Technical Paper

Utilization of 3D Data for Welding Robot

Masaki Abo

Hiroki Nakanishi

Koji Inada

In Komatsu, arc welding work has conventionally been automated with the welding robots. A robotized system requires quick preparation for mass production of a new model and continuous efforts for improvement. In programming of the welding robots, we have developed an off-line teaching software utilizing 3D model data and used it for teaching. For the monitoring of the robot operating status, we have built the system which allows easy check of the operation status by displaying the robot status on the 3D model in conjunction with KOM-MICS.

Key Words: *Welding robot, 3D data, Off-line teaching, Visualization*

1. Introduction

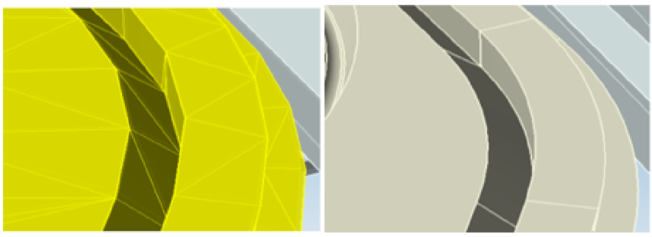
In Komatsu, arc welding work has conventionally been automated with the welding robots. A robotized system requires quick preparation for mass production of new models and continuous efforts for improvement. Programming for the robots has to be made by a person and the person is required to have specialist knowledge and skill of both welding and robots. After the automation, continuous monitoring of the robot operation status and program improvement to reduce short stop and enhance the operating ratio are necessary. As parts of construction machines have many welding lines and many part numbers, these works are especially important. The off-line teaching software and the operating ratio monitor Komatsu developed can utilize 3D data, enabling efficient operation. Here we introduce the software.

2. Utilization of 3D data in off-line teaching

2.1 Off-line teaching software for welding robot

Komatsu has conventionally utilized the off-line teaching which teaches the robot not with the actual machine but in the 3D space on the PC [1]. Usually, program teaching for robots uses the teaching playback method in which a person operates the robot to move it to the target points and registers its positions one by one for programming. The off-line teaching is possible on the PC, which enables teaching before starting the machine or without stopping the production by the machine in operation.

The conventional off-line teaching software can read polygon models only. This time, we have made a significant version upgrade of the off-line teaching software to enable reading of STEP file, a general CAD format, in addition to STL file. With polygon data of STL file, as arc shapes are approximated by polygonal shapes, the tool path function described below cannot be realized. STEP file has the data of accurate arc shapes (**Fig. 1**), so that the tool path function can be realized.



STL file STEP file

Fig. 1 STL file and STEP file

2.2 Operation particular to welding robots for construction machines

The welding robot system for construction machines handles very large workpieces, so it needs to be equipped with not only the robot but also the travel axis and the positioner axis (**Fig. 2**). Therefore, the functions of the off-line teaching software enable the simulation of the systems with the travel axis and the positioner axis. The off-line teaching software also has the functions working on the condition of the interlock with the travel axis and the positioner axis.

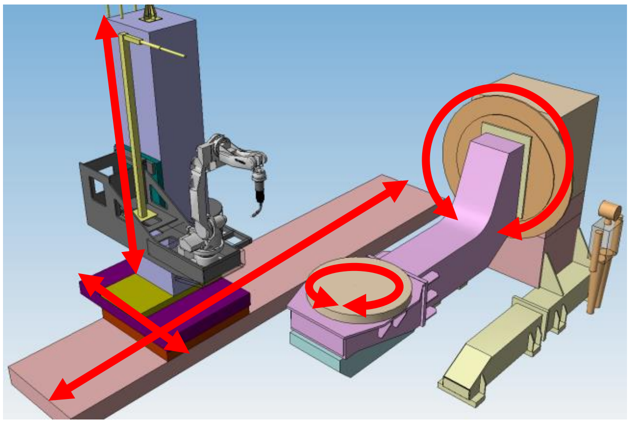
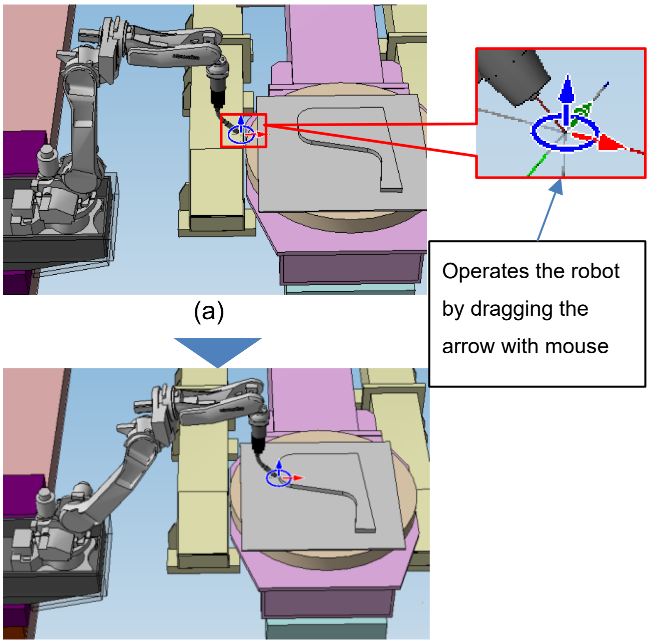


Fig. 2 System example with 3 travel axes and 2 positioner axes

For example, when you want to operate the robot posture from **Fig. 3 (a)** to **Fig. 3 (b)**, it is possible by moving the TCP (tool center point) with mouse operation (**Fig. 3**). With the robot system equipped with the travel axis, the TCP position of the robot can also be changed by operating the travel axis. However, in the case of **Fig. 4 (a)** where the posture of the robot is stretched, it is desirable to change the posture as shown in **Fig. 4 (b)**. When you operate the travel axis, the TCP position of the robot is moved, but by operating the TCP in the opposite direction, the operation to make the position of the TCP fixed relative to the workpiece is possible (**Fig. 4**). Other convenient operation methods for robot teaching including the torch axis operation, the tool coordinates operation, the torch direction operation as the robot operation are also provided.



(b)

Fig. 3 Example of robot operation with mouse

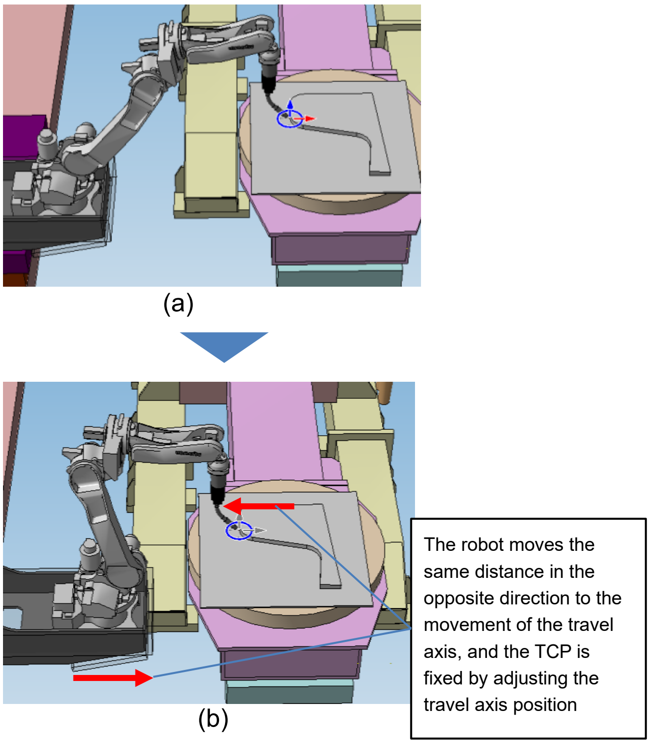


Fig. 4 Example of robot operation with the TCP position fixed

2.3 Reading welding symbols

For teaching of weld line, welding information needs to be read from a 2D drawing (**Fig. 5**). Because product drawings are complicated in shape and have many weld lines, they take a long time to be read.

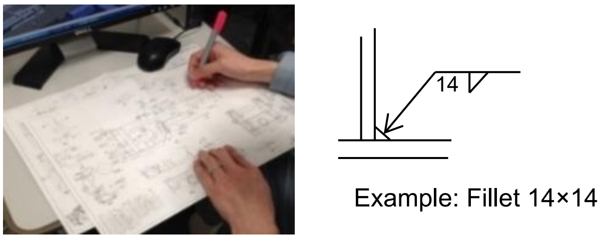


Fig. 5 Image of 2D drawing

For the solution, we have been conducting the application trial of the 3DA model (3D Annotated Model) that is a 3D model with product characteristics (dimension, material, notes, etc.) and necessary information for production. It enables the off-line teaching software to read welding symbols added to the 3D model. The read welding symbols are displayed to overlap the 3D model (**Fig. 6**), so that the welding lines are easily recognized. By selecting the weld line, necessary information such as leg length can be checked (**Fig. 7**).

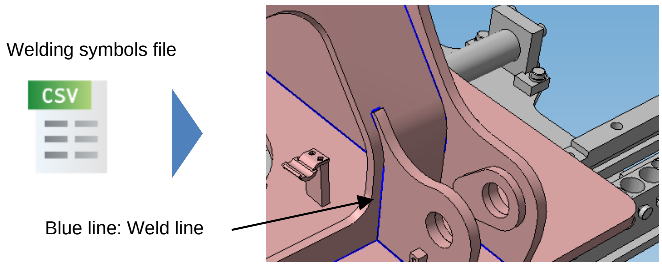
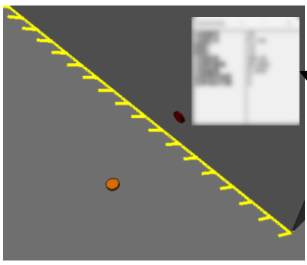


Fig. 6 Import of welding symbols



Welding symbols	
Welding symbol	Fillet
Leg length 1	14
Leg length 2	14

Example of displayed welding symbols

Fig. 7 Display of welding symbols

2.4 Tool path generation function

In arc welding, the molten metal is affected by gravity, so the posture during welding is important. The flat welding posture shown in **Fig. 8** makes the welding quality stable and heavy-current welding possible. Therefore, the TCP (tool center point), the tool angle and the positioner angle need to be created and taught to the robot. When teaching them with the actual robot, they are created in order as shown in **Fig. 8**. In arc welding, the positioner angle always changes, so at least three positioner postures have to be created for one arc (**Fig. 9**) and it takes time for the teaching.

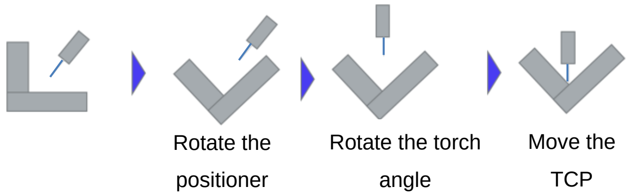


Fig. 8 Teaching example of flat welding

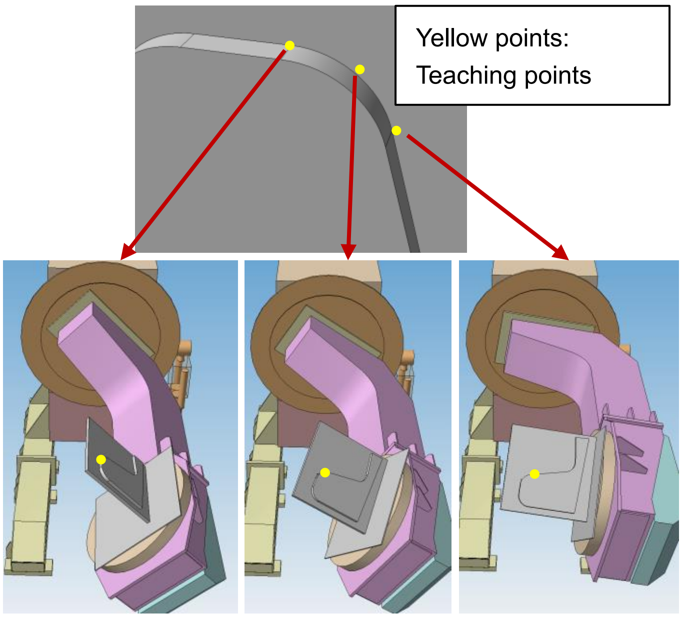


Fig. 9 Example of positioner posture in arc flat welding

Also, for collision avoidance between the robot and the workpiece, the robot departure from its operation area, and the singularity, adjustments of the position of the travel axis and the posture of the torch axis (**Fig. 10**) are necessary. In normal teaching, after teaching the three points, the movement of the robot needs to be checked by executing the robot program and then to be modified, which takes time and effort for teaching.

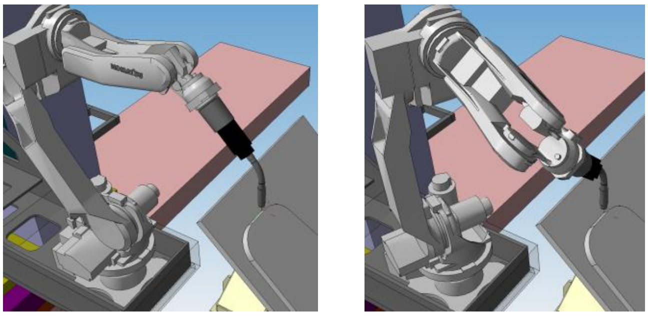


Fig. 10 Posture adjustment of torch axis

To make the teaching easier, the off-line teaching software is installed with the tool path function which automatically generates the positioner angle, the torch angle, and the torch position from the welding symbols or the edge information of the CAD model (**Fig. 11**). The tool path function generates the position information including the movements of the robot, the travel axis and the positioner axis. By moving the robot to an arbitrary position on the tool path, the robot posture at the time can be checked (**Fig. 12**).

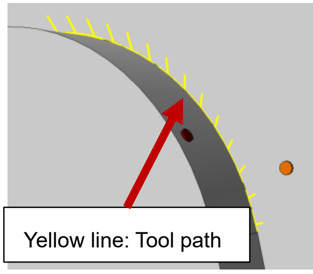


Fig. 11 Tool path function

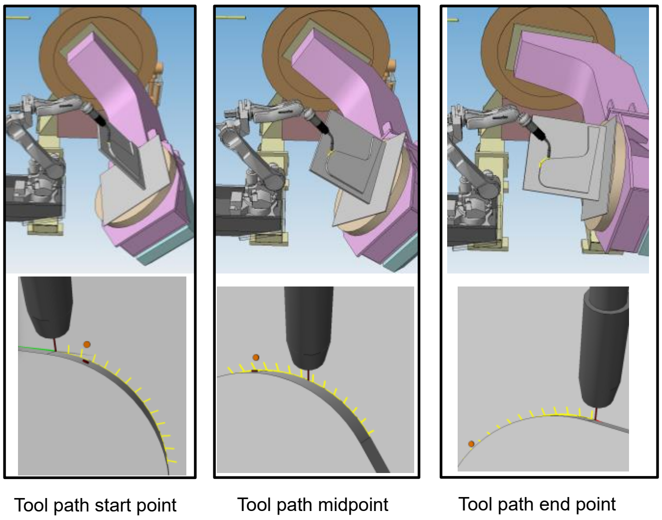


Fig. 12 Applications of tool path function

In welding, sometimes the torch angle and the positioner angle are adjusted for the teaching of asymmetric fillet weld and down hill welding. The tool path function can handle such adjustments by the parameter adjustment.

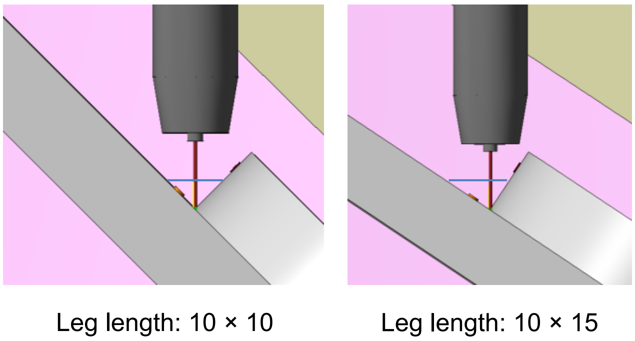


Fig. 13 Designation example of asymmetric fillet

It also allows the multiple selection of straight lines and arcs (**Fig. 14**). By automatically operating the robot on the created tool path, the check of the collision with the workpiece and the judgment of the robot departure from its operation area are possible.

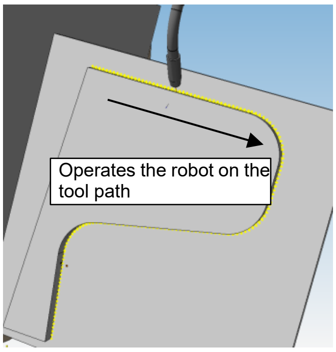


Fig. 14 Example of multiple edge selection

After the automatic operation on the tool path, the bottom of the bar with the part allowing normal operation is displayed in light blue, with the part making collision with the workpiece in red, and with the part out of the robot's operation area in yellow. **Figure 15** shows an example of collision between the robot and the workpiece.

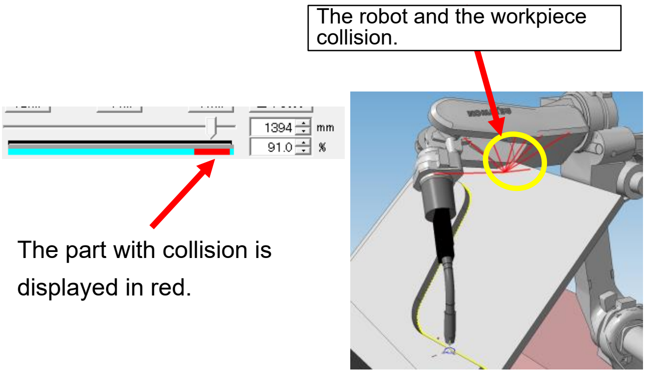


Fig. 15 Collision check function of tool path

The adjustment after teaching can easily be made by the procedure that is to move the robot to the position having collision with the workpiece, adjust the position of the torch axis or the travel axis, and then execute the collision check again (**Fig. 16**).

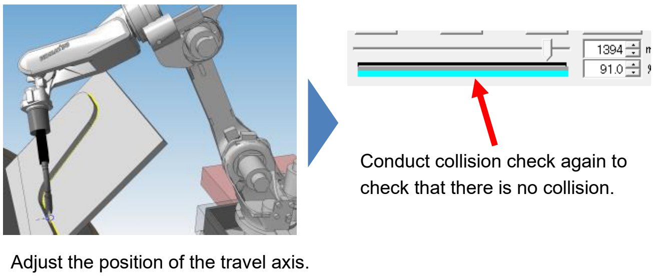


Fig. 16 Teaching collision avoidance of tool path

By using the tool path function, the teaching time for weld line can be reduced by 50% , and by 80% just for arc parts.

As mentioned above, we have developed the functions dedicated to construction machine welding utilizing 3D model for welding robot off-line teaching and proceeded with easier robot teaching work.

3. 3D data utilization in process improvement

The conjunction of the off-line teaching software mentioned above and Komatsu's productivity improvement system KOM-MICS [2] realizes various process improvements.

3.1 3D model management function with KOM-MICS

In-house Komatsu, there are various production facilities including welding robots and machine tools. KOM-MICS is the system which collects the operating ratio data from these facilities and visualizes the data with various applications for improvements (**Fig. 17**). The parts of Komatsu products are produced not only internally but also by our subcontractors, so we make KOM-MICS available to our subcontractors as well. Thus, KOM-MICS functions as the system of efficiency strategy for the production in entire Komatsu group.

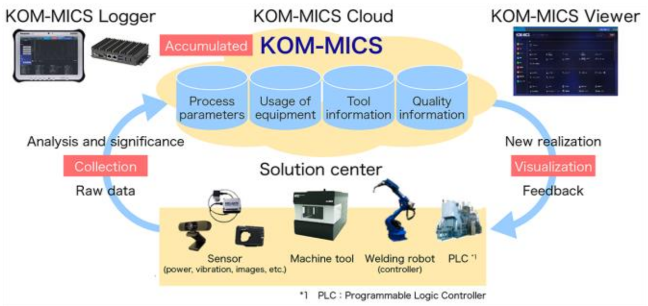


Fig. 17 Overview of KOM-MICS

The welding robots are connected to about 500 facilities in Japan and overseas including the subcontractors' sites and their operating ratio data are collected day by day. The strong point of this system utilizing 3D model is the unified management of the 3D models of the robot system, the workpieces, and the positioners mentioned above as a database. As shown in **Fig. 18**, you can select an arbitrary system from the list of the robots in Japan and abroad and can display and download its 3D model with the system. This means that the users of KOM-MICS can conduct new teaching and operation checks of welding jobs by using registered 3D models.

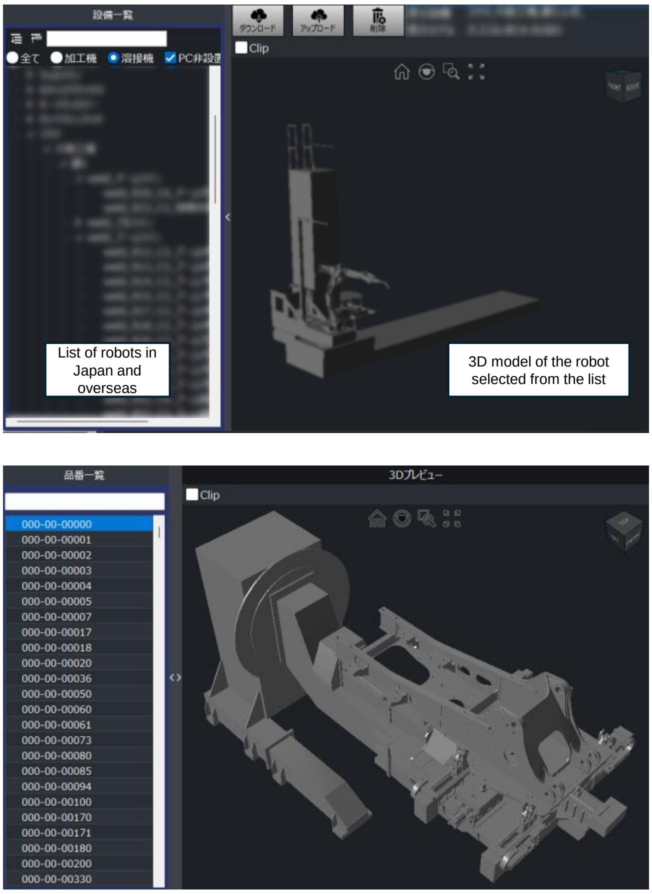


Fig. 18 Database of facility 3D models in KOM-MICS

3.2 Process improvement in conjunction of operating ratio data and 3D model

The operating ratio data collected by KOM-MICS includes the robot position data, the positioner rotation angle, etc. on a moment-to-moment basis, but the data is only numerical values and it is difficult to imagine the movement of the robot with them as it is. Therefore, KOM-MICS has the function of conjunction with the off-line teaching software, as mentioned above. As shown in **Fig. 19**, while displaying the welding current value in the operating ratio data as a graph by KOM-MICS, we can check the position and posture of the robot at an arbitrary time by the off-line teaching software. Utilizing this, we can intuitively grasp, for example, whether the welding position and order of welding is appropriate and which posture frequently makes error stops, for further improvement.

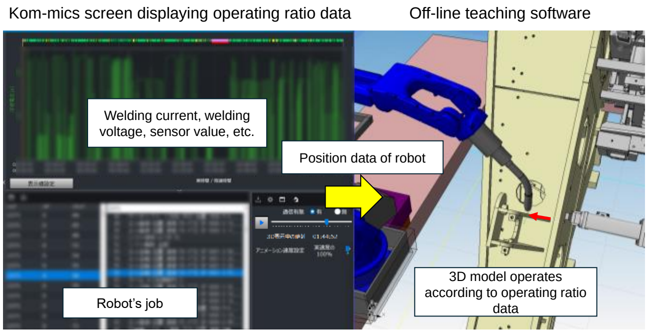


Fig. 19 Conjunction of KOM-MICS and off-line teaching software

The conjunction function above contributes to the reduction of cycle time of the multiple-robot system, the system in which several robots perform welding of one workpiece. **Fig. 20** is one of the examples. The multiple-robot system frequently has waiting time as shown in pink in the time chart before improvement. This is because while one robot is welding, other robots have no available weld line to work on. Using the conjunction function, efforts to reduce the waiting time have been conducted by changing the welding order to be appropriate with the monitoring of the postures of the robots and by leveling the jobs of the robots, as mentioned above. With such efforts, in the example of **Fig. 20**, the cycle time has been reduced by 15%.

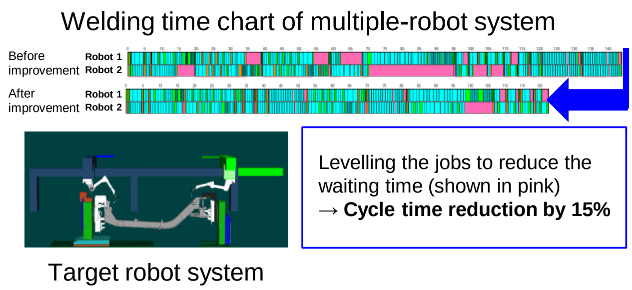


Fig. 20 Improvement of cycle time of multiple-robot system

3.3 Function displaying welding locus on 3D model

The off-line teaching software has the function to read the operating ratio data and display the welding locus on the 3D model (**Fig. 21**). The points with displayed locus is the part automatically welded by the robot. The user can grasp the part that is not automatically welded by comparing this locus and the welding symbols given to the 3D model beforehand. For the parts without the automatic welding, automation is proceeded day by day through the creation of newly established welding conditions and the development of new functions of the robots.

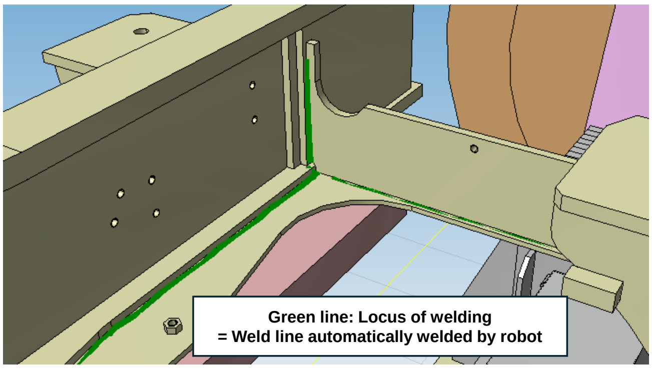


Fig. 21 Function displaying welding locus

4. Conclusion

The results acquired through the research and development of "Utilization of 3D data for welding robot" are as follows.

(1) The off-line teaching software has been updated to deal with a general CAD file and the reading of welding symbols added to the 3D model.

(2) The tool path generation function which automatically creates the robot posture, the travel axis, and positioner posture from the welding symbols and the shape data of the 3D model has been developed.

(3) By the conjunction with KOM-MICS, checking the robot operation status on the 3D model is made easy.

References

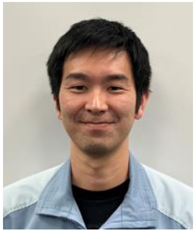
[1] Nobuyoshi Yamanaka, "Off-line Teaching System "TCHMORE"", KOMATSU TECHNICAL REPORT, VOL.51 No.155, pp.17-21, 2005

[2] Naoto Saito, Keisuke Tsuboi, "KOM-MICS, a "Tsunagaruka" System for Production Sites", KOMATSU TECHNICAL REPORT, VOL.62 No.169, pp. 9-14, 2016

Introduction of the authors

Masaki Abo
Joined Komatsu Ltd. in 2017.
Manufacturing Engineering
Development Center,
Production Division

Hiroki Nakanishi
Joined Komatsu Ltd. in 2020.
Manufacturing Engineering
Development Center,
Production Division



Koji Inada
Joined Komatsu Ltd. in 2010.
Manufacturing Engineering
Development Center,
Production Division

[A comment from the authors]

We expect further utilization of digital data in design, manufacturing, and operation of construction machines in the future. With that purpose, we would like to build a system to enable acquisition, conjunction, and utilization of data in various processes.