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Welding Systemization in Japanese Heavy Industries†

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Abstract

Production systemization in place of conventional automation is desirable in heavy industries. Teaching-less CAD/CAM continuous systems or off-line programming systems are essential for systemization. Shipbuilding, bridge and steel column fabrication in Japan have been introducing welding systemization with the above systems. In NKK, multi-sensing systems with arc sensor and CCD camera, simulation of CAD/CAM and CAPM, collision control system between multi-robot, are incorporated to support a multi-robot welding system with CAD/CAM and CAPM. The High Speed Rotating Arc welding process provides precise arc sensing and efficient productivity. Knowledge base is noted for implementation of human ability to advanced systemization towards CIM.

KEY WARDS: (Welding) (Systemization) (CAD) (CAM) (CIM) (Heavy Industry)

1. Introduction

In recent times Japanese industries are facing many economic problems, such as the collapse of the bubble economy, the end of the time of mass-production, diversified market needs, megacompetition, shortage of young and skilled labor, aging problems, etc., so that innovative production styles that provide more efficient and labor-saved production are urgently desired.

To achieve such modernized systems in place of so-called 'point- and line-automation', which has been carried out conventionally in welding fabrication fields for 'multi-kind and small lot production', integrated control of the whole production process(area automation) the use of CAD/CAM,CAPM (computer aided production management), multi-robots, material handling, etc. is necessary. Furthermore, sensing of welding joints and adaptive control of welding robots and welding power sources, and enhancement of the efficiency and stability of the welding process itself, are indispensable.

This paper describes recent developments and applications of welding systemization and related key technologies in Japanese heavy industries, and considers what the systemization -CIM in welding fabrication- should be in future.

2. Present Status of Welding Automation in Japan [1-2]

In Japan, arc welding automation was started with multi-electrode one side welding machines applied in shipbuilding during the ten years from 1965. Since around 1980, welding automation has progressed remarkably through technological innovation, i.e. welding sensors for seam tracking and adaptive welding parameter control, arc welding robots with articulated arms, transistorized welding power sources with inverter control, flux-cored wires for decreased spatter, and various new kinds of welding process.

The recent situation of arc welding automation and robotization in various industries in Japan is shown in **Fig.1** which was collected by the inquiry made by the Technical Commission on Welding Processes of the Japan Welding Society. In industries carrying out mass production like automobile, construction machinery, etc., automation has become remarkably advanced. On the other hand in many other industries, it has not been widely spread. It can be pointed that automation in such heavy industries like shipbuilding can not be easily achieved in similar way because of the features of the work, i.e. multi-kind and small lot, heavy-thick-large, complicated with narrow spaces,and inconsistent accuracy.

The purposes of automation in industry can be summarized as follows: (i) productivity, i.e. increase of production output and efficiency, consistent quality, cost reduction, lead time reduction, etc., (ii) production style, i.e. labor saving, unmanned operation even at night,

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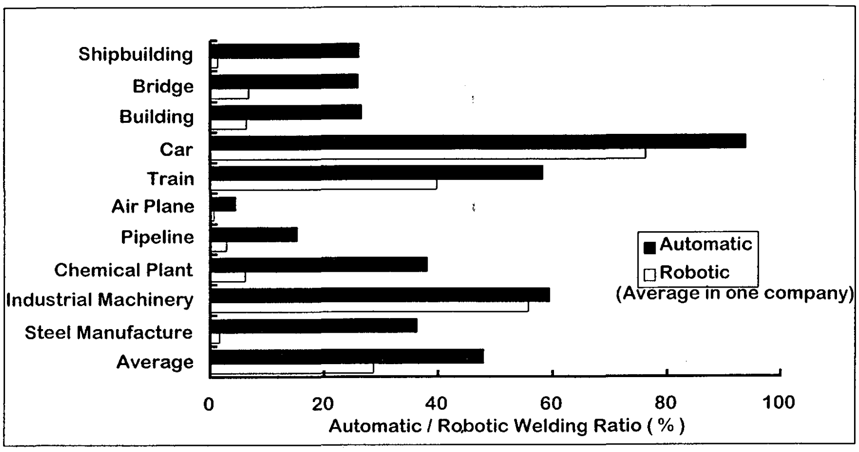

Fig. 1 Automatic / Robotic Welding Ratio in GMAW (Deposited Metal).

problems, improvement of pworking environment, etc..

2.1 Systemization of production

Production automation has been traditionally carried out either for a specific objective (point automation) or a specific production line (line automation). In recent heavy industries, featured by multi-kind and small lot production, dramatically advanced automation is strongly demanded,so that it can be applied flexibly to various kinds of work with integrated control of the whole production process (area automation : namely systemization) including material handling and workers arrangement, etc., see **Fig.2**.

In this systemization,necessary information must be suppliedto the network of all sub-systems or processes. The core of hardware should be robots. CAD/CAM or off-line programming and computer aided production management (CAPM) control the robots, including material handling. In welding systemization, sensors are indispensable to cope with various errors, e.g. work positioning, parts fitting, welding deformation, etc..

3. Trend of Welding Systemization in Japanese Heavy Industries

3.1 Bridges

The first systemization in a bridge panel fabrication line was applied in Miyaji and Yokogawa, both full-time bridge makers, in around 1990 [3-4]. A specially designed cartesian welding robot with twin torches was hung on a mobile gantry and its motion was controlled with an off-line teaching system. Wire touch sensing for both ends of the joint and weaving arc sensors for seam tracking were installed. The system has been applied in bridge panel fabrication lines.

Another welding system with commercially available articulated arm robots was reported by Mitsubishi-Kobe. In this system,an off-line teaching system had a function of graphical simulation capable of being linked with CAD. Two robots were hung on each of 2 mobile gantries. Wire touch sensors and arc sensors were also installed. Monitoring functions to be coped with future CIM, i.e. working time, system error, wire consumption, welding efficiency, etc. were installed [5].

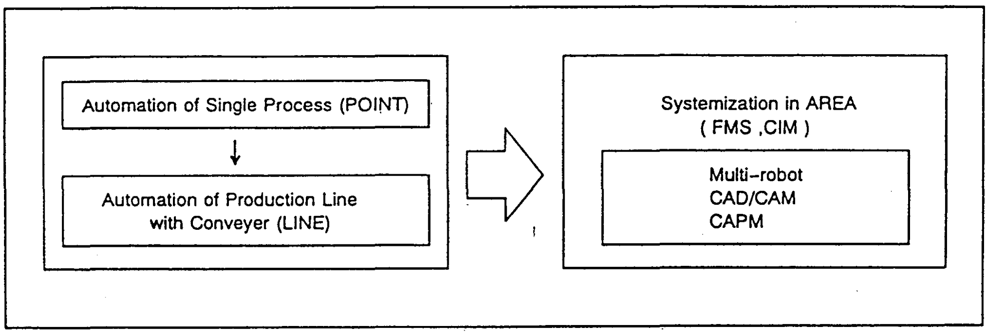

Fig. 2 Trend of Production Automation in Heavy Industries.

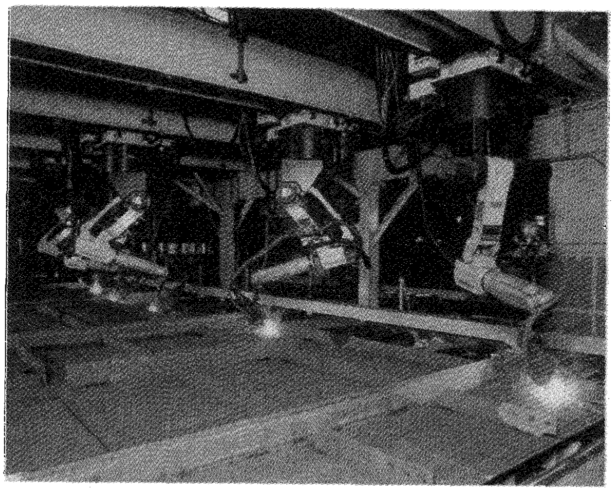

Fig. 3 Web Panel. Robot Welding System.

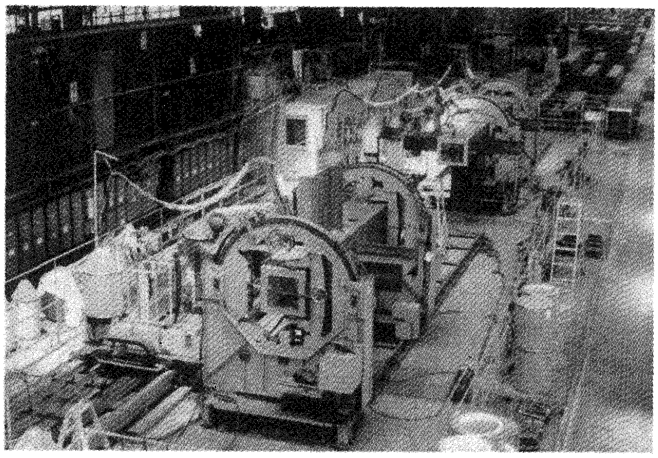

Fig. 5 Steel Column Robot Welding System.

NKK developed integrated multi-robot welding systems with teaching-less CAD/CAM systems for box girder panel assembly lines in steel bridge fabrication in 1992, see **Figs.3-4**. Two lines consisted of fitting, welding, re-forming, drilling and finishing. All the line equipments were controlled by an integrated computer system. 14 articulated-type arc welding robots with external axes were installed. Similar systems were also installed with 10 robots in another line [6-7]. The teaching-less CAD/CAM system is essential to automatically generate multi-robot programs for multi-kind and small lot production. High Speed Rotating Arc welding processes provides highly efficient welding, and the arc sensor provides quality controlled welding with seam tracking, bead connection and joint end detecting functions.

3.2 Building columns

Automation and robotization of building steel columns have been reported by a number of fabricators and makers. The objectives have been limited to a part of total fabrication. Recently, robotic systemization for assembly welding has been being sought . A welding system with a robot and a positioner with off-line programming was applied to the assembly of steel building frame [8]. The latest application was reported by Shimizu Works, NKK, where 3 welding robots travel independently on mobile carriages, positioning of the work is controlled by 2 sets of positioners, and movements are controlled by off-line programming, see **Fig.5**. The joints between flange plate (32 mm thick.) and column are made by two pass vertical upward welding with weaving method. Other joints are made by flat fillet welding. The system provides efficient production, stable welding quality and tolerance for joint gap variation [9].

3.3 Shipbuilding

In shipbuilding in Japan, the first systemization was reported by Hitachi-Ariake in 1989. Two systems were developed and applied. One system is for small sub-assembly work. Originally an off-line teaching system, named simplified CAM, was installed. The system provided interference avoidance processing. One robot with twin torches was hung on one gantry having arc

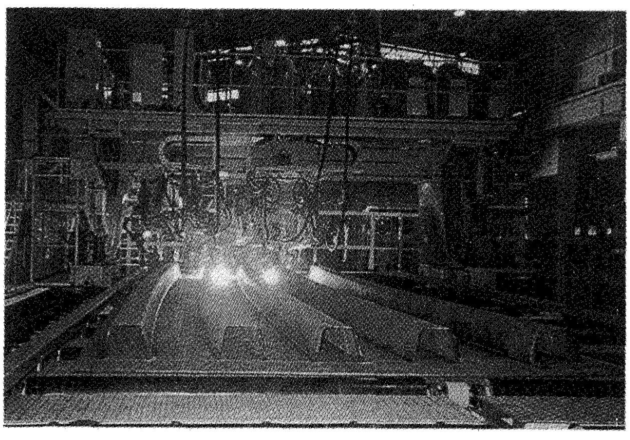

Fig. 4 Flange Panel Robot Welding System.

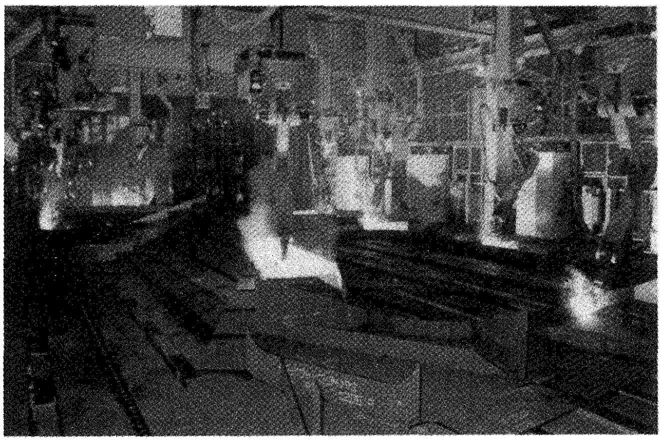

Fig. 6 Ship Trans. Panel Robot Welding System.

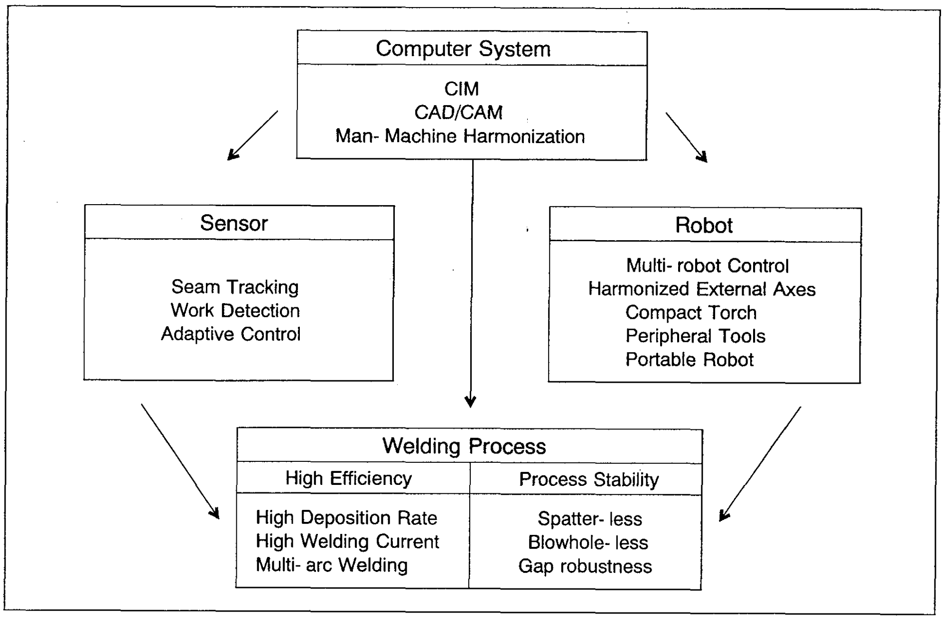

Fig. 7 Key Technologies in Welding Systemization.

sensors and wire touch sensors [10]. Another system was for the assembly welding of lattice frame panels. An articulated arm welding robot with 5 axes was mounted on a mobile carriage. The carriage controlled the travelling direction to follow the joints. Welding targets were slot parts and longitudinal joints. Off-line teaching systems, arc sensors and wire touch sensors were provided as above [11]. Since then, similar types of system for slot welding have been installed in some other shipyards with success.

A multi-welding robot system using 10 welding robots with 3 dimensional external axes hung on a large gantry has been developed and used for subassembly in shipbuilding at Tsu Works, NKK since 1995, see **Fig.6**. The system is integrated with CAD, CAM, CAPM (Line Management), and multi-sensor systems. A collision avoidance system between robots and work, optimization of welding sequence based on robot simulation, coordinates transformation system with a CCD camera and an interference check system between adjacent robots are newly installed[12]. Another 16 welding robot system,hung from a tall gantry,is installed for slot part welding in hull assembly blocks.

4. Key Technologies for Welding Systemization in NKK

The key technologies of welding systemization applied in NKK involve the welding process,the sensor,the robot and the computer system, see **Fig.7**. The basic technology is the welding process itself. A highly efficient welding process increases the cost performance of the process and shortens the lead time of the system. Stability of the welding process ensures product quality. Sensor technologies compensate for the various errors in the processes i.e., errors of the work positioning, the cutting and fitting errors of work members work welding heat deformation. Advanced technologies have been implemented into the robot systems in recent years. The processing capacity of the robot controller has enlarged the application fields because of its versatile functions. Multi-robot welding provides for space-saving assembly and shortens the lead times. Computer systems linked with CAD/CAM and CAPM integrate all of the systems that provide flexible and efficient fabrication.

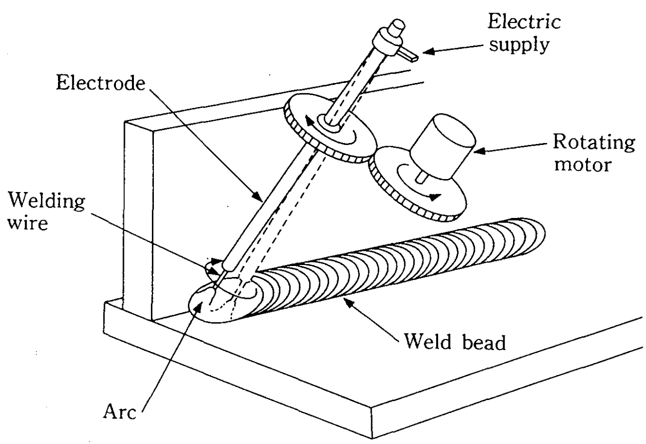

Fig. 8 Principle of High Speed Rotating Arc Welding Process.

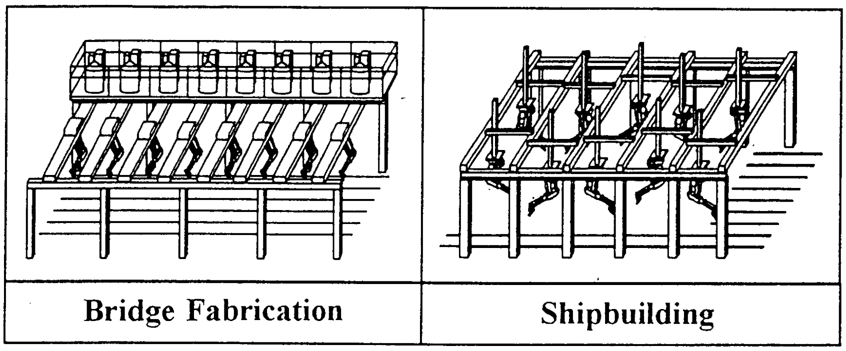

Fig. 9 Examples of Multi-robot Mechanism for Heavy Industries.

4.1 Welding Processes

In case of the robotization of the welding process, the use of a highly efficient welding process itself and stable welding phenomena directly affects the system efficiency.

The High Speed Rotating Arc welding process [13] provides high efficiency with higher welding current and welding speed, see **Fig.8**. The principle of this welding process is shown in Fig.5. The high speed arc rotation up to 100 Hz is applied to the molten pool by mechanical electrode rotation to decentralize the arc pressure and arc heat. Thus, the process provides a flat bead shape, even under high welding current conditions with double the welding speed of conventional GMAW processes. Another advantage is provided by arc sensing for seam tracking and detecting joint/bead ends. Flux-cored wire and inverter controlled welding power sources ensure decreased spatter levels and pitting.

4.2 Multi-robot welding systems

The total number of welding robots is a simple parameter for estimating the production capacity of the welding fabrication. The space-saving arrangement with multi-robots can achieve an efficient production style, even for large scale panel fabrication.

4.3 Multi-robot mechanisms

An example of the multi-robot mechanism is shown in **Fig.9**. Tight arrangement decreases the arc time ratio because of the interference between adjacent robots motions. Optimization of robot number, external axis arrangement, welding space, and robot layout is an important task. For example, eight welding robots are installed based on the bridge production estimation. The robot operation space is determined with maximum work size. As a result, eight welding robots are arranged in each 2m longitudinal space. The robot is hung only on a transverse sliding unit to avoid of collisions. A transverse panel subassembly stage with 10 welding robots is hung from 3 dimensional, wide range external sliding units (x, y, z). Covered areas of the multi-robot welding systems are 8 m width,16 m length and 1.5 m height.

4.4 Multi-robot control systems

Control systems have been developed to avoid mutual interference of robots and allow multiple robots to operate cooperatively in the overlapping areas. Thus the multi-robot control system checks the present position of adjacent robots and predicts any collision occurrence when

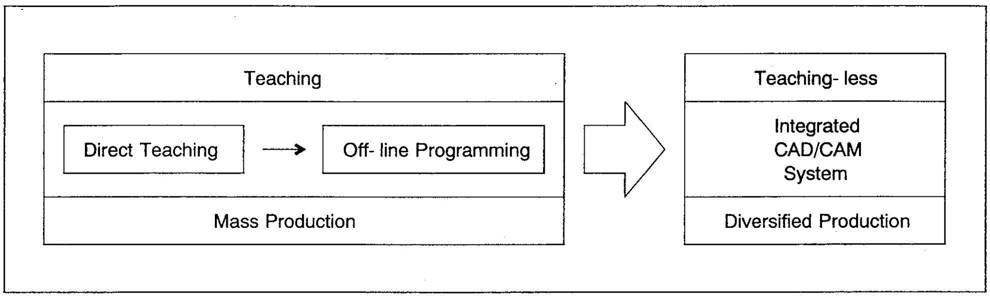

Fig. 10 Relation between Teaching System and Production Style.

a robot requests permission to operate in the overlapping area. Permission is issued if no overlap of motions exists, otherwise,the robot is ordered to stand still until the risk of interference is over.

4.5 Teaching-less CAD/CAM systems

The teaching system for welding robot changes according to the production style, see **Fig.10.** In mass production such as automobiles, teaching with actual robots (so called 'direct teaching') or off-line programming with dialog display are utilized. However in multi-kind and small lot production, a CAD/CAM system is essential in order to achieve cost effective production.

A developed CAD/CAM system is based on a teaching-less automatic programming system. The system consists of CAD, a robot motion data generation system, a data conversion system, a robot simulator, a data transmission system and a multi-robot control system, see **Fig.11.** The configuration data of all structural members and welding design data for the objective work are stored in a CAD database on the host computer. The robot motion data generation system on the EWS uses these configuration data then generates the robot motion data automatically for every robot and saves in the robot database.

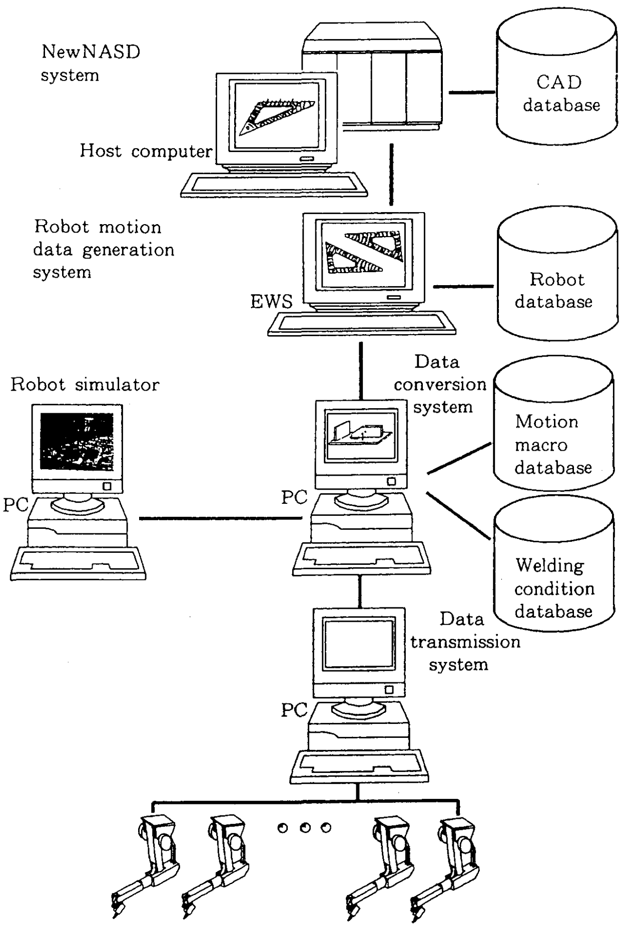

Fig. 11 Configuration of CAD/CAM System.

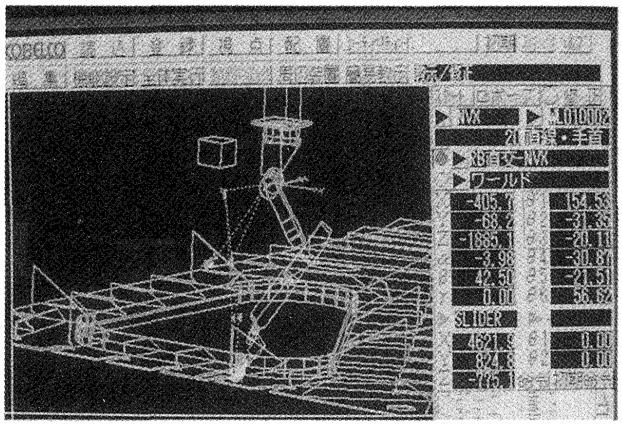

Fig. 12 Typical View of Robot Simulation.

The data conversion system on the PC picks up suitable motion patterns and welding conditions from each database for specific parts of the welding joint. The motion pattern is roughly grouped into approach, retract, wire-touch sensing, arc start and arc end motion. The interference check is automatically achieved by the robot simulator. If the system detects possible collisions, the operator can avoid them with interactive operations as shown in **Fig.12.**

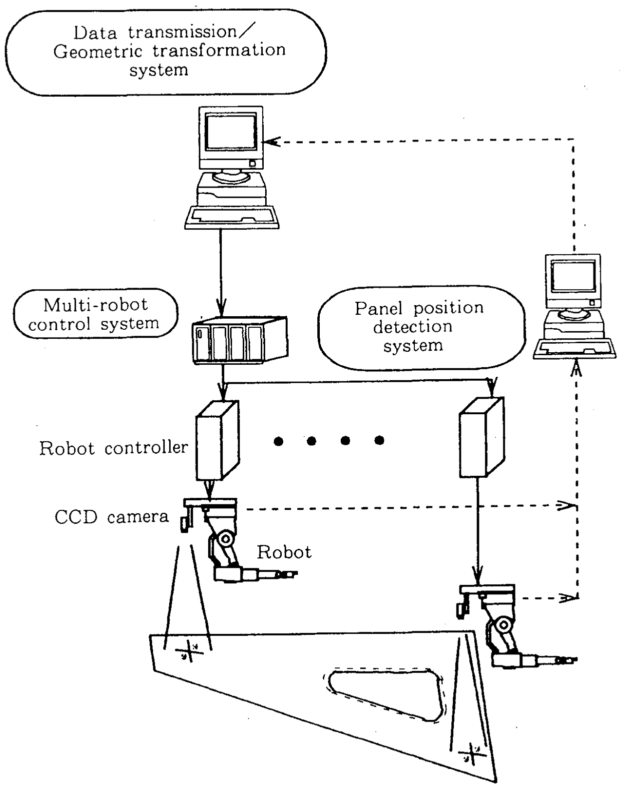

Fig. 13 Coordinates Transformation System.

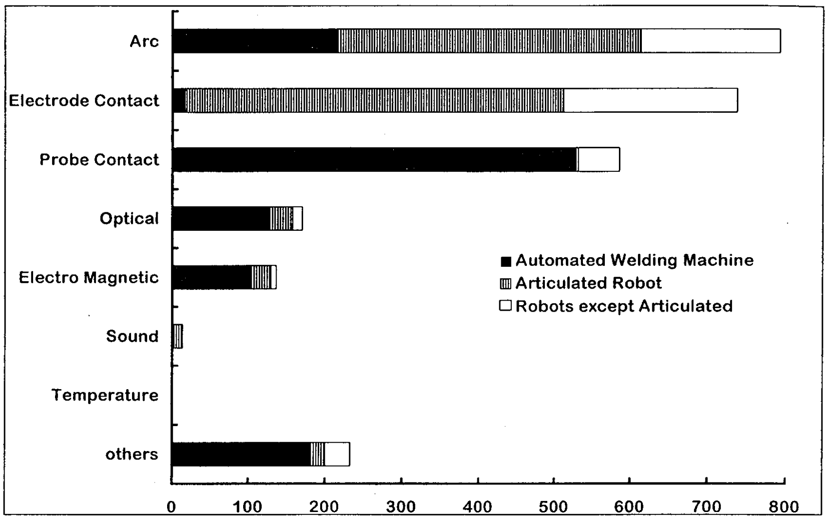

Fig. 14 Application of Arc Welding Sensor in kind in Japan.

4.6 Multi-sensor systems

CAD/CAM is the core technology in robot welding systems in heavy industries. But the system cannot be constructed by CAD/CAM alone. In welding systemization, the best utilization of sensors compensate CAD/CAM to cope with various errors, e.g. work positioning, parts fitting, welding deformation, etc.. The error compensations are categorized into two types: one is a pre-correction before welding execution, the other is a real time correction during welding by means of arc sensors.

4.7 Coordinates transformation systems

Coordinates transformation systems have been developed to compensate for work positioning errors. It is difficult to mechanically or manually set up complex, heavy and large work in the appropriate positions according to CAD/CAM data. Thus, two sets of CCD cameras equipped on every robot individually detect the marked guide points on the work, the image processor recognizes the difference between the actual position and the CAM data position and the coordinate transformation system corrects the robot program data in CAM, see **Fig.13**.

4.8 Joint and bead position sensing

Wire-touch (electrode contact) sensors as well as arc sensors are widely used in robot welding in Japan,as see **Fig.14.** Their typical application is to detect actual positions of both edges of the joint prior to welding. However, a problem of the sensing process is that its air-cut motions decreases the arc time ratio. Therefore, edge detection with High Speed Rotating Arcs sensors in real time has been developed. This simplifies the robot motions and achieves precise sensing [12].

In multi-robot welding, a welding joint is often divided between two robots due to the limitation of the robot motion area. The position of the edge of the prior laid welding bead is detected by similar means to the joint sensing method.

4.9 Seam tracking

Arc sensors with the High Speed Rotating Arcs provide precisely accurate seam tracking (include torch height control) and stable welding bead shape. They have approximately 10 times the feedback rate compared with the conventional arc sensors and the weaving method. The arc sensor finally compensates for any deviation of the joints caused by work positioning, cutting, fitting, welding deformation, etc.. It can also follow knuckled or curved welding lines and it does not require any teaching operation for such kinds of complicated joint line. The arc sensor can simplify the robot programs.

Development of CAPM (Computer Aided Production Management) is indispensable for flexible manufacturing of multi-kind but small lot production. All of the process management data for each stage are estimated in CAPM using CAD/CAM data. Specifically, the processing time of the robot welding stage is estimated with a robot simulator in the CAD/CAM system.

Short term scheduling has been carried out in the

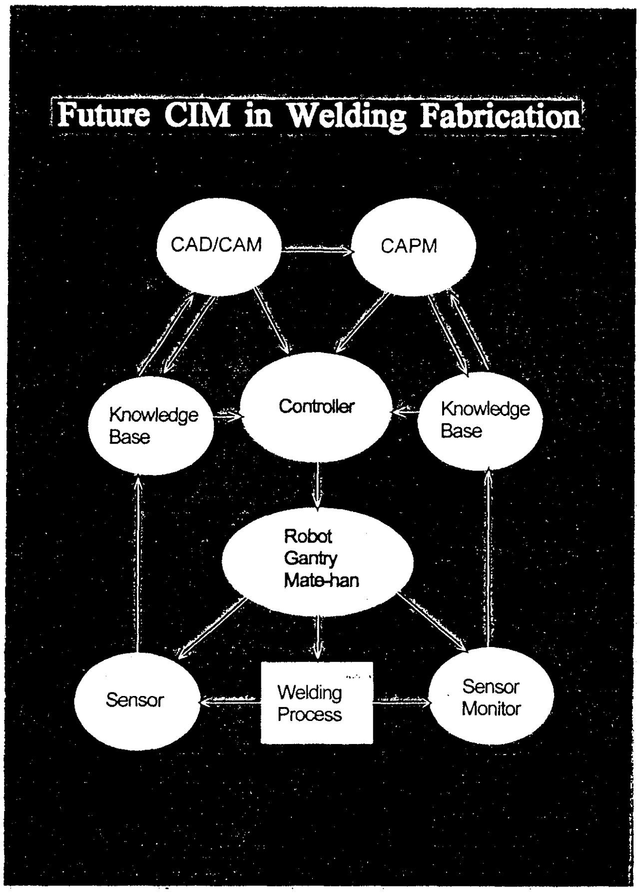

Fig. 15 Configuration of CIM in Welding Fabrication.

system using the above process management data. The line manager can check the progress of each stage, e.g. fitting, robot welding, finish welding, etc., on the CAPM system. The CAPM system deals with the process output data collected from each stage to make a just-in-time report. Rescheduling is carried out by using a simulation system in CAPM if some deviation between scheduling and execution is occurring.

5. Future Subjects

Industries are expecting flexible, high efficient and labor saving production systems through the installation of computer integrated manufacturing systems (CIM). It can be expected that welding systemization,recently applied in Japan and also overseas progressive countries,will be advanced to become real CIM in the near future. It is said that an essential of the CIM is the cooperation between human, robot, and computer system with best contribution of human abilities. What are the human abilities?. We can list for example, intelligence, sense, knowledge, expertise, skill, etc..

As described in the paper, CAD/CAM continuous systems provide the core technology to control the welding robot. But, it cannot provide satisfactory production by itself. It needs the intelligent support of sensors for, e.g., coordinates transformation, seam tracking and adaptive welding parameter control. Simulation technology is also indispensable today for compensation of CAD/CAM and CAPM. We, welding engineers, supply a lot of database for CAD/CAM, i.e. welding conditions and torch motions (UNBOU in Japanese). Selection of optimum values for these needs a number of welding tests, though in the case of conventional manual welding, skilled welders do not need such tests. In the case of adaptive welding parameter control to cope with root gap variations, more databases will be necessary and, in addition, application of welding model or expert systems etc. will be necessary.

The above mentioned support technologies for CAD/CAM, CAPM, and sensor/monitor based control are being installed in the robot welding system even today. Henceforward these technologies are generally termed 'Knowledge Base (KB)'. Better implementation of KB into welding systemization will be the goal of the construction for CIM system. The concept of CIM in welding fabrication is shown in **Fig.15**.

6. Conclusions

Teaching-less CAD/CAM continuous systems or off-line programming systems are essential for integrated welding systemization in heavy industries.

Efficient and stable welding processes with the aid of modern welding consumables and welding power sources, multi-robot welding systems, sensor/monitor-based compensations for various work errors, seam tracking, adaptive welding parameter control systems, simulation technology for CAD/CAM and CAPM, respectively, provides more effective and modernized production systems.

Implementation of Knowledge Base as support technologies for CAD/CAM, CAPM and sensor/monitor-based control will be important for advanced welding systemization towards CIM in the future.

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