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Portable Arc Welding Robots - A Practical Shipbuilding Tool?

IIB-3

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ABSTRACT

An overview of the application of portable welding robots in shipbuilding is given, with particular reference to a pilot project undertaken at a British shipyard. A general basis for cost justification is outlined, and applications and limitations of the robot sysem discussed. Particular attention is drawn to the requirements imposed on other shipyard systems when using robots.

INTRODUCTION

Developments in Japan

In the mid 80's the Japanese shipbuilding industry, supported by funding from their Ministry of Transport (MOTO) invested heavily in a 5 year R&D program to develop a range of devices to automate arc welding, painting, assembly and other shipbuilding processes.

The objective was to make shipbuilding both more attractive to the Japanese workforce, since recruitment was becoming increasingly difficult due to poor public image and inferior salary structure of the industry, and to create manpower savings within what was (and remains) a labor intensive industry. The intent was to improve productivity and thereby address the considerable price differential existing with respect to the Korean yards on newbuilding contracts.

A productivity improvement target of between 60 and 100% over a ten year period was felt necessary to redress the situation. The major yards themselves believed automation on a large scale offered the only realistic means of attaining this target.

Assessment Of The Need For Robotics

The most commonly quoted reasons for introduction of robots are:

-improved quality;
-low labor costs;
-greater volume of output; and
-improved working conditions.

In actual fact, these are incidental benefits as the only real reason for introducing robotics or any other item of capital equipment is to make more money. That is, to increase profit, give an acceptable return on the investment and to maintain an adequate cash flow (1).

However, before assuming that robotics or automation is the key to making more money, a detailed business review should be undertaken to determine where the priorities lie.

Typically, in shipbuilding, it is found that the most profitable investments can be made by concentrating on systems rather than hardware, for example:

Design - to reduce work content;

Planning - to organize the work in the most cost effective manner and to ensure that the right material and information are in the right place at the right time; and

Quality - to eliminate defects at every stage.

However, it may be felt that such systems either have already been developed to the point at which further benefits will be difficult or expensive to make (as in some Japanese yards); or will be in the foreseeable future. In such a case, introduction of robotics may give a higher return than other investments in production hardware or software.

Also during the mid 80's British Shipbuilders were themselves striving to significantly improve the production performance of their subsidiary yards by various methods including low cost automation (2). A high level executive study tour of Japanese shipyards was therefore undertaken to view the Japanese shipbuilding methods and equipment. A range of robotic devices, components of the MOT0 funded initiative, were viewed during the visit and their potential quickly realized. The Japanese yards were already substantially more productive than their UK counterparts and it was considered that widescale adoption of automation could well place them completely out of reach. British Shipbuilders initiated a program to consider the benefits and implications of introducing such automation within the UK industry. Recognizing the effort the Japanese were devoting towards the design and implementation of robotic devices, it was considered prudent to similarly consider the production possibilities of robots.

ROBOT SELECTION

A very large number of different arc welding robots were available during the investigation period.

The majority of these were of the fixed location revolute type developed for general engineering duties. These offered only a limited working envelope. and demanded that the workpiece be presented to the robot for welding. An extensive program of trials with such a robot type had already been conducted by British Shipbuilders (3). Whilst of benefit in creating an understanding of robotic arc welding, together with the associated supporting disciplines applied within the shipbuilding environment, such machine types are not well suited to the mainstream of shipbuilding construction. Robots within this general category were not considered further.

Additionally, any robot not capable of seam tracking, or rapid recognition of the spatial relationship between itself, the workpiece and the weld start point was similarly discounted as being unlikely to address the production realities of shipbuilding. Any robot welding systems without such software capability were excluded.

It must be realized that the total world market for arc welding robots in ship building is small in relation to the order-of costs likely to be incurred in the development of systems with the necessary mix of hardware and software complexity. There exists therefore insufficient commercial synergy between the manufacturers of such robot systems and the shipyard end user to develop the systems in the first instance without recourse to "independent" funding.

Two distinctly different robot " types " remained after the initial filtering exercise was completed. It is not surprising in view of the above that these machine types had each been developed specifically for welding operations within shipbuilding. These are:

(a) Large multi (>6) axis machines which can automatically access all points to be welded on the workpiece. Movement from one job to another on the workpiece is carried out by at least two more axes on a travelling support, either a gantry or base, which is not controlled during welding. These axes are commonly used for coarse placement of the robot Sensors are then used to detect the actual position of the job.

Examples of this type are the Hitachi Unit Welding Robot as deployed at the Ariaki shipyard in Japan, and the Rosenlaw, Wartsila, Kemppi joint development installed at Helsinki.

The working envelope is dictated by the length and spacing of the rails or beam outreach. Due to the limitations of working envelope size and location, production planning and material control need to be more disciplined. Whilst this in itself is obviously beneficial, failure to achieve such discipline can present a major obstacle to the successful use of robots in a poorly organized shipyard. The capital investment required for this sort of system is substantial, and return on this investment is dependent on a high throughput of (usually) major assemblies (i.e. a healthy and reliable flow of orders) and application to a bottleneck. activity.

Such robot systems demand a hiqh degree of uniformity in ship - internal design to ensure machines can gain effective access and reduce the probability of collision between the robot and ship structure. Also demanded is a high degree of accuracy of constituent piece part location within the large assemblies due to potential interference between the robot

arm and the structure. This degree of fit up was considered beyond the capability of British Shipbuilders' yards at this time. By default of their size and complexity, such systems can only operate at fixed workstations within the unit/block assembly areas. The gantry type is suitable only for 2 l/2 D assemblies, such as primary and secondary stiffened panels, demanding completely unhindered top access. The Hitachi column and boom approach enables larger 3D workpieces be processed but nevertheless still requires largely unhampered side access for successful deployment.

Robot welding systems such as these demand that off line programming techniques be employed, since it is patently unrealistic to attempt a teach-program approach.

(b) Very small machines capable of being moved easily to a point of application as required (Figure 1).

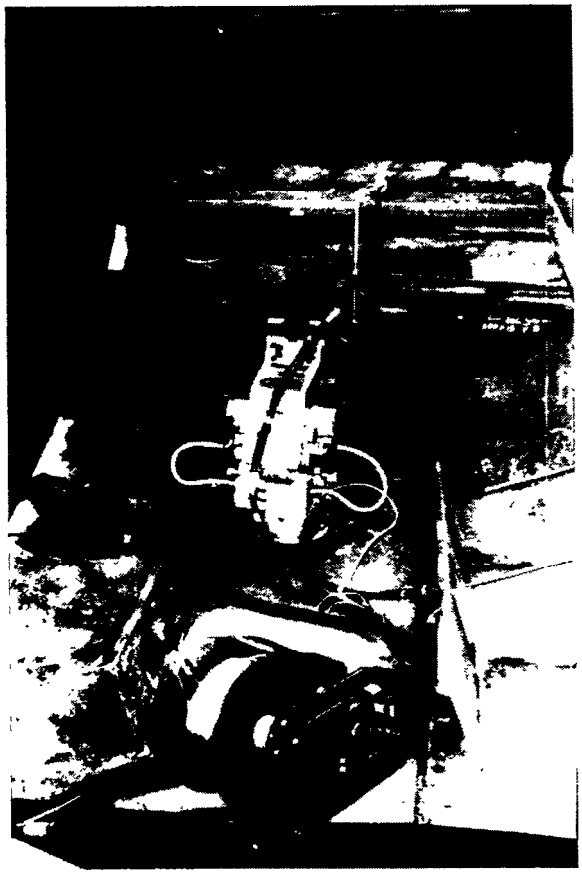

Figure 1. Hitachi M5030Z

The working envelope of such a robot is fairly small, but the robot is repositionable over an area dictated by the length of the various cables between it and the controller and wire feed unit. This working area can be further extended by mounting all the associated hardware (power source, controller, wire feed unit, etc. on, for example, a travelling gantry which can also serve as a support for handling aids. Due to the much more flexible working envelope of the portable robot system, it can cope with a less rigid organisation of material, and is therefore better suited to an initial robot installation where organization of work is less than ideal. First cost is a fraction (typically 1/20th to 1130th) of the cost of the larger system, and as a result of the much areater flexibilitv of this configuration, return on investment is not as dependent on a particular type of assembly.

A possible hybrid intermediate between the types of systems is the use of a large "pick and place" robot to relocate a number of portable robots within a more rigid workstation (4).

The potential to use such portable robots both within the unit and block assembly stage and during ship construction on the berth or in the dock was considered significant.

Robot Choice

If block assembly and erection could be reduced from major events (as they were at that time), to routine operations, then a very significant effect upon the overall build cycle times and the effectiveness of capital plant and equipment deployed would be realized (5).

It is important to remember that the ultimate productivity of an arc welding robot is process limited. The robot is merely a sophisticated tool to manipulate a basically standard wire feed torch. The physics of the weld pool itself determine the maximum weld deposition rate, particularly during positional work to which the robot is best suited. Long runs of downhand or horizontal-vertical welds are almost certainly more cost effectively addressed by less sophisticated weld mechanization or automation.

Nevertheless, a robot arc welding system is able to handle higher currents for longer periods than would be possible by a manual welder using a similar process and robots can generate improvements in welding time as a consequence.

The decision was reached to further investigate robots of the portable type. Only three machines of this type were known to exist:

-Hitachi Zosen WRL 50;
-Yaskawa Motoman V5ZA, and
-Hitachi M5030.

At the time only the Hitachi M5030 was available, through agents, within the UK. This robot type was therefore to be considered for primary introduction within British Shipbuilders, together with its associated programmable welding power supply and wire feed units.

Whilst portable, this machine is not readily handled manually and it was recognized that bespoke handling aids would need developing to effect rapid and safe transfer between successive work locations. Such aids may well need to be structure specific in certain circumstances.

Cost Benefit Analysis

The primary application of automation should be at the hull construction stage, as in almost all cases, this will be a bottleneck. It can be argued that as the main resource applied is manpower, then use of robots in fabrication would release manpower for use elsewhere on the berth or dock and have a direct effect on cycle times. There are limitations to this argument:

-Too great a manning density will lead to reduced productivity;

-Excessive manning levels can result in out-of-sequence work and structural distortion;

-In the typically restricted spaces of ship construction, there is a physical and safety limit to the number of welders who can be deployed; and

-Increasing productivity locally in fabrication may unbalance the production system and lead to an increase of work in progress.

Although it was intended eventually to introduce robot arc welding throughout unit block assembly areas and the ship construction stage on the berth or in the dock, initial assessment of the potential benefits of arc welding robots was concerned only with the unit assembly stage of ship production. It was considered that the more controlled environment and better access possible within the steel shops would be conducive to a more rapid production development period. Subsequent introduction to production would be both sooner and more readily managed than elsewhere in the yard.

A 22,600 dwt general cargo vessel under series construction in one yard was analyzed to identify those areas which might benefit from the application of the Hitachi M5030 arc welding robot.

Selection of the appropriate application took into account the factors that follow:

-Repeatability of structure.

-Size of each job (usually defined by all activities carried out by the robot between relocations). The repeated elements of structure should be small enough to be welded without relocating the robot.

-Access to components. An acceptable torch angle must be maintained along each joint.

-Weld positions. The weld positions determine whether another form of automatic or mechanized welding is used.

-Weld length per job. The greater the weld length per job the lesser is the effect of set-up times on the robot utilization. As the robots are designed to operate between frames, there is an optimum frame size/spacing range within which set-up times are least significant (Figure 2).

-Access to the workpiece. Vertical access is obviously easier than maneuvering the robot horizontally through manholes.

Within the ship type analysed, the selection criteria were best met by the transverse/deck/longitudinal connections, some 3,300 in total being required per ship.

An additional benefit of this application was the knowledge that the robot(s) could be initially deployed within a dedicated work area located towards the end of the panel production line.

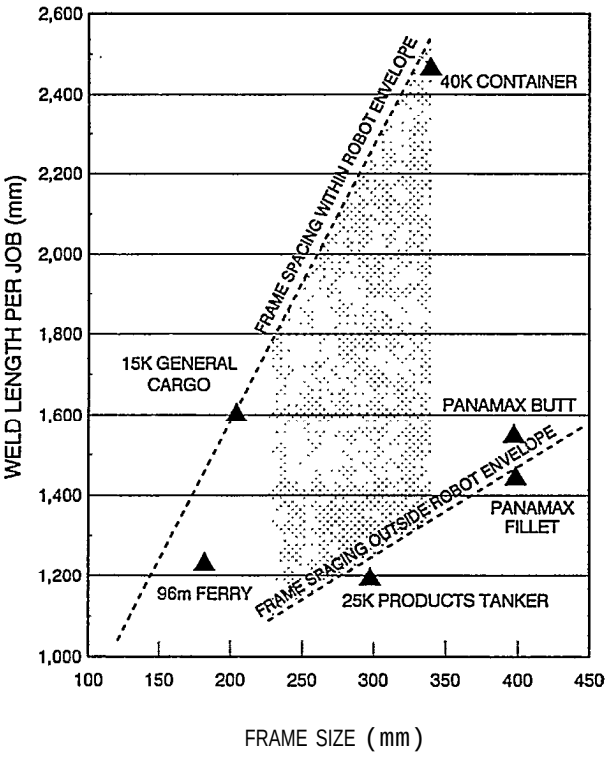

Figure 2. Effect Of Ship Size On Weld Length Per Job

Robotic Welding Times

Setting up times for the robot were obtained from the robot manufacturer, and arcing times were derived from established weld procedure parameters.

Two different deployment methods were considered as described below.

One Man Operating One Robot. In this situation the operator is effectively reduced to a spectator role whilst the welding activity is being performed by the robot and should therefore always be available to immediately re-set the robot at the next work location. A high robot utilization is therefore possible but at the expense of inefficient use of labor.

One Man Operating More Than One Robot. When one man operates more than one robot, there are two possible operational patterns, as follows:

-The total weld completion time of any one robot is shorter than its associated relocation and set-up time. In this situation there exists idle time when one (or more) robot has completed its full cycle but must wait upon the operator completing the set-up of another robot. The time demands upon the operator are continuous if maximum arc-on time is to be attained from all robots. System performance is thereby restricted by the sustainable labor effectiveness of the operator, an undesirable condition.

-The total weld cycle time of any one robot is greater than its associated relocation and set-up time. The relationship between the arc-on time and set up time will determine the number of robots it is viable to employ under the control of one operator. The maximum possible utilization of each robot can be expected from this scenario.

A cost benefit analysis performed to determine the order of savings which might be expected from the deployment of the robots on the transverse / longitudinal connections indicated a saving in excess of 2,600 manhours per ship was possible. At a production level of some 2.7 ships per year of the series vessel considered, an annual labor saving of over 7,000 steel manhours per year was available. This is equivalent to an internal rate of return on the capital investment of more than 50% over the five year period considered, assuming these 7,000 hours can be effectively utilized during hull construction.

The decision to purchase was given mainly on the basis of this analysis but tempered with a strong need to know just what could and could not be reasonably expected of robotics for arc welding within shipbuilding.

Further investigations were also made to determine the suitability of the M5030 robots to the structure of 40,000t dwt container vessels commencing production at another British Shipbuilders' yard. Figure 3 shows the times required to weld one watertight bulkhead to the bottom shell structure, using:

-conventional semi-automatic equipment;

-one robot worked by one operator; and

-two robots worked by one operator.

It can be seen that cycle times are significantly reduced even when using one robot per operator. This is due mainly to the effects of welder concentration and discomfort which are exacerbated by the long runs required on this structure.

Following this, calculations to determine productivity of the butt welding of longitudinals were undertaken. There is less similarity between different ship types at the hull construction stage than there is at the interim product stages. A

Panamax tanker was selected as providing the easiest structure to which portable welding robots could be applied and therefore the savings indicated would be the best which could be hoped for. Analysis of a typical British Shipbuilders' shipyard with two berths indicated a saving of over 4.5% in the total steelwork hours and a keel lay to launch duration reduction of at least 3 weeks, thereby offering the potential of increasing throughput by over 11%.

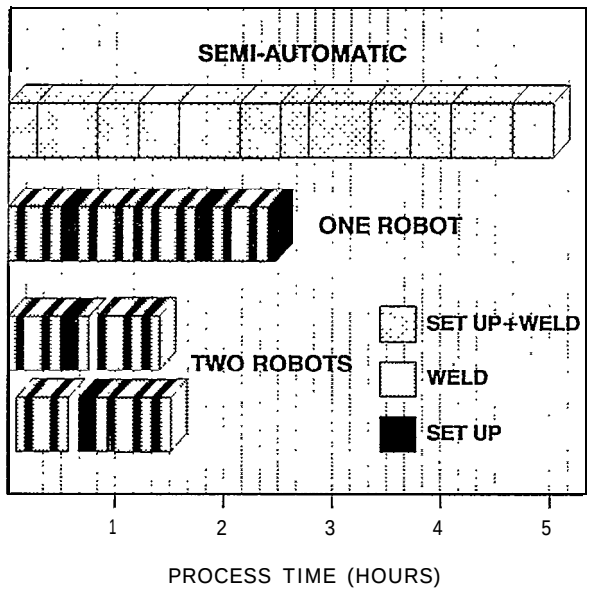

Figure 3. Comparison of Process Times For One Watertight Bulkhead

Development Plans

A training, development and work preparation area was set up in a convenient location adjacent to the workstations for sub-unit and unit assembly. The robot power packs, controllers and other hardware were located in a small enclosure upon the existing services gantry some 3m (10 feet) above the shop floor. This gave a good view of the production area (it was found that it was desirable to be able to see each robot from its controller), and maintained the cables above the floor, thereby preventing damage. This initial installation permitted the machines to be used both in production and in the development area for training and programming.

It was decided that a full scale mock-up should be used for programming (Figures 4 and 5). This allowed each job to be run with the arc off to ensure that the job structure was correct, and that the touch sensing routines, including the handling of the various shift registers, were error-free. Programming 'on the job' was not considered as it is a time consuming activity which would interfere with production.

Figure 4. Adjustable Mock-Up For Programming

Figure 5. verification Of Programmed Torch Positions and Welding Parameters

A delay in delivery of the robots had lost the original target ship to the program, so trials commenced instead upon the structure of a series of 93m Ro-Ro ferries commencing production.

The vessel midship section, general arrangement and steelwork process analysis was examined with the previously described criteria in mind in order to select an appropriate application. The initial application chosen for the robots at British Shipbuilders was the welding of transverses and transverse bulkheads to longitudinal bulkheads in the sub-unit assembly of wing tanks (Figure 6-l). This application had a further advantage in that only 24m of such joint length was required per day according to the production program. Therefore as each machine is capable of about 10m per hour on such structure, there was ample time for programming of subsequent applications. Whilst the long term aim of the project remained to improve productivity by reducing the ship construction cycle time it was recognized that this application is demanding in terms of weld procedures, accuracy of components, quality of edge preparations and access. A series of increasingly demanding applications was deemed to present the most structured approach to permit designers, management, programmers and robot operators to gain experience prior to final installation of the machines in the building dock. The subsequent applications (Figure 6) selected were as follows:

-Double bottom sub-unit assembly, stage 1 (i.e. welding of transverses to tank top (Figure 6-2)). Access is vertical, and jobs are of a similar nature to the initial application.

-Thruster room center section sub-unit assembly (Figure 6-3). This involves the welding of tightly spaced, deep longitudinal and transverse structure to each other, and to the bottom shell. The thruster room units were long lead units, and this was partially due to the unpleasant work involved in the welding in the confined spaces. Access was vertical but would require operation of the robot in an inverted position.

-Double bottom sub-unit assembly, stage 2 (i.e. welding of transverses to the bottom shell (Figure 6-4)). Job and program structure would be relatively simple and similar to the first two applications, but access would be horizontal, and require the design and manufacture of a different handling aid.

-Unit butts between longitudinal stiffeners after erection (Figure 6-5). Access problems should be resolved by previous applications and designs of handling aids. However, it was anticipated that the midship section of the ferries would not present an ideal structure, due to the limited joint length per job and the number of decks and tanks. There is a limit on the suitability of portable robots to weld in confined spaces, such as double skin structure, due to the fact that the machines require an operator, who is exposed to fume just as a welder would be. This effectively limits the number of robots and hence the productivity of the application. However, at the time of the project instigation at British Shipbuilders, the shipyard involved had been constructing general cargo ships and large barges for which access and spatial restrictions were less demanding.

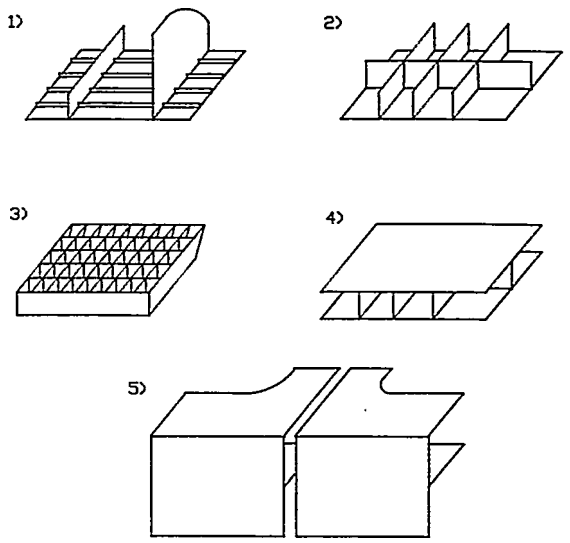

Figure 6. Initial Assembly Types For Robotic Welding

The Hitachi M5030 Portable Robot

The Hitachi M5030 range comprises two models, the M5030T (equipped with a traversing base); and the M5030Z (equipped with a rotating base). The M503OZ model was chosen by British Shipbuilders as this was felt to be more useful for welding typical ship structure (Figure 7).

The body is of the revolute (jointed arm) configuration, having five simultaneously controlled axes. An optional auxiliary twist axis on the wrist was selected in order to give maximum flexibility. The general design of the wrist differs from conventional welding robots in that the torch is mounted above the joint, thereby allowing greater access into tight spaces, and reducing interference problems with the workpiece.

The controller for the M5030 range is based upon a 16-bit

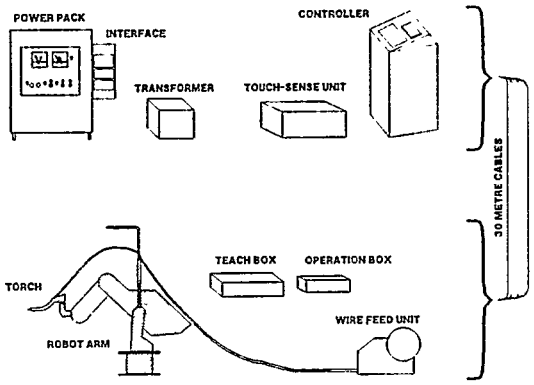

Figure 7. Hitachi M5030Z System Components

microprocessor, giving a maximum of 256 programs, and 100 jobs. A program or job may contain 2,000 steps. Path control is by continuous path using either articulate, linear or circular interpolation in any plane. In addition to the usual controller modes (e.g. program teach, playback), a diagnostic mode, and a monitor mode (to display production control information) are supplied. A tape streamer is used to backup job and program data, and to transfer it between controllers. The weld parameter database can store 100 combinations of current, voltage and speed. All these parameters and timers may be changed on-line via the teach-box. The teach-box, along with all these usual servo controls and condition buttons, has manual control of wire feed, and arc-on (for tacking). An operation box with remote over-ride of certain controller modes and functions (sufficient to operate the robots without reference to the controller) is also supplied. The robot body, operation box and teach-box are connected to the controller by thirty meter cables, enabling the robots to be used over a substantial area. The remaining hardware consists of a touch sensing unit (also used for seam tracking); the welding power supply and robot interface; and a transformer.

PROJECT FINDINGS

Robot Arm Design

Although the project specification for the design of the portable robots built by Hitachi, Hitachi Zosen and Yaskawa called for the machines to be light enough to be carried by two men, and to enable them to pass through a standard manhole, it was discovered that the robot arm with the torch, magnetic base, and wire feeder was too cumbersome to be moved around safely, except between adjacent jobs. A handling aid was designed which would assist in lifting and placing the robots and also act as a base for the robot controllers, power packs and associated hardware, thereby extending the operational area of the machines from a 30m radius to an entire unit assembly bay (Figure 8).

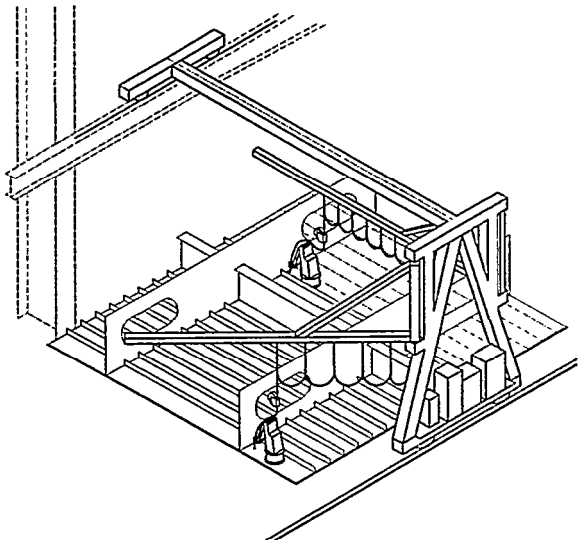

Figure 8. Robot Handling Aid For Vertical Access

The size and characteristics of the robot operating envelope, together with the size and shape of the robot arm dictate how effectively a robot can be applied. Generally speaking, the fewer the number of controllable axes, the greater the limitations. It is the relationship between the size of the repeating structural elements to be welded and the robot operating envelope which determines how effective the robot will be in a particular application. (For example, frame spacing compared to arm outreach at a particular stand-off distance from the workpiece). This relationship also depends on the particular welding consumables in use, as tolerance to changes in torch angle vary from one wire to another.

It was found during trials at British Shipbuilders that modification to the welding torch shape enabled the robot to access more intricate structure without interference, although the structural configuration of the ferries under construction was at the extreme lower limit of the M5030Z's capabilities. The auxiliary 'twist' axis was only found to be necessary in a very small number of cases, but nonetheless was regarded as

essential. A sixth controllable axis, in the form of a third wrist axis, would have permitted greater flexibility in choice of consumables, and would have reduced programming times.

Design For Production

In many cases, a design which may be manufactured with difficulty by traditional methods, will be impossible to produce using robotics. The use of robotics therefore focuses attention on detail design for production. The principles of standardization and simplification are particularly important for automated manufacture. At British Shipbuilders, for example, analysis of conventional structure showed that significant improvements in productivity, both with and without robots could be made by standardization of collars to only 9 designs. Additionally, the three-quarter collar in use was found to be impossible to weld by robot. Further investigation showed that considerable difficulty was experienced in welding these manually, leading to poor productivity and excessive rework.

There are certain design features which have a major bearing on robotic production but are of limited importance for non-robotic production. (For example, frame spacing). Extensive trials were undertaken to determine and quantify these features with respect to the limitations and capabilities of the M5030Z machines.

Quality

The initial application highlighted the need for upstream process control as the robots were not as adaptable as a human welder in respect to the quality of work presented to them such as gap size and edge preparation. This actually helped many employees to grasp the concepts of internal customers and Total Quality Management. Steps were then taken to modify upstream processes to reduce the variation in output. Use of the robots for butt welding at the hull construction stage would have imposed still greater demands on the control of the various production processes, and preparation for this application would be required in conjunction with extensive training in the principles of quality assurance. It is highly likely that these measures would have resulted in productivity improvements in themselves.

The quality of welds produced (given acceptable workpiece quality) was found to be exceptionally good (Figure 9).

Figure 9. Robot-Welded Collar

Industrial Relations Aspects

At first, shop floor employees were cautious of the prospect of a robot carrying out mainstream production welding. The attitude of the labor union for a short while prior to delivery was that the robots represented a threat to employment. Once the machines had been set up and were operational, this attitude disappeared, because of the physical size of the robot arm. The reality of a portable arc welding robot obviously did not match the pre-conceived ideas held by many people, based on myth and television programs about automated production lines. Throughout the project, the development compound was left open so that no mystique developed amongst shop floor personnel.

Extensive efforts to maintain communications with all employees resulted in an acceptance of the robots within an unexpectedly short period of time.

One aspect which gave some cause for concern was the machine monitor function. This measures usage in terms of the number of arc-ons, the total arc-on time, etc. This was viewed with suspicion by some union members as the exact amount of work carried out by each robot (and therefore each robot operator) could be monitored daily. As, at that time, there was very little accountability for progress at the shop floor level, this was viewed as a major change in management style.

Adaptive Control

With existing ship structures, it is not considered possible to universally apply an arc welding robot with less than six controllable axes and seam tracking hardware attached to the welding torch. In many cases, it was found that in order to access a joint with an acceptable torch angle and stickout, the torch would be almost touching the structure. Therefore, for a welding robot of the M5030 type, the only practical method of tracking a joint would be a suitable 'through-the-arc' technique in combination with a synergic pulsed power source.

A number of mock-ups were welded without seam tracking and the resulting weld quality was poor. A lack of seam tracking could, to a certain extent, be compensated for by the apposite use of touch sensing. However, touch sensing is time consuming to program and to effect.

The majority of welding robots available incorporate adaptive controls developed with the main users in mind. The specific needs of shipbuilders are not generally a concern for robot manufacturers, and hence software which is designed for use downhand on clean, unprimed steel may not operate correctly in a multi-positional shipbuilding environment.

Certain software functions available on the Hitachi M5030 range were found to be of limited use for shipbuilding. The 'Co-ordinates Translation' feature allows spatial distortion in a variety of forms (e.g. mirror image, uniform size change, non-uniform size change, angular distortion), but was only of interest for mirror imaging of offset bulbs. The various tasks involved in co-ordinates translation took almost as long as re-programming from scratch due to the difficulty in establishing accurate, fixed reference points.

A similar problem was experienced with regard to the 'Displacement Correction Function' (DCF). This function is designed to enable the robot to re-orientate itself after being moved from one job to another. Reference points are re-taught so that a rotational shift of the program geometry can be carried out. This requires that the robot be manually driven to both reference points which is very time consuming, and inaccurate unless lighting conditions are very good.

Setting bars which jig the robot into position against two reference surfaces were therefore designed. These permitted reduced set-up times from those required when using the DCF.

Choice Of Consumables

The following points are of particular importance when considering the use of a robot:

-deposition rates;

-weld quality;

-current density and current ranges;

-effect of changing consumables on calibration of the seam tracking system;

-slag properties (can a weld be carried over slag and can an arc be struck on slag?);

-tolerance to change in torch angle; and

-effort involved in establishing parameters.

CONCLUSIONS

Design for production is of primary importance to any successful shipbuilder. If robot-arc welding is to be successfully implemented "design for robots" will also be essential. Robot systems cannot be effectively installed as "after the event" bolt on productivity improvement hardware but must be considered at the earliest stage of the ship steelwork design activity.

Standardization of the internal detail topology throughout a ship, and where possible between ship types, together with the reduction in variability of material types and sizes are probably paramount. The robot system's operational envelope should be recognized as a ship design criteria (6).

If "teach to learn" programming is to be employed this must be undertaken off line since it is very time consuming. Direct off-line Numerical Control programming via computer-aided design input would appear to be the direction in which future development should concentrate. However, positional arc welding is a complex process to automate since the constant compensating adjustments undertaken by a manual welder ideally must be replicated by real-time dynamic feed back within the system. Visual weld line fit up assessment is one area receiving much research attention which will almost certainly result in larger and more complex robots of increased first cost and reduced operational dexterity, certainly within the

foreseeable future. The alternative now is to exercise tight dimensional statistical control to the production of all component parts, minor sub and major assemblies to be robot welded to present a workpiece which is sufficiently consistent to allow existing blind welding be performed.

Consumables should be selected to give the best compromise between speed and ease of welding and acceptable quality standards. Consumables should also include or take cognizance of the shop primer used within the yard. British Shipbuilders experience points towards the inorganic zinc silicate primers as probably being the most weld process friendly although it is recognized such primers can cause problems in their own right.

The Portable Arc Welding Project did not produce the hoped for result. The M5030Z robots proved not to be suitable for production as intended. The barriers to be overcome relating to use of the seam tracking with consumables and primers required to produce acceptable welding quality eventually proved insurmountable. They did serve to indicate, however, the true latent productivity potential resident within arc welding robots and that, given the economic need, all encountered problems would be successfully overcome.

However the next generation of devices will need to be lighter and even more compact if the maximum benefits of the portability are to be exploited.

In summary, portable arc welding robots definitely have the potential to become shipbuilding tools and an effective means to increase throughput and profit. However, it is crucial to get the fundamental shipbuilding processes under control before robots are considered as a means of improving performance.

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REFERENCES

1) E. M Goldratt, J. cox, The Goal, North River Press, 84. 19

2) J R Hewit, J M Kalogerakis, "The Ferret - A Robot for Welding in Inaccessible Places" - Robot Systems and Robotics in Hostile Environments, Washington, USA, March 1987.

3) A Marsh, S E Duffy, C Kuo, J M Kalogerakis, "Application Experience of Robotic Welding in Shipbuilding", ICCAS 1985.

4) Acton, J B, Sizemore, J M, Kroczynski, P, Gilmore, P D, Kalogerakis, J M, "Optimal Utilization of Vertical Access Robots in Shiobuilding" Robots 9 Conference of RI/SME, Michigan, June 1985.

5) Hargroves, M R, Teasdale, J A, Vaughan, R, "The Strategic Development of Ship Productuion Technology", Trans NECIES April 1978.

6) Bruce, G J, "Ship Design for Production - Some UK Experience", Journal of Ship Production, February 1988.