Technical Paper

Operating Rate Monitoring System for Welding Robots

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The operating rate and the cycle time of the welding robots have conventionally been analyzed by means of the time study involving humans manually measuring the time. A cycle time, however, can be more than 10 hours for some heavy-duty construction machines, making the time study virtually unpractical. To solve this problem, the authors developed a monitoring system that automatically monitors welding robots for operating rate and cycle time analysis. Data thus gathered is sorted using an application software for analysis into the cycle time, welding efficiency, frequency of errors, areas where errors occurred and other items, and eventually complied into a database. The database is in conjunction with a Web application to offer accessibility on the company network.

Key Words: *Operating rate monitoring system, Welding, Robot, Database, Monitoring*

1. Introduction

The manufacturing industry has been undergoing a massive change in business environment due to the globalization of production, digitization of production sites to cope with diversifying customers, and ever-intensifying competition particularly from the rapidly growing China. Faced with all this, Komatsu has been actively trying to break new ground in novel technologies for higher production efficiency and quality.

In line production at automotive and construction machinery plants, identification of the bottlenecked processes and reduction of the momentary stops (of robots by errors) are required for efficient production. In the construction machinery manufacturing, which is characterized by manufacturing of various types of products in small volumes, cycle time (the time a robot takes to process one workpiece) and the frequency of momentary stops differ from one product type to another, making it difficult to find and understand what actually is going and troubleshoot existing problems. The robot welding process is one of the processes which can easily become a bottleneck and which often experiences momentary stops.

Up until now, time study has been the only method available to grasp actual situations of bottlenecks and momentary stops on the line: in time study, time spent in the process is measured by humans using a stopwatch while errors are manually counted. This method, however, is not practical for large workpieces like construction machines on which cycle time can be more than 10 hours. All this has been a setback to improvement, leaving little room for expectations for achieving higher production efficiency.

To resolve this situation, the authors thought that a system would need to be developed that is capable of collecting data from welding robots, analyzing it and then displaying the results. That is how the “operating rate monitoring system for welding robots” was developed (**Fig. 1**). The system is adaptive to a networked global production environment involving welding robots at overseas production sites. As part of the system development, a number of specific application software were also developed for data collection, analysis and networking. The “operating rate monitoring system for welding robots” collectively refers to the related hardware and software.

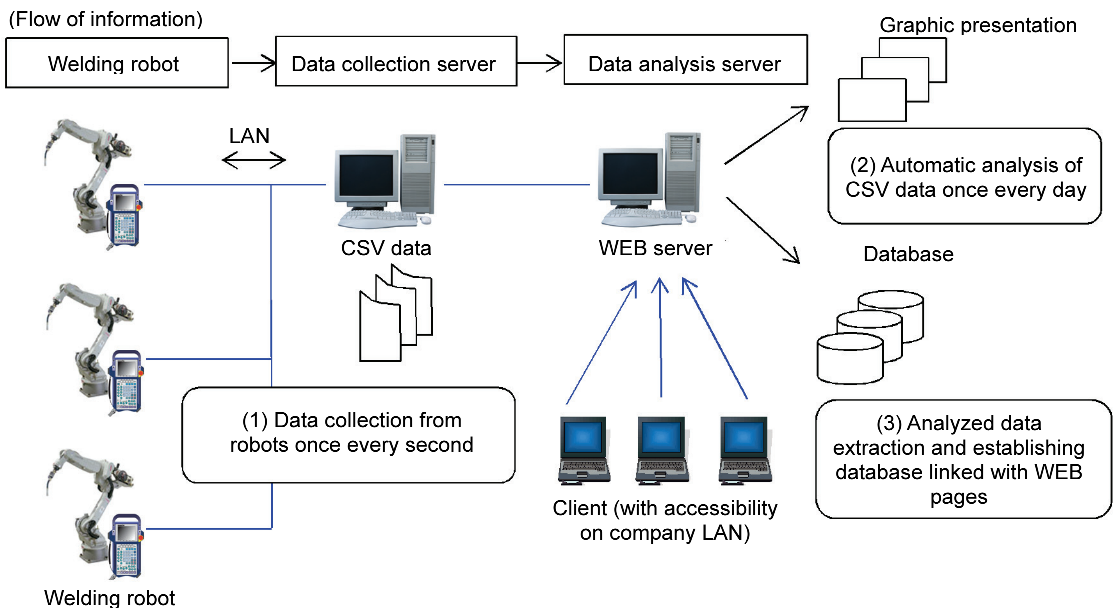


Fig. 1 Schematic of the operating rate monitoring system for welding robots

Table 1 Application software composing the operating rate monitoring system

No.	Software	Application	Development environment
(1)	Data collection	Collection of data from welding robots (Sampling: once/sec)	Windows application (VB.net)
(2)	Data analysis	Analysis of CSV data (Analysis: once/day)	Windows application (VBA)
(3)	Database	Database creation and synchronization with WEB application	Windows SQL server, Windows application (ASP.net)

2. Purpose and Process of the Development

The term "operating rate monitoring system for welding robots" may give the impression that the system grasps the status of robots and displays it on a real-time basis. However, the robot welding process has already been equipped with a malfunction alert system and there has been no need for real-time display of robot status such as "welding" or "transferring". On the other hand, there has been a strong need for information on "which robot is working efficiently and which robot is not." This led the authors to focus on the development of a system capable of identifying issues on welding robots that need to be resolved and displaying information useful in improving the welding process. **Table 2** shows some of the issues identified and user requests raised for the development of the monitoring system. Efforts were made to meet the requests as much as possible.

The operating rate monitoring system that was thus developed offers not only the operating status of welding robots but also other useful information such as weld efficiency which can be used for productivity index and the frequency and breakdown of errors. The major purpose of this system is to "visualize" the information of welding robots in an easy-to-understand style for best possible utilization in our company. To help enhance usability, the system is networked, offering anyone at Komatsu accessibility to the information.

Table 2 Issues identified and user requests raised for the development of the monitoring system

Issues	Actions
Connectivity to the multiple types of robots (C3, Cxx, KXRC, NX) in Komatsu	Add-on communication circuit boards were produced for each type of the robots and installed.
Installation of communication infrastructure at every plant	A data collection server was installed at each plant while analysis is centrally conducted.
Requests	**Actions**
At-a-glance presentation of the status of the entire line	A WEB program linked with database was developed to present the entire data.
Index for evaluation of cycle time, weld efficiency and error frequency	A program was developed to present E-value, error frequency and other indications.
Data by product type as a welding robot manufactures some types of product	A function to provide product-type specific data was added to each robot.

3. Data Collection from Welding Robots

An add-on communication circuit board was produced for each of the multiple types of welding robots at Komatsu (except the C3 robot equipped with NIC (Network Interface Card)). **Fig. 2** shows one of these communication circuit boards. With the RS-232C or Ethernet communication interface and a PC for communication, the data application software automatically collects data from the welding robot.

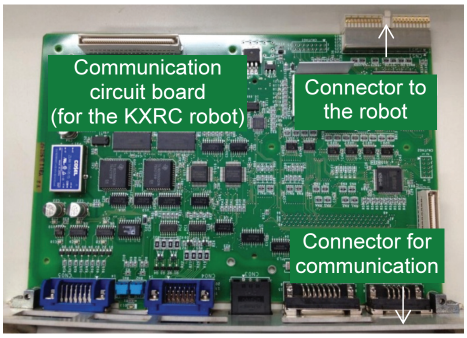


Fig. 2 Communication circuit board (for KXRC robot)

Fig. 3 shows an example of stand-alone PC connection. Multiple connection up to 40 welding robots is possible using LAN. (Conversion from RS-232C to Ethernet is required.) **Fig. 4** shows the data collection application software. **Table 3** shows the communication specifications. The data collection software is a Windows application, communicating once every second and retaining data at every phase change: there are six phases for the welding robots —— (1) welding, (2) transfer, (3) waiting, (4) search, (5) stop and (6) power OFF. The robots indicate their phases by numbers: e.g. "1" for welding and "2" for transfer. These numbers are saved in communication PCs in the csv format.

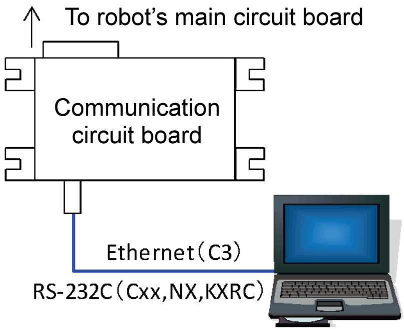


Fig. 3 Example of stand-alone connection (1 PC)

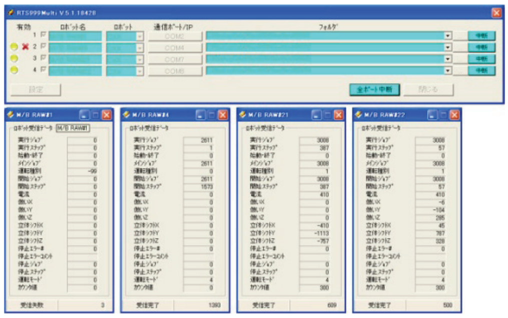


Fig. 4 Data collection application software

Table 3 Communication specifications

	C3	Cxx, NX, KXRC
Interface	Ethernet	RS-232C
Communication protocol	TCP/IP	Asynchronous (ASYNC) *Details skipped
Sampling time	1-10 sec/sampling	1-10 sec/sampling
Communication speed	-	9600,19200,38400 bps
Max. No. of robots to be connected to a PC	40 units	40 units

4. Analysis of Collected Data

Data saved in communication PC is analyzed using the data analysis application software. Data analysis is automatically carried out every day and the results are presented in graphs. **Fig. 5** shows input data and output data of the data analysis application software. Output data is produced for each type of workpiece: for example, if the robot handles three different types of workpiece, analysis is made for each of the three types.

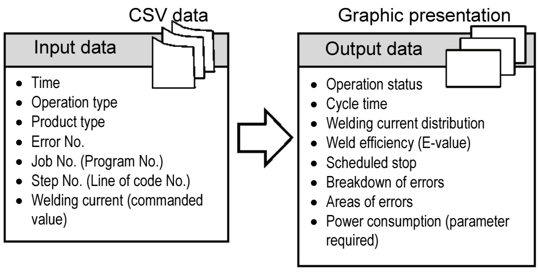
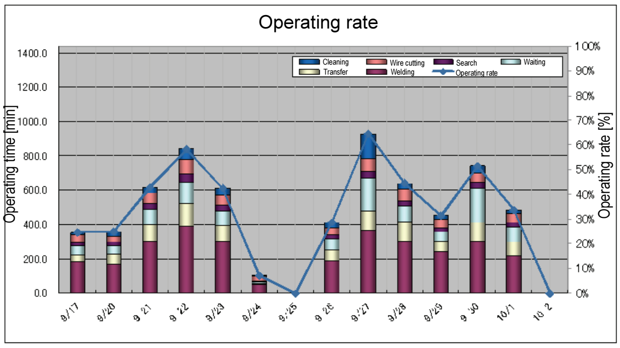


Fig. 5 Input and output of data analysis application software

The following paragraphs briefly describe output data graphs and suggested utilization of data for welding process improvement.

4.1 Status of robot operation

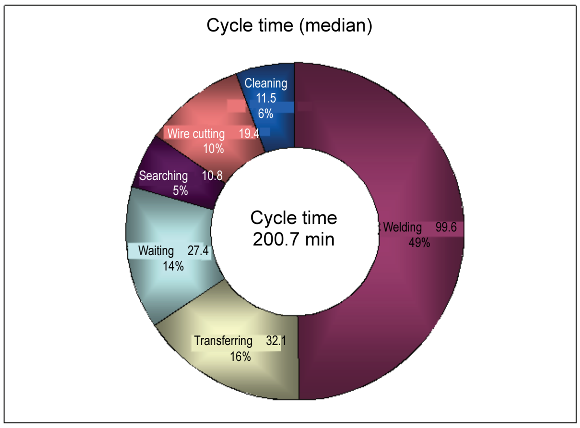


Operation status	The robot's daily operating time and efficiency are displayed. The operating time is the robot's automated running time. The operating time is made up of welding, transfer, waiting, search, wire cutting and cleaning. The operating time does not include downtime (stop by error, scheduled stop and tooling change)

Fig. 6 Operating Status Graph

If it were enough just to determine whether the welding robot is welding the workpiece or stopping, monitoring would be simply to observe I/O signals of the welding robot. However, a welding robot also performs associated jobs such as transferring between workpieces, waiting for input signal from external equipment, searching (for the weld line), wire cutting (cutting a welding wire to an appropriate length) and nozzle cleaning (to remove spatter). The monitoring system identifies these jobs by a combination of operation-type data (welding, transfer, waiting, search and stop) and jobs (program Nos.) input to communication PC. Daily operating time is the sum of welding and welding-associated jobs, and operating rate is obtained by dividing the sum by 24 hours.

4.2 Cycle time

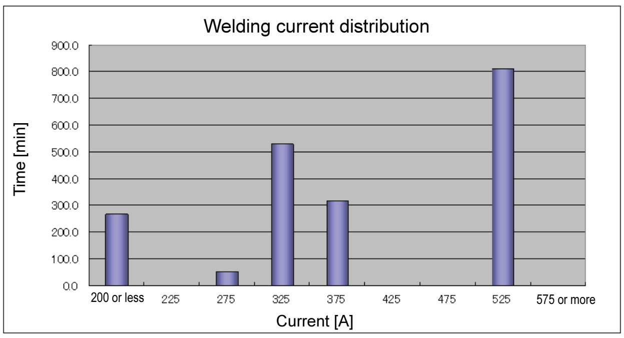


Cycle time	The system displays the cycle time for a workpiece. (One unit on the horizontal axis corresponds to one workpiece.) The cycle time consists of value adding jobs (welding, transferring, waiting, searching, wire cutting and cleaning) and does not include stops (stop by error, scheduled stop and tooling change).

Fig. 7 Cycle Time Graph

Cycle time is calculated based on operation-type data and counter reading (product-type data). Cycle time can be defined as "the sum of welding time and time spent on welding-associated jobs." With no error-induced stops, a workpiece should be completed in the cycle time. **Fig. 7** shows the breakdown of cycle time, and it indicates that a significant portion of non-welding time is spent on transferring and wire cutting. This means that higher priority should be placed on how to shorten transferring and wire cutting time.

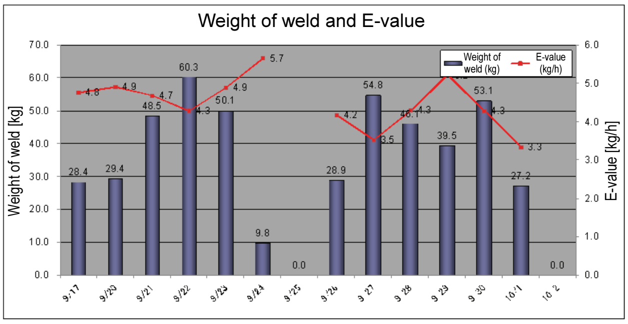
4.3 Welding current distribution and weld efficiency



Welding current distribution	This graph shows a histogram of welding current and time. The values on the horizontal axis are the median for each class, which has a range of 50A. The graph is based on the entire data of one month.

Fig. 8 Welding current distribution graph

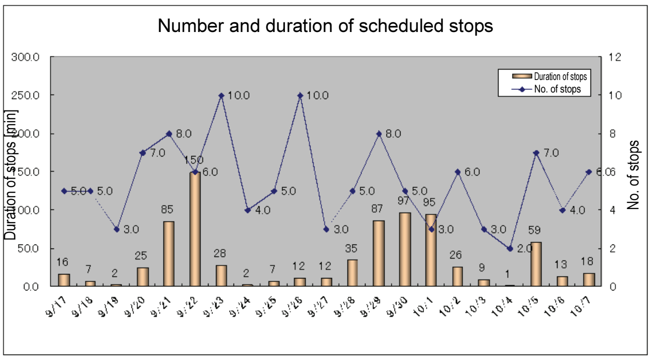
Welding current is displayed in a histogram (**Fig. 8**). As higher welding current results in higher weld efficiency, welding should be carried out with higher current for higher productivity. The efficiency, however, cannot be judged simply by the distribution of welding current as the proportion of welding time in the cycle time can be small even when welding is carried out at high current. For that reason, the system is programmed to calculate the weight of weld produced per operating hour (kg/h) (E-value), which is then indicated in a graph of welding robot efficiency (**Fig. 9**). The weight of weld (kg) is calculated based on current command using the approximation formula saved in the data analysis application software. The efficiency of a welding robot can be checked simply by checking this graph.



Weld efficiency	Daily weight of weld produced (kg) and weld efficiency (kg/h) are displayed. The weight of weld is shown in a bar graph while weld efficiency is shown in a line graph. Weld efficiency (kg/h) is obtained by dividing the weight of weld by operating time.

Fig. 9 Weight of weld and weld efficiency

4.4 Stops

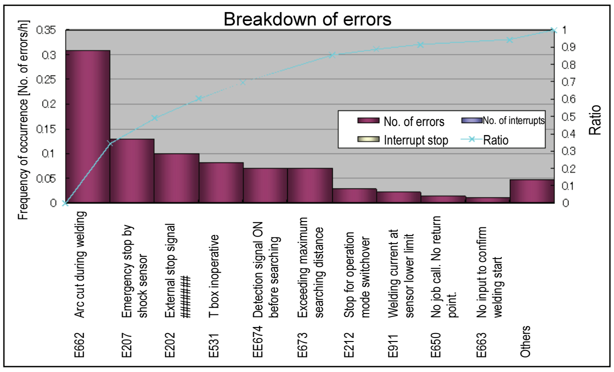


Number and duration of scheduled stops	Daily stops (excluding those caused by errors) are displayed. The number of stops is shown in a line graph while the cumulative time of stops is shown in a bar graph. Scheduled stops include those for tooling change.

Fig. 10 Scheduled Stops

The system calculates the cumulative time of stops occurred in cycle time, excluding those caused by errors. The system is programmed to stop automated robot operation for nozzle cleaning, slag removal in multi-layer welding, contact tip replacement, etc. While stops for quality check must be maintained, other stops can be shortened. For example, nozzle cleaning to remove the spatter and fume attached to the nozzle has been automated.

4.5 Breakdown of errors and location of errors



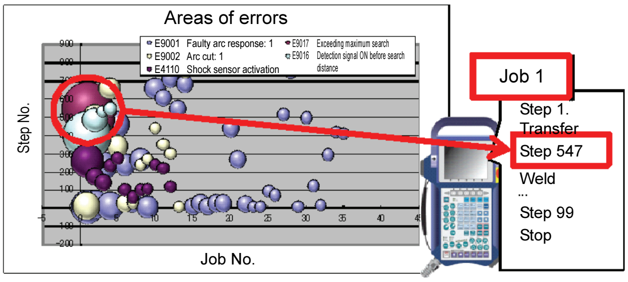
Breakdown of errors	All errors that have occurred over a month are shown in a Pareto chart (10 most frequently occurring errors). The frequency of occurrence (no. of errors/h) is obtained by dividing the number of errors occurred over a month by the total operating hours in that month.

Fig. 11 Breakdown of Errors

Ten most-frequently-occurring 10 types of errors are identified by the job being performed, the error number and the time when the error occurred, and are shown in a Pareto chart (**Fig. 11**). The welding robots only send out error numbers when they occur, and the data analysis application software displays the error messages using the table of error numbers and corresponding error messages stored in the software. The most frequent errors of welding robots include arc cut, search error and one related to the shock sensor.

In addition, information on the areas of errors occurred is available to identify where in the program the errors occurred (**Fig. 12**). The horizontal axis represents job (program) numbers and the vertical axis represents step (line of code) numbers. The size of bubbles indicates the frequency of error occurrence while the color of bubbles indicates error numbers.

For example, **Fig. 12** shows that the search errors (search unsuccessful due to an incorrect teaching point) were occurred in Job 1, Step 547 so that you can identify the point to be corrected in the program easily.



Areas of errors	Five most frequently occurring errors during a given period are shown in a bubble chart. A larger bubble indicates that the error occurs more frequently. The numbers of Job and Step can be determined by the location of that bubble on the corresponding axes.

Fig. 12 Areas of Errors

5. Database Creation and Link with WEB Pages

From daily analysis results, key data is extracted and accumulated to form a database, which can then be used to monitor the progress in welding process improvement and production efficiency throughout the line. The database is linked with the WEB application software to provide easy accessibility for anyone on the company network. **Fig. 13** shows an example of WEB pages linked to the database. The horizontal axis represents time period and the vertical axis represents facilities. Key parameters including operating rate (%), weld efficiency (kg/h) and the frequency of error occurrence (No. of errors/h) are each shown on the dedicated page. Line performance is rated by color for easy recognition: good performance is shown in green, which turns more reddish as performance slips. Each facility has a link, through which detailed data for the most recent month can be accessed.

Fig. 13 Database Linked with WEB Pages

6. Conclusion

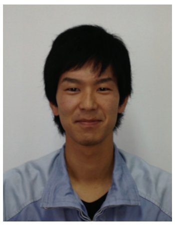
Through our research and development of the operating rate monitoring system for welding robots, the following have been achieved.

(1) Add-on communication circuit boards for welding robots and data collection application software were developed to enable data collection from welding robots.

(2) Data analysis application software was developed to "visualize" information including cycle time, weld efficiency and the frequency of error occurrence.

(3) Database is linked with WEB pages for data accessibility on the company network.

Introduction of the writers



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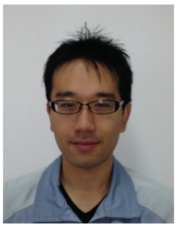

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[A few words from writers]

We hope that the information and communication technology (ICT) will be utilized in production sites and help improve related operations. To contribute in that direction, we will continue our effort in R&D while keeping in mind the importance of knowing what kind of information is needed in production sites as we develop systems.