Digital Transformation (DX) Technology Contributing to Further Automation of Robotic Welding

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Abstract

Information and communication technologies, as well as DX technologies, are advancing, raising expectations for the acceleration of automation and labor-saving in production sites. Kobe Steel has been focusing on the development of various functions, including welding robots, aiming at automating welding operations. However, the introduction of welding robot systems has created new tasks requiring manual work such as teaching and maintenance. Using DX technology to reduce this manual labor can further enhance the effectiveness of introducing welding robot systems, contributing to increased productivity for our customers. Combining the ARCMAN™ Offline Teaching System with DX technology, Kobe Steel has developed new functions for automatically generating welding programs and simulating cable behaviors to reduce manual teaching work. Furthermore, connecting laser sensors, interpass temperature sensors, and cameras linked with ARCMAN™ View to the robot system has automated the measurements required for welding.

Introduction

Kobe Steel has an extensive background in developing and marketing welding robot systems for welding medium-to-thick plate, which is widely used in a variety of industries and applications such as architectural steel frames, construction machinery, bridges, and shipbuilding. In this way, we improve our customers' productivity by automating and reducing labor needs in the welding process. Components in these industries and applications are composed of large workpieces. Gaps between components from misalignment during assembly are common, and the repeated application of heat for multi-pass welding can cause thermal distortion. This can shift the target position of the weld joint, precluding a sound joint. Industry requirements for welding architectural steel frames include standards for thermal input and interpass temperature control, necessitating manual temperature measurement between passes.

To meet these requirements, our welding robot system has a laser sensor and a non-contact temperature sensor to measure and automatically control shape and temperature, thereby furthering automatic welding. The laser sensor sends out a beam that measures the root gap for automatic selection of optimal welding conditions. This enables automated narrow-gap welding, which was previously only a semiautomatic welding performed by skilled technicians. Two types of measurement methods are available; production cycle time can be minimized by using the appropriate method for the measurement point. Temperature sensors foster automation of the measurement and control of interpass temperature, improving throughput by reducing cycle time and manual labor.

This combination between the welding robot system and measurement technology promotes automation. However, welding robot systems require their own set of manual tasks not required with conventional manual welding, such as robot teaching, robot operation, and recovery from certain temporary stoppages (e.g., sensor failures, wire jams). To help eliminate these manual processes, we developed the ARCMAN™ [Note 1)] Offline Teaching System (hereafter, KOTS™ [Note 2)]) to support teaching and ARCMAN™ View to visualize robot-guided production and reduce temporary stoppages.

In Section 1 of this paper, we describe a case study in which we reduced teaching time by incorporating DX technology into KOTS™. Sections 2 and 3 contain examples of how we have further automated and optimized robot welding using various sensors.

1. ARCMAN™ Offline Teaching System

This section introduces use cases involving KOTS™, an offline simulator designed for the ARCMAN™ welding robot system. KOTS™ can reproduce the movements of peripheral equipment and mounted workpieces in addition to the main ARCMAN™ body. This software is an effective solution for a variety of situations, including preliminary application studies.[1)]

Note 1) ARCMAN is a trademark of Kobe Steel (1715437).
Note 2) KOTS is a trademark of Kobe Steel.

1.1 Automatic welding program generation function

Welding robots achieve high throughput in the mass production of identical workpieces because they operate in accordance with data points taught in advance. Producing workpieces of different shapes, however, necessitates individualized teaching data, making it difficult to achieve high throughput.

Kobe Steel developed an automatic welding program generation function to overcome this challenge. This function turns the teaching methods of skilled technicians into rules and automatically generates welding programs based on factors including such rules, the system configuration, and welding process execution information. With this function, even operators with limited teaching experience can easily create welding programs, with teaching time reduced from two days to one day.

1.2 Cable simulation

KOTS™ has an optional cable simulation function. With this function, the operator can use the KOTS™ interface to check the behavior of the torch cable via ARCMAN™ as well as how the cable is wound around the manipulator and the interference between the workpiece and the cable when entering a confined space.[2] Particularly when checking cable behavior in a confined space, interference between the cable and workpiece may place an unexpected load on the robot and damage the robot or workpiece. Previously, it took about two days to model the cable curvature via CAD for each robot pose and check for the presence of interference. With KOTS™, it is possible to evaluate the risk of movements that may cause interference in advance (**Fig. 1**), reducing the evaluation time to only about half a day.

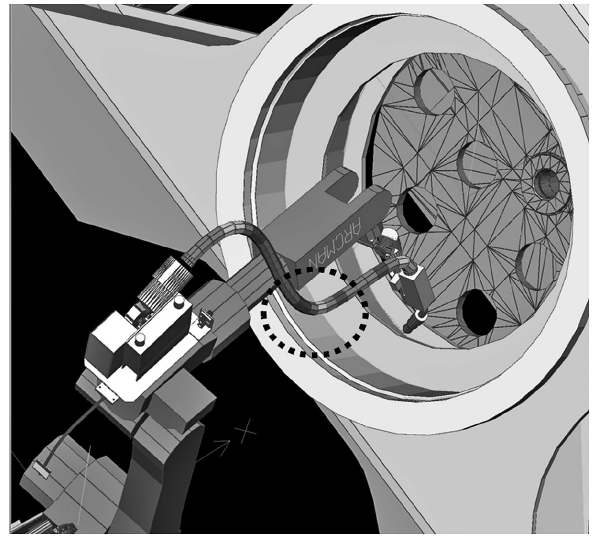


Fig. 1 Cable simulation and curvature display

1.3 Using robots in multiple-variety mixed-flow production

The automatic welding program generation function makes it possible to automatically create welding programs from workpiece models and welding process execution information. Thus, operators do not need to perform teaching operations for every workpiece in multiple-variety mixed-flow production. Our current focus in developing this function centers around the construction machinery sector. We will later expand the scope of development to include further applications, such as the welding of steel segments to prevent bridge collapse (**Fig. 2**). Kobe Steel is developing a function for the welding robot system to compensate for machine error as well as additional sensing functions to make the simulated environment more similar to the production environment and reduce the need for teaching corrections. Our ultimate goal is to fully automate the welding process by using CAD data to automatically create welding programs, which in turn will be used to automatically create teaching programs, all of which will be linked to the robot system.

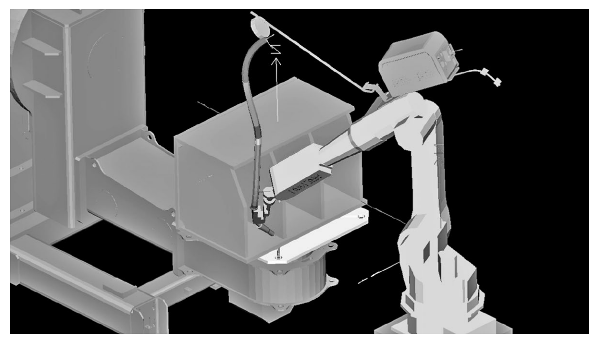


Fig. 2 Feasibility study for application to anti-collapsing devices for bridges

1.4 Efficiency improvement via KOTS™

At Kobe Steel, we work to understand the customer's situation before proposing the optimal welding robot system. We select robots, sliders, positioners, and other equipment based on their suitability for the dimensions of the target workpiece. We also determine how this equipment is structured and laid out, which requires an enormous amount of time for validation. Creating a teaching program to determine the feasibility of robot welding accounts for a considerable proportion of

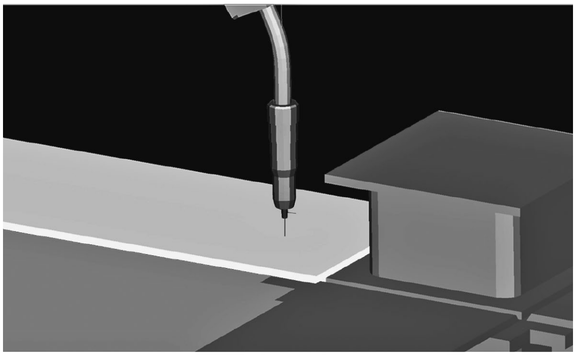


Fig. 3 3-way sensing simulation

Fig. 4 Welding torch with laser sensors

the configuration design time. To overcome this challenge, we used the automatic welding program generation function to shorten the welding program creation time and standardize the quality of the welding programs created, reducing validation time and improving quality.

In addition, Kobe Steel's welding software for architectural steel frames can automatically generate teaching programs in advance based on workpiece dimensions, such as columns and joints.[3)] Operators can use KOTS™ to verify the suitability of the teaching programs the software creates, making it possible to validate operations without preparing workpieces of various sizes or setting up actual systems. KOTS™ also includes functionality for touch sensing, a robot function that could not previously be simulated, enabling sensing that accounts for workpiece misalignment. This reduces the workload of developing software related to the automatic generation of welding programs as well as the cost of workpiece procurement (**Fig. 3**).

These technologies make it possible to propose to our customers the optimal system for welding automation.

2. Sensing technology

Kobe Steel's welding robots have sensing technologies, such as touch sensing, that eliminate the need for special measuring equipment. They also have arc sensors to compensate for groove irregularities and distortion. However, these sensing technologies cannot measure complex groove shapes. Additionally, certain workpieces are subject to temperature control requirements, hindering robot welding. The following sections detail how our system achieves automated welding of complex grooves using laser sensors and automated welding of architectural steel frames using temperature sensors.

2.1 Laser sensors

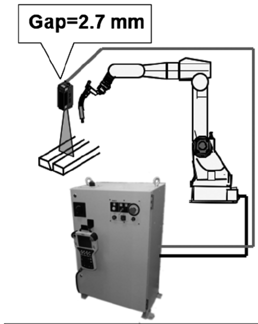
Laser sensors strike the groove and weld zone for high-speed measurement of grooves of various shapes, a function that touch sensing cannot accomplish. Unlike touch sensing, laser sensing can accurately measure a wide range of joints, including flare bevel grooves and T-joints. Additionally, a small-profile laser sensor enables stable sensing even where there is little clearance[4)] (**Fig. 4**).

2.1.1 Automating difficult welds

Large structures are often constructed of welded medium-to-thick plate, where distortion and misalignments can cause unintentional gaps in the weld line. Conventionally, human operators had to fill these gaps using semiautomatic welding before robot welding. Now that the gap can be measured via laser sensing, a robot can fill the gap, thereby reducing the operator's workload. This function automates the process, as the robot selects the optimal welding conditions from a database of welding conditions based on the gap width measured by the laser sensor (**Fig. 5**).

2.1.2 Cycle time reduction using laser sensors

Laser sensing involves striking the groove with a laser line to gather abundant data in a single measurement, unlike touch sensing, which requires multiple measuring operations to capture the same data. Conventional root gap measurement using a wire requires three measurement operations, which takes about 10 seconds. Laser sensing takes one second, or one-tenth of the measurement time. Our laser sensing system offers two measuring



DBK according to the gap

Gap[mm]	DBK
0≦gap≦1.0	101
1.0＜gap≦2.0	102
2.0＜gap≦3.0	103

SELECT

Fig. 5 Switching welding conditions using laser sensors

methods: scanning and one-shot. In the scanning measurement, the laser sensor scans a fixed distance in the direction of the weld line to collect multiple data points, which are then averaged. This reduces the influence of measurement error caused by scratches from machining or assembly, or by fumes or spatter in the groove or on the surface of the workpiece from the welding process. One-shot measurement measures a single point rather than scanning a line and is therefore faster. Custom commands can be set up to define the appropriate measurement method based on the measurement point.

2.2 Overview of interpass temperature sensors

There are standards for interpass temperature control in the welding of architectural steel frames. Common practice is for an operator to measure the temperature at a specific location using a thermometer or temperature-indicating marker just before welding the next pass. The operator then starts the next pass after confirming that the interpass temperature is below the set value.

Our interpass temperature measurement function for welding robot systems that process steel frames automates the measurement and control of interpass temperature. This function eliminates the need for operators to measure the temperature between passes. As such, this time can be reallocated to other tasks to reduce cycle time. Additionally, reliably controlling interpass temperature ensures weld joint quality.[5] This function also improves safety because the operator no longer needs to enter the safety fence to measure the temperature between passes.

This function has already been integrated at steel fabrication shops with S-grade certification.

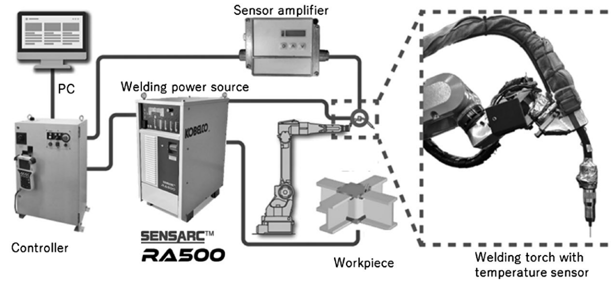


Fig. 6 System using temperature sensors

(Japanese factories can become certified by the Ministry of Land, Infrastructure, Transport and Tourism, an agency of the Japanese government, based on standards of quality control and technology. “S” stands for “Super” and is the highest grade achievable.)

2.2.1 System configuration

Fig. 6 shows the configuration of a system with the interpass temperature measurement function. The non-contact temperature sensor is near the wrist of the robot in a location that does not interfere with welding, precluding the need to switch between the temperature sensor and the torch. The sensor amplifier and controller transmit data from the temperature sensor to the computer. The temperature can be viewed on the monitor and the teaching pendant.

2.2.2 Process flow of interpass temperature measurement

Fig. 7 shows the process flow of the interpass temperature measurement function. Just before welding, the robot moves to the measurement point and measures the temperature. If the temperature is higher than the set value, the robot waits to start welding until the temperature drops below it. The temperature can be observed on the monitor during this process. This process is repeated until the final pass.

2.2.3 Interpass temperature log

This welding robot system can automatically record data, including welding current, arc voltage, and thermal input to create a welding procedure report. Previously, an operator had to record interpass temperature on paper or into a computer program. With this function, interpass temperature is automatically entered into the welding procedure report, eliminating the work of manual entry and the possibility of reporting errors (**Fig. 8**).

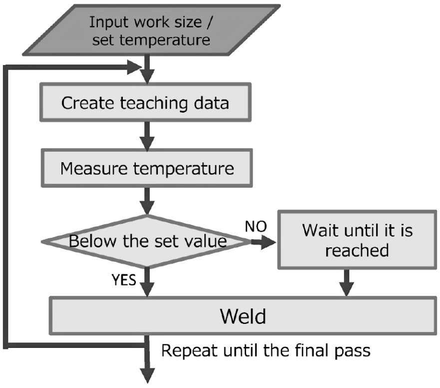
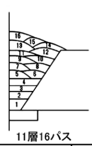


Fig. 7 Temperature measurement workflow

工事名称				作業日	2022/06/30
柱番号				ロボット名称	
継手名				オペレータ	
母材		部位	コラム	記録者	
板厚	32mm	ルート間隔	8.9mm	積層図	
開先角度	35°	溶接姿勢	下向姿勢		
溶接材料	規格				
	ワイヤ径				
	メーカー				
	銘柄				
管理	パス間温度	250℃			
	溶接入熱	30000J/cm		11層16パス	



パス	区間	溶接電流(A)	アーク電圧(V)	溶接速度(cm/min)	溶接入熱(J/cm)	パス間温度(℃)
1	直線	318	34.8	24.0	27666	100℃以下
	コーナ	301	33.3	24.0	25058	
2	直線	295	35.8	26.8	23644	100℃以下
	コーナ	289	34.4	26.2	22767	
3	直線	280	36.0	26.3	22996	100℃以下
	コーナ	269	35.1	25.2	22480	
4	直線	283	35.7	25.3	23959	102
	コーナ	280	35.1	24.1	24468	
5	直線	282	34.8	32.7	18006	100℃以下
	コーナ	270	34.2	32.1	17259	
6	直線	288	35.1	30.7	19756	113
	コーナ	270	34.7	31.1	18075	
7	直線	286	35.1	29.7	20280	134
	コーナ	281	34.4	29.6	19594	
8	直線	286	35.1	28.2	21358	136
	コーナ	259	34.8	28.0	19313	
9	直線	290	35.2	30.1	20348	116
	コーナ	269	34.7	29.9	18731	
10	直線	282	35.2	28.5	20897	137
	コーナ	259	34.5	27.6	19425	
11	直線	283	34.9	30.0	19753	157
	コーナ	274	34.6	30.0	18960	
12	直線	277	35.2	27.1	21587	152
	コーナ	264	34.6	26.4	20760	
13	直線	256	33.6	32.4	15928	126
	コーナ	247	33.6	30.0	16598	
14	直線	270	33.3	31.3	17235	132
	コーナ	231	33.4	27.9	16592	
15	直線	264	33.6	31.6	16842	145
	コーナ	235	33.6	27.8	17041	
16	直線	254	33.9	29.7	17395	143
	コーナ	245	33.7	26.3	18836	

Fig. 8 Example of a welding procedure report generated by the system

3. ARCMAN™ View

This section describes use cases involving ARCMAN™ View, an optional function of ARCMAN™ PRODUCTION SUPPORT[6]. This function supports production management and the analysis of temporary stoppages and welding defects by collecting operating data from the welding robot system and visualizing welding and production data.

3.1 Overview of ARCMAN™ View

ARCMAN™ View is an optional function that enables real-time display and recording of robot operation via cameras connected to the network (**Figs. 9** and **10**).

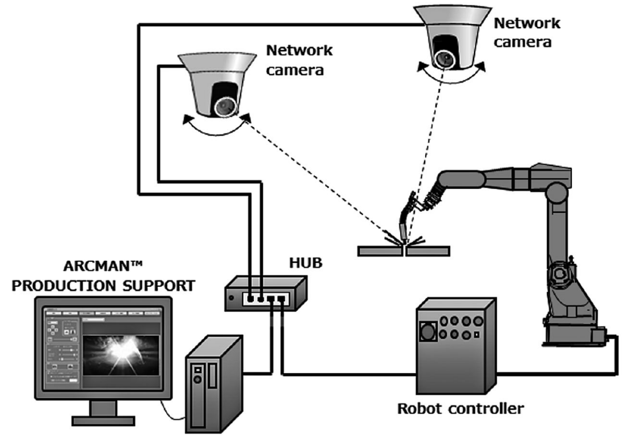


Fig. 9 ARCMAN™ View system configuration

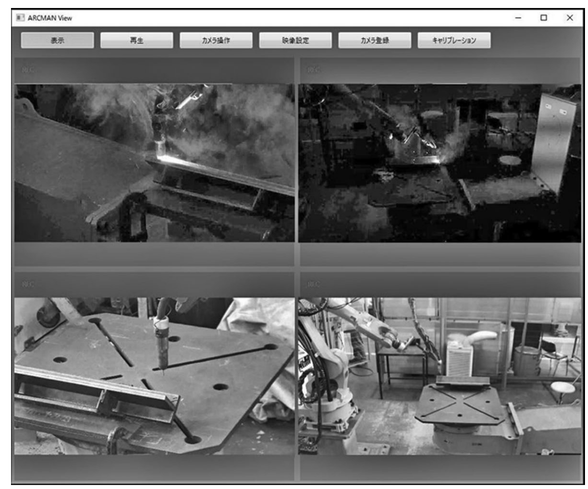


Fig.10 Sample image of ARCMAN™ View

3.2 Safety improvement with ARCMAN™ View

One feature of ARCMAN™ View is the ability to have the camera track the tip of the welding torch on the robot so it is constantly in view.

With this function, the operator can use the monitor for robot operation and to continuously observe the area around the tip of the welding torch without moving the camera manually.[7]

Remote operation via the monitor makes it possible to safely operate the robot from outside the safety fence, even in situations where it is conventionally necessary to enter the safety fence for operation via line of sight (**Fig.11**). A manufacturer of rolling stock reported a case in which the ARCMAN™ View monitor was used to perform recovery operations from outside the safety fence when a temporary stoppage occurred during welding at height.

Fig.11 Sample of remote operation outside the Fence

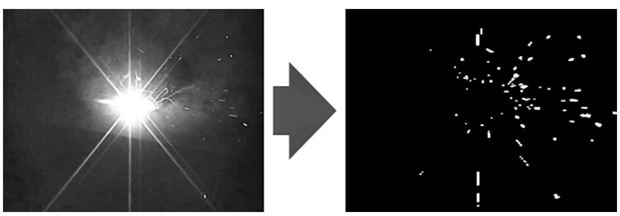


Fig.12 Image of spatter detection

3.3 Weld evaluation with ARCMAN™ View

We developed a spatter measurement function for ARCMAN™ View. This module identifies areas corresponding to spatter in images taken during welding, provides a real-time indication of the number of pixels as a numerical value, and saves it to a log (**Fig.12**). This function makes it easy to quantify the change in spatter volume based on welding conditions. As such, welding defects can be detected sooner, and the process for evaluating the effects of changing conditions is faster (**Fig.13**).

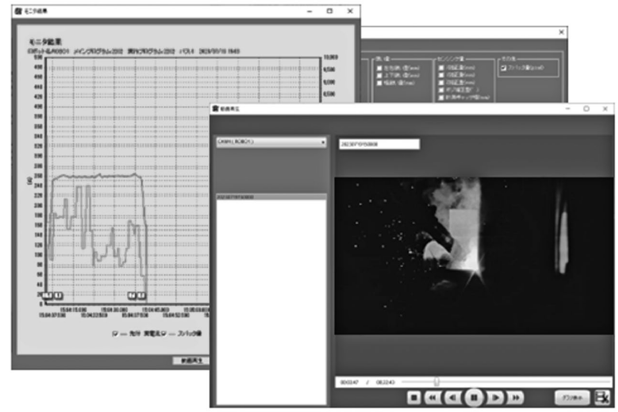


Fig.13 Image of spatter measurement display

Conclusion

This paper introduces teaching functions and measurement technologies for welding robot systems utilizing DX technology. Japan's declining birthrate and aging population are projected to intensify the need for automation and workforce reduction in production. Given this backdrop, we aim to alleviate the challenges of labor shortages and heavy manual labor by automating welding processes and improving quality, thereby improving productivity and safety in our customers' operations.

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