**Technical Paper**

# High-Efficiency Weld Robot

Nobuyoshi Yamanaka

Tairo Samejima

*An anti-collision function and follow-up welding function to operate a system that uses plural weld robots at a high efficiency were developed. Also developed was a laser search sensor that drastically shortens the time to detect a welding start position.*

**Key Words:** *Weld robot, Crash detection, Follow-up control, Arc sensor, Wire touch sensor, Laser search sensor*

## 1. Introduction

The principal parts of construction machinery are welded structures and arc welding is mainly used as a welding technique. The welding process has been automated for more than 25 years through the use of robots and 90% or more of total weld lines are currently automated.

The weld robot system is necessarily bulky, since works to be welded and multiple-joint robots, the operating space of which is about 2m, are mounted on traveling equipment that moves longitudinally, horizontally and vertically. A positioner to turn works is combined with a system to allow the robot to adopt the desired welding position. Weld robots approach works from above and are mostly of the ceiling suspended type.

The system is large and expensive and subject to considerable demands for its high-efficiency operation. Robots of high efficiency have been built by developing tandem welding, namely by equipping a robot with two welding torches, a cutting-edge digital power source for welding and other means. Recently, as shown in **Fig. 1**, more systems installed with several robots to perform welding have been adopted.

When all robots engage in welding, the corresponding productivity increases based on the number of robots installed. However, in reality, the welding times of the robots do not become uniform, resulting in wasteful waiting time and a lack of anticipated positive effects. One challenge for robot systems with several robots has been to reduce this waiting time.
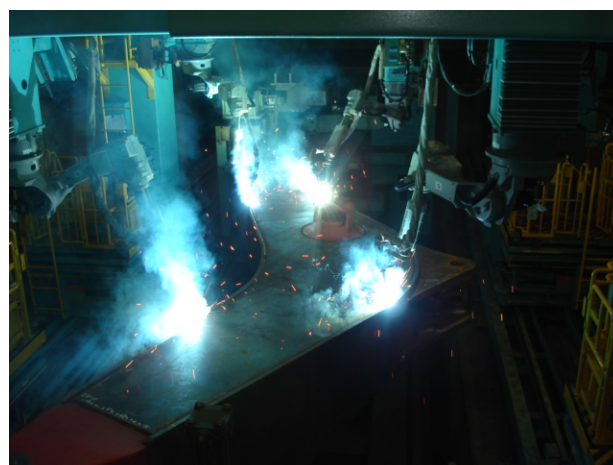


**Fig. 1** System with four ceiling suspended robots

The work thermally deforms due to welding for an extended period at a high current and almost all robots are installed with a wire touch sensor to detect the welding start position and an arc sensor to correct drift during welding.

The time required for a wire touch sensor to detect the welding start position and trim the wire length by a cutter before detection is considerable and the challenge has been to reduce these functions.

This report describes technology that solves the foregoing two challenges of efficiently operating several weld robots and reducing the operating time of the wire touch sensor.

## 2. High Efficiency of a System with Plural Robots installed

### 2.1 Challenges of a System Installed with Plural Robots and Solutions

Construction machinery comprises several long weld lines, many of which are 1m or less. Most of the welded joints are welded by fillet welding.

In welding jobs using several robots, work is turned by a positioner to weld joints in flat and horizontal welding positions, with weld lines allocated to the robots involved. The positioner is further turned to weld other joints when welding in these positions is finished. All joints are welded by repeating this operation.

Positions of individual robots are normally decided to maintain some distance between each of them and hence avoid crashes. However, the allocation of weld lines to robots tends to become unbalanced where the robots are mutually distant. While some robots engage in welding, others wait by after finishing welding ahead of others. These waiting robots significantly waiting each turn of the positioner reduce efficiency significantly and reducing this waiting time has become a challenge.

The following two technologies were developed to solve this problem.

The first is an anti-crash function to predict the crash of robots and pause robot motion. Robots can be made to approach each other more closely when there is no further potential for a crash through the anti-crash function, meaning weld lines can be allocated evenly to robots and the waiting time can be shortened.

The second technology is a function enabling the multi-layer welding of a single weld line by plural robots. Where weld lines cannot be evenly allocated and waiting time is inevitable, a waiting robot performs the multi-layer welding of one weld line jointly with another robot, which thus eliminates waiting time and shortens the overall welding time.

### 2.2 Anti-Crash Function

The anti-crash function was developed by modifying the off-line teaching software of the weld robot.

The off-line teaching system is the "Tchmore"[1] developed by Komatsu. As shown in **Fig. 2**, this system comprises a personal computer, the control section of a robot controller and a teach pendant. Receiving the present positions of motors of the robots, traveling axes and positioners, the personal computer moves the robots, traveling axes and positioner that are output by the robot controller.

Using a state-of-the-art personal computer, positions of several tens of cycles per second are received and updated so that the displayed robots move smoothly by operating the teach pendant. The robots are moved and operating programs created by moving the robots in the same operational sense as that in actual teaching (robot program creation). Programs thus created are run and robot motion can be confirmed on the personal computer screen. Crashes between robots and work or robots themselves are detected by image processing and a warning is issued by changing the display color.

Using this function, crashes involving robots were considered detectable. However, this function could not be used in its
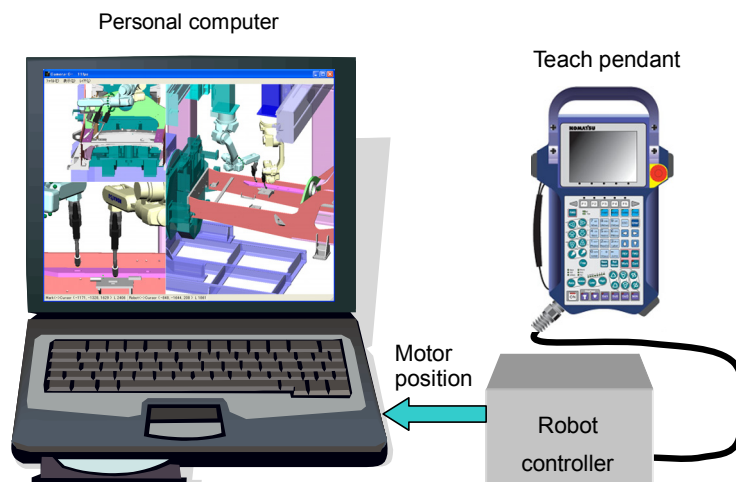


**Fig. 2** Off-line teaching system "Tchmore"

current form as anti-crash function for plural robots, since the off-line teaching software only detected the crashes of robots on screen after the actual event had already occurred. Robots are damaged in such crashes and should instead be paused before a crash is detected.

A crash can be detected by forecasting the motor positions ahead of time to a certain extent, by moving the robots to the forecast positions and displaying them for checking. Weld robots are of the multiple-joint type and resemble human arms. The robot structures show low rigidity and are prone to vibration, meaning the motors repeat acceleration and deceleration smoothly. Based on acceleration and deceleration, positions ahead of that at present are calculated using the present positions of the motors, speed and acceleration.

The software of the robot controller in use was modified and a function to output the present position, speed and acceleration in succession was added as shown in **Fig. 3**. A further function was also added to pause the robot operation after receiving a pause request from the personal computer in case the latter detected a crash.

The personal computer side receives the present positions $p$, speeds $v$ and accelerations $a$ of the motors received from the robot controllers and calculates positions $p'$ after time $t$.

Robot operation has to be paused before robots collide to prevent a crash. As illustrated in **Fig. 4**, a check is made to assess whether robots will collide by forecasting a position $p'$ in which the robots move for a predetermined time $tc$ from the time the position is received and in which the robots then decelerate for time $td$ and pause. However, even with this method, the robots collide when they pause and crash must be prevented by lengthening the time $tc$ till deceleration by about 1s compared with the actual robots. In other words, the robots pause in position one second before any crash takes place.
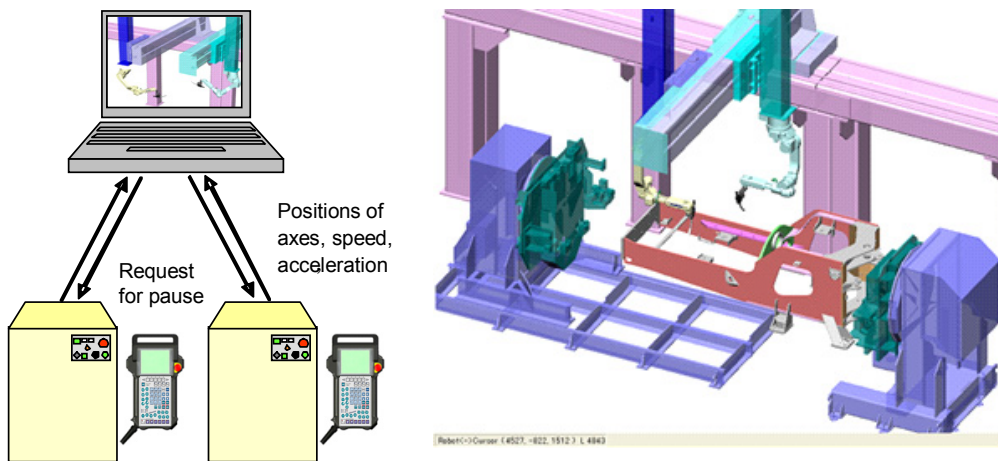


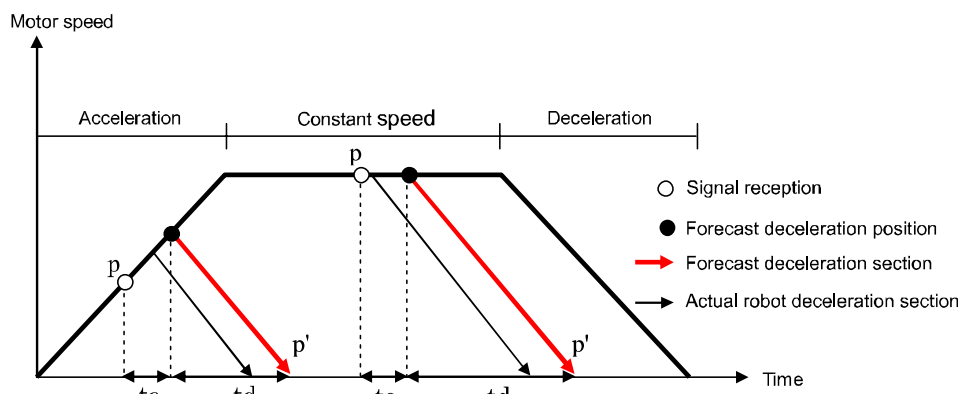**Fig. 3**  Configuration of the crash prevention system



**Fig. 4**  Crash prevention timing chart

The time $tc$ is the time lag till deceleration takes place after the time needed to process a check for crash and a request for pausing robot operation has elapsed. The time $tc$ is increased by 1s, while that needed to process a crash check and output a request to pause robot operation is confirmed as short, less than several ten ms, using the most recent type of personal computer.

The deceleration time $td$ varies in proportion to speed and can be expressed by the following expression:

$$td=(v+a \cdot tc)/da$$

where "$da$" is acceleration in a deceleration section.

During actual operation, a personal computer is connected to several robot controllers, each of which sends information to the personal computer, namely, motor positions for six axes and traveling axis of the robots, speeds and accelerations. A check as to whether or not robots are crashing is made by calculating the position $p'$ in which each motor decelerates and pauses and by changing the motor positions for the traveling robot and traveling axis to $p'$. If a crash occurs, a robot operation pause is requested to the robot controller. This process is repeated at intervals of several tens of ms.

When two robots are approaching and their arms are manipulated to collide as shown in **Fig. 5**, the personal computer screen on the right shows the robot operation forecasting one second ahead. The screen shows the crash of robot arms and the arms light up in red before the actual crash. Detecting the potential crash, the personal computer side outputs a pause request and the actual robots pause before it occurs.

Because robots do not collide by mistake, they can be made to work in proximity as shown in Fig. 5. Likewise, where many weld lines are located in a single place, weld lines are equally allocated to two robots and welding can be performed without waiting.
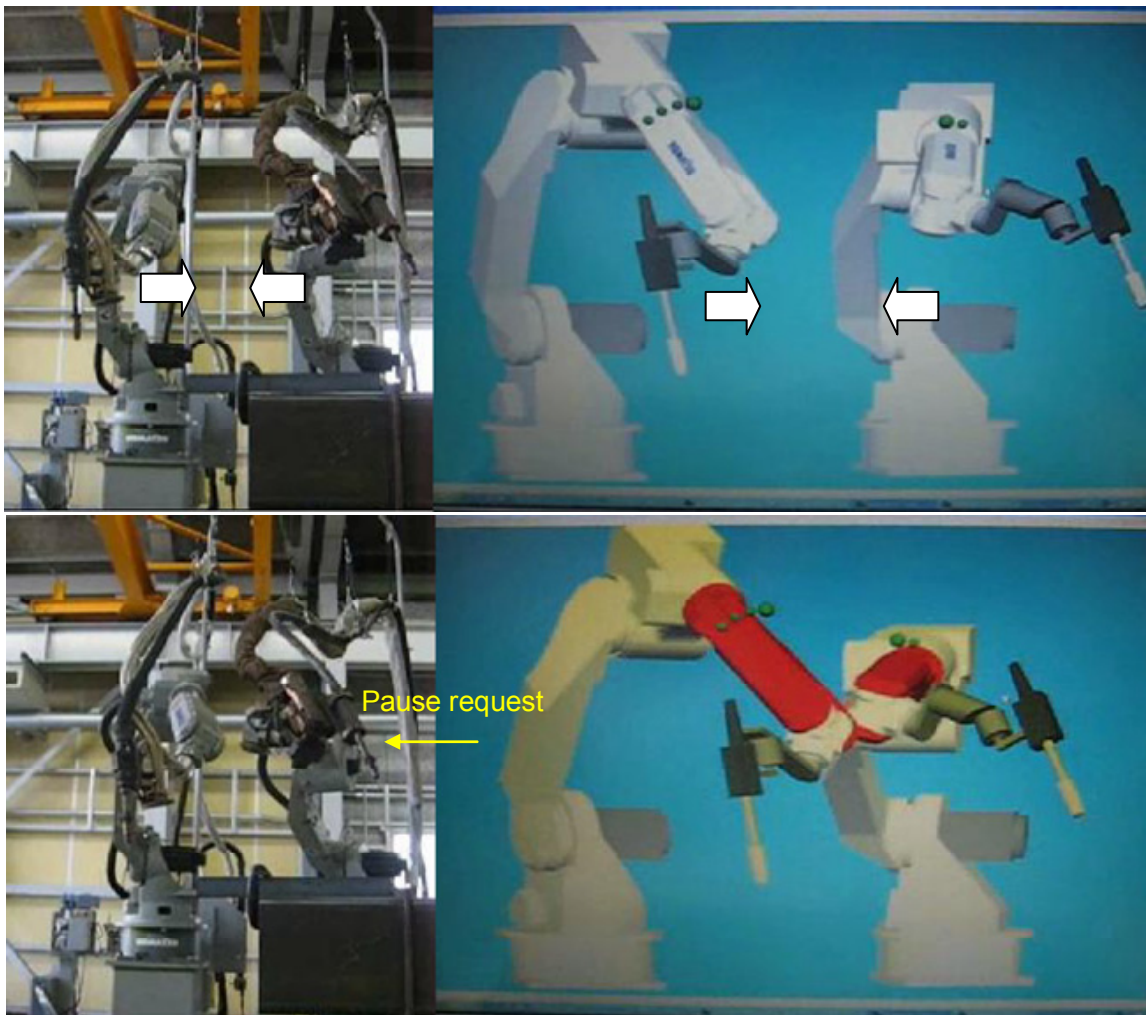


**Fig. 5** Robot operations and personal computer screens when a crash is detected

## 2.3 Follow-up Welding Function

When welding a long multi-layer weld line, the efficiency is low if one robot welds and waits until the other robots finish. Long multi-layer weld lines are split and robots mutually weld different sections. If a weld line is split, a weld joint is produced, which must be manually corrected later and this prevents automation of welding. As shown in **Fig. 6**, follow-up welding is performed in multi-layer welding, whereby another robot follows up and welds the second layer after one robot has done the first one.

This method was not feasible, however, in welding using an arc sensor. Robots use an arc sensor that corrects weld distortion in the first layer. However, the arc sensor cannot detect the second layer and onward because weld beads are deposited. This is why a function called memorized play is used when welding is performed by one robot by memorizing the correction amounts of the arc sensor for the first layer for each predetermined distance and ensuring memorized quantities are reproduced in the second layer. This is because the robot to weld the second layer does not memorize the correction amounts of the first layer and cannot weld by memorized play when two robots perform follow-up welding.

A function to send correction amounts of Robot 1 for welding of the first layer to Robot 2 to provide the same correction amounts to the robots as shown in **Fig. 7** was developed. Robot 1 memorizes the correction amounts for individually predetermined distances, with correction amounts output to Robot 2 at this time and saved by Robot 2 in an area to be used in memorized play to reproduce the operational conditions. Follow up welding by Robot 2 immediately after welding by Robot 1 is desirable and the welding condition can also be reproduced while receiving correction amounts of Robot 1. Robots are connected by Ethernet to exchange correction amounts.
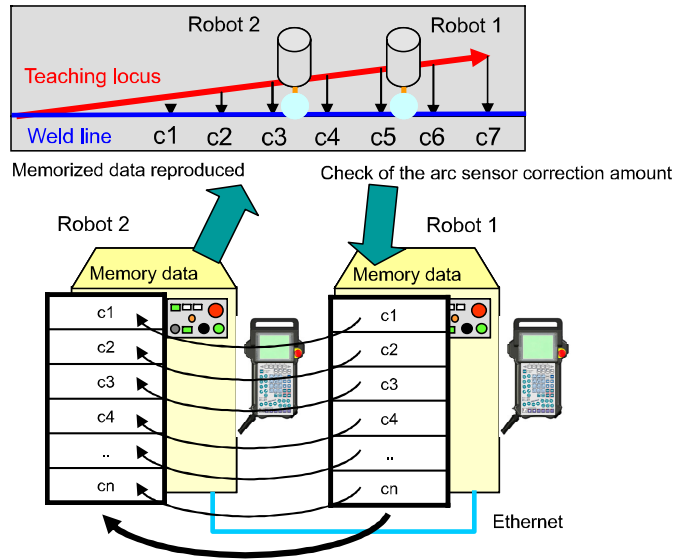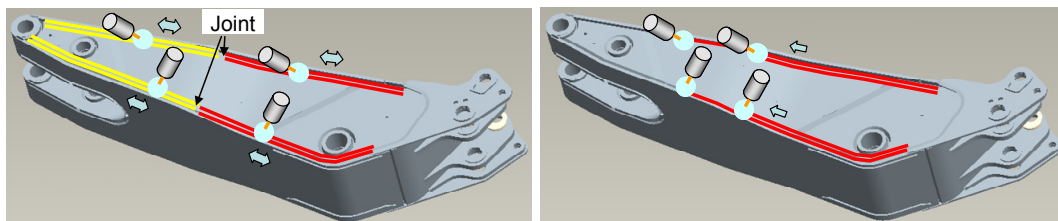


**Fig. 7**　Exchange of correction amounts between robots



Before: A weld line is welded divisibly by four robots　　　After improvement: Follow-up welding

**Fig. 6**　High-efficiency welding by follow-up welding

Thanks to the anti-crash function, robots can be made to approach each other closer and follow-up welding is performed by the second robot that literally "chases" the first immediately after as shown in **Fig. 8**. If the number of layers is even in multi-layer welding, two robots weld to the last layer. However, if the number of layers is odd, the second robot welds another weld line after finishing follow-up welding, to shorten the waiting time.
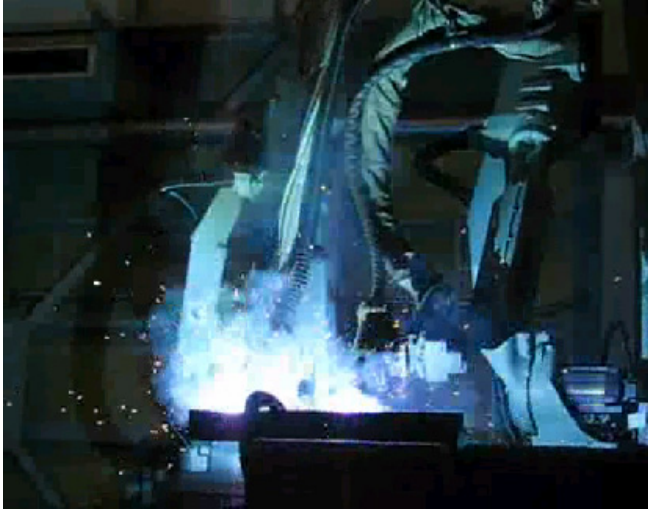


**Fig. 8**   Follow-up welding by two robots

## 3.  Laser Search Sensor

### 3.1    Challenges of Wire Touch Sensor and Solutions

Gas shielded arc welding of the consumable electrode type is used in the welding of construction machinery. The wire is fed from the tip of the welding torch and welding is performed by fusing the zone to be welded and wire by an arc.

The wire touch sensor detects a short circuit during contact with the wire by exposing the welding wire to voltage. A robot is moved until the welding wire comes into contact with the work to detect its position and then shifts to an appropriate welding start position. Normally, the welding start position is decided by detection from wire touch sensors operating in three directions, where more than ten seconds are required for detection. Additionally, about one further minute is needed to adjust the welding wire length by the wire cutter before detection occurs. Reducing this time has been a challenge.

The laser search sensor consists of a laser light source and CCD camera as illustrated in **Fig. 9** and is mounted near the welding torch. The position of a joint is detected by processing the image obtained by irradiating a slit-shaped laser beam onto a weld joint. It takes time before the wire touch sensor contacts the work, while the laser search sensor can detect under stationary conditions, accelerating detection and eliminating the need to cut and use welding wire, significantly reducing the time required.
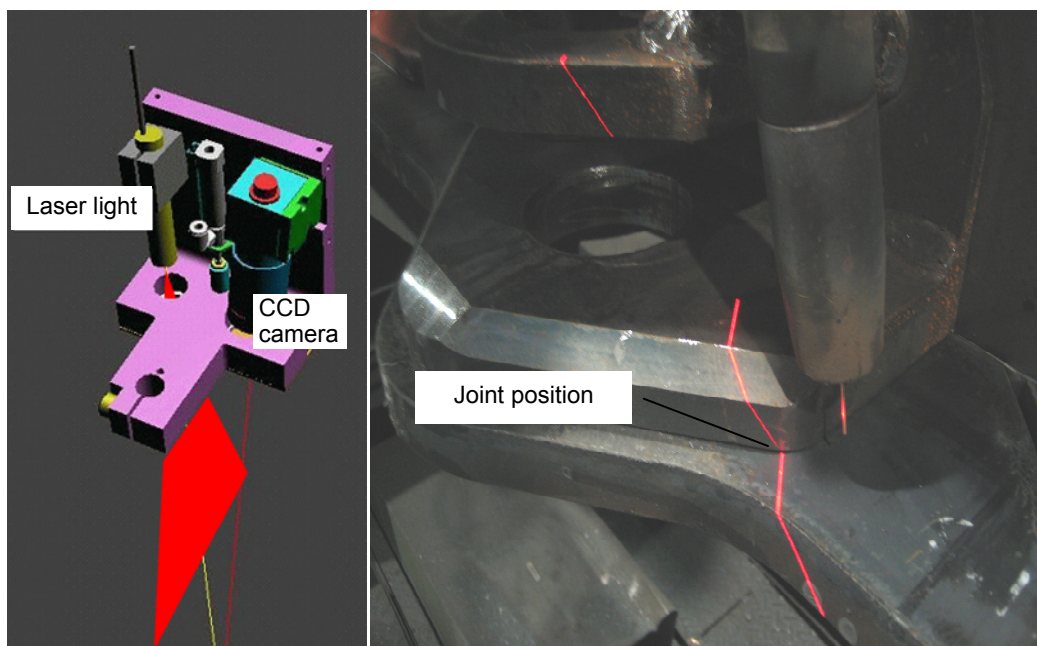


**Fig. 9**   Structure of the laser search sensor and joint detection method

## 3.2 Features of the Laser Search Sensor

When a laser search sensor is added to a pre-installed robot, an increase in interference with the work becomes problematic as a laser search sensor is normally installed near the tip of a torch. The laser search sensor is therefore installed in the position shown in **Fig. 10**. This configuration reduces interference and enhances the reliability and durability of the sensor as the shock sensor to detect a crash between the torch and work and pause robot operation also functions with the laser search sensor.
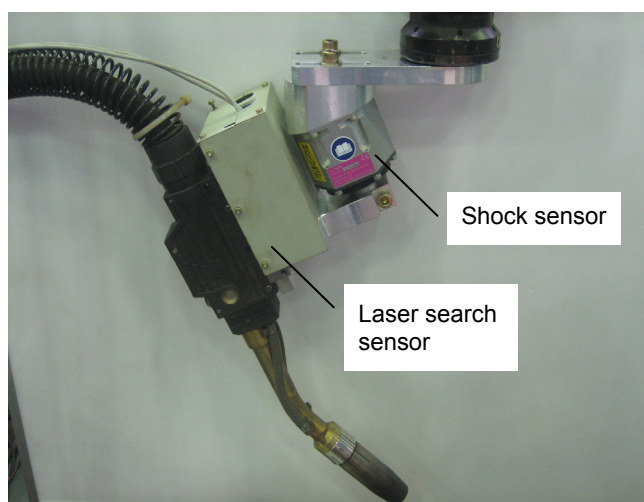


**Fig. 10**　Laser search sensor

The center of a laser slit beam irradiated during teaching by moving the robot needs to be aligned onto the joint. The center of a slit beam cannot be detected by the naked eyes, hence the diffracted zone of a slit beam was aligned to the refracted zone of a slit beam onto the center of an image by operating the robot while watching a CCD camera image on the monitor screen. This operation is considerably time-consuming compared with the teaching time of a wire touch sensor and has become problematic. A function to align without watching an image has therefore been added. First, a robot is moved to align the tip of the welding wire to the joint to be detected. Subsequently, the robot is made to move so that the center of a slit beam would move onto the joint position of when the key on the pendant is pressed. This enables the teaching time to be shortened to the same duration as that required for a wire touch sensor.

A laser search sensor was actually mounted to replace the detection operation performed by a wire touch sensor. Consequently, the search time could be reduced by half through joint

work and the end of the welding wire could be detected by making a temporary pause as shown in **Fig. 11**. There is no longer any need for a welding wire cutter and the operation time other than for welding by robots is drastically shortened.
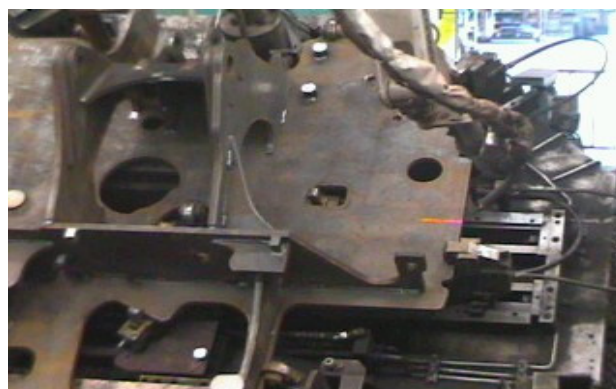


**Fig. 11**　Edge of work is detected by laser search sensor

## 4. Conclusion

Anti-crash and follow-up welding functions were developed to operate a system involving the use of plural robots at high efficiency. These functions allow the uniform allocation of welding times required by individual robots and reduce the waiting times among the latter.

A laser search sensor featuring less interference with the work was developed to replace the wire touch sensor, which shortened the detection time and eliminated the time taken previously to cut the welding wire.

The work to allocate weld lines decided upon by the teaching operator needs to be optimized to further shorten the waiting times of robots, while skills of teaching operators are necessary to decide the laser beam irradiating position when using the laser search sensor.

Teaching work becomes increasingly difficult. A function to create an optimum program automatically by computer is considered necessary in future, instead of depending on human operators.[2]

**References:**
1) Yamanaka, Journal of Japan Welding Society, Vol. 77, 70-73 (2008).
2) Hashimoto, Technical Report, Kobe Steel, Ltd., Vol. 38 1998-10 (No. 342)

## Introduction of the writers

**Nobuyoshi Yamanaka**

Entered Komatsu in 1983.
Currently assigned to the Manufacturing Engineering Development Center, Production Division.

**Tairo Samejima**

Entered Komatsu in 1988.
Currently assigned to the Manufacturing Engineering Development Center, Production Division.

**[A few words from writers]**

Many zones and areas are still welded by humans because welding of these zones and areas by robots is not feasible. The writers wish to continuously develop technologies to automate welding of these zones and areas.