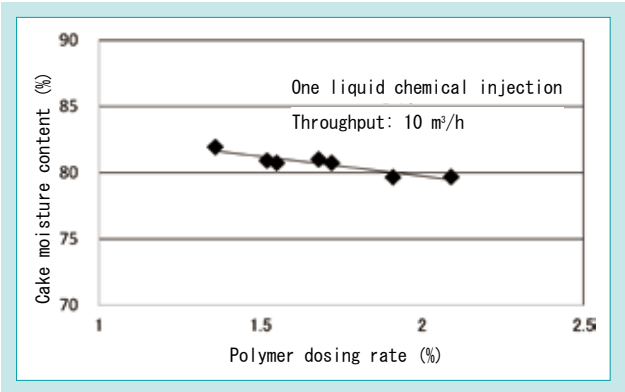


Fig. 9 Results of Changes in Polymer Dosing Rate (B Treatment Plant)

3)C treatment plant

[1]Testing of polymer dosing rate variation

Figure 10 shows the relationship between the polymer dosing rate and the cake moisture content. The cake moisture content decreased the most with a polymer dosing rate of 0.5%, for which 74% was obtained. This was equivalent to that of the existing current machine. The power consumption was 0.90 kWh/m^3 compared with the 1.35 kWh/m^3 for the existing current machine, so an energy saving of about 33% was achieved.

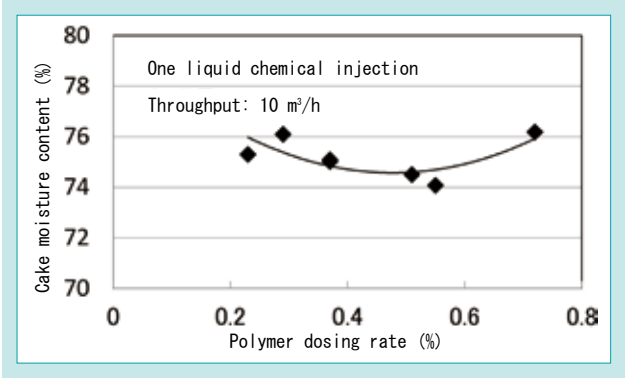


Fig. 10 Results of Changing Polymer Dosing Rate (C Treatment Plant)

[2] Throughput testing

Figure 11 shows the relationship of the cake moisture content and power consumption to the throughput. We varied the throughput from 10 m^3/h to a maximum of 19.5 m^3/h and the cake moisture content tended to decrease. This is considered to be because the sludge concentration decreased as the throughput was increased, meaning that the actual polymer dosing rate increased. On the other hand, while the power consumption at 10 m^3/h was 0.90 kWh/m^3, when the throughput was increased to 19.5 m^3/h, the low value of 0.64 kWh/m^3 was obtained.

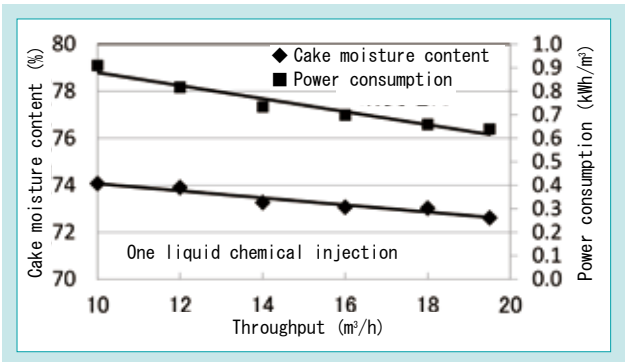


Fig. 11 Results of Changing Throughput (C Treatment Plant)

[3] Centrifugal effect testing

Figure 12 shows the relationship of the cake moisture content and power consumption to the centrifugal effect. Although the centrifugal effect was reduced from the rated 2,500 G to 1,800 G, there was no significant effect seen on the cake moisture content. On the other hand, the power consumption was 0.90 kWh/m^3 for 2,500 G, but the very low value of 0.63 kWh/m^3 was obtained for 1,800 G.

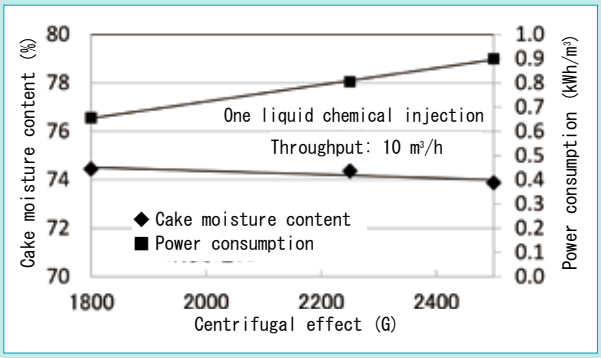


Fig. 12 Result of Centrifugal Effect Test (C Treatment Plant)

From the above, it was confirmed that greatly energy saving operation at 0.6 to 0.7 kWh/m^3 is possible by either increasing the throughput or reducing the centrifugal effect.

6. Conclusion

Kubota has so far developed and launched a variety of sewage sludge dehydrators that respond to the customer needs and technological changes. As a result, we have been recognized and highly rated by customers as an “all-round dehydrator manufacturer” with dehydrators that meet various requirements. Looking ahead, we will continue to develop dehydrators that satisfy the changing demand.

Contribution to SDG targets

6.3 Improvement of water quality through reduction, recycling and so forth of untreated wastewater	Contribution to the reduction of wzzaste sludge by reducing moisture content
7.3 Improvement in energy efficiency	Contribution to the improvement of energy efficiency on water and sewerage infrastructure

Reference

1) Ministry of Land, Infrastructure Transport and Tourism press release materials The number of people who can use sewage treatment facilities is steadily increasing! - Summary of the rate of sewage treatment use in the population at the end of FY2018 -
https://www.mlit.go.jp/report/press/mizukokudo13_hh_000422.html (Reference date 2019-11-18)

2) Ministry of Land, Infrastructure, Transport and Tourism Sewerage Policy Research Committee Meeting materials 3rd Meeting materials
4-2 Analysis of current situation of resource and energy measures in sewerage
http://www.mlit.go.jp/common/001022698.pdf (Reference Date 2019-11-18)

Development of Energy-saving Fertilizer Technology by Non-heat Reforming of Sewage Dewatered Sludge

Water and Environment R&D Dept. Ⅲ

We have developed a new sludge fertilizer technology that can reduce the moisture content of sewage sludge to the same level as that obtained using conventional heat-drying technologies without requiring a high temperature heat source. The dewatered sludge is modified at room temperature with commonly used chemicals and physically compressed at temperatures below 90°C. Due to most of the water in the sludge being removed in liquid form, this technology is superior in terms of energy saving compared to heat-drying technology that evaporates water in the sludge. In addition, by applying this technology, the product can also be used as a fertilizer, and the growth and yield of the crop were higher compared to the case where conventional sludge fertilizer was used. Since small and medium-sized sewage treatment plants are facing severe financial difficulties, low life-cycle costs (LCC) are required at the time of the installation and replacement of facilities. This technology has a lower LCC than conventional sludge fertilizer technology due to the implementation of a new energy-efficient approach, which makes small and medium-sized sewage treatment plants cost competitive.

【Key Word】
Sewage Sludge, Energy Saving, Fertilizer

Related SDGs

1. Introduction

The Ministry of Land, Infrastructure, Transport and Tourism is strongly promoting the use of sewage sludge as fertilizer. The revision of the Sewage Act in 2015 included an obligation to make an effort for the effective use of sludge (as fertilizer, fuel, etc.). However, the introduction of facilities to convert sludge into fertilizer has been limited to just 38 treatment plants nationwide and the main reason for this has been the "high operating costs." In many cases, small and medium-sized waste treatment plants outsource the final disposal of sludge to landfills or private industrial waste disposal sites. This is an issue as the disposal costs are high.

The development of a technology to convert sludge into fertilizer with a lower LCC is necessary to meet the social needs for sludge recycling, including for conversion to fertilizer, as well as to meet the needs of small and medium local governments to reduce operating costs.

2. Development concept and goals

2-1 Development concept

The development concept was to take the sludge (microorganisms) discarded after the sewage biological treatment process and then, after mechanical dewatering, to modify it (dissolve the cell membranes of microorganisms) and to also squeeze out the entrained water to reduce the moisture content from 80% to 30% (See Fig. 1). This makes it possible to achieve significant energy saving (low fuel consumption) compared with drying by heating to evaporate all the water. Furthermore, the energy saving performance can be further improved by utilizing the low-temperature waste heat that remains unused in the treatment plant, such as the warm wastewater from power generation using digestion gas. (See 3-1)

In addition, the sludge is heated to a temperature higher than the boiling point (65°C) of the modifying agent (methanol) in order to increase the recovery and reuse rate of that modifying agent. However, as the heat source for that can be 90°C or lower, the risk of the ignition of the sludge is lower than when using heat for drying, which uses a heat source higher than several hundred degrees. It is also possible to reduce the odor during the treatment process and the odor of the end product (hereinafter called “recycled sludge”).

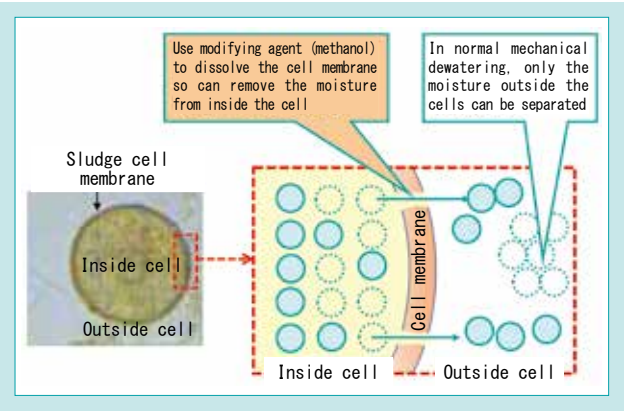


Fig. 1 Schematic Diagram of Development Concept

2-2 Development target value

Table 1 shows the target values for the development. From the viewpoints of the use of recycled sludge as fertilizer, and the realization of a lower LCC than for drying by heating, we set targets for the moisture content, fuel consumption and modifying agent consumption.

- Moisture content: Consideration of the ease of handling when using direct fertilizer
- Fuel consumption: Set as a 30% reduction from drying by heating
- Modifying agent consumption: Set as 1% or less of the amount of agent input

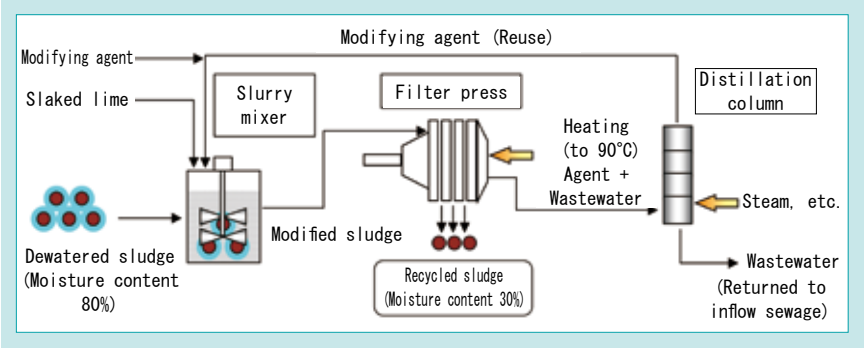
Table 1 Development Target

Item	Performance targets
Moisture content of recycled sludge	30% or less
Fuel consumption	55 L/t-cake or less (Conversion to heavy oil A)
Modifying agent consumption	10 kg/t-cake or less

3. Details of the development

3-1 Flow of the system developed

Figure 2 shows the flow in the system developed. The input sludge (Moisture content: 80%), modifying agent and slaked lime as a release agent for the filter press are agitated in a slurry mixer to produce slurry-like modified sludge. The reformed sludge is pressed and dehydrated by a filter press in which a filter plate is warmed with 90°C warm water. This forms recycled sludge with a moisture content of about 30%, and then fragmentation is performed according to the requirements of the latter stage. If there is any unused low-temperature waste heat in the plant, then it can be used to heat the filter plate. The mixture of the modifying agent and the wastewater is separated in the distillation column in the later stage, the modifying agent is reused, and the wastewater is returned to the inflow sewage.



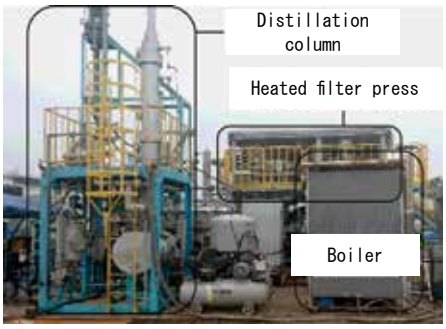


Fig. 2 Development System Flow

3-2 Outline of the demonstration equipment

In order to investigate the effect on the system of changes in the sludge properties due to the four seasons and climate, we conducted demonstration testing at an actual sewage treatment plant for about one year. Table 2 shows the outline of A treatment plant where the demonstration was performed. The type of dewatered sludge was digested dewatered sludge with a moisture content of about 80%. The dewatered sludge is fermented by storing and agitating it for two or more months to produce sludge fermentation fertilizer, which is used as fertilizer in the surrounding area.

Table 2 Overview of Verification Test Site A Treatment Plant

Item	Details
Water treatment system	Standard activated sludge process
Sludge treatment method	Concentration → Digestion → Dewatering → Conversion into sludge fermentation fertilizer
Type of dewatered sludge	Digested dewatered sludge (Moisture content around 80%)

Table 3 shows the specifications of the main components of the demonstration equipment. The filter press was based on the "Runfil" dehydrator for commercial use, and was upgraded to a specification that warms the sludge by passing hot water through the filter plate. This lowers the viscosity of the water and increases the filtration rate, and also increases the rate of reuse of the modifying agent as the heating is to above the boiling point of the modifying agent (65°C) and the small amount of modifying agent remaining in the sludge is recovered.

Table 3 Main Equipment of the Demonstration Facility

Main equipment	Equipment specifications
Slurry mixer	Vertical spiral blade agitator
Filter press	Traveling filter cloth type (90°C warm water heating)
Distillation column	Shelf type distillation column

4. Experiment results

4-1 Results of system performance checks

4.1.1 Dewatering performance

Figure 3 shows the results of the investigation of the correlation between the modifying agent addition rate and the moisture content of the recycled sludge. It was confirmed that the moisture content of the recycled sludge could be reduced as the addition rate of the modifying agent was increased. This trend was almost unaffected by the seasonal variation and the variation in the moisture content of the input sludge. The modifying agent addition rate to satisfy the target moisture content of 30% was 85 wt%/cake.

Table 4 shows the results of the analysis and comparison of the odor indices of the recycled sludge and the dried sludge[*1)]. Recycled sludge has a lower odor index than dried sludge and this low odor helps promote its use as sludge fertilizer.

In this testing, the target moisture content for the recycled sludge was set as 30% because the assumption was that the recycled sludge would be used as fertilizer. However, use as a supplementary fuel for thermal power plants and incinerators can also be expected if the rate of modifying agent addition is raised to reduce the moisture content to 20% or less.

*1) Sludge with the moisture content reduced to 30% by drying the input sludge in storage at 110°C

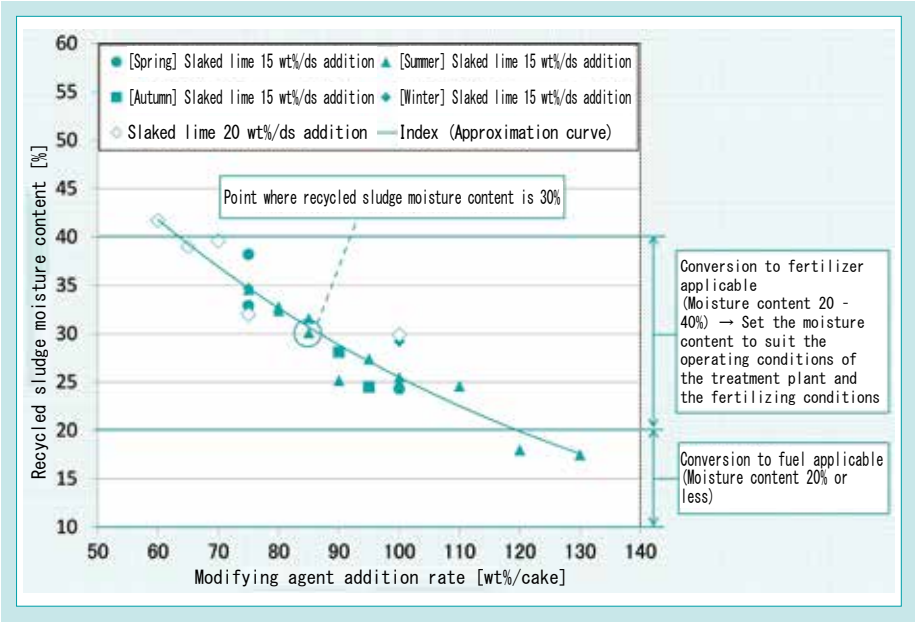


Fig. 3 Dehydration Performance Test Results

Table 4 Odor Index of Recycled Sludge and Dried Sludge

Item	Units	Odor index
Recycled sludge	[–]	35
Dried sludge	[–]	50

4.1.2 Modifying agent recovery performance

Figure 4 shows an example of the input and output of the modifying agent in this system.

The modifying agent introduced into the system is captured together with the filtrate derived from the squeezed sludge in the solvent recovery section (filtrate storage tank, condenser and bubbling tank) after the heating filter press. A distillation column is then used to separate this liquid into modifying agent and wastewater.

In the results, the recovery rate of the modifying agent was over 99%, and the consumption of modifying agent (supplementary agent added) was 7.5 kg/t-cake (= 0.6 kg / 80 kg × 1000 kg/t) in the sludge input. This satisfied the target of 10 kg/t-cake or less.

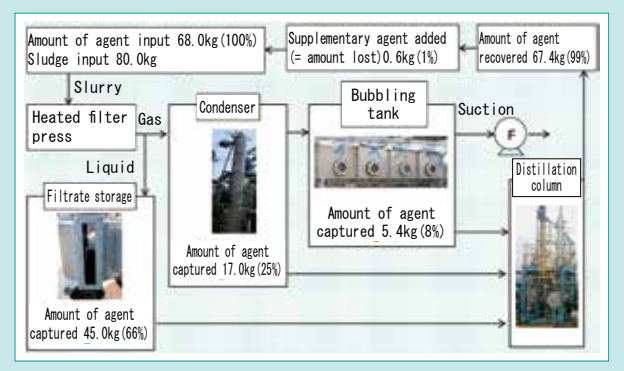


Fig. 4 Recovery Performance of Modification Aid

4.1.3 Energy saving performance

Figure 5 shows the results of an investigation of the effect of input sludge moisture content variation on fuel consumption, to compare the energy saving performance of this system to that of drying by heating. The fuel consumption of this system, which is based on a dewatering mechanism, was almost constant and was almost unaffected by the input moisture content. The target of a 30% reduction from drying by heating was almost satisfied. On the other hand, in the case of drying by heating, the fuel consumption increases as the sludge moisture content increases. This is because of the mechanism of drying by heating, in which the moisture in the sludge is evaporated and then removed. When the moisture content of the input sludge increases, more heat is required for the latent heat of vaporization.

As described above, this system is almost unaffected by the moisture content at the inlet. In other words, it can exhibit stable energy saving performance regardless of the state of dewatering in the preceding stage.

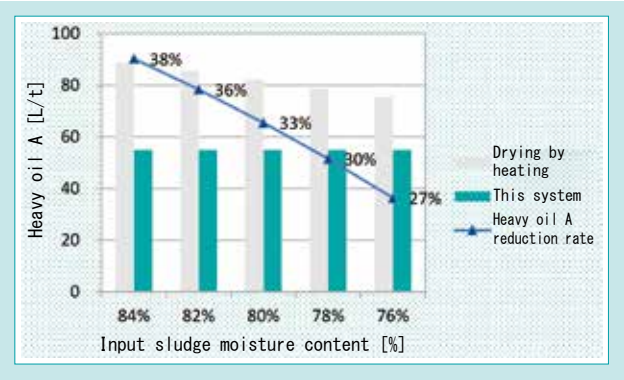


Fig. 5 Energy-saving Performance

4-2 Results of confirmation of applicability of recycled sludge as fertilizer

4.2.1 Fermentation testing

When sewage sludge is used as fertilizer, a selection must be made between two different methods depending on the user. The first of these methods is to just reduce the water content and use it as direct fertilizer (sludge fertilizer). The other method is to also put the sludge through a fermentation process for use as higher quality fertilizer (sludge fermentation fertilizer). In the fermentation process, air is supplied and aerobic fermentation is performed. However, the moisture content before the fermentation is high, at about 80%, so it takes about two to three months to complete because a large amount of water must be evaporated. There were therefore issues with this such as the equipment is excessively large, and secondary materials such as rice husks are necessary to improve the air permeability during fermentation. On the other hand, in this new system, no secondary materials were used and the initial water content was adjusted to about 50% by mixing dewatered sludge (with moisture content of 80%) and recycled sludge (with moisture content of 30%), so the fermentation process was completed in less than one month (Fig. 6). As a result of the above, the use of this system for conversion into sludge fermentation fertilizer is a technique that helps solve the issues of conventional methods.

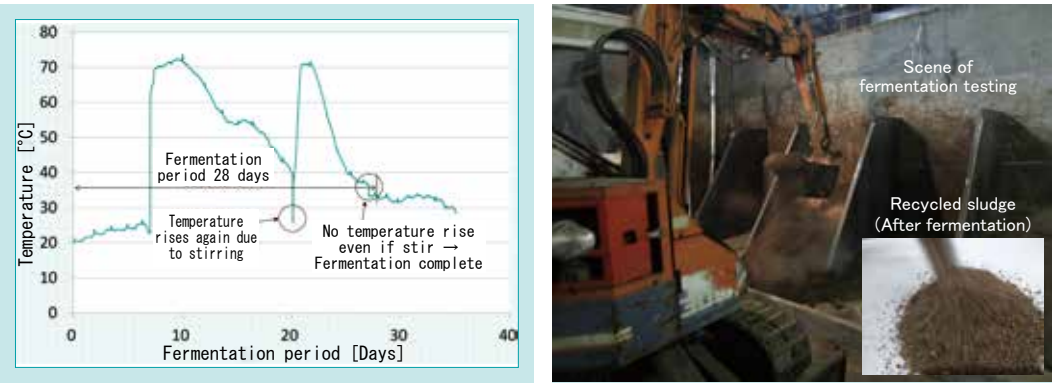


Fig. 6 Product Temperature Trend During Fermentation and Test Scenario

4.2.2 Fertilization effect confirmation testing

Table 5 shows the results of analysis of the fertilizer effect and harmful components of the recycled sludge and the existing product (sludge fermentation fertilizer) from A treatment plant.

In the results, the fertilizer effect components were contained in equivalent amounts in the recycled sludge from this system and the existing product. Also, for the sludge fertilizer in particular, the nitrogen content is kept high because there is no ammonia volatilization due to fermentation. In addition, the recycled sludge contains the calcium that is added as a release agent for the filter press, so in addition to the fertilizer effect components, it could also be said to be a fertilizer premixed with a soil conditioner that neutralizes acidic soil.

The inclusion of heavy metals such as lead was also roughly equivalent to that on the existing product. All of these were below the standard value in the Fertilizer Regulation Act (Lead: 100 mg/kg-dry, arsenic: 50 mg/kg-dry, cadmium: 5 mg/kg-dry).

Table 5 Fertilizer and Harmful Components of Recycled Sludge

Item	Units	Recycled sludge (Sludge fertilizer)	Recycled sludge (Fermentation fertilizer)	Existing product (Fermentation fertilizer)
Nitrogen	%-dry	5.21	3.68	2.82
Phosphoric acid	%-dry	3.99	3.23	3.59
Potassium	%-dry	0.20	0.38	0.50
Calcium	%-dry	7.99	14.20	1.42
Lead	mg/kg-dry	16	19	15
Arsenic	mg/kg-dry	1.8	2.8	1.6
Cadmium	mg/kg-dry	<1	1	<1
Bulk density	–	0.6	0.6	0.2

4.2.3 Fertilization testing

We performed fertilization testing using recycled sludge as fertilizer. Buckwheat was selected as the crop to be cultivated, and the amount of fertilizer applied per unit of cultivated area was set as 1 kg-fertilizer/m^2-cultivated area (Table 6)[1]. Figure 7 shows the results. With the recycled sludge, the buckwheat yield was equivalent to or higher than that when using the existing product, which was used as fertilizer for comparison. It is thought that this was because the recycled sludge does not contain secondary materials such as rice husks, which have a low bulk density. As it only contains sludge, which has a high specific gravity, it is thought that this resulted in less dispersion after the fertilization, so that the deposition rate in the soil was higher.

It was therefore confirmed from the above that the recycled sludge can be used as a sludge fertilizer or a sludge fermentation fertilizer.

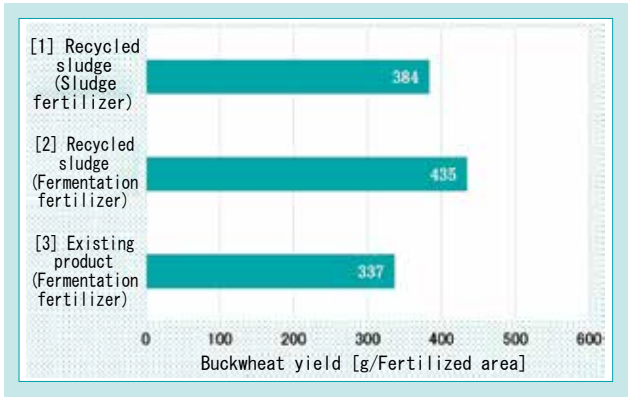


Fig. 7 Comparison of Yield of Buckwheat During Fertilization Test

Table 6 Fertilization Test Conditions

Item	Figures
Fertilized area	140 m^2 (4 m x 35 m) x 3 conditions
Amount of fertilizer applied	140 kg x 3 conditions


Scene of buckwheat cultivation

4-3 Assessment of system LCC

4.3.1 Conditions for trial calculation of LCC

We performed a trial calculation of the LCC for the installation of this system.

Figure 8 shows the flow of the LCC assessment and Table 7 shows the trial calculation conditions.

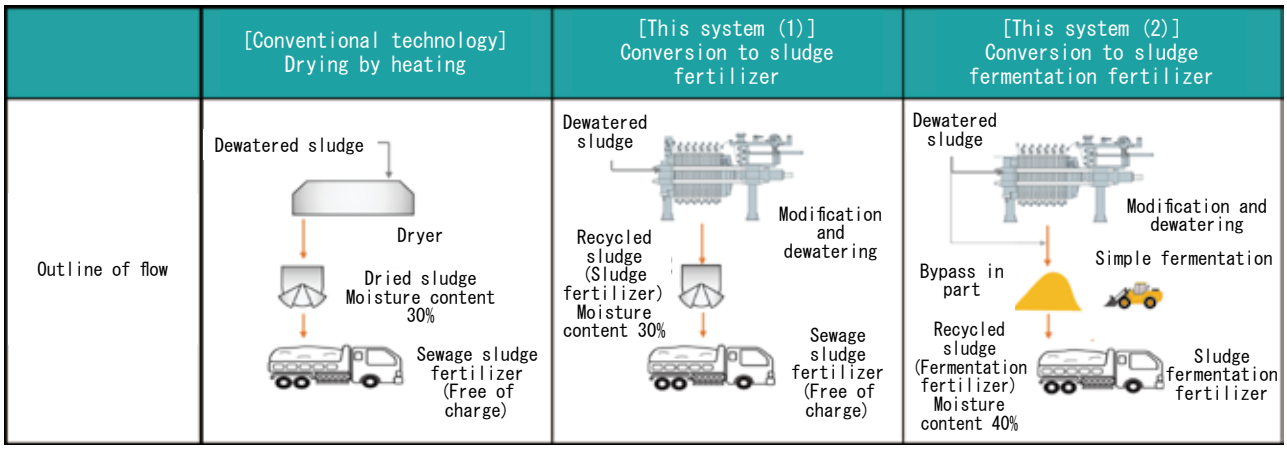


Fig. 8 LCC Evaluation Flow

Table 7 LCC Calculation Conditions

Item	Trial calculation conditions
Cases considered	[Conventional technology] Drying by heating, [This system (1)] Conversion to sludge fertilizer, [This system (2)] Conversion to sludge fermentation fertilizer
Scale of the facility Xd, Annual operation days	10 t/day (24 h/day), 340 days/year
Input sludge moisture content	–Mixed raw sludge (Sludge that has not undergone digestion): 76%, 78% –Digested sludge 80%, 82%, 84%
Service life	–Mechanical, electrical: 20 years[2] – Civil engineering, architecture: 45 years[2]
Operating personnel	Conventional technology [3]: $1.918Xd^{0.324}$, This system (1),(2): 1 person (A central supervisor combines this with other work during night hours)
Fertilizer conversion method of the product	Conventional technology, this system (1): Conversion to sludge fertilizer (Distribution free of charge), this system (2): Conversion to sludge fermentation fertilizer (Sold at a price)

4.3.2 Results of trial calculation of LCC

Figure 9 shows the results of the LCC estimation. One merit of this system is that it has low fuel consumption even though the moisture content reached is low. It is also not necessary to have any of the countermeasures associated with high-temperature heating, so operation management is easy and automation and labor saving operation are possible. This meant that the fuel costs and maintenance and management costs such as operating personnel costs were low and it had low LCC.

Figure 10 shows the rate of LCC reduction (from drying by heating) for different input sludge moisture contents. Compared with drying by heating, it was possible to obtain an LCC reduction effect of 24% or more for (1) Conversion to sludge fertilizer, and of 33% or more for (2) Conversion to sludge fermentation fertilizer. The effect was even higher in the region where the input sludge moisture content is high, where drying by heating has a disadvantage in fuel consumption.

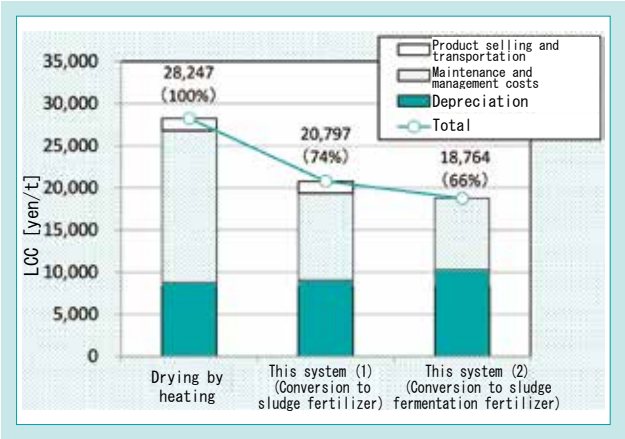


Fig. 9 LCC Calculation Results
When the Input Sludge Moisture Content is 80%

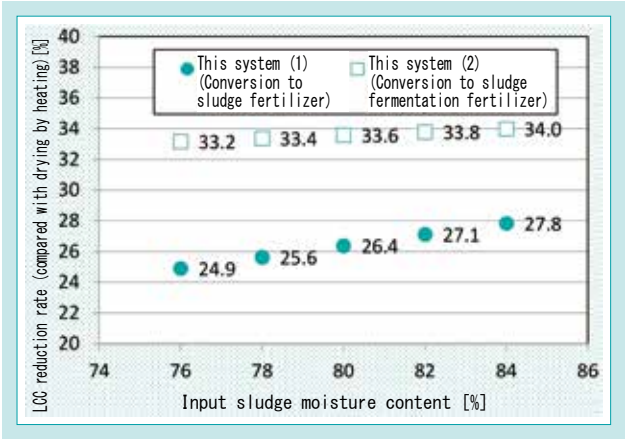


Fig. 10 LCC Reduction Rate Relative to Input Sludge Moisture Content

5. Conclusion

In this report, we introduced fertilizer conversion technology in which the sludge generated in a sewage treatment plant is modified without heating so that a low moisture content equivalent to that of drying by heating is achieved with reduced energy consumption. The technology also achieves a lower LCC than drying by heating, and it can be applied to the renewal of existing fertilizer production facilities.

This system is also suitable for new installation at sludge treatment plants that do not have final sludge treatment facilities and currently pay high outsourcing costs. We therefore believe that this system can help reduce the LCC in the sewage treatment business.

Contribution to SDG targets

6.2 Strengthening access to sewage and sanitation facilities	Promotion of the installation of final treatment facilities for sludge due to low LCC
9.4 Industry improvement through the introduction of environment-friendly technologies	Contribution to industrial improvement with fertilizer technology that achieves a low moisture content with reduced energy consumption
12.5 Prevention and reuse of waste	The recycled sludge generated can be used effectively

Reference
1) Manual for the Promotion of Effective Sewage Sludge Utilization, (2015), pp. 90, Japan Sewage Works Association
2) Revised Sewage Sludge Energy Conversion Technology Guidelines, (2015), pp. 57-58, Ministry of Land, Infrastructure, Transport and Tourism
3) Manual for the Wide Area Utilization of Sewage Sludge (2019), pp. 41, Ministry of Land, Infrastructure, Transport and Tourism

Application of Submerged Membrane SP to Industrial Wastewater

Membrane Systems Dept.

Since its launch in 2011, SP models of the Submerged Membrane Unit have been installed in approximately 50 projects in the sewage treatment industry in North America, Europe, the Middle East, Japan and other countries. In 2017, Kubota conducted a pilot test using SP models at one of the major food processing companies in Japan in order to promote these models to the mid- and large-scale industrial wastewater market. During the test, design parameters and maintenance requirements were confirmed. The pilot test was successful and the food processing company became the first ever customer in the industrial wastewater market to adopt SP models. In this report, the efforts and activities involved in optimizing SP models for the industrial wastewater market are described.

【Key Word】
Membrane Bio Reactor (MBR), KUBOTA Submerged Membrane Unit®, Industrial Wastewater

Related SDGs

1. Introduction

A membrane bioreactor (hereinafter called an "MBR") is a wastewater treatment technology that uses biological treatment using the action of activated sludge, combined with solid-liquid separation treatment using a membrane. It is characterized by its space-saving and its clear treated water.

The performance of Kubota in the domestic industrial wastewater sector has remained unchanged for several years. We have continued to deliver conventional submerged membranes (510, 515) for mainly small-scale projects with a drainage volume of 300 m^3/day or less. In order to expand the scale of the business from now on, it will be necessary to capture medium- and large-scale projects. To achieve this, it will be necessary to newly propose the submerged membrane SP, which has excellent energy-saving and maintainability and already has proven results for sewage treatment.

The submerged membrane SP is composed of a membrane block and an air diffuser block. A membrane module is mounted on the membrane block (Fig. 1).

The membrane block has a simple structure in which membrane modules are stacked in the vertical and horizontal directions. Compared with wastewater treatment equipment using the conventional submerged membrane 515, the membrane blower power is reduced by 15%. In addition to the ease of conventional chemical cleaning, it has the feature that the disassembly and assembly time for checking the membrane can be reduced by 50%.

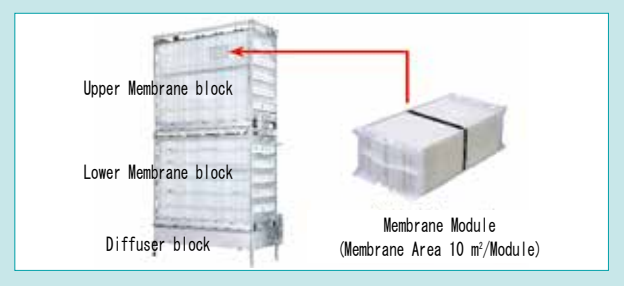


Fig. 1 Submerged Membrane Unit SP600

2. Applicability of submerged membrane SP to industrial wastewater

2-1 Applicability check items

The following items were checked to confirm whether the submerged membrane SP that was originally launched for the sewage market could be applied to industrial wastewater.

[1] Facility design specifications for different wastewater types

The characteristics of industrial wastewater differ depending on the type of wastewater, such as that from food, beverages or chemicals, and depending on the actual products within each of these types. It was therefore necessary to check the facility design specifications suitable for each of these, including regarding the concentration of the activated sludge (MLSS), the amount of filtration (flux) and the amount of membrane aeration.

[2] Membrane maintenance method

In the case of industrial wastewater, the operation of the factory may be adversely affected if the membrane becomes clogged or damaged and the wastewater cannot be treated. It was therefore necessary to check the maintenance method for the membrane in advance.

2-2 Evaluation of applicability through demonstration experiments

We installed a small experimental device (membrane area of 40 m^2) in the wastewater treatment equipment of a food company factory and the membrane filtration operation was carried out for the existing activated sludge. In the demonstration experiment, the flux was varied while the operations were continued for around seven months at the rated film aeration quantity. As a result, it was confirmed that stable operation was possible, with no sudden rise in the transmembrane pressure difference during the evaluation period (Approximately 2.5 months) (Fig. 2). Furthermore, although it was only for a short period, it was also confirmed that there were no problems with the equipment such as deterioration of the resin parts.

It was possible from this operation data to confirm the design specifications for the submerged membrane SP for this food factory.

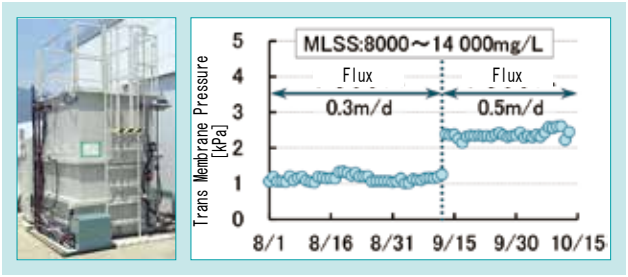


Fig. 2 Experimental Equipment and Time vs Trans Membrane Pressure

2-3 Check of maintainability

The transmembrane pressure difference recovery effect of the chemical cleaning was confirmed during the experiment. Also, at the end of the experiment, it was possible to confirm the maintenance items that could be handled on-site and their procedures. This included checks of the method for detecting the presence or absence of damage to the membrane module at the site, the method for resolving blockage caused by sludge in the membrane module, and the methods for replacing consumable parts.

In Japan, Kubota Membrane Co., Ltd. has developed after-sales service business that makes it possible to continue the stable operation of submerged membranes for a long period of time and to prevent problems before they occur. It was also possible to construct an after-sales service menu for the submerged membrane SP in the same way as for the conventional type. This was achieved by incorporating items such as the inspection frequency and emergency response methods into the inspection items and procedures confirmed through the experiments.

3. Conclusion

As a result of this demonstration and subsequent technology proposal activities, we were able to deliver the submerged membrane SP600 to this food company factory in August 2019, as the first unit for industrial wastewater (Fig. 3). The installation was part of a wastewater treatment facility expansion project (to increase the wastewater volume and improve the ease of maintenance).

From now on, we will increase the types of wastewater to which submerged membrane SP can be applied by also conducting experiments as necessary on other types of wastewater where large-scale projects can be expected, such as for meat processing and chemicals. In doing so, we will aim to further expand sales of the submerged membrane and to contribute to the maintenance of water resources around the world.

Fig. 3 Delivered Wastewater Treatment Equipment
(Scale: 2500 m³/d)

Contribution to SDG targets

6.3 Improvement of water quality through reduction, recycling and so forth of untreated wastewater	Contribution to water quality conservation through involvement in wastewater treatment at more than 6,500 sites
7.3 Improvement in energy efficiency	Contribution to the reduction of power consumption

Development of All-plastic Flange

Kubota ChemiX Co., Ltd.

Almost 50 years have passed since many factories were built during Japan's high growth period. Now there are concerns that corrosion is affecting the metal pipes used in those factories due to the fact that the factories were built in coastal areas and a long time has elapsed since their construction.

Kubota ChemiX is entering the factory pipeline market with its polyethylene pipes and fittings that are easier to install and have anti-corrosion properties. However, the currently used flange has metal components that make it vulnerable to corrosion. This report describes the development process for an all-plastic flange which is easier to install and is corrosion resistant.

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

Related SDGs

1. Introduction

Many of Japan's factories were built during the period of high economic growth and about 50 years have already passed since their construction. In addition, many of the factories have been constructed in coastal areas, so there are concerns about corrosion and water leakage on the steel pipes that account for the majority of the piping materials used. KC is developing this market with the aim of changing the coolant piping, seawater intake piping, exhaust piping and other plant piping materials to resin.

During these activities, the ministerial ordinance on outdoor water supply piping for fire extinguishing was revised in 2015 (Ministry of Internal Affairs and Communications) and made it possible to use resin pipes for buried fire extinguishing pipes. In response to this revision, customers who had problems with corrosion and water leakage on fire extinguisher pipes began to consider the use of resin pipes and also some local governments have started to recommend the use of polyethylene pipes for buried fire extinguishers.

However, in a polyethylene pipeline system, the flanges used to join different kinds of pipes and valves are made of metal, so there have been issues with corrosion resistance and workability.

This report details the status of development to solve these issues by converting the loose flange (hereinafter called an "LF"), which is a metal part, to resin, with the aim of improving corrosion resistance and workability. It also reports the situation of measures to improve the workability and to secure performance with a new shape, in response to the reduction in strength that is a concern for a change to resin.

2. Description of the technology

2-1 Development concept

Figure 1 shows the development concept. A flange consists of a polyethylene flange adapter (hereinafter called an "FA") and a metal LF.

First of all, we changed the LF to resin in order to improve the corrosion resistance and to improve the workability by reducing the weight. This means that all of the flange is made of resin, but there are concerns that the reduction in strength due to the change to resin may lead to a deterioration of the performance, such as with water leakage.

We therefore worked to devise a new profile to secure the performance at the same time as improving the workability (eliminating misalignment).

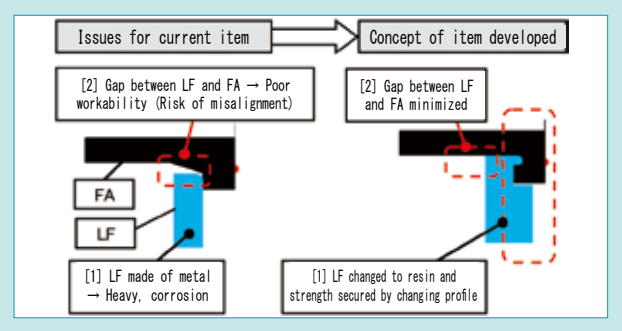


Fig. 1 Development Concept

2-2 Details of development so far

When deciding the shape of the flange, we selected water leakage during bending to check the performance of the flange and verified this by analysis and on actual equipment (Fig. 2).

First, we used analysis as shown in Figure 3 to explore a shape for the developed product that would be less prone to water leakage than the current product. We also confirmed that the required performance was satisfied if the physical properties of the LF were changed to those of fiber reinforced resin.

Next, as shown in Figure 4, we used an actual machine to compare the shape of the developed product determined by the analysis with that of the current product, and confirmed that the performance had been improved. (The LF was made of metal.) In the future, we will check the performance by using an LF actually molded from fiber reinforced resin.

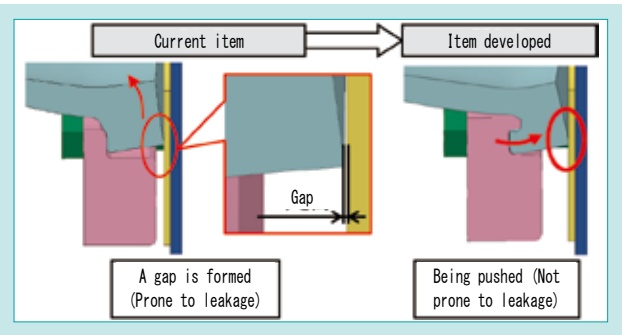


Fig. 3 Analysis Results of Bending Water Pressure Test

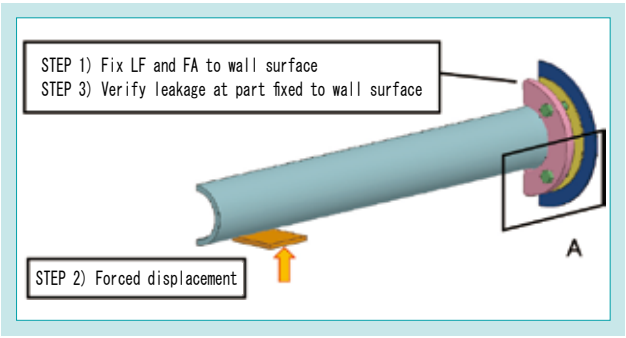


Fig. 2 Conditions for Bending Water Pressure Test

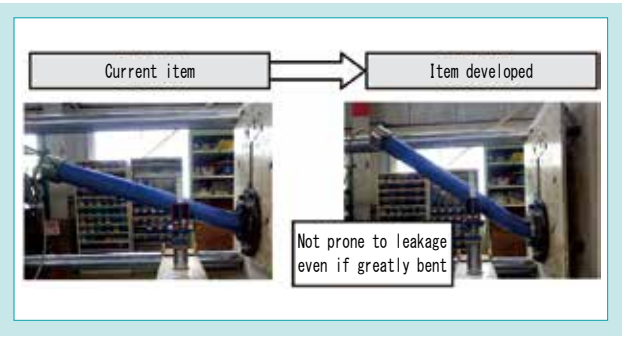


Fig. 4 Experimental Results of Bending Water Pressure Test

3. Conclusion

KC is the leading manufacturer of synthetic resin pipe materials in Japan. The strength of those products has been particularly demonstrated in the infrastructure field. However, it is unavoidable that the declining population will lead to a decline in demand for those products. In response to that situation, we have sought to enter new markets in order to achieve sustained growth.

In the plant market discussed in this report, not only is it possible to take advantage of the merits of resin pipes, but there has also been a benefit from the revision of the ministerial ordinance in 2015. Furthermore, if we also include the piping for other applications in a plant (such as those for cooling water, seawater intake and air), then it is an attractive market with even greater possibilities.

We will continue to promote the use of resin for piping components, to provide higher quality pipelines.

Contribution to SDG targets

8.2 Improvement in productivity through innovation	The use of resin for loose flanges makes it possible to create lightweight piping that is easy to install
9.1 Development of high-quality, sustainable and resilient infrastructure	Contribution to the realization of resilient pipelines that prevent water leakage

Cloud-type Pipeline Management System [WATERS-Cloud]

1. Introduction

Kansouken Inc. has been developing and selling pipeline management systems designed for water supply utilities. Conventional systems are used on office PCs, whereas the cloud type pipeline management system that we have developed allows the user to refer to their water supply pipeline drawings through a worksite tablet and/or smartphone.

More specifically, this system is designed for worksite use such as water leakage repair, construction and disaster recovery. Fig. 1 shows an overview of the system.

Fig. 1 System Overview

2. Product overview

(1)Water supply pipeline drawing view function

Water supply pipelines are displayed on Google Maps, urban planning drawings and aerial photographs.

(2)As-built drawing view

The as-built drawing view function decreases the effort required of the user to print drawings and carry the printed papers to the site.

(3)Street view

Valve locations are shown on the street view.

(4)GPS positioning view

Since the positioning of the tablet is shown on the map, the locations of accident responders and water tank trucks can be viewed.

(5)Site information sharing

The user can take water leakage photos and share them, while on site, with experienced coworkers in the office to seek their instructions remotely.

Fig. 2 shows the system functions.

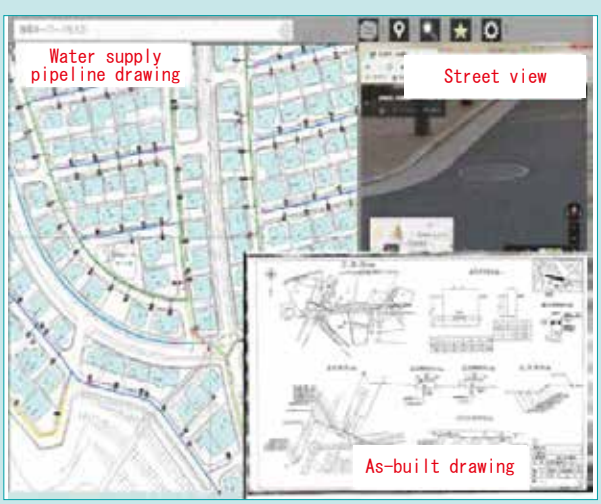


Fig. 2 Function of System

3. Conclusion

We hope this system meets customer expectations for use in many of their water supply field operations.

The system will continue to be upgraded with the addition of new functions, including those coordinated with KSIS and for the assistance with water outage operations.

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AI taking the place of humans in analyzing data and detecting abnormal operations “Manhole Pump AI Abnormal Operation Detection System”

1. Introduction

A manhole pump (Fig. 1) is a piece of equipment that sends domestic sewage discharged from households to the sewage treatment plant. Some municipalities have more than 500 manhole pumps. Although it is desirable for preventive maintenance to be carried out with a good use of operation data, it is difficult to check all of the data on a daily basis due to the shortage of labor. As a result, operations may fail without an abnormal condition being noticed, and pumps are forced to take emergency measures in some cases.

In this report, we are pleased to announce that we have recently introduced artificial intelligence (AI) into our cloud management system. AI, which takes the place of humans in analyzing operation data, enables early notification of trouble and their status. This allows the user to be ready to take measures before an emergency shutdown of facilities thereby enabling efficient maintenance.

Fig. 1 Manhole Pump Unit and Submersible Pump

2. Product overview

AI takes over the work from humans by monitoring water levels and pump current data and automatically sets operations into the normal range according to each manhole pump. Notifications about deviations from the normal operation, if detected, are displayed on the monitoring screen once a day. The AI system can detect fluctuations in operation data that would have required meticulous human checks. In addition, the display of estimated causes of trouble contributes to the enhanced efficiency in the setup of maintenance work, such as the selection of tools to carry and the confirmation of the order of overhaul check points (Fig. 2).

The AI abnormal operation detection system is available without adding a new device if the Kubota “MU-1000” series monitoring system has already been used to retrieve data of water levels and pump currents.

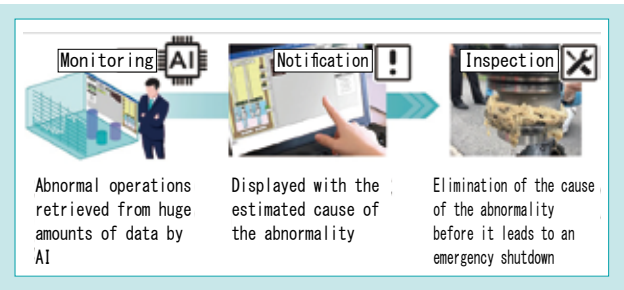

Fig. 2 Maintenance Flow with AI Support System

3. Conclusion

The AI abnormal operation detection system is part of KSIS (KUBOTA Smart Infrastructure System), which is Kubota’s IoT solution system, and delivers services in a package as a “Manhole Pump AI Support System” combined with the “Cloud Facility Ledger”, which can centrally manage various kinds of information such as facility repair and renewal logs and inspection results.

We will continue to support people’s comfortable lives by improving the efficiency of work operations and by proactive trouble prevention activities.

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