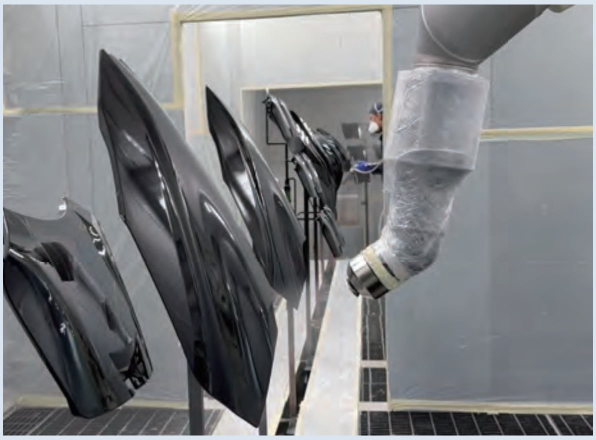
Innovative Coating Technology to Reduce Environmental Impact



The Kawasaki Heavy Industries Group is committed to achieving carbon neutrality, targeting Scope 1 and 2 emissions by 2030 and Scope 3 by 2040. Given the significant CO_2 emissions from our coating processes during product manufacture and the production and logistics of coatings, minimizing coating waste is essential. To achieve this objective as part of our efforts to reduce our environmental impact, we have developed an innovative coating technology. This includes a two-pack coating machine that is easy to clean and a virtual reality system that simplifies the teaching of complex operations to painting robots for highly efficient coating.

Introduction

Many types of energy, including water, steam, mains gas, and electricity, are used for production in the coating division. Reducing the consumption of these energy sources important for achieving carbon neutrality. Moreover, reducing the consumption of coatings used in the coating division is also a critical effort toward carbon neutrality with an eye to the overall lifecycle, including the production and logistics of coatings. As the Kawasaki Heavy Industries Group is committed to achieving carbon neutrality, targeting Scope 1 and 2 emissions by 2030 and Scope 3 by 2040, we aim to reduce coating waste.

1 Problems with the coating process

Disposal loss from coating is largely broken down into two types as shown in **Fig. 1**. The first loss is the disposal of blended coatings. Two-pack curable coatings are used for the resin cowlings and fuel tanks of motorcycles. This type of coating is designed to blend the base coat and the hardener, and cure the mixture in a low-temperature drying oven. The disadvantage is that curing the reaction progresses even at room temperature. This disadvantage means that large amounts of coating are disposed of every day in the coating division, which must change coating colors about 20 times a day. The second loss is the

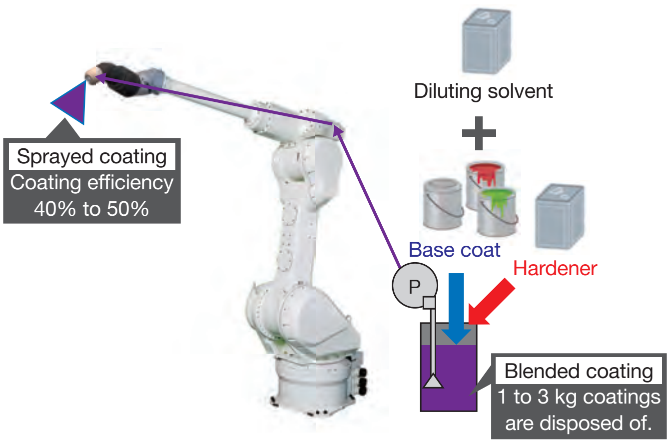


Fig. 1 Waste from a coating process

disposal of sprayed coatings. Coating efficiency, which indicates how much of the coating sprayed from the coating machine adheres to the object to be coated, is about 40% to 50% for electrostatic coating with a painting robot and as low as around 10% for manual non-electrostatic coating. Coating materials that do not adhere to a target surface are disposed of without going through any process.

2 Development of a two-pack coating machine to reduce coating waste

Once blended, two-pack curable coatings cannot be used on the following day even if some of them remain unused. Daily washing and disposal are required, so in general, two-pack coating machines are used. However, businesses such as Kawasaki Motors that handle various coatings find it difficult to ensure stable coating quality with conventional two-pack coating machines.

(1) Problems with conventional two-pack coating machines

(i) Problem of washability

Figure 2 shows a sectional view of an electrostatic rotary atomization bell, which is a conventional two-pack coating machine. The paint feed tube in the diagram supplies a coating and the bell cup that rotates at high speed atomizes it. The base coat and the hardener go through the static mixer shown in **Fig. 3**, which is built into the coating machine's paint feed tube, where they are blended and churned. However, because it has multiple blades of complicated shape, the static mixer is difficult to wash, which leads to a higher probability of coating defects due to an increase in the consumption of cleaning solvent and accumulation of coating residues that result from insufficient washing.

(ii) Problem of blendability

Figure 4 shows the feeding paths for the base coat and hardener. The base coat path connects to the

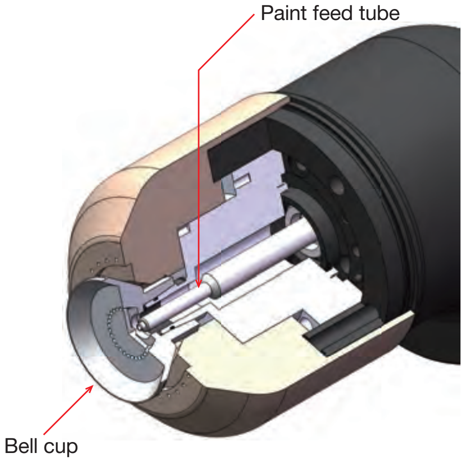


Fig. 2 Section of an electrostatic rotary atomization bell

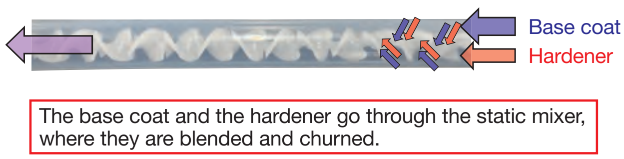


Fig. 3 Built-in static mixer in a coating machine

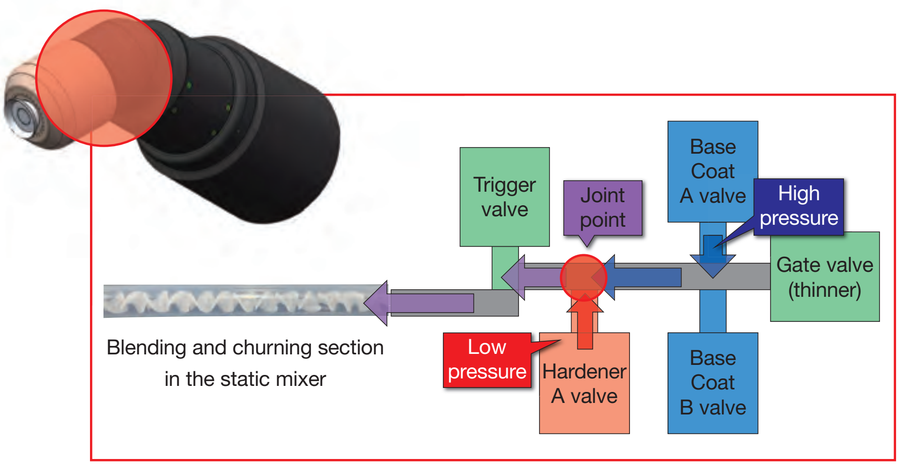


Fig. 4 Feeding paths for the base coat and hardener inside a coating machine

hardener path midway. As long as the supply pressures of the base coat and the hardener are comparable, no problem occurs. However, if the hardener's supply pressure drops it cannot be added, causing insufficient curing.This does not cause a problem as long as the ratio of base coat to hardener is fixed to 3:1 like they are for coatings in the automobile industry. However, the coatings we work with have varying base coat-to-hardener ratios, ranging from 3:1 to 11:1. Especially when the hardener ratio is small, supplying a tiny amount of hardener and keeping a constant supply pressure is difficult, so insufficient curing can happen.

(2) Development of a coating machine that blends two-pack at the tip

We overcame conventional problems by developing a new two-pack coating machine with an innovative blending function based on an unprecedented hydrodynamic idea.

The interior of the electrostatic rotary atomization bell contains a paint feed tube that has a double-tube structure. A coating is supplied to the central section and a cleaning solvent is supplied to the outer part. **Figure 5** shows the paint feed tube Kawasaki Motors developed through focusing on this double tube structure. This paint feed tube has a simple structure, with the tapered nozzle cap fitted onto double tubes. We anticipated that, in this structure, the hardener input through the central section of the double tube and the base coat input through the outer section would merge in the nozzle cap, with the sectional area of the nozzle cap gradually decreasing. This would accelerate the flow speed and mutually blend the base coat and the hardener.

To validate this structure, we carried out two patterns of computational fluid dynamics (CFD) analysis. In verification 1, the hardener and the base coat were input through the central section and outer section of the paint feed tube with the double tube structure, respectively. In verification 2, we attached the nozzle cap to the tip of the paint feed tube under the same conditions as verification 1. The analysis result is shown in **Fig. 6**. Red, blue, and white indicate hardener, base coat, and good blended state, respectively. The base coat and hardener began to blend when they hit the rapidly rotating bell cup in verification 1 as shown in **Fig. 6(a)**. In verification 2, blending started inside the nozzle, and the base coat and hardener sufficiently blended at the nozzle outlet as shown in **Fig. 6(b)**. This result suggests that a shear force occurs due to the flow speed difference at the interface between the base coat and the hardener and that the nozzle further accelerates the flow to promote blending.

We jointly developed a coating machine with a coating machine manufacturer based on this analysis result. **Figure 7** shows a sectional view of the developed coating machine.

This machine is easy to wash because it does not require a static mixer and has an extremely simple structure with a nozzle cap added to the tip of the paint feed tube. This means no risk of coating defects. In addition, because the point where the base coat path and the hardener path merge is inside the nozzle, two-pack with different flow speeds are blended due to their shear force. This means that unlike in the past, their supply pressures do not have to be exactly the same.

(3) Introduction cases

We have defined this coating machine as our Group's global standard coating machine and plan to gradually deploy it to our bases in Japan and overseas. We are already operating this coating machine at our resin coating factories in Japan and Mexico (**Fig. 8**), which is helping to reduce blended coating waste.

In addition, because we jointly developed this coating machine with a coating machine manufacturer, it is now

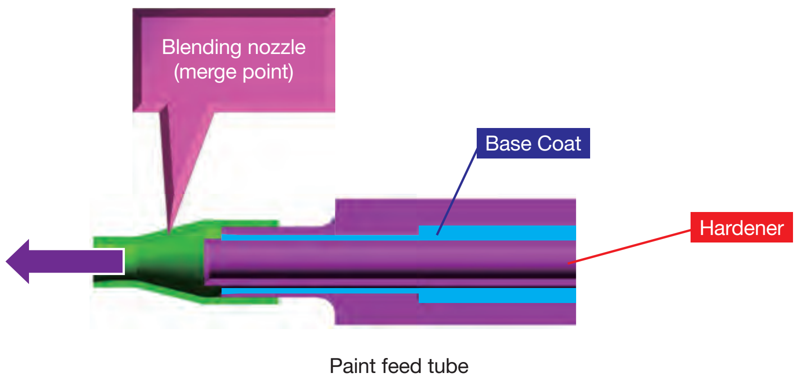


Fig. 5 Paint feed tube developed by Kawasaki Motors

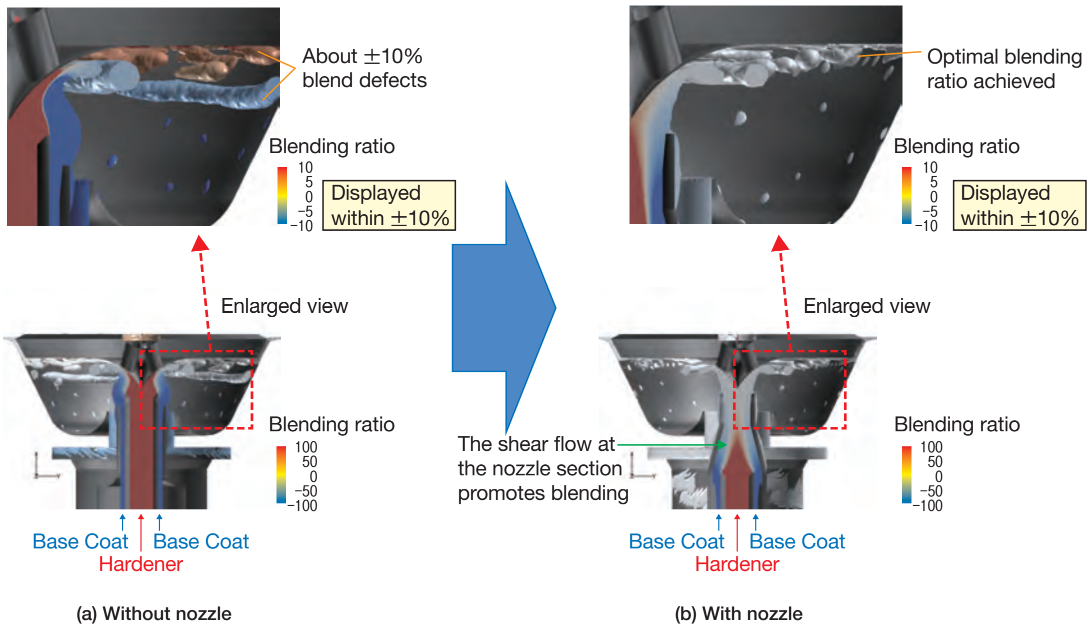


Fig. 6 CFD analysis results

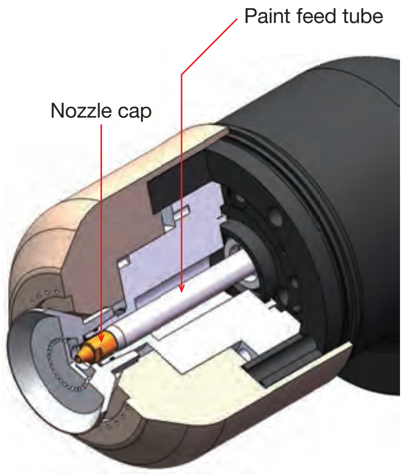


Fig. 7 Section of the coating machine that blends two-pack at the tip

Fig. 8 Installation at a factory in Mexico

also commercially available. This technology will contribute to reducing coating waste across the coating industry and help to create a future of sustainable manufacturing.

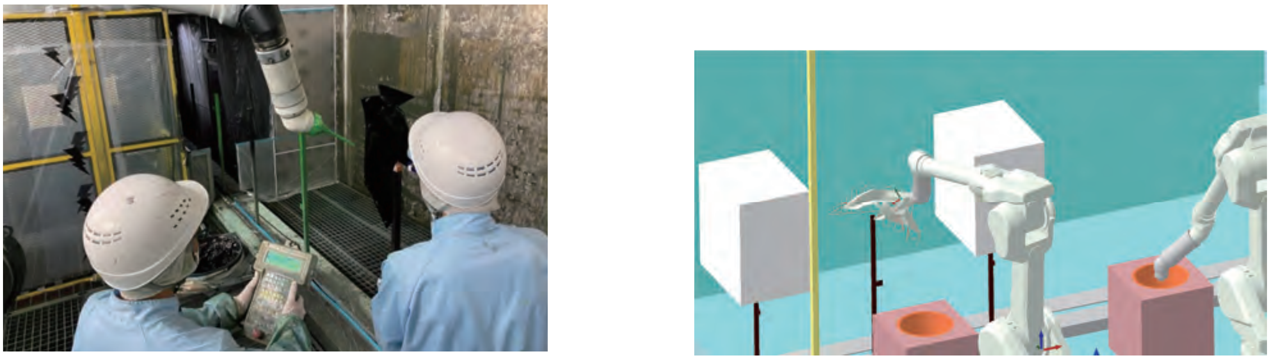
3 Teaching a robot to reduce coating waste during coating

(1) Creating of a painting robot teaching program

Improving coating efficiency is the most effective way to reduce coating waste during coating. As proximity coating using an electrostatic rotary atomization bell with a high coating efficiency has recently become mainstream, we have also started introducing it. However, for proximity coating with a good coating efficiency the distance between the coating machine and the object to be coated must be 100 mm, which is closer than that in the past by 150 mm. The key is robot movement, because the collision risk rises as the coating machine is placed closer to the object to be coated as shown in **Fig. 9**. Moreover, a large amount of coating adheres to the object to be coated, which may cause the coating to accumulate at the edge of the object to be coated, which could lead to coating failures. Therefore, we had to create a robot teaching program to move the robot along a new track (**Fig. 10**). In other words, robot coating is more important than ever for achieving high-efficient coating, so teaching

(a) Conventional coating (b) Proximity coating

Fig. 9 Bell-type coating: distance between a coating machine and an object to be coated



(a) Robot teaching using a teach pendant (b) Robot teaching using OLP

Fig. 10 Method for teaching coating robots

a pain robot requires the programmer to have a high degree of skill.

There are two methods available for teaching the painting robot how to operate the coating machine, as shown in **Fig. 10**. Specifically, you can teach the robot using a teach pendant in the field or offline programming (OLP). If you opt to teach the robot in the field, the workload on production engineers increases because they must work from evening into night after production ends at the factory. In contrast, OLP using a PC enables robot teaching regardless of the production situation in the field but it may take about one day per part. Therefore, we need a new OLP tool to create robot teaching programs easily and efficiently.

(2) Problem of robot teaching using OLP

The OLP environment must be the same as the real-world environment (the positions of the painting robot and object to be coated) to make the most of painting robot teaching programs created using OLP. If there are differences between the OLP environment and the real environment, the robot operating tracks will also differ. In other words, the coating efficiency drops even if a coating machine with a high coating efficiency is used.

We have highly accurate 3D models for parts to be coated, such as resin cowlings and fuel tanks, because we use 3D CAD for product design. However, we lack highly accurate 3D models for coating booths and other equipment partly because they were built based on 2D drawings. Moreover, coating equipment is a large structure that differs from the drawings at the construction stage, making it difficult to create highly accurate 3D models from 2D drawings. Therefore, we scanned actual coating equipment with a LiDAR (light detection and ranging) instrument, built a point cloud model based on the scanned data, compared the built model with a 3D model created based on a 2D drawing, and checked for differences (**Fig. 11**).

(i) Differences regarding the painting robot

Figure 11(a) shows a comparison between the point cloud model and the 3D model. Because the installation position of the base plate for the painting robot differed

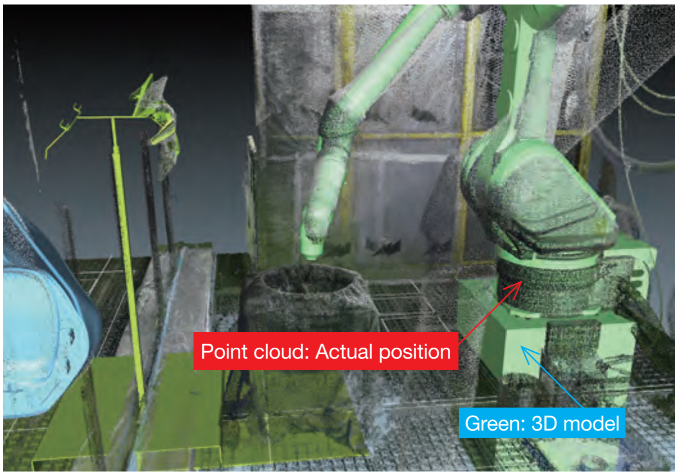
slightly from that in the drawing when coating equipment was constructed, the painting robot's installation position shifted, changing the relative positions of the coating machine for the painting robot and the object to be coated.
(ii) Difference regarding the coating jig

Figure 11(b) presents a comparison between the point cloud model and the 3D model. Although the coating jig was designed using 3D CAD, the inclination and sag due to its own weight and center of gravity of the object to be coated were not considered. Moreover, the coating jig used in the field had deformed due to aging and become different to that in the 3D model.

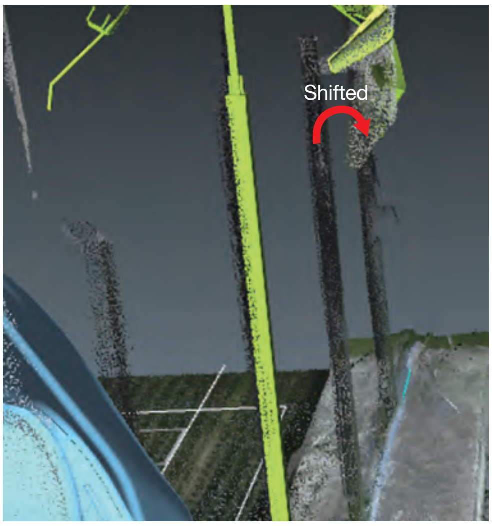
The key to improving the accuracy of the 3D model used during OLP is to build and compare a point cloud model for actual coating equipment. We succeeded in reducing differences from the real environment by correcting the 3D model based on the comparison result. This work enabled us to use the robot teaching program created with OLP without local adjustment on some coating lines, significantly reducing local work time.

(3) Development of the next-generation robot teaching system

We developed a next-generation robot teaching system by leveraging the technology of Successor Wizard (**Fig. 12**). Successor Wizard is a remote robot cooperative system developed by Kawasaki Heavy Industries. This system uses a technology to remotely operate the robot intuitively in line with the user's hand movement by moving a dedicated controller called Wizard in place of the teach pendant when operating the robot. We set a goal of creating robot teaching points with the user's hand



(a) Difference with respect to the painting robot



(b) Difference with respect to the coating jig

Fig. 11 Comparison of point-cloud and 3D models

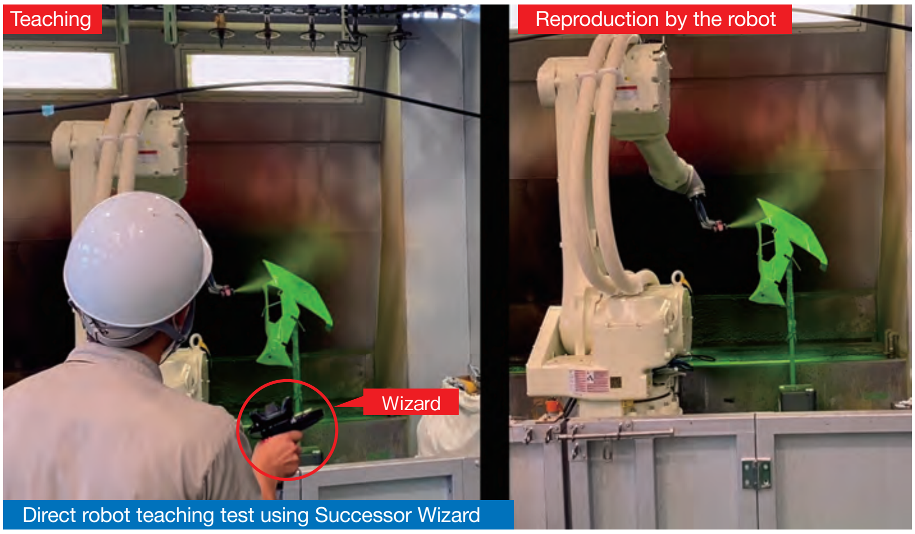


Fig. 12 Successor Wizard

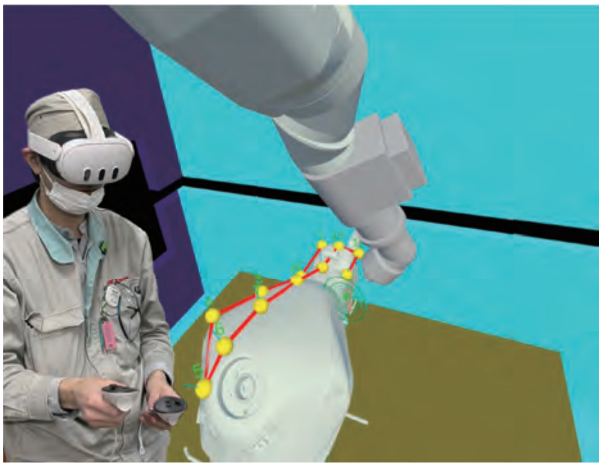
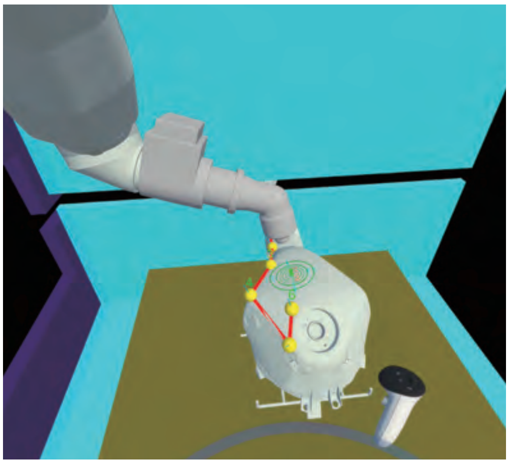


Fig. 13 Selected VR device

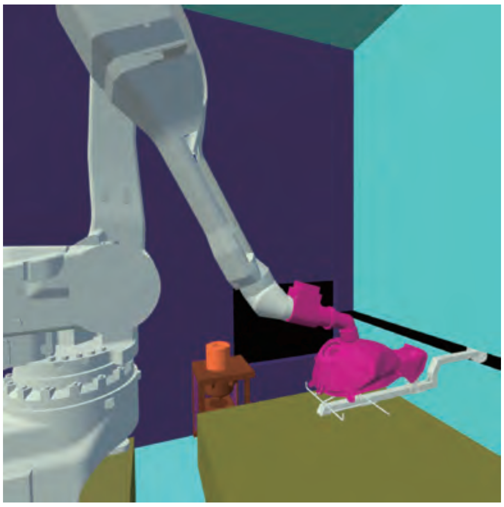
movement and placing teaching points at desired locations accurately and quickly by leveraging the controller tracking technology used in this technology. In addition, by combining this technology with VR technology, you can enter the environment created in OLP as if you are actually teaching a robot.

We selected Meta Quest 3, which has a see-through function, as the VR device used in this system so you can visually confirm the surrounding environment for safety even when you wear VR goggles. A special K-ROSET that supports the VR function is installed in the PC for OLP and is used for operations to replace 3D models. The K-ROSET simulates robot operation with high accuracy. As the controller attached to Meta Quest 3 is used to operate the robot, you can intuitively operate the robot by moving your hand as shown in **Fig. 13**. Furthermore, you can visually display teaching points and tracks in a way that is easy to understand (**Fig. 14(a)**), display the contact between the robot and the object to be coated (**Fig. 14(b)**), and perform other operations as VR-specific visual effects not available through robot teaching in the real world. We are still developing the robot teaching assistance function and plan to upgrade it as needed.

This system has become an OLP that anyone can easily handle because you can work in the 3D model at the same scale as actual factory equipment and intuitively operate the robot with your actions. Our mainly development target at the moment is painting robot teaching work, but in future we aim to apply this system to handling, welding, and other processes.



(a) VR display function (displaying teaching points and track)



(b) VR display function (contact with the robot)

Fig. 14 Example of VR display functionality


Fumihiro Nakagawa
Global Production Management Department,
Manufacturing Division,
Kawasaki Motors, Ltd.


Takayoshi Adachi
Global Production Management Department,
Manufacturing Division,
Kawasaki Motors, Ltd.


Ph.D. (engineering)
Hideki Kawamoto
Mechanical System Research Department,
Technical Institute,
Corporate Technology Division


Tatsutoshi Asato
Product & Market Management Office,
Robot Business Division,
Precision Machinery & Robot Company


Yoshiki Naito
General-purpose Robot Design Department,
General-purpose Robot Group,
Robot Business Division,
Precision Machinery & Robot Company


Yuma Ishi
Automotive System Department,
General-purpose Robot Group,
Robot Business Division,
Precision Machinery & Robot Company

Conclusion

We developed new coating technology and partially introduced it to verify its effect on reducing our environmental impact, and will gradually introduce it at domestic and overseas bases to reduce environmental impacts across the Kawasaki Heavy Industries Group.

The coating process consumes a lot of energy and generates much waste in reality, though it is intended to protect products and improve appearance. We will continue to reduce our impact on the global environment for the future of sustainable manufacturing.