13. The Arc Welding Robot for Hull Sub-assembly Works

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Summary

The development and application of an Arc Welding Robot for ship building sub-assembly works are studied here.

Robots for such purposes should require a minimum teaching time and should be able to track out welding lines. Moreover, they should be flexible enough to accommodate any size of constructions and different workpiece laying positions, in accordance with the change of production schedules.

A large gantry type Arc Welding Robot with the robot language capability and with the arc sensor, which tracks out the welding line and detects its ends, has been newly developed and the new application engineering for this robot has been studied, incorporating task level robot language functions in the sub-program.

The robot and its application engineering bring forth the following remarkable features:

(1) By use of the robot with task level welding programs, teaching items are reduced to 1/35 of the original.

(2) Almost entire welding, including boxing at the ends of welding line, can be performed by the robot throughout the sub-assembly works.

(3) More freedom is given to sub-assembly laying positions without altering the welding program.

Thus, the sub-assembly works having complicated stiffener arrangements can be welded by the robot reducing the welding man-hour by 75%.

1. Introduction

Nowadays, in order to overcome the labor shortage in Japan, it is necessary for the Japanese shipbuilding industry to transform themselves into the equipment intensive industry which assures higher productivity with more mechanized and automated manufacturing process, rasing an added value per worker.

In shipbuilding works, arc-welding process consumes more than 1/3 of the whole labor hour for hull construction. Accordingly, the proportion of flat position welding has been increased to improve the productivity of the welding process. Moreover, the research and development of welding techniques and the mechanized welding have been made for higher productivity.

In sub-assembly works, for the simple shaped welding lines, specialized welding machines are applied to 70% of welding length effectively. However, for the remaining portions, such as, both the ends of welding line, vertical welding positions and complex-shaped welding lines are to be manually welded with low productivity. About 80% of the welding labor are consumed for 30% of the total welding length. It is therefore an imminent problem to develop an improved method of welding for these portions by means of higher mechanization and automation, in order to reduce the manufacturing cost and better the working circumstance.

Flexibly moving robots are most suitable for the automatical welding of complex-shaped works. However, in order to adopt such robots, new features which have capability of boxing weld at the both ends of welding lines and also of cost reduction must be developed.

In this paper, the Arc Welding Robot system

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for hull sub–assembly is introduced, which has an arc–sensor with terminal detecting ability for tracking as well as boxing of welding lines and has task level robot language in order to reduce teaching time.

2. Main Aim of the Development[1)]

2.1 Cost Reduction

The application of industrial robots must contribute to the reduction of manufacturing cost. Since, however, teaching for robots is performed by operators, it requires a certain amount of labor hours. In the case of repetitive pattern of operation, the allocation of teaching time to each work can be minimized keeping a good economical effect. However, the operation in shipbuilding has few repetitive works. Therefore, the teaching cost takes more than those of other industries.

As shown in Fig. 1, it takes 1.4 minutes to teach one point by practical robots, setting the teaching point at ± 1.0mm which is required for ensuring the quality of welding. In the case of horizontal fillet welding, the operation consists of 24 motion lines as shown in Fig. 2. This means more than 150 items to be taught as shown in Table 1. Therefore, it takes about 34 minutes to teach for one welding line. Fig. 3 and Table 2 show the typical shape of a sub–assembly work and the amount of task, respectively. Thus, it is suggested that the teaching time of this work which involves 35 horizontal fillet welding lines takes about 20 hours. It is supposed that the welding time takes about 50 minutes, assuming that arc time

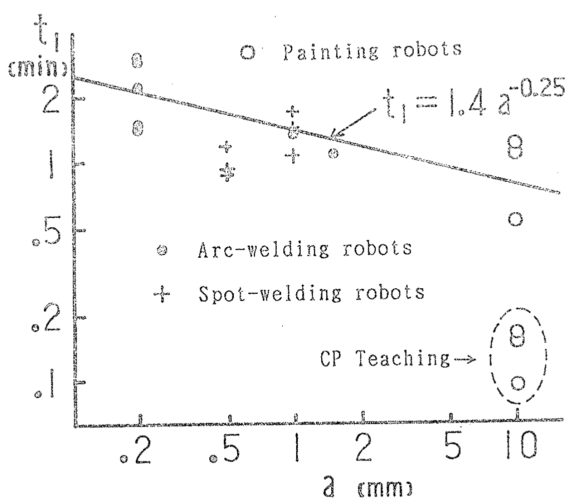


Fig. 1 Relation between time required for teaching and accuracy of teaching

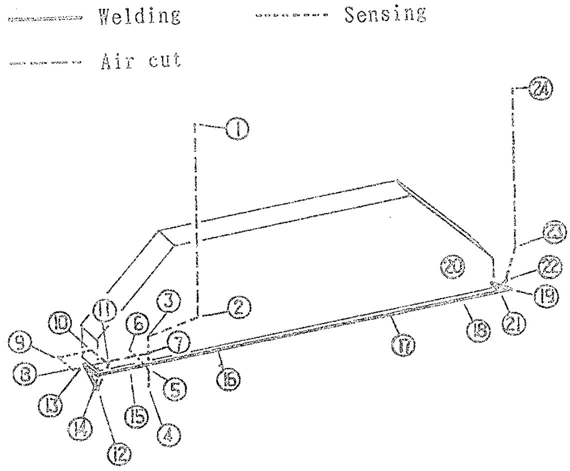


Fig. 2 Breakdown of movements throughout the fillet welding task

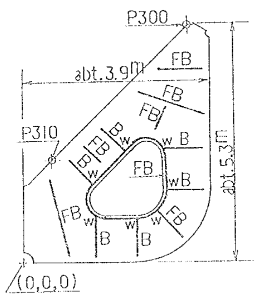


Fig. 3 A hull sub–assembly to be welded by Robot

Table 1 Number of teaching items required for a fillet welding task

Teaching items		Position	Attitude	Speed	Curr Volt	Weaving	Arc-sens	Total
No. of data		3	3	1	2	4-15	6	(30)
Air cut	Points	14	5	13	0	0	0	–
	Sum	42	15	13	0	0	0	70
Welding	Points	10	3	6	6	3	3	–
	Sum	30	9	6	12	12	18	87
Total	Points	24	8	19	6	3	3	–
	Sum	72	24	19	12	12	18	157

Table 2 An application of the Robots on hull sub–assemblies

Ship's type Construction	LPG 78km^3 Bilge Trans.
Size (m) No. of repeat	Length 4.7 Width 6.5 60
Fillet weld(m) No. / Leg(mm) Vert'l weld(m) No. / leg(mm)	41.0 36 / 5.0 1.5 20 / 5.0

ratio is 50% and welding speed is 600mm/min.. Namely, the teaching time takes 20 times more than the welding time. Therefore, the following measures should be developed to secure economical effects.

1) The indirect teaching which is to use robot language should be adopted in order to avoid lower robot operating time which comes from the direct teaching.

2) The robot language which is able to order welding tasks in one lot should be developed in order to minimize the indirect teaching time.

2.2 Higher Welding Speed and Tracking out of Welding Line

In the case of fillet welding, the welding torch should be placed within the range of ±1.0mm from the correct torch position in order to keep welding quality. However, the marking line may have an allowance of ±3.0mm and the accuracy of cutting of ±5.0mm, on the basis of JSQS (Japan Shipbuilding Quality Standard). When large works are welded, the heat input causes deformation and position shift. Further, the operating position is affected by robot's mechanical error, bend of link, backlash of gear and so on, because of using numerically controlled robot for reducing teaching time. Therefore, the following capability should be developed in the view point of increasing welding speed and securing welding quality.

1) The capability of detecting the end point of weld line by use of an arc sensor should be developed in order to complete the welding automatically.

2) The arc sensor with high stable limit welding speed should be developed for reducing manufacturing cost as much as possible.

3) The touch sensing program for all positions, which is independent of welding line position and direction, must be developed in order to detect the welding start point.

2.3 Capability of Correspondence to Alteration

In the manufacturing system of shipbuilding industry, it is common that the works are brought in and carried out by overhead cranes in order to meet the fluctuation of manufacturing procedures, because the alteration of a construction schedule and design is inevitable in the shipbuilding production process. Therefore, the welding robots should have the following capability, in order to choose the procedures and the positions of welding works and to correspond to design alterations.

1) Task level program should have the description which is not affected the workpiece position and direction.

2) The robot language should have the manner of free expression of the coordinates.

3) The execution of robot control program should be done by the interpreter mode which runs concurrently with translating the program of welding.

4) The motion level program should be generated by the robot controller itself.

3. Mechanism and Control of Robots[1)]

3.1 Mechanism

As the overhead crane is used, it is necessary to arrange more than two works at the same time. The horizontal operational space should be 4.5m×20.0m because the robot treats the large sub-assembly works. Articulated robots do not have such a large operational space as mentioned above. Therefore, the articulated robots should be installed on the gantry which has two rectangular axes in horizontal directions as shown in Fig. 4. The

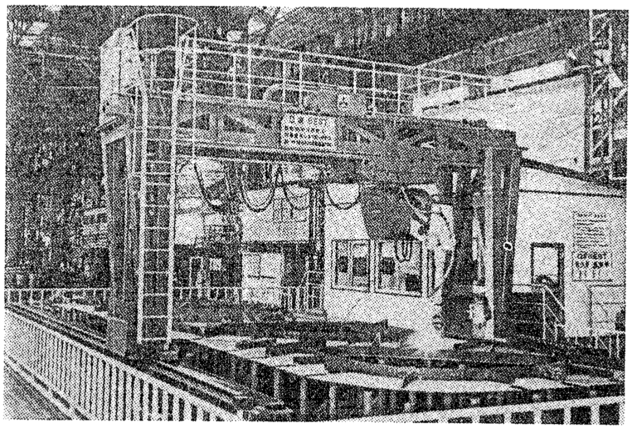


Fig. 4 A photograph of the arc welding Robot for shipbuilding sub-assembly works

motion of approach and secession before and after welding is almost perpendicular. Further, the motion needs the height of at least 700mm in order to avoid obstacles. Thus, the articulated arm should have larger operational space than general robots as shown in Fig. 5. The arm should be installed on the gantry inclining 75 degrees ahead in order to secure the large perpendicular operational space, reducing the interference of works and decreasing the bend of arms by its own weight.

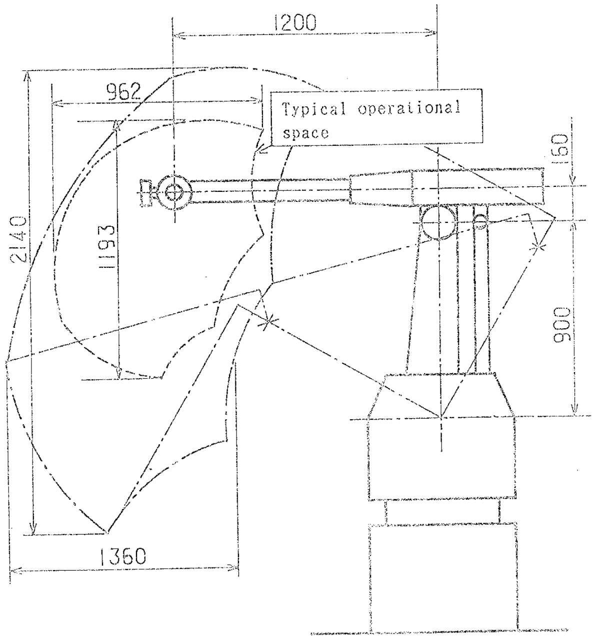


Fig. 5 Operational space of the main body of the Robot

In the case of using straight torch, an operational torch angle and position can be made by five degrees of freedom because the torch revolution with torch center line as a pivot do not cause the alteration of torch angle. However, when an arc sensor is used the direction of torch weaving has to keep a right angle with welding direction, so that one degree of freedom should be added. Moreover, since the second arm must be kept almost vertical, the robot mechanism should have seven degrees of freedom with one redundancy as shown in Fig. 6 by JIS symbol.

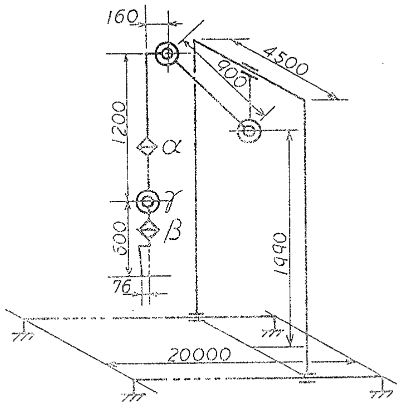


Fig. 6 Mechanism and link dimensions of the Robot

3.2 Control System

In order to move accurately with the shortest motion during boxing weld, it must take less than 120 ms to interpolate torch path by each interval of 1 mm in welding speed of 500 mm/min.. The adopted central processing unit of the robot controller must be a multi-processor organization, in order to process the language translation of interpreter mode, moving path interpolation, detection of abnormal operation and axes angle control within that time interval.

Fig. 7 shows the hardware configurations of this controller. System monitoring, robot language editing and translation, communication control, teaching pendant processing and computed path control are assigned to a main processor unit with 16 bits. Coordinates calculation of the path, coordinate transformation and calculation of axes angles are assigned to an arithmetic unit with 16 bits. The axes

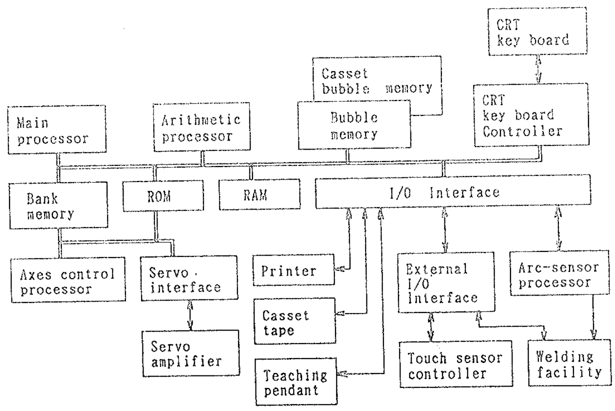


Fig. 7 Block diagram of the Robot controller

control of software servo and weaving which turns back on 100 ms in shortest is assigned to an axes control processor unit with 16 bits. The main processor and the axes control processor are connected by a common bank memory. An arc sensor which tracks out welding path and detect weld line ends is controlled by an exclusive processor with 16 bits, since it is necessary for welding condition to be always monitored.

Table 3 shows the system software configuration of the robot controller and the storage allocation of its memory. The system program was coded mainly by PL/M (Program Language for Micro-computer). Since these processor had not enough capability of processing, it was necessary that such a capability was properly distributed to the each processing job and a part of the system was coded by the machine language instead of PL/M. Also, software size is large, because it must have functions for the geometrical calculations to generate path. Then, it was necessary to save storage with optimization of symbol size etc..

Table 3 System softwear of the Robot controller

Subsystem		Size	Modules
Main CPU	Monitor	42kB	40
	Editor	8kB	20
	Compiler	80kB	65
	Execution	88kB	120
	Mathematical calculation	36kB	90
	Teaching	34kB	100
	Data area	256kB	-
	Main program	544kB	435
Axes control (ROM:16kB RAM:16kB)		32kB	50

Individual motion of welding task is generated by sub-program of motion level. Since the execution is the interpreter mode to deal with alterations successfully, sub-program is brought into random access memory (RAM) with ASCII format of 80 characters by a line as it stands. There are 157 teaching items per straight welding line in horizontal fillet as mentioned at section 2.1. The total number of teaching items is 766 per welding line, because 87 items out of 157 depend on 8 kinds of terminal shape of welding line. It is estimated that the total of sub-program which includes statements for program flow control and definition of program is approximately 1,200 lines. Since there are three types of welding task as explained later, sub-program is to occupy about 290 k bytes of the RAM. So as to decrease the total lines, the sub-program should be of the hierarchy construction enabling to store common portions jointly within the data area of RAM.

The welding operation is shown by a welding program in the task level. The program with three lines is required per welding line in order to teach the kind of welding and the positions of both ends for each line. In case of a large workpiece, that has about fifty welding lines, the program of about 170 lines are required to weld each workpiece. The size of external storage is 512 k bytes in order to store 1,700 lines which corresponds to 10 welding programs per day and 3,600 lines of sub-program. The medium is a magnetic bubble cassette which is easy to handle in the field and has good anti-dust features.

The language editing key is set in the teaching pendant and it can modify the robot language program, in order to alter the welding operation by the robot. The alterations are reflected on the robot language program and stored in storage by means of its source image, in order to adapt it to the next workpiece.

3.3 Welding Control[2)]

The arc sensor should be adopted for tracking out welding line. This sensor detects the average welding current Ia (A), the effective welding current Ie (A), the welding voltage V (V) and the wire feeding speed F (mm/min.) and, by use of functions (1), (2), (3), (4) and (5), calculations are carried out for the voltage drop Ve (V), the arc voltage Va (V), the wire extension Le (mm), the arc length La (mm) and the distance between tip and base metal L (mm).

$$Le=(F-0.310Ia)/(4.78\times10^{-5}Ie^2) \quad (1)$$

$$Ve=3.98\times10^{-3}((8.09\times10^3F/Ie^2) \times(\exp(1.49\times10^{-4}LeIe^2/F) -1)-0.142Le)Ia \quad (2)$$

$$Va=V-Ve \quad (3)$$

$$La=(Va-0.0212Ia-15.1)/(0.992+0.0011Ia) \quad (4)$$

$$L=Le+La \quad (5)$$

The path crossing the welding line is amended by the asymmetric component of "L" wave which fluctuates by weaving. The distance between welding line and torch should be adjusted by the average of "L" fluctuation. Moreover, the rapid change of "L" detects the ends of welding line.

The authors tried to find the best welding condition and the limit speed for arc sensor to be able to track out as shown in Table 4. As the experimental result, we got maximum welding speed of 900 mm/min.. However, practical speed is 600 to 700 mm/min. if there is a gap between the base plate and stiffeners. The relation among the torch attitude, the tracking out capability of arc sensor and the bead shape were investigated in the welding test, and then the most suitable torch attitude was determined as shown in Fig. 8 avoiding interference between the workpiece and the torch. The torch attitude was changed gradually from the end part to the center part in the shifting region of 200 mm in length.

Table 4 Conditions for fillet weld

Weld positions	Fillet weld			Vertical Weld
Weld speed (mm/min)	500	700	900	150
Weld current (A) voltage (V)	300 34	350 38	380 41	150 22
Leg (mm)	5	5	5	6-6.5
Inclination angle(deg) Fore & aft angle (deg)	45 0	45 0	45 0	45 0
Wire extension (mm)	20	20	20	22
Weaving (mm) (Hz)	1.8 3.0	1.5 5.0	1.3 5.0	2.5 2.5
Max. tracking angle (deg)	±5	±2	±1	Min 3

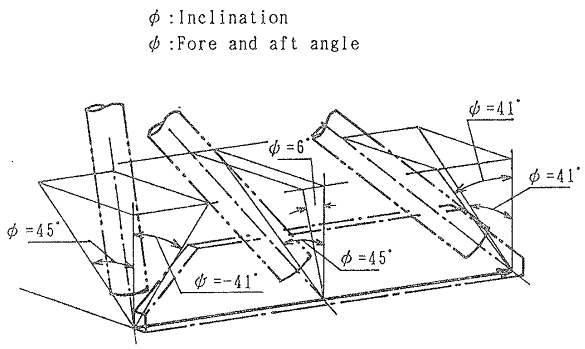


Fig. 8 Torch angle

In order to decrease a remaining welding line by using robots, the welding in the both ends of welding line was classified into 8 types according to the shape of the end and the distance from an adjacent workpiece. The best path of welding was determined from the result of many welding experiments as shown in Fig. 9. Fig. 10 shows the good bead shape in the boxing weld.

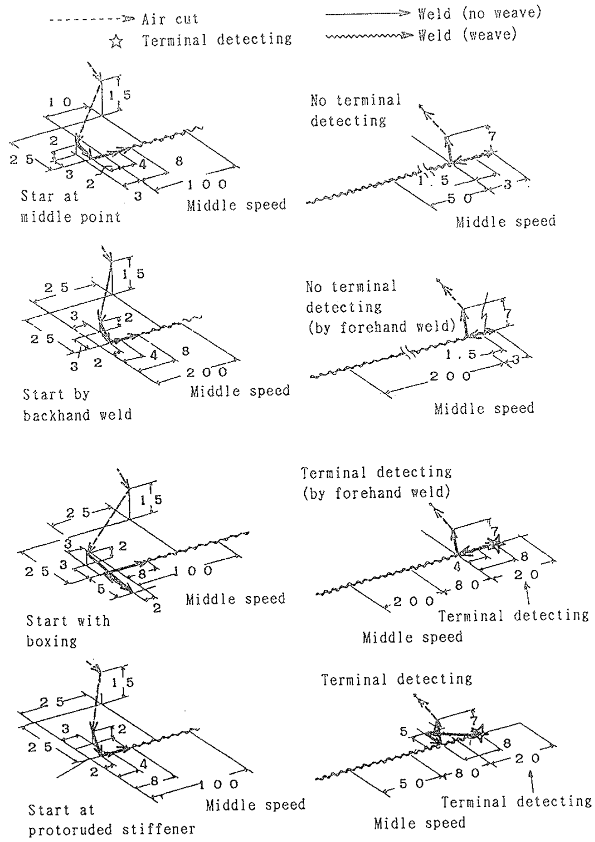


Fig. 9 Details at ends of welding lines

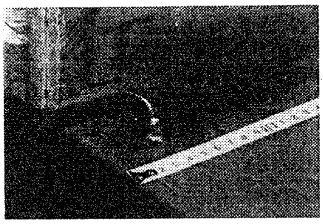


Fig. 10 A detail at an end of welding

4. Development of the Task Level Robot Language[3)]

4.1 Path Analysis of Welding Operations

In general, there is a module of frame space in hull structural arrangement and base plates are placed horizontally when weld work is done. Then, the welding path can be standardized on the basis of such features on the sub–assembly works.

1) The welding work of sub–assemblies except butt joints of base plates can be classified in three types, as shown in Fig. 11, of straight horizontal fillet welding, horizontal fillet welding with circular arc welding line and vertical upward welding.

2) The touch sensing for detecting the start point is standardized in seven patterns as shown in Fig. 12.

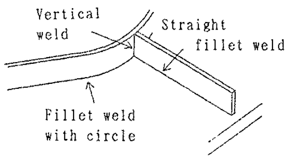


Fig. 11 Types of weld in hull sub–assemblies

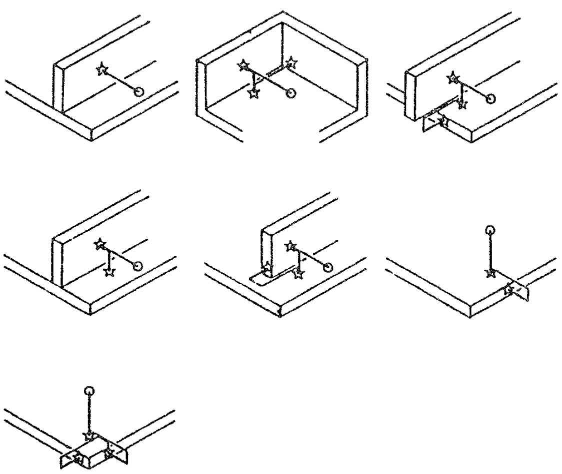


Fig. 12 Variations of touch sensing patterns

3) The air cut from a welding end point to the next start point can be standardized as shown in Fig. 13.

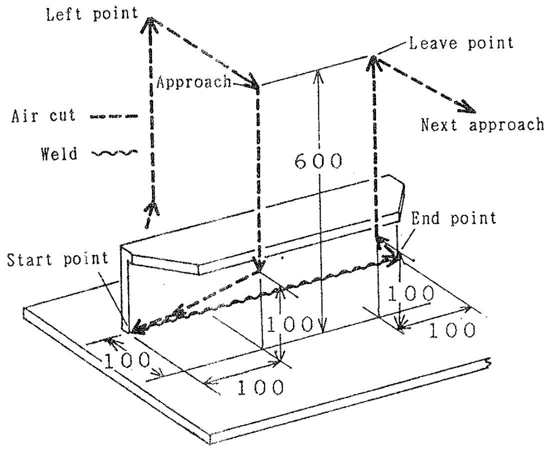


Fig. 13 Standardized approaching path and leaving path

4.2 Construction of Program

The welding works can be taught in a lump using MACRO which is made for each task of three kinds of welding, detecting workpiece position and cleaning torch. MACRO is the name of sub–program which produces each motion concerned each work. The working conditions such as the indication of the both end positions, the welding side and the kind of welding at both ends are shown as the index. Namely, MACRO has a faculty as the task level language. MACRO should be described by motion level language for easy alteration.

The hierarchy construction should be adopted in the common part for some tasks in order to decrease the sum of sub–program. The hierarchy construction consists of independently registered MACRO as shown in Fig. 14.

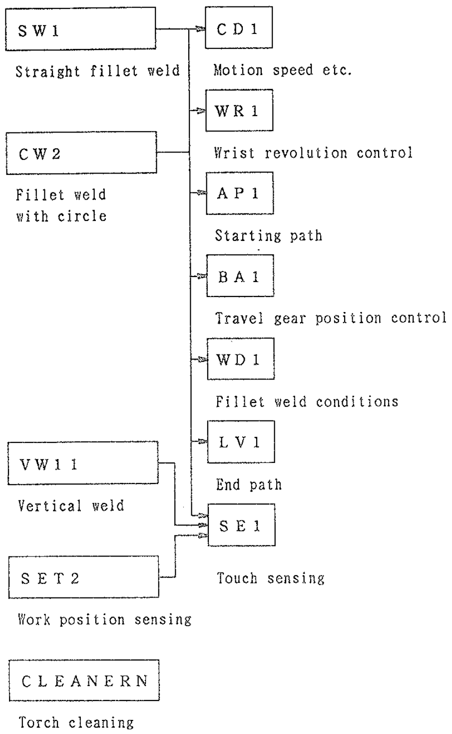


Fig. 14 Construction tree of MACRO

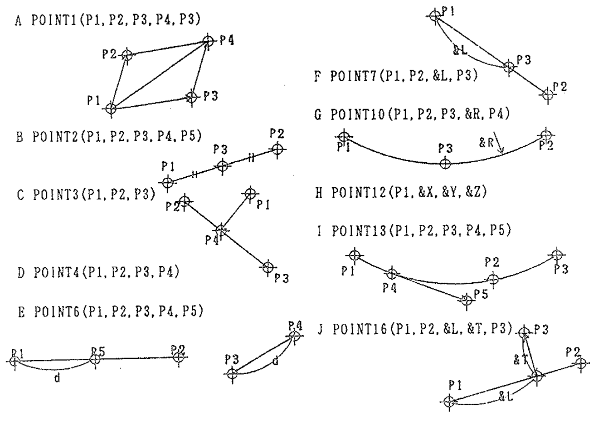


Fig. 15 Geometrical calculation packages

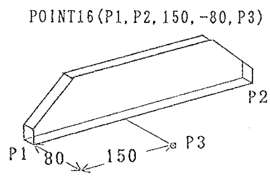


Fig. 16 Definition of a position by the calculation packages

4.3 Required Capability for Robot Language

Since the program producing each motion has to amend corresponding to the alteration of ship type and the kind of workpiece, it should be described in the motion level language. The language translation of interpreter mode should be adopted in order to deal with the alteration in working field.

In the same kind of welding, the task level program should be common for all the welding lines with different positions and different directions. Then, the motion level program must be so described as not to be affected by the position and the direction of welding line. Therefore, all the positions of robot motion should be defined by coordinate system based on welding line. The geometrical calculation packages as shown in Fig. 15 should be developed to define position by such a coordinate system. As shown in Fig. 16 as an example, the definition of position can not be affected by the direction and the position of welding line.

Since the wrist motion of robots is controlled with the coordinate system fixed to the robot, the calculation packages, which transform the coordinate value between the coordinate system fixed to the robot and coordinate system fixed to the welding workpiece, are to be added to the instructions of the robot language.

In order to teach the tasks in a lump, the following capability must be developed:

1) Sub-program capability which is able to quote with the calling name MACRO.

2) Capability to call MACRO out of the memory storage and faculty to link it to execute.

3) The capability of arguments to show the suitable operating condition, for example, the both ends of welding line.

4.4 Task Level Language

The welding program, as shown in Table 5 as an example, consists of the following few-simple-easy reduced contents by use of MACRO which has the capability of task level language.

1) The definition of the value on the coordinates concerning the both end points of welding line (the same number as the both end points).

2) The definition of the three reference

Table 5 List of a welding program

```
PROG GSXMP
DATA
  P1=(693,325,0)
  P2=(356,1740,0)
  P3=(1410,327,0)
  P4=(1410,728,0)
        :
  P101=(10,0,0)P1
  P102=(10,0,0)P2
        :
  P64=(0,0,100)P4
  P66=(0,0,85)P6
        :
  P300=(3795,5232,0)
  P310=( 400,1818,0)
  P330=(0,0,300)P300
P320=(+1200.5,+4454.6,+345.6)
P321=(+3988.5,+7058.6,+49.6)
P322=(+1316.5,+4354.6,+37.6)
P323=(+3920.5,+7122.6,+345.6)
DEND
SEQ
  SET2(P320,P321,P322,P323,P300,P310,
       P301,P311,P331)
  TRANS P301,P311,P331,P300,P310,P330
   VW11(&D,P12,P72,P11,P401)
   VW11(&D,P20,P80,P35,P19)
          :
   CLEANERN
   SW1(&D,P18,P17,-1,4,4)
   SW1(&D,P17,P18,-1,4,4)
          :
   CW2(&D,P124,P36,P155,P4,P4,1,3,3)
   SW1(&D,P3,P4,-1,4,3)
          :
  ETRANS
  STOP
 SEND
 PEND
```

points which is used to define the workpiece position (3 lines).

3) The statement to quote the sensing MACRO which detects the workpiece position (1 line).

4) The indication of the direct teaching for the path points to detect a workpiece (4 lines).

5) The order of coordinate transformation and its stop order (2 lines).

6) The MACRO's name appointing the kind of welding line, the point mark of the both ends and the index showing the kind of terminal welding (the same number as the welding lines).

7) The name of welding program and the statements of starting and ending of the program (4 lines).

The line number of program P is determined by the number of welding line W according to the function (6).

$$P=W\times 3+14 \tag{6}$$

Concerning the sub–assembly works which generally consists of about 30 welding lines, the quantity of producing program is compared with the number of lines. When the motion level language is used, the program with about 120 lines is required. Therefore, the quantity of welding program amounts to about 3,600 lines. In using the MACRO program with task level, the line number amounts to 104 according to function (6), that is, the quantity of welding program is reduced to approximately 1/35 by means of MACRO with capability of task level language.

4.5 Motion Level Language

(1) Control for Keeping Robot Arm within the Operating Angle.

To avoid abnormal operations, it is necessary that the axes of arm should be kept within their operating angle during the whole welding operation. Therefore, the peculiar algorithm for robot mechanism and control is added to the motion level program.

In the case of the mechanism of this robot, there are two sets of solutions on the three wrist axes which perform assigned torch attitude. The mutual relation between both the solutions are shown by the functions (7), (8) and (9). The marks of the axes are shown in Fig. 6.

$$|\alpha_1-\alpha_2|=180^\circ \tag{7}$$

$$|\beta_1-\beta_2|=180^\circ \tag{8}$$

$$\gamma_1=-\gamma_2 \tag{9}$$

The better set of solutions is chosen and then the three axes are controlled within those operating angle. The three wrist axes are set in the center of the each arm's operating angle and the torch is fixed on the position Ⓝ as shown in Fig. 17. This position Ⓝ is called neutral position. In the case of linear horizontal fillet welding, any one of relay position Ⓐ, Ⓑ, Ⓒ, or Ⓓ, in Fig. 17 is chosen according to the decision table as shown in Table 6. Then, the

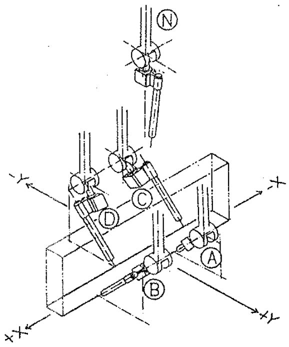


Fig. 17 Neutral position of wrist and wrist revolution to weld

Table 6 Decision table for wrist revolution

Weld side	x ≧ 0	x < 0
Right*1	Ⓓ	Ⓐ
Left*1	Ⓑ	Ⓒ

*1 Look for welding direation
*2 x : Difference of x-compornent between an end point and a start point

torch is set to the welding position by the way of the relay position.

In some cases, function (10) may be approved, where α_t means the angle of α axis at welding end point and α_s means it at welding start point.

$$|\alpha_t - \alpha_s| \geqq 180° \tag{10}$$

When the function is satisfied, the α axis rotates to the direction of $\pm 180°$ of α axis angle in air cut running. Therefore, when the torch is carried upward after welding, the torch is set in the relay position the same as before welding. Then, the α axis is rotated to the direction of its origin. After that, the direction of β axis revolution at the next welding are compared with the direction of it at the last welding. In the case of different direction, such an order that sets the torch in neutral position has to be inserted. The air cut time does not take much, because this control is done in the processes between falling and rising. Table 7 shows MACRO for the wrist revolution in horizontal fillet welding. In the case of circular welding, the limit of center angle in circular arc must be added. In vertical upward welding, the controlling algorithm for the wrist revolution is also done in the similar way.

Table 7 List of MACRO program for wrist revolution

```
MACRO WR1(P1,P2,P100,P20,W112,&D,&A)
SEQ
MF9=T(3)
POINT14(P1,P141)
POINT14(P2,P142)
POINT1(P141,P142,P100,P112)
POINT12(P112,&X,&Y,&Z)
 &G=2+&A
IF &X GT 0 GOTO *FF
 &G=-2+&A
*FF:
P11=(&G,0,0)
POINT15(P11,P151)
POINT15(P100,P150)
W112=A(20*&A,-5),F(P150,P151)
IF ABS(&D-&G) GT 0.5 GOTO *CG
  RETURN
*CG:
GET P12
POINT14(P12,P143)
P144=(0,-1000,0)P143
IF &G/&D GT 0.25 GOTO *SD
 POINT15(P144,&X,&Y,&Z)
 B12=(&X,&Y)
 POINT15(P20,P152)
 W12=A(0,0),F(P150,P152)
 WMOVE B12,W12,MF9
*SD:
 P145=(0,-900-(ABS(&G)-2)*198,0)P143
 POINT15(P145,&X,&Y,&Z)
 B112=(&X,&Y)
 WMOVE B112,W112,MF9
&D=&G
RETURN
SEND
MEND
```

MACRO mastering the travel gear position controls to keep the joint angles of robot arms within their operating angles and also to keep the second arm almost perpendicularly. Table 8 shows the MACRO program of such control. Firstly, parameters a and c are obtained using the functions (11) and (12), where a is a horizontal component along the welding line from wrist center to torch top, c is a horizontal component which cross the welding line with a right angle and ϕ is a forehand welding angle. The marks are shown in Fig. 18.

Table 8 List of MACRO program to get travel gear position

```
MACRO BA1(P1,P2,&A,&F,B1)
SEQ
POINT16(P1,P2,-7.4*&F-118,
     -&A*(375-1.22*&F),P3)
POINT14(P3,P143)
P144=(0,-700,0)P143
POINT15(P144,P4)
POINT12(P4,&X,&Y,&Z)
B1=(&X,&Y)
RETURN
SEND
MEND
```

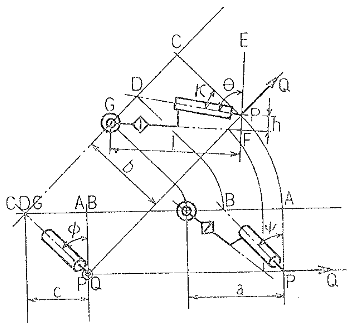


Fig. 18 Position of center of wrist and inclination of torch

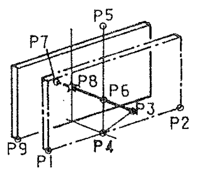
$$a = -7.4 \times \phi - 118 \tag{11}$$

$$c = 1.22 \times \phi - 375 \tag{12}$$

Secondly, the wrist center position is obtained by means of the calculation package substituting a and c. Then, the gantry travel gear is controlled to run with the distance of about 700mm.

(2) Touch Sensing

The touch sensing which detects the actual position of workpiece utilizes a feature of which sub-assembly works cross vertically each other and it senses in parallel with rectangular coordinate system based on the welding line and the perpendicular line. On the basis of the welding line and perpendicular lines, the points along the sensing path are geometically defined as shown in Fig. 19 so as not to be affected by the workpiece position and direction. Moreover, the actual points detected is obtained by means of synthesis of vector in the geometrical calculation package. Table 9 shows the MACRO for touch sensing.



P 1 ~ P 2 : Welding line
P 3 : Start of sensing
P 4 : Vertical leg from P 3
P 5 : Above of P 4
P 6 : Vertical leg from P 3
P 7 : Target of sensing motion
P 8 : Touch point
P 9 : Corrected point

---- Designated position
—— Actual position
—— Motion of sensing

Fig. 19 Geometrical calculations for a touch sensing task

Table 9 List of MACRO program for touch sensing

```
MACRO SE1(P51,P52,P3,&L1,&B,P101)
SEQ
&L2=12
&L3=12
&L4=3
&L5=8
MF1=S(500),F(1)
MF2=S(2500),F(1)
POINT12(P3,&X,&Y,&Z)
P103=(&X,&Y,&Z)
*RESEN:
 POINT1(P103,P3,P51,P1)
 POINT1(P103,P3,P52,P2)
 POINT4(P3,P1,P2,P9)
 P30=(0,0,100)P9
 POINT4(P3,P9,P30,P14)
 POINT9(P14,P3,&L1,P15)
 SENSE P15,P12,MF1 *ER1
 POINT7(P12,P3,&L2,P13)
 MOVE P13,MF2
 POINT1(P14,P13,P9,P5)
 POINT9(P5,P13,&L1,P6)
 SENSE P6,P7,MF1 *ER1
 POINT1(P13,P7,P12,P101)
 P8=(0,0,&L2)P7
 MOVE P8,MF2
 POINT1(P9,P1,P8,P14)
 POINT9(P14,P8,&L3,P15)
 POINT1(P13,P12,P15,P16)
GOSUB *MIMI
 MOVE P22,MF2
 POINT1(P9,P101,P1,P24)
 POINT4(P20,P101,P24,P101)
RETURN
*ER2:
 POINT9(P14,P15,&L1,P25)
 MOVE P25,MF2
*ER1:
PAUSE:ｾﾝｽ ｸｶﾝﾊｽﾞﾚ ｻｲｷﾄﾞｳｾﾖ
GET P3
GOTO *RESEN
*MIMI:
 MOVE P15,MF2
 POINT9(P16,P15,&L4,P18)
 MOVE P18,MF2
 POINT1(P15,P14,P18,P17)
 POINT9(P17,P18,&L1,P19)
 SENSE P19,P20,MF1 *ER2
 POINT4(P20,P14,P15,P22)
RETURN
SEND
MEND
```

(3) Detection of Workpiece Position and Coordinate Transformation

The position of both ends on welding line is defined by "workpiece coordinate system" which is fixed on the workpiece, so that welding program is not affected by the alteration of workpiece position. The coordinates transformation has to be executed between both coordinate systems, because the robots operate using "robot coordinate system". The reference points are defined while the value of workpiece coordinate system is programmed by choosing corner point Pw_1 and point Pw_2 on an edge as shown in Fig. 20. The workpiece is set in arbitrary position and direction within the operational space of welding robot. The value of coordinates based on "robot coordinate system" is obtained by means of touch sensing on Pr_1 and Pr_2 so as to avoid the alteration of program. Total 4 path points for sensing motion of Pr_1 and Pr_2 are taught manually.

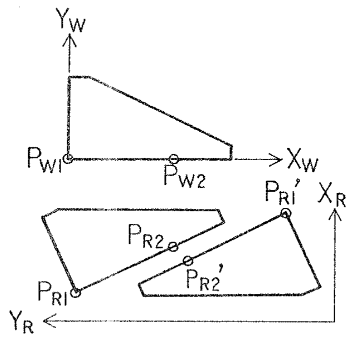


Fig. 20 A transform from workpiece coordinate system to robot coordinate system

Then, the order which convert the points Pw_1 and Pw_2 to the points Pr_1 and Pr_2 is executed, and the value defined on work coordinates system is converted to the value defined robot coordinates system. All the coordinate transformation is executed immediately by only robot's controller. It can deal with the alteration of position sitting workpiece immediately and easily. Therefore, it is suitable for welding task in the stage of hull sub-assembly production schedule which is altered very often.

5. Application[4)]

5.1 Performance of Robot

Fig. 21 shows the daily records of operation hour for a certain month. Fig. 22 shows the monthly records of the unmanned operating hour ratio, the automatic operating hour ratio

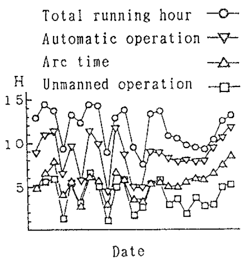


Fig. 21 Daily hour records of operation

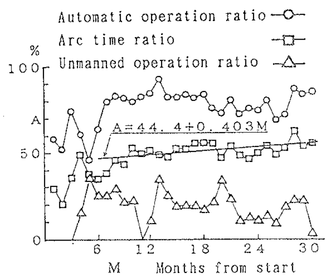


Fig. 22 Monthly records of operating hour ratio

and the arc time ratio against the total operating hour since the robot started to operate. The low unmanned operation hour ratio in some months is due to mainly the decrease in the total quantity of operation. Concerning automatic operating hour ratio and unmanned operating hour ratio, the fluctuations have been decreased after six months from the start of robot operation. A function (13) expresses the approximate relationship between M (number of months passed after operation started) and A (arc time ratio).

$$A = 44.4 + 0.403\,M \qquad (13)$$

The arc time ratio is getting gradually higher, and it is now about 55 percent. It shows that the arc time ratio is in high level and is getting higher. Then the operation is practiced very well.

About the abnormal stop record, the situation and the cause were analyzed. The phenomena at the time when the abnormal stop occurred were recognized as touching of torch, no arc starting and touch sensing miss. However, the main causes which account for 1/3 of the total number of abnormal stop are given to poor workmanship at the preceding process.

5.2 Decreasing Welding Task Time

The method using plural handy type welding machines by a single welder can bring the highest productivity for complex shaped sub—assembly works except the method using robots. Fig. 24 shows the result in which the welding task time required by handy type welding is compared with that by robots for the workpiece shown in Fig. 23. There are some more portions remained to be welded by hand when the handy type welding machines are used than the case of welding robots. So the mannual welding takes a lot of task time. In case of using robots without operator, the welding task time of robot can be reduced. Moreover, the portion remained to be welded by hand is smaller. Thus, manual welding task time decreases. Therefore, the robot welding is possible to reduce about 75% of welding task time even taking teaching time into account.

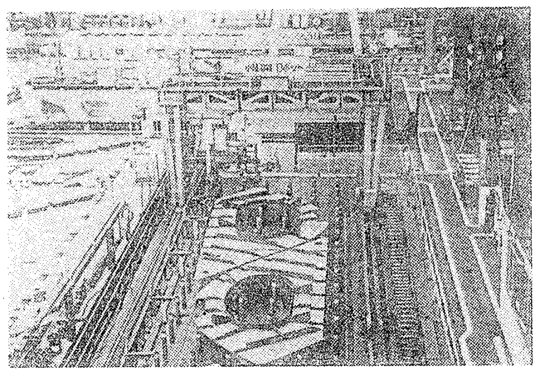


Fig. 23 A photograph of hull sub—assemblies to be welded by the robot

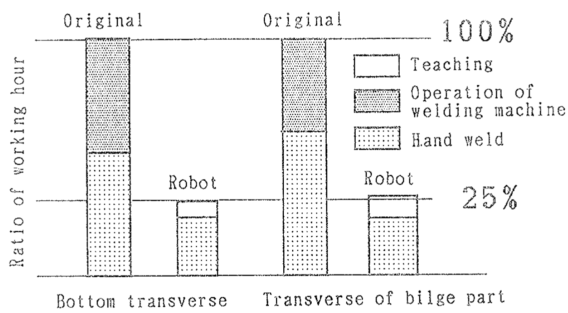


Fig. 24 A comparipon of productivity between robot welding
and original one

6. Conclusion

The Arc Welding Robots for hull sub–assembly works are developed and applied, which are intelligent robots and suitable for individual production. They have succeeded to improve the productivity. These robots have following capability and can materialize a new suitable technique for individual production and also can lead to the clue of the secondary engineering innovation.

1) The capability of task level language has been developed and applied to the shipbuilding production. The quantity of the programs are reduced to 1/35 of the original.

2) The capability of detecting both the ends of welding lines has developed and it enables to practice boxing weld. The welding task time is decreased to 25% of the original.

3) The capability which immediately corresponds to the alterations of workpiece position and shape in prduction field has been developed. The new system can respond to the various alterations which is unavoidable in shipbuilding.

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