ROBOTIC MIG WELDING

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INTRODUCTION

The manufacturer's specific requirements in the field of fabrication under the present day competitive pressure demand a proper planning and detailed investigation to optimize the processes and find a solution. The key to the success of optimising the solution lies in the use of robots for automated welding. The total automation of production needs novel machines, which can perform functions similar to those performed by a skilled human being. A man has enough flexibility and inbuilt intelligence, but he does not exhibit consistency when asked to produce the weldments in quantity. Industrial robots on the other hand combine both flexibility and consistency in producing weldments. Two types of Industrial robots find wide applications in automated welding. The first category belongs to deaf, dumb and blind robots, while the second category belongs to the Intelligent and smart robots. Intelligent robots need various types of sensors like touch, force, vision etc. Robots using vision system provide an excellent opportunity to produce better quality welds, but they are quite expensive. For the advances in production, productivity, and product quality in the area of welding, blind robots incorporating, precise actuator control, programming and process control play an important role.

Welding has been a tiresome, and boring task for a human being. It causes damage to the eye if proper care is not taken. Robotic welding on the other hand not only protects a fatigued human being but provides flexibility, faster speed, consistent repeatability and reliability in describing the weld trajectory. One of the major advantages of robotic welding lies in its off-line teaching and programming along the Straight-line paths and complex contours using triangular or trepezoidal weaving. The other facility of robotic welding provides closer control of decisive welding conditions that have far-reaching effect on the geometry of the weld. Microprocessor-based welding part positioners can be coupled to arc welding robots to have better positional and backlash control.

In automatic welding the welding conditions or variables are the welding current, the arc voltage and the welding speed. The weld geometry is also affected by the position of the electrode (the electrode may be held upright, tilted forward or tilted backward), the position of the work, edge and joint preparation (the inclined angle, root face and root gap). It is also affected by the kind of current and polarity and the diameter of electrode.

The primary objective of the paper are,

(a) to establish a robotic arc welding set up by interfacing MIG welding equipment with a six axis electrically driven revolute model PUMA robot. The MIG Welding equipment comprises of welding power supply, wire feeder, regulated CO_2 gas supply and weld torch to be mounted on the robot wrist. The main idea is to organise hand-shaking between the robot controller and MIG welding controller.

(b) to develop softwares the weld trajectories with continuous path motion following straight line, triangular and/or trapezoidal weaving.

(c) to study the influence of various welding parameters on a single-pass straight line butt welding and find out the most optimum welding condition for having defect free weldments.

BASIC COMPONENTS OF A ROBOTIC WELDING SYSTEM

A complete robotic welding system includes the robot, its controls, suitable fasteners for the work and the welding equipment. If necessary it may require one or more welding positioners with controls. While installing a system care should be taken to provide correct safety barriers and screens, around the work station. The component units of a robotic welding system are described below:

Robot Main Body

The robot has six degrees of freedom (DOF) and a jointed structure similar to a human arm. The various links and joints are driven by DC Servo-motors. The drive system is called servo-assembly which incorporates a DC servo-motor, an incremental encoder, a potentiometer. A magnetic brake is attached to maintain the robot posture when power is turned off.

Controller

The input and output signals of the robot system are all processed by the robot controller. It consists of a microcomputer for every joint and an overall computer to supervise the work relating to the entire arm motions and interface with the external world. It consists of various switches like ON-OFF switch, Robot initializing switch, and arm power switch etc. It directs and controls the sequence of arms, wrist and end effector.

Teach Box

This is necessary when teaching. It is equipped with switches for operating the robot manually and indicators for communicating messages of the system conditions from the controller.

Terminal

This is a key board accompanied by either a video display unit (CRT) or a printing device (IIY), and is used for communicating with robot language, VAL. It is used when indicating the system conditions, editing and executing the robot work programs. However it can be separated from the controller when the robot is operating according to the work program.

Floppy Disk

This device has functions to store Robot work programs and positional information and to transfer these data to random access memories (RAM) of the controller. A floppy disk can be incorporated into the controller.

Input-Output Modules

In actual application the robot system and other equipment such as MIG welding system must operate in harmony. Therefore, the system is equipped with signal lines for receiving signals to determine conditions for external equipment and sending commands to external equipment. These functions are performed by I/O module which is also capable of relay drive and relay output reception. The I/O module can be incorporated into the controller.

PUMA A 560 SYSTEM

PUMA A 560 is a revolute type robot that is driven by DC servo-motors and has been employed in the present investigation. The motions of the robot are controlled by "VAL" software system. It is a medium size robot with a payload capacity of 2.5 kgf. and a positional repeatability of +0.1 mm. Fig 1 shows PUMA robot System.

Main Body

PUMA A 560 main body is an anthropomorphic robot with 6 degrees of freedom. The maximum working range and maximum speed for each axis is given in Table I.

Control Section

The method of control is computer-controlled electric servo control. The

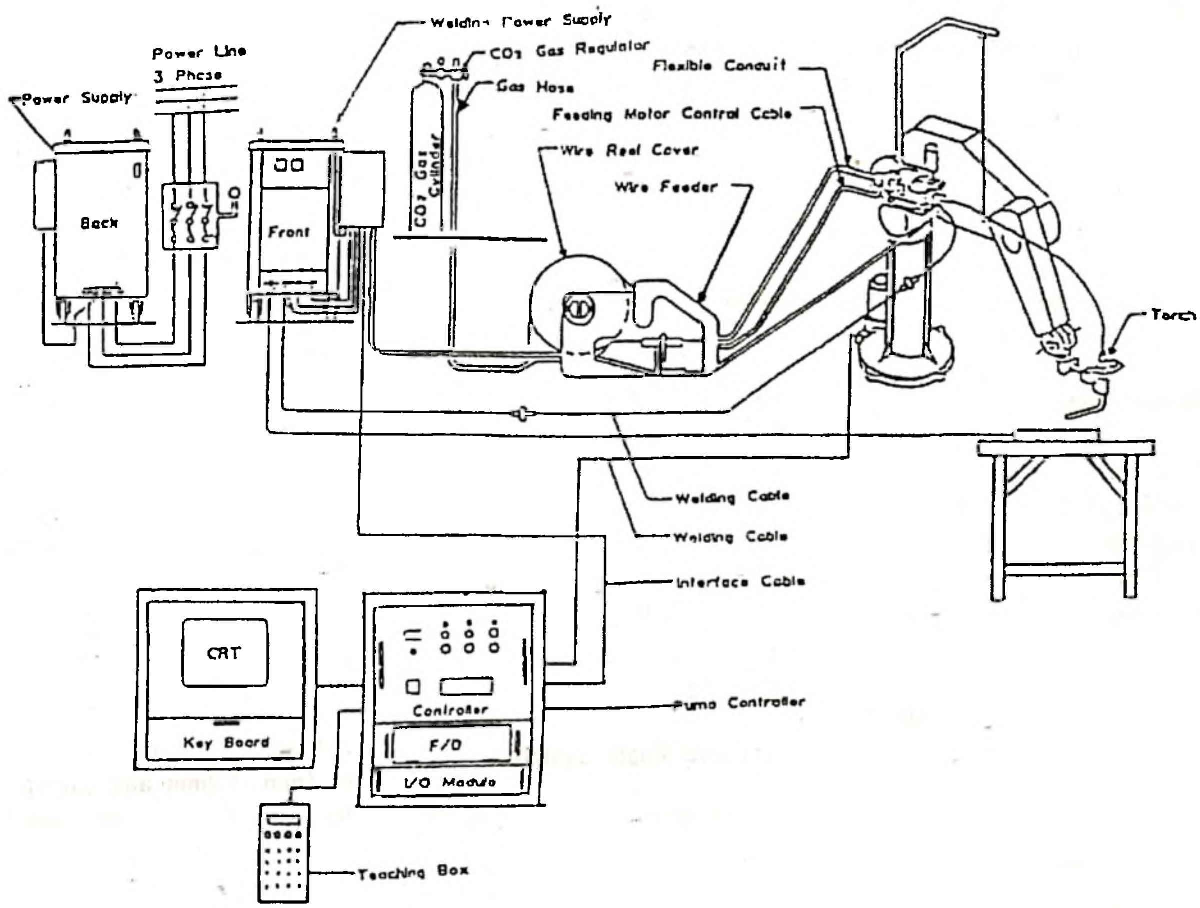

Fig. 1 : System Components of the Robotic Welders

Table I : Puma A 560 Range and Speed

No.	Axis	Max. Range	Max. Speed (at 100%)
1.	Waist rotation	30^0	80^0/sec.
2.	Shoulder rotation	250^0	55^0/sec.
3.	Elbow rotation	270^0	120^0/sec.
4.	Wrist rotation	280^0	150^0/sec.
5.	Wrist bend	200^0	160^0/sec.
6.	Flange rotation	520^0	150^0/sec.

N.B. : The maximum straight line velocity which can be achieved is 500 mm/sec.

computer has a user's memory capacity of 12 KB (RAM). The speed range is from 2 mm/sec. to 500 mm/sec. The welding conditions both voltage and current are digitally set with welding speed range from 2 mm/sec. to 33 mm/sec. The weaving is executed by coordinated motion of six axes and any pattern can be set. A CRT terminal is used for display. A Manual control box is available for control.

Software System

The software system used in the PUMA A 560 is "VAL". The method of instruction for operations is either by manual control box or programs that are written by VAL language on both.

The motion control can use PTP (Point to point) or CP (Continuous Path) control. The motion can be a joint interpolated motion or straight line motion. The various modes for manual control are joint mode, world mode, tool mode, free mode and computer mode. Speed adjustment can be done providing program speed. The speed of execution will be expressed as Monitor Speed (%) x program speed (%).

The program editing can be done for changing or modifying a program like inserting a step, deleting a line, changing the name of the program, etc.

Co-ordinate System

In either 'World' or 'Tool' mode, a robot wrist can be operated on the basis of individual coordinate systems. The operation has been realized by the fact that VAL executes calculations for coordinate transformation, on the basis of each individual setting, value of neutral zero point in the coordinate system, and it provides the reference value of each arm operation for each arm control circuit.

World Coordinate System

In case of power on or initialization, the neutral zero point of world coordinate system has been set up at the position. In the world mode operation a wrist is operated in accordance with the corresponding coordinate axis, and the coordinate system itself can be shifted in parallel and rotated by BASE command.

Tool Coordinate System

In case of power on or initialization, the neutral zero point of Tool Coordinate system has been set up at the position. In the tool mode operation, a wrist is operated in accordance with the corresponding coordinate axis, and the coordinate system itself can be shifted in parallel and rotated by Tool Command.

Environmental Conditions

The operating temperature range should be within 5°C to 40°C and Relative Humidity should be within 20% to 90% without any condensing.

MIG WELDING SYSTEM

It is a powerful welder intended for CO_2 gas shielded semi-automatic and automatic arc welding. It consists of a unique thyristor - IC controlled constant voltage DC Power supply incorporating wire feed control circuit and gas control circuit to be used exclusively for CO_2 gas shielded arc welding, wire feeder, torch and attachments.

Welding Power Source

It has rated current of 350 A 3-phase, voltage of 50 Hz frequency is used as input source. The primary rated input is 18 KVA. The output current ranges from 60 amperes to 350 amperes, output voltage ranges from 15 to 36 volts. It contains operator control mechanism.

Wire Feeder

The wire feeder is of the type CM-231 which can feed wire diameters of 1mm, 1.2mm and 1.6mm. The feed wire speed ranges from 1.5m/min to 15m/min.

Welding Torch

It contains gas nozzle for supplying CO_2 gas to the welding zone and contact tube through which the wire electrode is fed.

CO_2 Gas Supply Unit

It consists of a CO_2 gas cylinder fitted with CO_2 gas flow meter regulator. The regulator is fitted with two pressure gauges and one gas flow meter. One of the pressure gauge, indicates cylinder pressure (kgf./cm^2) and the other indicates the pressure (kgf/cm^2) at which CO_2 is released. The gas flow meter measures the quantity of gas flowing in l/min.

Robot Control For Welding

Programming modes for a welding controller include speed and position settings, arc voltage, wire-feed speed and pulsing data, and other operating parameters. The starting and ending phases of each weld (with special parameters such as pre and post flow of shielding gas, puddle formation, crater filling, and after burn time) are programmed in separately stored routines.

Movements of welding robot are programmed independently by a separate control. The operator determines when the robot should switch from one workpiece to the next. The operator also can interrupt and adjust the program at will, even during the welding process.

Test Piece Preparation

Mild steel plates have been chosen for square butt welding as prior to welding, edges of the parts to be joined are to be specially prepared. For the plates of thickness 5 mm, the edges along length of the workpieces have been made square. The fusion faces should be free from slag, lamination, notches, or other irregularities, which might be the cause of defects or would affect adversely the quality of weld and the workmanship. The surfaces adjacent to fusion faces should be free from scale, moisture, oil, paint or any other substance. Two pieces of mild steel plates are tacked manually at both the ends to maintain the root gap constant. A root gap of 1.5 mm is maintained for all the test specimens.

Welding Position

Welding can be done either in forward direction or in backward direction. In this project the forward welding has been carried out in Horizontal position and the motion of the gun was set from Left to Right.

Setting The Welding Parameters

In order to have quality weld, it is necessary to set right weld parameters. The high current technique of CO_2 gas welding ensures higher melting rate and deeper penetration. In the present investigation the parameters that have been chosen are :

Electrode

The MS wire electrode of diameter 1.2 mm has been used in this process. The electrode was copper coated to protect the wire from getting rusted.

Electrode Extension

Free end of electrode protruding out of contact nozzle carries high current densities (over 100 A/mm^2). The arc current falls with the increase in its length. So a constant electrode extension of 12mm was maintained between the nozzle face and the workpieces.

Welding Speed

The welding speed of 6mm/sec. has been chosen for the test specimen of 5mm thick square butt welding. It was kept constant throughout the process. The speed has been selected after several trial runs.

Welding Current

In a high current technique for an electrode diameter of 1.2 mm maximum current of the order of 350 Amps can be used. Taking current to be an important parameter, it has been varied from 160 Amps to 240 Amps to see the effect of current on the welding.

Welding Voltage

In the above welding process max. voltage used is of the order of 30V. To observe the effect of voltage on the welding, it has been varied from 18 volts to 24 volts.

Number of Passes

The welding was carried out in a single pass, as for 5 mm thickness plates, multipass welding is not required.

The plan of the experimentation is done, where variations in welding current and welding voltage have been made with constant electrode diameter of 1.2mm, constant electrode extension of 12mm, constant root gap of 1.5mm under constant CO_2 gas supply of 5 litres/min.

Forward welding has been followed along the straight line trajectory. Triangular weaving has been tried resulting in increased reinforcement and wider width of weld that are unnecessary for such specimens. Hence, all the weldments have been made and tested with straight line weld.

TEACHING AND PROGRAMMING THE ROBOT FOR AUTOMATED WELDING

Programs can be generated, edited and run using the robot language, 'VAL'. VAL is an user friendly computer based robot programming language suitable for defining the welding task. VAL is a real time system with trajectory computation being done continuously to permit complex motions. An interpreter is used to generate commands continuously so that it can interact with a human operator to provide on-line programs generating and monitoring.

For producing a program for welding, straight bead, three point weave and five point weave as shown in Fig. 2 may be employed.

In the present investigation, weldments have been prepared using both straight beads and three point (triangular) weave. In the actual weldment tests, only straight beads have been employed.

The programs for the weldments are illustrated herein :

Program Shiv

1. REMARK PROGRAM FOR ST. BEAD BUTT JOINT
2. WEST 1. = 5.00, 50.00, 40.00
3. WVSET 1. = 10.00, 7.00, 2.00, 0.00, 0.00, 0.00, 0.00
4. MOVE HOME
5. MOVE IP
6. MOVE STP
7. WSTART 1.0, 0.0
8. MOVES EDP
9. CRATERFILL 1.00, 1
10. WEND 0.00
11. MOVE HOME
    END

PROGRAM SUB

1. REMARK PROGRAM FOR TRIANGULAR WEAVE
2. WEST 1. = 5.00, 50.00, 40.00
3. WVSET 1 = 10.00, 7.00, 2.00, 0.00, 0.00, 0.00, 0.00
4. MOVE HOME
5. MOVE IP
6. MOVE STP
7. WSTART 1.0, 0.0
8. MOVES EDP
9. CRATERFILL 1.00, 1
10. WEND 0.00
11. MOVE HOME
    END

The points IP, STP, EDP and HOME are all taught through teach pendant.

The inspection methods such as visual and NDT after welding are done with a view to assess the quality of the weld. Table II indicates the description of defects and corresponding images.

RESULTS AND DISCUSSIONS

Different welded joints have been made under varying voltage and current maintaining a constant welding speed. The different combination of voltage and amperes has been shown in matrix form and

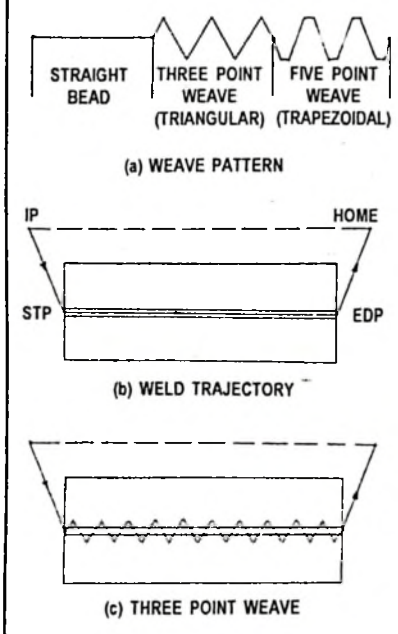

Fig. 2

illustrated in Table III. For example, the weldment prepared at voltage V_1 and current A_1 are called specimen SP_{11} and similarly the welded joint made with combination of voltage, V_2 and current A_1 are called specimen SP_{12} and so on. Radiography examination of specimen SP_{32} done at current of 240 ampere and voltage of 21 volt, weldment specimen SP_{33} done at current 240 ampere and voltage of 24 volt and spcimen SP22 done at current rating of 220 ampere and voltage of 21 volt indicate complete penetration of weldment due to high current range of 220 ampere to 240 ampere and the voltage range of 21V to 24V. The increase of current increases the pressure of the arc and more molten metal is driven deeper into the root gap resulting in increased depth of penetration. However, the width of weld remains more or less

Table II : Defects in Fusion Welds

No.	Defects	Description	Image
1.	Porosity	Gas pockets or voids	Rounded shadows of various sizes and densities, occuring singly, in clusters or scattered.
2.	Lack of Fusion	Lack of side-fusion, root fusion or inter-run fusion	A dark shadow usually elongat
3.	Incomplete penetration	Unpenetrated cavities at the root or between runs	A linear indication straight, dark and usually at the centre of the weld.
4.	Cracks	Narrow discontinuity produced by tearing of the metal when in a plastic or cold condition.	Fine dark line, straight or wandering.

unaffected. For other current and voltage combination the specimens indicate somewhere incomplete penetration along the partial lengths of welded joints. For insufficient current and voltage, specimens SP_{11}, SP_{12} and SP_{13} are found to be totally defective.

Examination of weldment specimens SP_{33} and SP_{32} made respectively at same current rate of 240, but varying voltage of 24 volt and 21 volt respectively reveal the joints to be free from any incomplete side fusion. Fusion is proper at higher currents. Insufficient current creates lack of side fusion. Lack of side fusion also depends on the arc length and so on voltage. In this project, the arc length of 12mm, is maintained constant and effect of current on the lack of side fusion is more predominant.

Examination of the results clearly demonstrates that the optimal welding condition for defect-free weldments can be achieved on a single pass straight line butt joint for current - voltage combination of 240 amperes and 21 volts at a welding speed of 6 mm/sec. The current plays a dominant role for defect free weldments. For high currents, the weldment shows better quality of weld.

CONCLUSIONS

Based on the foregoing experimentation, the following conclusions may be drawn:

1. Robotic welding has been found to be highly suitable in the area of arc welding of different weldment joints. The main

Table III : Various Combination of Voltage and Current

VOLTAGE / A \ V / AMPERE	V_1 18 VOLTS	V_2 21 VOLTS	V_3 24 VOLTS
A_1 160 AMPS	SPECIMEM NUMBER SP_{11}	SPECIMEM NUMBER SP_{12}	SPECIMEM NUMBER SP_{13}
A_2 220 AMPS	SPECIMEM NUMBER SP_{21}	SPECIMEM NUMBER SP_{22}	SPECIMEM NUMBER SP_{23}
A_3 240 AMPS	SPECIMEM NUMBER SP_{31}	SPECIMEM NUMBER SP_{32}	SPECIMEM NUMBER SP_{33}

advantage of continuous path robotic arc welding lies in its teaching and off-line programming. A number of such programmes can be stored in the robot's memory and a specific program along a definite trajectory can be implemented quickly. Robotic welding protects a human operator from all hazards involved during welding.

2. Multipass and multilayered welding along the complex trajectory can be done following either straight bead and or triangular weave and or trapezoidal weave pattern. The strength of change over to different weave patterns lies in the programming flexibility.

3. Almost defect free welded joints can be achieved by setting the most near optimal weld condition that can be accommodated in the programming.

4. The most important welding parameters have been found to be speed of welding, welding voltage and welding current. High welding current enables the pressure of the arc to penetrate the entire depth of root face and helps in homogenous fusion at the joint. Insufficient current causes lack of penetration along the depth of weld due to poor quality of heat.

5. For a straight line, 5mm thick mild steel square butt welded joint with a single pass, weld condition at a current range of 220 to 240 amperes and a voltage range of 21 to 24 volt at the welding speed of 6 mm/sec. have been found to be near optimal.

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