Robotic Arc Welding System Design

By V. L. Mangold, Jr.

The utilization of industrial robots for weld processes, with specific emphasis on gas metal arc welding (GMAW), has been a practice for some time. Industrial robots can positively impact the welding process by providing the following major improvements to the manual process:

1) Production increase.
2) Reduction of direct labor.
3) Improvement of weld parameter and process control.
4) Removal of the operator from a sometimes tedious and potentially hazardous environment.

While the basic concept of using an industrial robot to produce continuous-path, curvilinear welding in the GMAW process is technically and academically feasible, the market penetration of robots in this application niche has been substantially less than industry predictions. The failure to properly apply industrial robots to the arc welding process has contributed to this lack of overall market penetration. Arc welding robots, in batch manufacturing operation, typically require a substantial amount of scrutiny with respect to the actual process and part to be produced when compared with a conventional pick-and-place robotic application. This attention to process parameters (while minimizing the interest level associated with the robot itself) is crucial to the overall success of a robotic arc welding cell.

The basic cell concept is an island of automation connected with the appropriate software and control bridges to the remainder of a manufacturing operation. The cell concept should incorporate methods of local control for discrete machine operation, as well as integrated control for computer integrated manufacturing (CIM) and manufacturing automation protocol (MAP) purposes. This marriage of both island and plant-wide machine control is an essential building block to a successful arc welding robot system.

Application Definition

A wide variety of welding processes have been successfully automated through the use of industrial robots: gas metal arc, gas tungsten arc, spot, laser beam, submerged arc and electron beam welding. Of all the processes indicated, the over-whelming leader in terms of total dollar volume and gross units deployed in the field is the application of spot welding. Spot welding is used principally in the manufacture of automobile and other transportation products, as

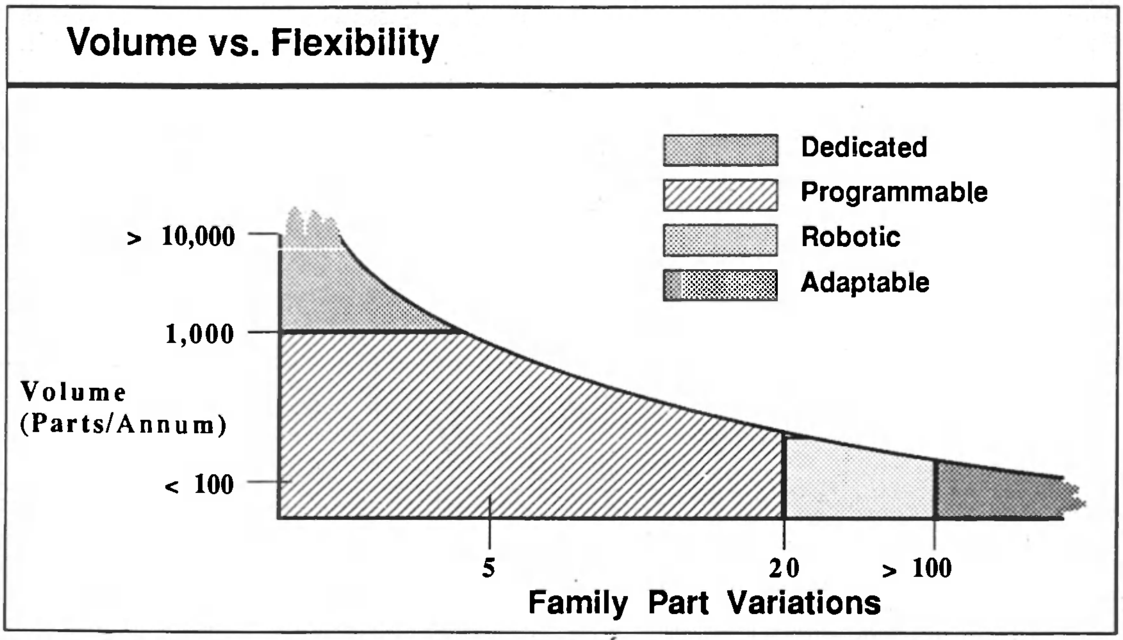

Fig. 1. *The interrelationship between part variations and overall production volumes to the type of automation*

Indian Institute of Welding

Tiruchirapalli Branch

SOJOM 91

Last Call for Papers

To

Symposium on Joining of Materials for 2000AD
12-14 December, 1991
at BHEL Complex, Tiruchirapalli, India

STATUS (as on 15 May 1991)

- About 80 papers received with wide international participation for Belgium, Czechoslovakia, France, Germany, India, Iran, Japan and USA.
- Mr. John Bartley, President, American Welding Society, gives a Key note address.
- Papers reflect state-of-the-art and new directions in materials joining in the world.

GUIDELINES

- Last date for receipt of Synopsis (200-250 words) from prospective authors - 15 June, 1991.
- Last date for receipt of full paper for all accepted Synopses - 15 September 1991.

Rush Your Original Papers Immediately

INVITATION TO DELEGATES

STATUS (As on 15 May 1991)

- Several eminent personalities in the welding world have expressed intention/already registered as delegates.
- The present trends suggest SOJOM'91 to have over 1000 delegates from all over the world, making it truly international.

GUIDELINES

- Send in your delegate fee with details at the earliest, but not later than 15 November 1991.
- Delegate fee is US$100 for foreign delegates and Rs.900/- for Indian delegates. The corresponding fee with spouse is US$150 / Rs.1200/-.

INVITATION TO EXHIBITORS FOR SOJOM'91 EXHIBITION

STATUS (As on 15 May 1991)

- 72 stalls have been planned and already 15 stalls have been booked.
- Three types of stalls are planned -

Type A Display Stall (3m x 3m)	Rs.	8000	/	US$	800
Type B Demonstration Stall (6m x 3m)	Rs.	20000	/	US$	2000
Type C Special Stall (9m x 3m)	Rs.	30000	/	US$	3000

GUIDELINES

- As allotment is on a first-cum-first-served basis, rush your order form with requisite fee immediately. The booking closes on 30 September 1991.
- Only limited special /demonstration stills are available.

INVITATION TO ADVERTISERS FOR SOJOM'91 SOUVENIR

STATUS (as on 15 May 1991)

- All cover pages have been booked already.
- Over 30 advertisers have availed the opportunity presently. This includes leading organisations from overseas.

GUIDELINES

- Rates for Advertisers

	From India Rs.	Abroad US$
B & W Half Page	2000	200
B & W Full Page	3000	300
Special Position Full Page	5000	500
Special Position Colour	10000	1000

- Rush your advertisement matter (art work/art pull/positives) not later than 15 August 1991

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well as agricultural equipment and electronic cabinetry.

A significant opportunity for future industrial robot growth is in the area of gas metal arc welding. Based upon robot manufacturing data from 1988, approximately 350 robots are deployed annually in the United States for the purpose of arc welding.[1] Approximately 40,000 companies utilize the GMAW or gas tungsten arc welding (GTAW) process in the manufacture of their end products. A greater emphasis must be placed on automating the arc welding process in such a fashion that the manufacturer can gain full benefit from the flexible nature of the technology.

In an effort to gain an understanding of the potential for arc welding robots, one must further define the specific type of welding cell that is suitable for increased market penetration. Three types of robotic cell concepts are freestanding batch, line process and dedicated batch. The term, freestanding batch application, implies that the arc welding manufacturer requires flexibility to produce a wide variety of weldments in batch sizes ranging from several hundred to one. This differs from the line process application, which implies that the robot performs an arc welding function on a body or frame assembly line in a high-volume operation. It also differs from the dedicated batch type of system with respect to overall part volume. Dedicated batch systems imply automotive levels of annual production which, by their very nature, require less flexibility than a freestanding arc welding robot, but must also accommodate part family variations.

Concentrating strictly on freestanding batch arc welding applications, basic system design criteria can be established. The substantive components of any arc welding robot system design evaluation are choice of parts, type of fixturing, choice of robot, system control architecture, material handling considerations and safety. The solutions to these items tend to drive the arc welding cell design into a truly freestanding manufacturing process.

The applicability of different types of automation to the arc welding process is depicted in Fig. 1, which shows the inter-relationship between part variations and overall production volumes to the type of automation to be supplied.

The part volume analysis consists of prioritized potential weldments rate by the total number of hours of weld per annum. By utilizing the list of selected parts and by basing an annual total utilization of approximately 6700 h of manual welding, a threshold can then be drawn to establish a base-line cost justification criteria for an arc welding system. This 6700 h of manual welding requirements (subject to adjustment based upon the analysis of the weld process) can be accomplished with a robot arc welding system in approximately 2000 man-hours (approximately one shift).

The second governing criteria is ease of welding. Factors that contribute to the analysis of ease of welding include part fitup and alignment, joint metallurgy, joint geometry, weld penetration requirements, extent of acceptable hear-affected zone, homogeneity of component parts, and cosmetic quality of the finished welded joints. For the purpose of the model assumptions, the weld process is consistent in terms of the previously mentioned factors for the angle, tube and box part families.

Within each subfamily of parts, a matrix can be established for the appropriate selection of components to be welded. A sample schedule, based upon model assumption, is shown in Table 1. individual weldments are listed in asynchronous order to reflect the discretion utilized in selecting specific family members in terms of their ease of weldability.

The following formula demonstrates the interrelationship between individual parts and their corresponding fixture and logistics cost:

$$S = \sum_{N=1}^{X} P_T . R - \left(\sum_{N=1}^{Y} P_T . 0.25R \right) - \sum_{N=1}^{Z} P_F$$

Where S = net savings in dollars, N = part number, P_T = part cycle time (h), R = rate (dollars/h), A = fixture family and P_F = part fixture costs in dollars. (X,Y and Z are integers.)

To properly utilize the formula, certain parameters must be identified. For the purpose of the model discussion, Table 2 depicts a sample of total welding hours required to produce the members of the part families along with appropriate fixture cost. By substituting the sample parameters into the formula, it is determined that the potential net savings per annum to the manufacturing concern is approximately $50,000. Depending upon the cost-justification practices of a specific manufacturing client, this approximate savings would be sufficient to justify the capital appropriation expenditure. Note that this basic, broad brush approach to arc welding analysis should provide only a framework for specific recommendations. Each actual application must be carefully scrutinized prior to producing a formal cost-justification estimate.

Based upon these considerations, a potential application can be analyzed in terms of productivity and cost justification. While it is true that every mild steel arc welding application has a degree of uniqueness, certain general parameters can be stated with a high degree of confidence:

1) Expected arc-on time improvement : 70%.
2) Expected feed rate improvement : 30%.
3) Net efficiency ration : greater than 4 to 1.

These assumptions are based on examples of industrial robots that have been successfully deployed in the field for the purpose of arc welding applications.

Table 1. Sample Parts Schedule Based Upon Model Assumption

Family	Widget
A	A_6, A_9, A_5, A_1 .....
T	T_3, T_2, T_7, T_8 .....
B	B_1, B_2 ....

Table 2. A Sample Calculation of Total Welding Hours to Produce Parts by Part Family

Angle family (12 parts) - 3900 h/annum
Tube family (8 parts) - 2400 h/annum
Box family (3 parts) - 2100 h/annum
Family fixtures cost - $15,000

Cost Justification

After the automation type has been selected and the application has been analyzed, and estimate of potential cost justification of a robot arc welding system is required. Regardless of technical feasibility, cost justification is critical to all manufacturing concerns. With few exceptions, the basic fabrication and assembly of mild steel weldments have a common base-line funding requirement. These communalities can be summarized into a number of basic identities and further formulated in a systematic approach to determine viability for a specific manufacturer.

The bast illustration of this process is to utilize a "model" evaluation. The model selected for this application is a group of fictitious parts known as the angle family (A), the tube family (T) and the box family (B). Once the constituent components are selected, the analysis for automation purposes can begin - Fig.2.

Physical Appearance

Three versions of the basic welding work cell design are depicted in Figs. 3-5, respectively. Figure 3 depicts a simple, single weldment produced identically on both sides of a central index table. The industrial robot is positioned on one side of the table, while the manual operator is located 180 deg from the robot. A center screen and divider (along with other appropriate safety equipment) prevent the unauthorized intrusion of an operator into the work cell area. Furthermore, the manual side of the index table is outside the physical reach of the work envelope of the industrial robot.

Figure 4 depicts a basic two-operation setup, which requires the robot to perform tack welding in Fixture

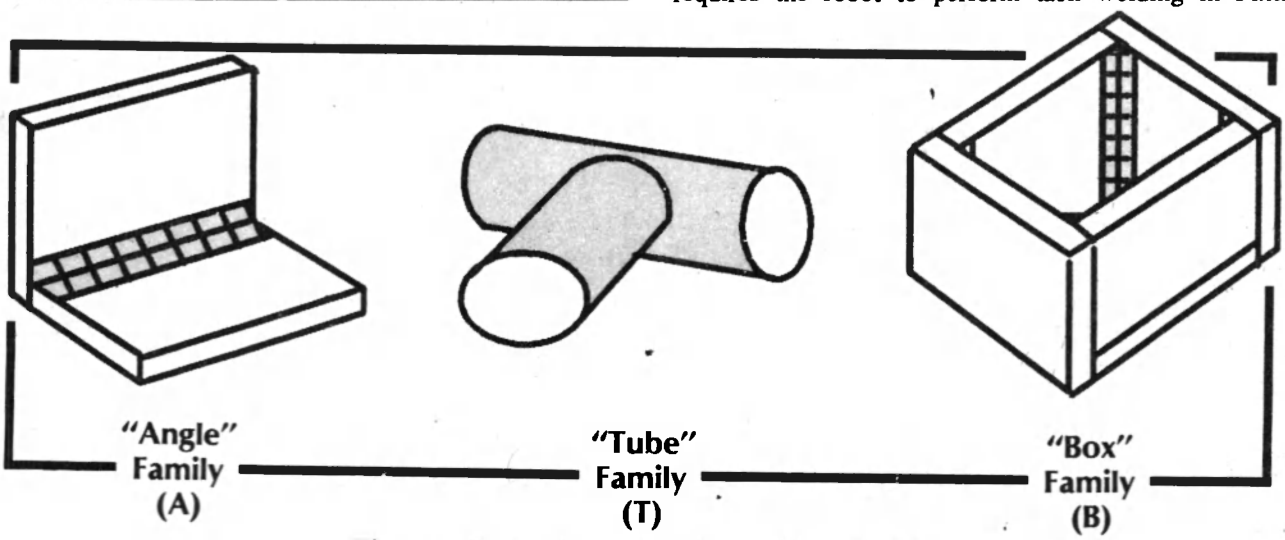

Fig. 2. *Parts chosen for the model evaluation*

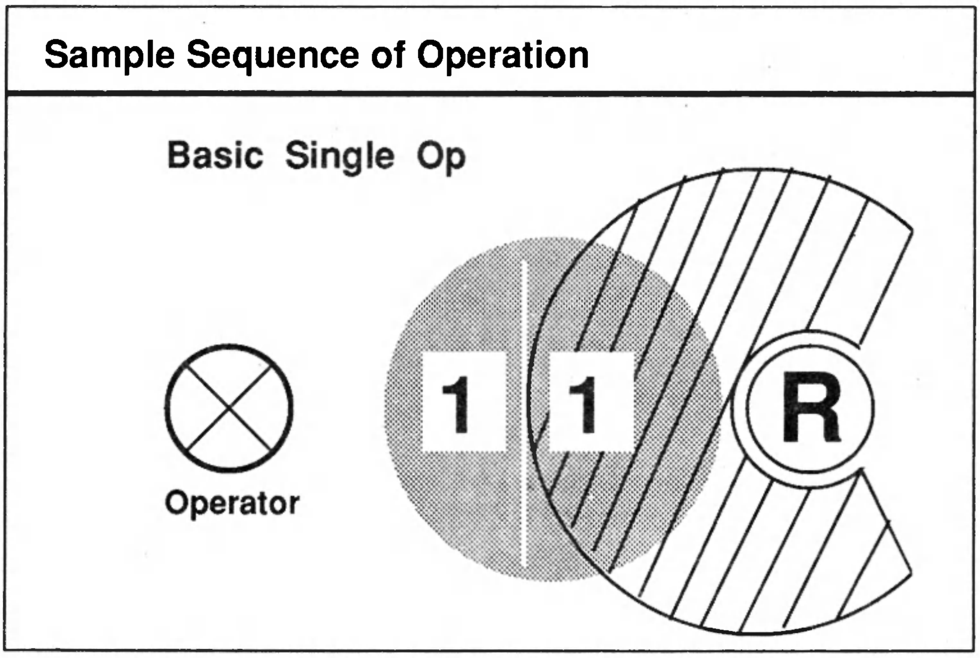

Fig. 3. *The configuration for a single, simple weldment produced indentically on both sides of the central index table*

1 and finish welding in Fixture 2. This type of system has a high degree of applicability to general small parts welding. Figure 5 indicates an operator pretack station. The pretack process may be required in the event that historical process data information is unavailable. Variants to the basic system design included gang or multiple part fixturing, secondary rotary positioners and fabrication of dissimilar parts on opposite sides of the index table.

The basic system platform, as described in this article, can be adapted to virtually any industrial robot and arc welding system.

Safety Considerations

Safety is of prime importance in any arc weld system design effort. While regulatory agencies and organizations such as American National Standards Insti-

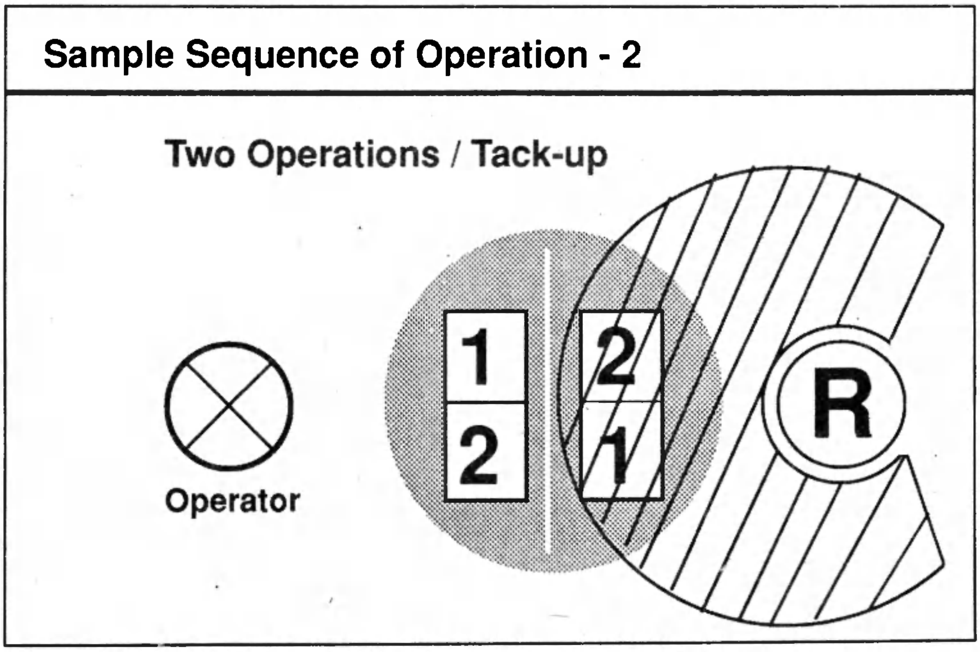

Fig. 4. *A two operation setup requiring the robot to perform tack welding in Fixture 1 and finish welding on Fixture 2*

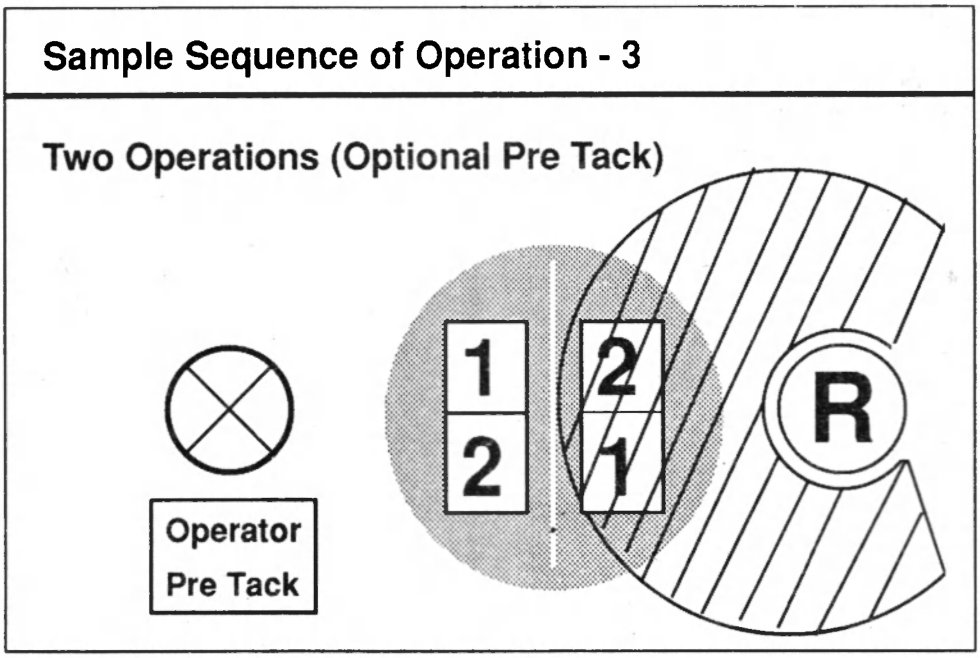

Fig. 5. *The configuration for an operator pretack welding station*

tute (ANSI) and Robotic Industries Association (RIA) have specifications pertaining to the subject of robot safety, in the United States OSHA regulations take precedence over any industry trade group (for United States-based robot installations only). OSHA Specification No. 19.212 indicates that any self-starting automatic machinery must be mechanically safeguarded from outside operator intervention. Light curtains and safety mats are not considered intrinsic safety barriers for robot system. For this reason, workpieces should be shuttled, indexed or transported to the envelope of the arc welding robot. At no time should an arc welding system be deployed utilizing a "fixed table" system design methodology. While the method of material handling can negatively impact the overall cost, the inherent benefits of employing an intrinsically safe arc welding system are self-evident.

Robot Selection Mechanics

A generalized set of operating criteria can be established for arc welding robot applications. These generalized criteria are as follows:

1) Robot repeatability: 0.2mm.
2) Net reach: 800 mm (31.5 in.), minimum.
3) Continuous path capability: 0.4% continuity.
4) Minimum continuous path velocity: 1000 mm/min (39.4 in.).

A wide variety of robot products meet the general criteria discussed earlier. Note that these are general requirements only; the degree of resolution and, ultimately, robot sophistication is highly application dependent. Each arc welding application must be individually analyzed to determine the suitability of the basic arc welding system design criteria to the actual application intended.

One obvious fact that is derived from the basic robot criteria is this: the industrial robot is typically a small part of the overall system concern when designing an arc welding work cell. A wide variety of industrial robots, specifically designed for the arc welding application, can be utilized in applications with a high degree of interchangeability. Virtually 90% of all mild steel and mild-to-high-strength steel job shop arc welding can be accomplished utilizing robots that meet the basic criteria indicated.

The robot products currently offered for arc welding can be subclassified by type of mechanical system as follows:

1) Push rod link system.
2) Direct drive.
3) Chain and sprocket.

The aforementioned mechanical drive systems have been prioritized based upon the long-term reliability and maintainability of each - Figs. 6 - 8.

The type of robot drive system selected has a direct impact on arm stability and robot repeatability. Generally speaking, direct drive and push rod link

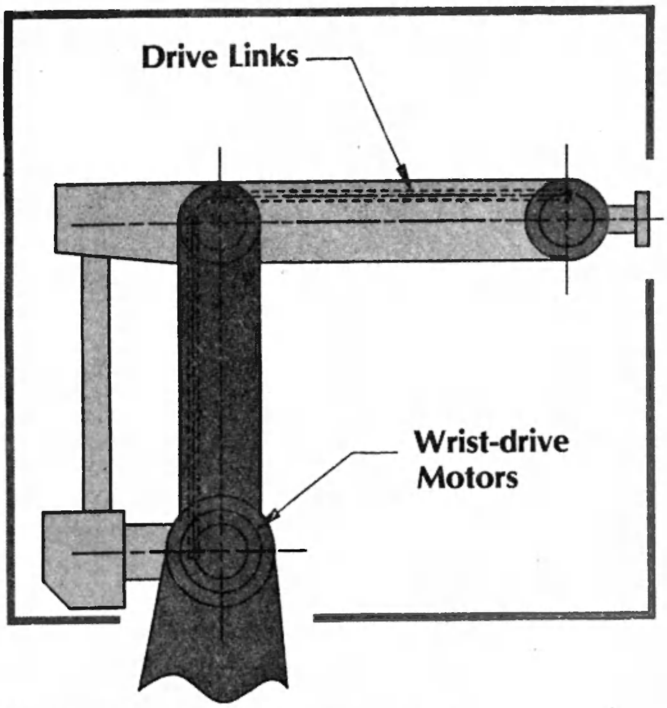

Fig. 6. *A push rod link system robot*

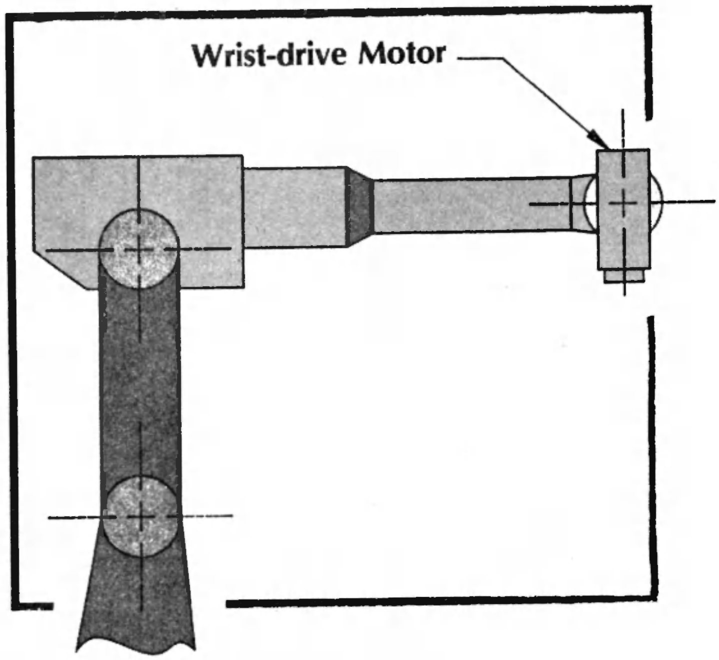

Fig. 7. *A direct drive robotic system*

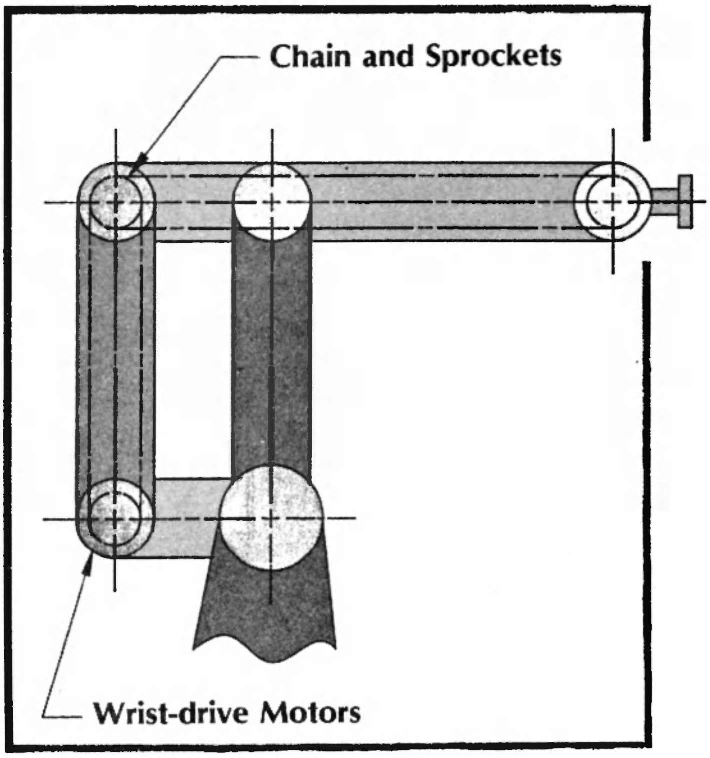

Fig. 8. *A chain and sprocket robot system*

systems are superior to chain and sprocket types, due to the reduction of backlash and rigidity of the outer arm link.

Currently, there are approximately thirty different manufacturers of arc welding robots, comprising a total of approximately fifty different models. Regardless of the type of robot selected, the basic system design criteria and its implementation logistics are unchanged.

Integrating the Welding System

Arc welding robotic systems have not achieved the level of performance success or net productivity of reasons that have little or nothing to do with arc welding or robotic technology. In most cases, the first-time user of industrial robots for arc welding assumes that once the selection of robot and welding equipment has been made, the need for additional engineering of system analysis is completed. This type of shortsighted thinking has contributed to the number of arc welding robot failures that have been experienced within the industry.

An arc welding robot, unsupported by necessary system peripherals and support equipment, is useless in an actual production environment. For an arc welding robot application to be truly productive, it must be viewed in the same manner in which a computer-numeric-controlled machining system is viewed. The arc welding robot can be considered a "CNC welding machine" since the same basic approach to part programming and database management apply. Part presentation, joint geometry and process parameters must be refined to produce a repeatable manufacturing process for each cycle.

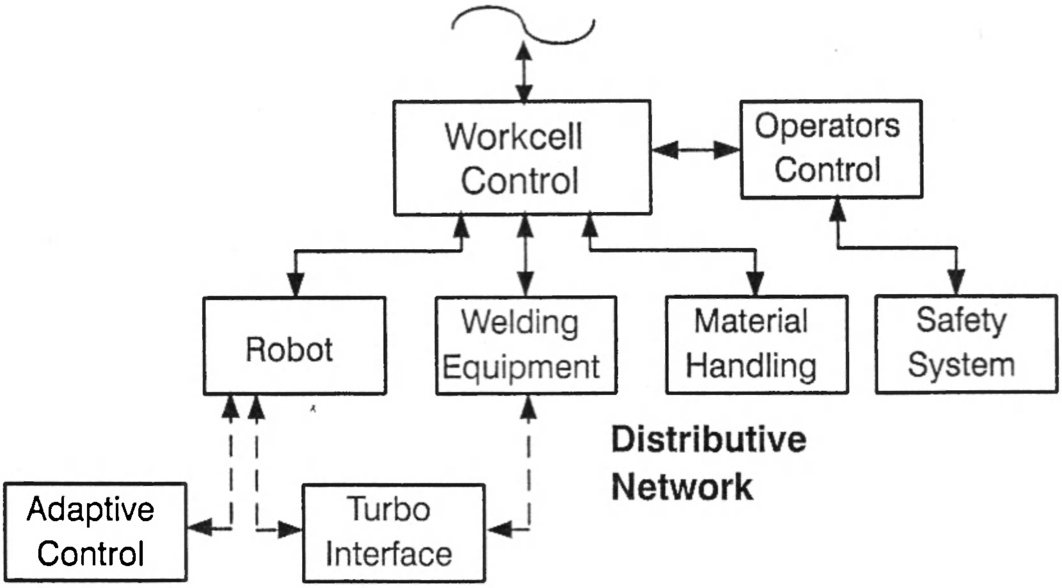

Fig. 9. *A model for system control architecture*

Once this has been established, the system requires control capability to allow for batch control and asynchronous control of the welding environment.

To achieve this level of system utility, proper system control architecture must be implemented - Fig. 9.

By utilizing a central work cell controller of either a programmable logic control (PLC) or minicomputer-based technology, the arc welding manufacturer will prevent the creation of an unattached island of automation.

In addition, by slaving all functional devices to the work cell controller and allowing the work cell control to disseminate the logical sequence of events for the weld process, trouble-shooting and maintenance debugging are greatly enhanced. It should be emphasized that, in an actual batch manufacturing, automated environment, the robot control system should never be utilized as a work cell controller. By maintaining the hierarchy, as depicted in Fig. 9, robot interface, programming and, ultimately,, long-term performance are significantly enhanced since the control system becomes multitasking in nature. A

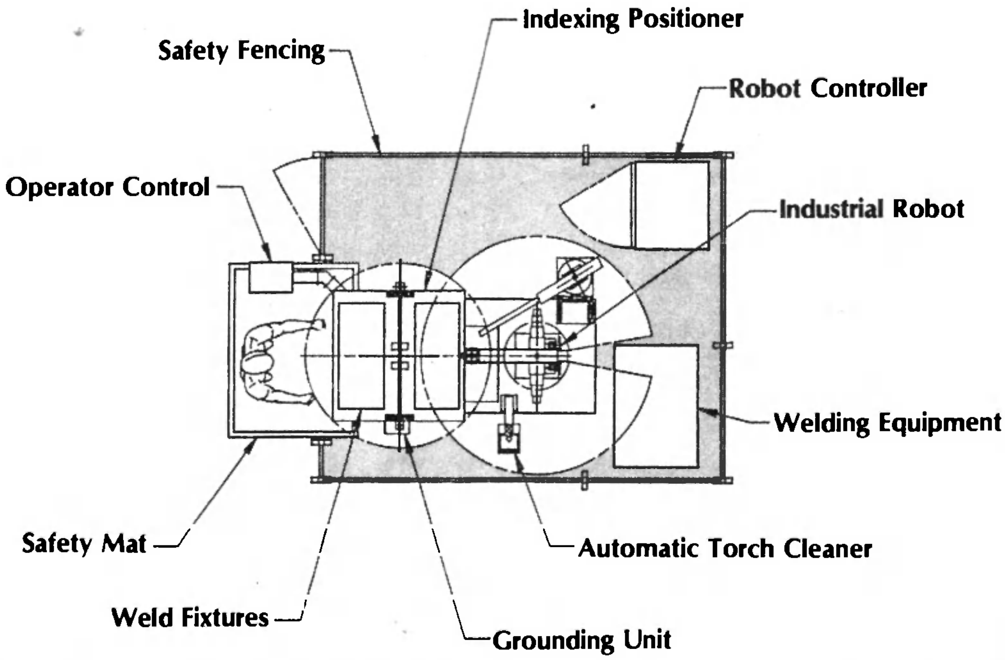

Fig. 10. *An overhead plan view of the typical robotic work cell configuration*

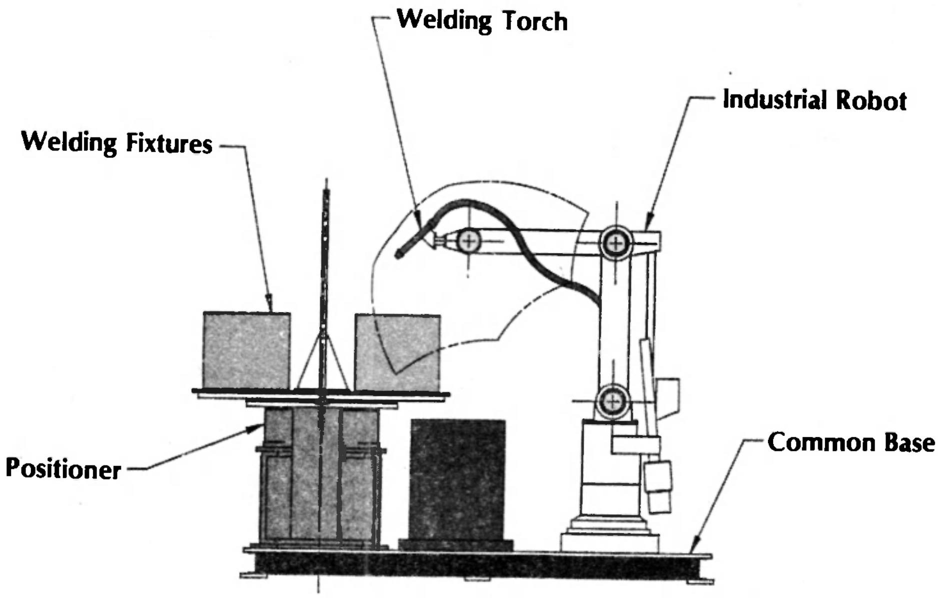

Fig. 11. *A side view of the robotic work cell*

theory applied to this concept embodies the notion that the robot should be employed to perform that function which it does best: trace a continuous-path, three-dimensional curve. This allows other functional devices with their own type of local control to perform the functions for which they are best suited. By designing a system based on this architecture, the arc welding manufacturer can recognize increased utility and flexibility of the automation.

A robotic arc welding work cell that encompasses the aforementioned design consideration is depicted in Figs.10 and 11. With robot and part positioning equipment mounted on a common base and with the safety fence enclosure designed for maximum intrinsic safety, an arc welding system that approximates this basic design can provide the requisite level of productivity and efficiency to the arc welding manufacturer.

Summary

The choice of industrial robot for a potential arc welding automation project should be the least of the design engineer's concern. Robots specifically designed for arc welding purposes that are marketed by the major manufacturers of industrial robots provide essentially the same level of path repeatability and positional accuracy required for normal mile steel welding requirements. The critical factors for the success of a robot arc welding system can be summarized as follows:

1) Intelligent choice of family part selection.
2) Concentration on refinement of manufacturing practices prior to the arc welding requirement.
3) Production and utilization of high-integrity, machinetool quality, Class A fixtures.
4) Detailed and documented evaluation of required weld parameters for a specific process.
5) Judicious use of part and material handling equipment.
6) Proper system control for maximum operator efficiency.

Regardless of the arc welding robot selected, by adhering to the aforementioned criteria and prioritizing the manufacturing engineering effort analogous to this schedule, the arc welding manufacturer should realize the requisite improvement in arc welding efficiency and product throughput. By pursuing the arc welding process in a logical, systematic function, the first-time user, as well as the veteran robot integrator, can avoid some of the difficulties that have plagued prior attempts by users to integrate robots into arc welding work cells.

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