January, 1995
NSRP 0439

SHIP PRODUCTION COMMITTEE
FACILITIES AND ENVIRONMENTAL EFFECTS
SURFACE PREPARATION AND COATINGS
DESIGN/PRODUCTION INTEGRATION
HUMAN RESOURCE INNOVATION
MARINE INDUSTRY STANDARDS
WELDING
INDUSTRIAL ENGINEERING
EDUCATION AND TRAINING

THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

1995 Ship Production Symposium

Paper No. 10: Robot Technology in the Shipyard Production Environment

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JAN 1995**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **The National Shipbuilding Research Program, 1995 Ship Production Symposium: Paper No. 10: Robot Technology in the Shipyard Production Environment**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Surface Warfare Center CD Code 2230 - Design Integration Tower Bldg 192 Room 128 9500 MacArthur Blvd Bethesda, MD 20817-5700**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**15**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

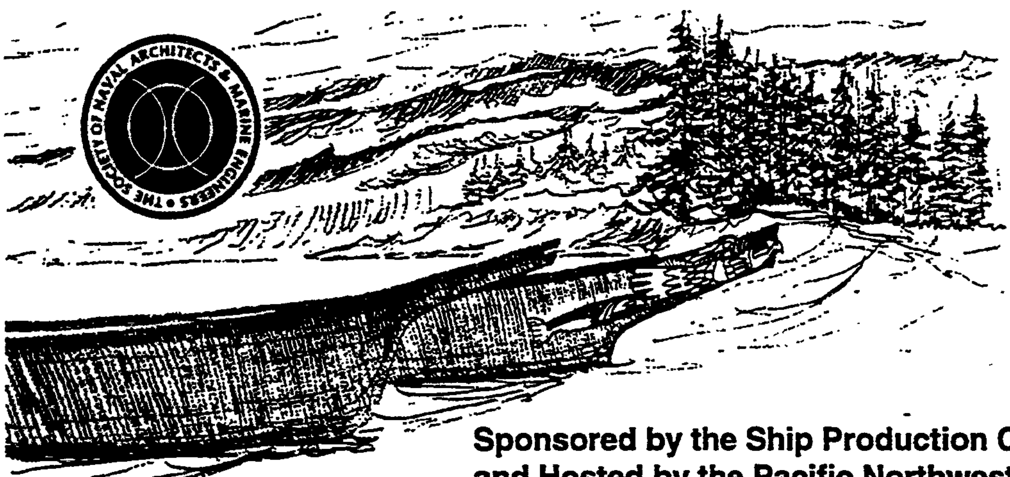
DISCLAIMER

0439

1995 SHIP PRODUCTION SYMPOSIUM

Commercial Competitiveness for Small and Large North American Shipyards

Seattle, Washington
The Westin Hotel
January 25-27,1995



**Sponsored by the Ship Production Committee
and Hosted by the Pacific Northwest Section of
The Society of Naval Architects and Marine Engineers**
601 Pavonia Avenue
Jersey City, New Jersey 07306
Phone (201) 798-4800
Fax (201) 798-4975

#0439

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
601 PAVONIA AVENUE, JERSEY CITY, NJ 07306
Paper presented at the 1995 Ship Production Symposium
Westin Hotel, Seattle, Washington, January 25-27, 1995

Robot Technology in the Shipyard Production Environment

Svein I. Sagatun (V), and Karl Erik Kjelstad (V), TTS International AS, Norway

ABSTRACT

This article presents the current status of robot technology in the shipyard production environment We focus on a case study in which a computer integrated and robotized web and component line is presented. This production line will be folly operational mid-1995.

An overview has also been included of the most relevant technologies with regards to robot production in the shipbuilding industry, and how these technologies contributed to the introduction of robots in shipyards. The need for integrating the robots with the rest of the shipyards' material flow, computer systems and organization is first discussed, while a brief survey of emerging technologies which may be useful for the shipbuilding community is presented afterwards.

INTRODUCTION

International shipbuilding is in a process of change. The established order of shipbuilders, with Japan being the major builder and South Korea being in second place building predominantly “simple ships”, is changing. Japan is experiencing cost problems due to high labor costs and currency depreciation. South Korea is taking the opportunity to increase capacity and to improve productivity. At the same time South Korea is building more complicated ships such as LNG tankers and container vessels. The combined market share of Japan and South Korea is, however, likely to remain at approximately 65%.

The rest of the market is experiencing rivalry from established Shipyards in Europe and China, with newcomers from Russia and Ukraine entering the field. In addition, the US shipyards are making serious efforts to enter the commercial shipbuilding market to compensate for the reduction in naval work With relatively favorable labor costs and a determined effort, it is probable that they will experience some degree of success.

To some extent the competition is between low labor cost countries who are investing in low to medium level of technology to improve their output and quality, and the high cost countries who are investing in high technology. The days of the simple shipyard consisting of a berth and some cranes is coming to an end, even in countries with low labor cost. Manhours per tonnage of steel and the time in dock must continuously be reduced as has been done in the last hundred years, see Figure 1.

In this article we will look at some of the "High Tech" developments now being implemented. The introduction of robotics in the shipbuilding industry is now gathering momentum after several false starts. It is being recognised that the robot itself is only one of many tools required for the introduction of CIM (Computer Integrated Manufacturing) in the shipbuilding industry. However for the robot to work the dimensional accuracy of the pieces to be welded by the robot must be exact. The extensive use of robotics in the steel fabrication requires heavy investments in the material preparation of plates, profiles and manufacturing of subassemblies. The successful introduction of robots to the shipbuilding industry has been made possible due to the technological developments over the past three decades. The challenges and obstacles have been many. The main challenge can be formulated as:

How do we efficiently use robots in small or one part production series in an environment with a low degree of dimensional accuracy of both the raw materials and the subassemblies?

The dimensional accuracy of the steel profiles from the steel mills was, and still is for some yards, a problem for automatic manufacturing. A human operator has no problem adapting his welding or cutting job to inaccuracies in the dimensions of the

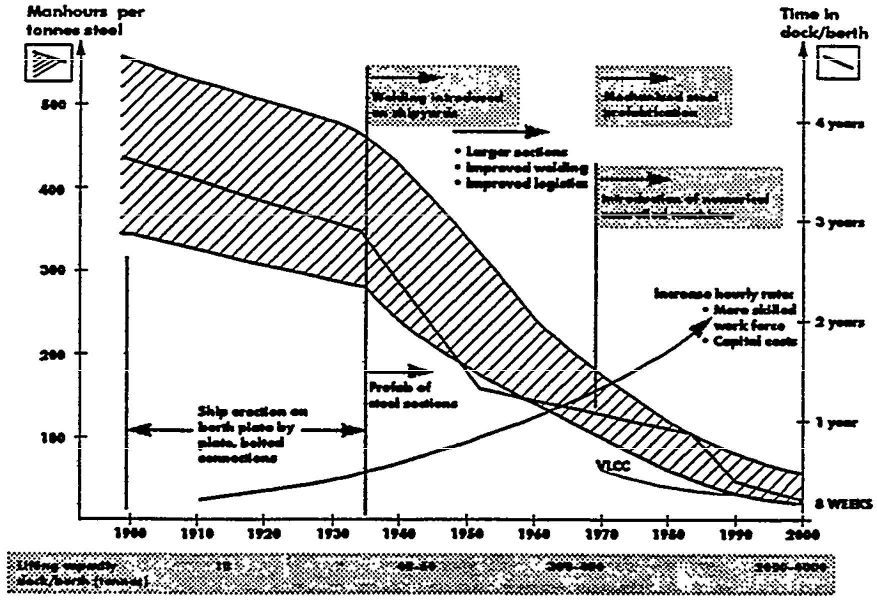


Figure 1. Global trends in shipbuilding in the last 100 years.

material. However, this is a problem for the robots. There are two ways to compensate for this. First, the yard can install milling machines which correct the dimensional deviations so that accurate profiles are used in the production. Second, we can equip the robots with sensors so that the robots can adapt their programs to the actual instead of the planned profile geometry. The disadvantage with the first approach is that it is costly, while the second approach may reduce productivity. The robot can weld plates with distortions from its designed geometry, but the amount of manual repair work and adjustment of the robot program may also reduce productivity. A combination of these two methods is recommended as a compromise. However, some yards have a third option. They can buy high quality profiles with the necessary dimensional accuracy directly from the steel mill. No or little milling is necessary and the robot uses very little time searching. There exist yards which are directly connected to the steel mills' ordering computer, so that orders can be placed directly. The delivery time is down to less than three weeks and the dimensional accuracy is very good.

The yard will achieve high productivity from its robot production lines if it focuses on dimensionally accurate production. On the other hand, robots produce with very accurate dimensions, so that this is a self-fulfilling situation. A robot-based profile cutting line is a good starting point for introducing robots at shipyards since accurate cut profiles are, together with plates, the starting point for all the subassemblies. It is important to notice that the key to dimensional accuracy, which forms the backbone of the efficient shipyard, lies in a detailed practical knowledge of the application of the shipbuilding technology and not in robotics, CAD or any other more narrow technology.

The other major challenge is how to efficiently program the robot system. We use the term robot system and not robot since the whole production line must be programmed, not just the robot manipulator itself The material transport, the printing device, the robot's external axes, the robot motions and the robot tool must all be programmed in a coordinated manner. This programming task must be performed efficiently since we have small series production, and most robot programs are used only once or twice. A natural starting point for the robot program is the geodetical data which already reside in the yard's CAD (Computer Assisted Design) system. The problem is now how to transfer design data in CAD format to production data in a robot source code format. This can be achieved in several ways and is discussed later in this article. However, this paper focuses the reader's attention on a method called macro programming. Macro programming builds on the fact that most tasks a robot performs are similar to one another. It can almost be said that the robot performs mass production on a smaller scale, a so-called task scale, see Figure 2. This fact is taken into consideration in macro programming. The importance of having an efficient off-lime programming system should be stressed. A skillfull off-line programmer can produce off-line robot code for a complete ship as it is being built.

A third issue that is important to consider design for production. The term design for production indicates that the production process is taken into consideration already at the detailed design phase of the production process. The detailed design engineer must know the capabilities and the limitations of the production equipment in order to be able to optimize yard productivity. Compromises with respect to material selection, dimensions and detailed layout may be necessary in order to achieve higher productivity and a lower cost for the ship from an overall perspective. Several yards have successfully implemented the design for production principle in their CAD offices, and, as a result, have substantially increased the efficiency of their off-line programming process and robotized production lines.

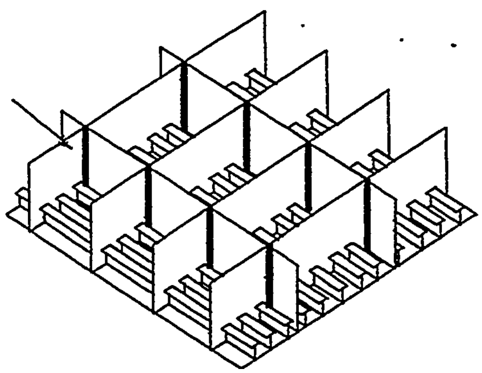


Figure 2. Example of robot welding macros for double bottom assemblies.

Contents

Section two introduces the reader to the present situation regarding robots in the shipyard production environment. Section three presents the current status of some key technologies for robot production. Section four stresses the point that robots should be treated as integrated parts of a production system and not as stand alone products. Section five presents an example of a robotized production line for the manufacturing of web and components. All the corresponding software and hardware components are discussed. Section six presents some work which may result in promising technologies which the shipyard production environment may benefit from.

PRESENT STATUS - A CHALLENGE

It is possible to divide the shipyard industry into three categories the yards which have no experience whatsoever with robot production systems, the yards which unsuccesfully employ robots at their yard, and the yards which successfully employ robots in their production.Only the two latter categories will be discussed in this article.

At shipyards which unsuccessfully employ robots in a stand alone production cell for welding or cutting small parts in small to medium sized series, the robot is usually programmed on-line by the "lead through" or "tech in" technique-no interface to the CAM (Computer Aided Manufacturing) system is present or needed. Material infeed and outfeed is usually manual or semi-automatic. This category of robot production units lacks two essential elements to be efficient: first and foremost, an efficient programming system for the robot and second, an efficient integration of the robot with the rest of the yard’s material flow. This category of robot installations was installed in yards in the 1980's when robot manipulator technology had matured. However, installations occured without a corresponding level of maturity on the off-lime programming and system integration frontier. The installation of these robots was met with an unreaslistically high expectation level from the production people. When expectations were not met, due to the lack of integration of the robots with the rest of the production at the yard, the production people sensed failure.

Shipyards which have successfully applied robots in production, have used a totally different approach. The installation and planning of the robot installation have often been carried out by personnel who are enthusiastic with respect to this new technology. The management has been committed to the introduction of robots at their shipyard, and the robot installation and corresponding software has often been developed in co-operation with an academic institution and fully or partly sponsored by national research agencies. This category of robot installations usually takes place at large shipyards, and the robotized production lines are frequently integrated with the rest of the yard’s production. The link to the CAD/CAM system is customarily a non-standard solution which is tailor-made for this particular CAD/CAM system, shipyard and application The same observations are also true for the shop floor control System if the yard has one at all. Functions such as reporting and logistics (material tracking stock yard control, etc.) are, if they exist at all, usually also tailor-made for the specific shipyard. The robots are customarily programmed in an off-line manner with a non-standard programming tool, either macro-based or else based on a VRI system (Visual Robot Interface). Several yards have successfully applied this approach, and up to 20% of the welding meters can realistically be expected to be cost efficiently welded by robots with these systems. There is, however, growing concern regarding the increasing costs associated with the maintenance and upgrading of the yards' various software packages. These costs can be reduced intwoways. First, costs can be reduced by buying proprietary software from a company which sells production equipment to more than one yard. The development and upgrade costs are in this way shared among the various yards. And seconod, by using standard file formats such as the graphical exchange format IGES (Initial Graphics Exchange Specification), (IGES 1991), the production model STEP (Standard for External Representation of Product Data), (Owens 1993) or an appropriate neutral robot programming language, see for instance (DIN 66312 1993).

THE CURRENT STATUS OF ROBOT PRODUCTION TECHNOLOGY

This section is included to make the reader aware of the current status of some of the most important technology elements of the robot production technology.

CAD/CAM systems

A fully computerized production system includes several modules, with each module taking care of different steps within the process of creating a product. Generally, the system may be divided into two main parts; one taking care of the production process, whereas the other takes care of the organizational part. The former part is discussed in this section.

The term CAD systems is used for a computer system which is used for the design and drafting. In addition, engineering calculations may be performed. The earlier CAD systems had limited capabilities, but as the hard- and software systems have evolved, a broader range of possibilities have emerged. The increased level of model and drawing complexity has led to an increased amount of data to be handled by the CAD-system. The contents of these databases may be divided into various parts: first, the technological data containing data about geometry, tolerances, material, etc.; second, the organizational object related data such as name, weight and lot number; and third, the data related to the drawing such as scale, drawing number and formats. The CAD database is an integrated part of a production system containing information that may be used as input for programming the production equipment. Some data processing is required to put the available data in an appropriate format for the production machines.

To increase the level of automation process data may be integrated with the data-flow sent to the production equipment. Process data is informatior about the manufacturing process, such as welding speed, shielding gas pressure, painting accuracy o grinding parameters.

The CAM system takes care of the computerized control of the manufacturing process. This implies direct control of production equipment as well as management of the materials and tools to be used by the production equipment Data entry and logging o process data may also reconsidered a part of a CAM system. The input to the CAM system may be files from the CAD system, along with process information Any required transformation of CAD data into a CAM appropriate format is done by the CAD system. For instance the representation of data in an ESSI (ISO 6582) format is common for many shipyards. The ESSI format, which is a standard for numerical programming of cutting machines, is generated by the CAD system. The CAM system may then use the information in this file for control of CNC-equipment.

Robot Manipulators

Robot manipulators have been developed from special purpo spot welding manipulations tailor-made for the automotive industry into multipurpose robust, flexibility, and easily programmable manufacturing tools. Today’s robot manipulators are inherently more robust, reliable, and flexible compared to those used 25 years ago. Advances in control technique, robot drive technology, mechanical design, computer engineering and software have provided the robot industry with the necessary technology to manufacture robot manipulators with a level of flexibility and adaptivity which make them applicable for the shipbuilding industry.

A robot can be described as a programmable multi-function manipulator designed to move material, parts or specialized devices through variable programmed motions for the performance of a variety of tasks. Here, a manipulator could be any structure with controlled joints and connecting links to support the physical functionality that is required to perform a given task. In an industrial environment or at least in a large number of industrial processes, a manipulator often is an anthropomorfous (humanoid) mechanical arm, with some resemblance to a human limb. In industrial applications such as arc-welding deburring painting gluing, handling and assembly, six-DOF (Degree Of Freedom) manipulators are often used. six DOFs are necessary to facilitate the possibility of reaching any position and orientation within the manipulator’s working range. Each DOF or axis is controlled by a servo drive, and the complete robot i automatically controlled by a designated computer. The input to the computer is the robot program, and the output is usually the command signal to each of the servo controllers.

Current industrial robot systems have reached a very high level of sophistication regarding performance, reliability, and robustness. The robots are sophisticated,flexible and reliable enough to be applied to the shipbuilding industry, a well- recognized fact in parts of the shipbuilding community.

Off-1ine programming

Two fundamentally different approaches, on-line and off-line programming are employed in robot programming. Only off-line programming will be discussed in this section.

Off-line programming is basically the same as computer programming. The robot's motion is programmed on a computer, graphically or by using a computer language without disturbing the robot. Hence, the robot can undertake a planned task while the operator programs the next one.

In shipbuilding, the input to the robot program usually consists of drawings on a paper or on a CAD system. There are three alternatives with respect to the link between the CAD system and the robot program complete manual programming such as macro programming; semi-automatic programming with the help of a VRI system or fully automatic programming where the CAD files are automatically processed on a computer with a complete robot program as the final result.

Complete manual robot programming is performed by entering the appropriate high level robot commands manually into a computer on the basis of a drawing. The advantages with manual programming are the low costs and complexity of the software and ease of use. Many shipyards successfully use manual programming. It is also relatively easy to upgrade this system to a more advanced configuration at a later stage if desired. This should be the entry level for shipyards with limited experience in robotized production.

The input to the VRI tool is the CAD files containing a complete product model, or parts of one. The output is robot programs in a certain format for example in a neutral robot programming language, robot control commands, or macro data files. VRI, in the traditional sense, works as follows. The robot, necessary peripheral equipment, and the work pieces are displayed on a high resolution graphical computer screen. The robot and the peripheral equipment are part of the VRI software while the work piece is displayed by ***importing*** the CAD file. The CAD file has to be in an appropriate format and converted to a graphical image on the screen. The operator manually moves the simulated robot on the screen over the desired welding or cutting trajectory by using a mouse. The corresponding robot commands for moving the actual real-world robot are then generated by the VRI system. The robot program can now be downloaded to the robot for execution of the
desired task. The advantage with this approach is that, compared to customized systems, it provides the user with a relatively flexible and inexpensive bridge between the CAD system and the robot production line. The disadvantage is that the software and especially the hardware maybe expensive compared to manual macro programming systems. The efficiency of this way of programming the robot may also vary between the different products and applications.

CAD files containing a complete product model, or parts of one, are also the input for a fully automatic robot programming system The output is robot programs in a certain format a neutral robot format, robot control commands, or macro data files. The robot programs are generated automatically without any human intervention. Process information, such as welding or cutting parameters, must reside in the product model if no operator interaction in the computer programming process is required This form of robot programming is usually tailor-made for the actual installation. That is, the program is specially designed for this particular application, CAD software, and type of robot. Robotized profile cutting lines **usually use this approach combined with macro** programming.

The advantage with this approach is that it is very efficient The disadvantage is that it is difficult or expensive to use the same program for different applications. Thus different programs are used for different types of robot operations. The program is usually customized for the specific application so that the initial programming expenses are high.

The point is that the three technologies described above have reached a level of maturity which make them applicable to the shipbuilding industry. However, this alone is not enough. The knowledge and technology involved in integrating these technologies into working and profitable production systems is new and, for some applications, untested. The next section discusses the importance of the integration aspect, while some key problem areas and challenges are pointed out.

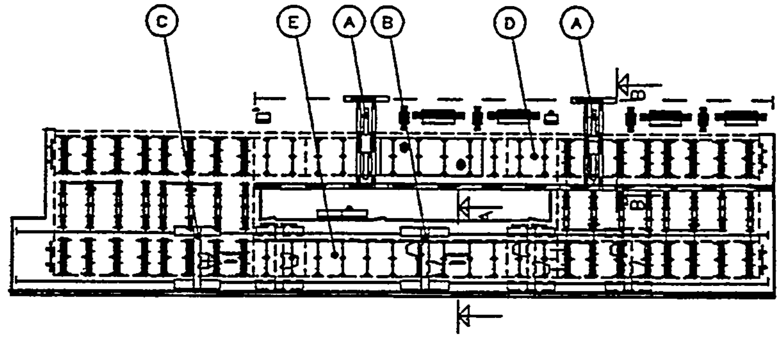


Figure 3. General arrangement of robotized web welding line, A: stiffner mounting gantry, B:double robot gantry, C: single robot gantry, D: tack welding area and E: robot welding area.

SYSTEM VERSUS PRODUCTS

It is important to note that a working robot production system must be integrated with the rest of the yard's production environment It is also important that the robot interacts with the rest of the yard's material flow. For instance, efficient material infeed and outfeed to a robot manipulator is vital to achieve a high degree of utilization of the robot production unit. The costs related to the material infeed and outfeed systems are usually higher than those for the robot manipulator with corresponding hardware and software. However, it is vital to incorporate this investment into the project when the rest of the robot production unit is purchased in order to achieve a justifiable return on investment For most shipyards, a stand alone robot manipulator without the necessary support equipment will be a bad investment and create prejudice against robot investments. On the other hand, an efficient robot production system fully integrated with the rest of the shipyard will be the showcase for the yard when presenting the yard to ship owners and investors-the investment in the robotized production line will be justifiable and sound.

bother major cost item in the investment budget for robotized production lines is the computer software. The software contains functions such as robot programming control of the material infeed and outfeed, marking,progress reporting, and sending status and quality data back to the work preparation office. The off-lime programming of robots is a particularly challenging task. However, an efficient implementation of this software can increase yard efficiency in a way that easily justifies the investment An efficient off-line installation with a skilled off-line programmer can take care of the programming job of a complete ship while it is being built. This does, of course, assume that the yard has a good library of robot macros and an effective link between the cdl-line system and the yard's CAD/CAM system. Some readers from production may ask themselves: "What about my particular needs? I only have my drawings on paper." This may be the case for some yards which build naval ships, for instance. The macro based off-line programming technique can also be efficiently applied o this category of production. An experienced shop-floor operator can easily keep several robots fully occupied with job tasks by manually entering macro programs to the robot control system. This is achieved by utilizing the paper drawings and the yard's library of cutting or welding macros. It is important to keep in mind that on a daily basis the operator normally uses 10-25 robot macros while a complete large macro library contains on the order of 100-200 robot macros.

It is very important to take into account a complete system when an investment in a robotized production line is being considered. The analysis must at least include items such as: material infeed, outfeed, computer hardware, software, a macro library, training and a software maintenance agreement. An analysis of how the new production equipment interacts with the other production lines should also be performed. Simulation is a useful tool in the analysis. Factors such as transportation requirements, personnel resources, necessary ground space, etc. should be included.

EXAMPLE OF AN INTEGRATED ROBOT PRODUCTION SYSTEM

In this section, a description of a production system for manufacturing of webs and components for tanker vessels, bulk-carrier vessels and container vessels is given. Such a production line is currently being installed at a yard in Europe by TTS International AS.

The presentation given in the following sections does not aspire to be a complete description of the production system. It merely indicates the capabilities of this new but commercially available computerized and robotized production system. The web and component line is designed for manufacturing of webs with stiffeners, restricted in terms of physical dimensions to a maximum dimension of 3 by 16 metres. The layout in Figure 3 indicates the various system components. The production line is constructed IRB2000 robots with S3 controllers. Two external axes are augmented to the robots, the position of the gantry and the position of the robot base along the gantry, see **Figure 4.**

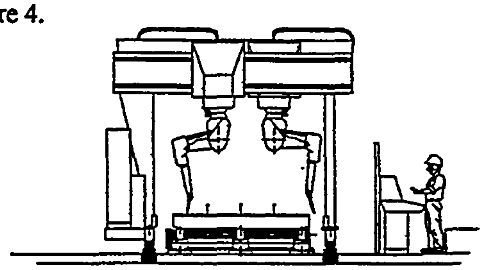


Figure 4. Robotized web welding station.

Capacity calculations and operator requirements

To give art example of the capacity of this line, it produces all webs and components for about four 160.000 tdw. bulk-carrier, tanker vessels or 3000TEU container vessels a year with 3-5 operators. Compared to manual welding or semi-automatic welding of the above mentioned products, this line has a substantially higher productivity. For a fully manually operated line with similar capacity, up to 20 operators are required. This figure is reduced to about 12 with a semi-automatic production line, while the robot line only requires about 3-5 operators. All the above calculations are based on a 230 day 17.5hr /2-shift cycle. These figures are largely affected by the complexity of the products to be processed. The above figures are based on low-complexity webs and components, which partly favors semi-automatic production. However, the robot production line is a multi-purpose production system and when the complexity and variation of the production increases, which currently is the case for several yards, the manual or semi-automatic alternatives require increased operator interference, while the robot production line is not affected by such complexity increases in the same way.

The work preparation tasks, that is the off-line programming of the robots, roughly require the services of one operator who is included in the total personnel requirement figure above.

Work Preparation

As illustrated in Figure 5, the total computer system layout of an integrated computer system in a around a transport system made up of a horizontal matrix conveyor system running in an endless loop, **carrying pallets for the production objects. One double-**robot and one single-robot-gantry are positioned over the transport system This line utilises ABB shipyard environment involves several system components at various levels. Note that the system presented here is one particular solution for the integration problem of this production line.

There are several ways and different strategies for conversion of CAD-data into a representation suited for generation of executable robot code. It is required that the operator tasks related to the process of transforming data from CAD data to robot code are reduced to a minimum. In genereal,the operation involves high-level quality control, inspection, and verification of the computer system performance, which today is a task no computer can do better than a trained human operator. Since the need for human interaction is reduced to a minimum, and one central site for these tasks can provide executable production programs for several production lines, the work preparation office is centralized and located in conjunction with the design department.

Three steps are involved in the work preparation.

Step 1. Design for production. The CAD-**operators and designers are creating a model of the ship by utilizing functions in the CAD-system. The** detailed design should take into account limitations and capabilities of the production system that will be used. The final result from this process is a computerized representation of the ship. Then, through so-called post-processor functions, the model representation is exported from the CMD-system and stored as a data-file on the yard's computer system. The post-processor solves topological conflicts and sorts the various CAD data into an object representation suitable for further precessing by the off-line programming system.

Step 2 Operations at the central work preparation office.

The next step is to perform the tasks in conjunction with the conversion of the data, and to create of input code for the robot production systems. By using a dedicated computer system specially developed for tasks of this kind, the data file containing the CAD-model is imported to the workstation-based system. Here, the assembly or unit released for production is displayed in a synthetic environment, visualizing the production line itself with the object to be processed. By using dedicated functions within the system, the operator can initiate semi-automatic functions whereby the model representation and create a data file containing those data which the robot system requires to be able to automatically generate the executable robot programs.

If a CAD representation is not available, an off-line manual assignment and scheduling of parameters to the chosen macros will take place. This method is practiced successfully at several yards and is under installation as a back-up method at this particular work preparation office.

For a completely automatic link to exist between the CAD system's post processor and the robot production line an automatic conversion from CAD drawings to robot programs must occur without any human intervention. This link is implemented for the robotized profile cutting line at this yard. Note that all the work preparation tasks for the entire yard take place at the centralized work preparation office.

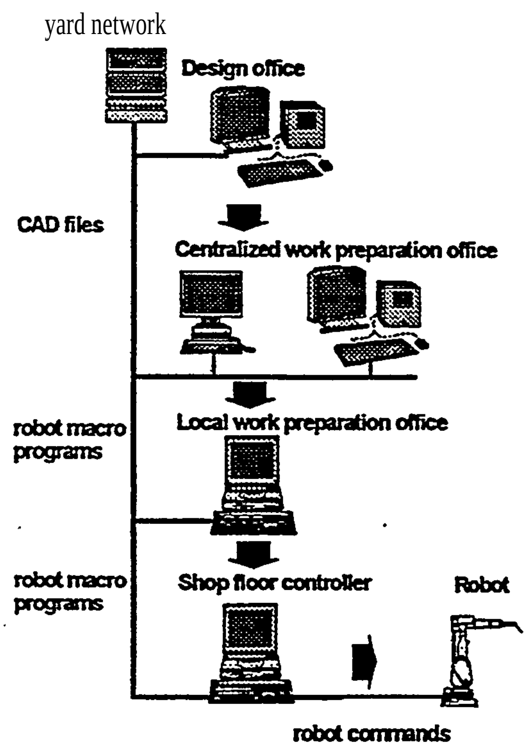


Figure 5. Computer system arrangement for off-line programming.

Step 3 From work preparation to shop-floor.
The third and last step in the conversion can be activated either at the central work preparation or at the local work preparation office, with the latter foreseen as the usual routine. Now the final robot programs will be created or compiled, This leads to the actual executable programs for the robot production system with additional peripheral equipment. At the local work preparation level the operators can select the input files for the robots on the basis of production orders from the planning systems and initiate the final automatic creation of the robot program This task may, as indicated above, also be performed at the central work preparation level since similar functions are available there. The software for these functions run on PCs, and the cost for redundancy is by far compensated for by the versatility of the total system From here on, the control of the robot operation is performed automatically at the production line itself, with possibilities for the robot operator to override and edit functions according to available production items or jobs present at the line.

All the types of systems referred to above use the macro technique for robot programming. The basic idea is that all the robot tasks that are foreseen to be required for a given production line are supported by a set of almost complete robot programming that is, semi-complete in the sense that the program files only need a few parameters characteristic for the object to be processed, the so-called macro methodology. In general, one type of production line will often repeat the same types of robot programs, only with small variations. This is described earlier in this article as mass production on a task level.

The production line described in this section has the Capabilities of all the solutions listed above. In sum, this robot programming environment incorporates a combination of some of the most desired and powerful functions that are available from the separate systems.

Figure 6 indicates that there are several available strategies and system solutions for the actual conversion of the data from the CAD-system A variety of robot vendors and system houses have developed different systems that all have special advantages over one another, but no system today is superior in terms of completeness.

Shop floor operations

The web and component line described in this section is matched with the integrated computer system described in the previous sections. This production line is the implementation and end result of the efforts that have been made to establish an integrated system that not only works on a theoretical level, but also utilizes the information exported all the way from the CAD-system to actually and physically produce the items that were initially designed. The following paragraphs give a general description of the material requirements and the modes of operation.

Transport system. The transport system is made up up from a horizontal matrix conveyor system, running in an endless loop, carrying pallets for the production objects. This system connects the onload and tack welding side of the production line with the robot welding areas on the opposite side. The control of the system is divided between the robot systems and the operators at the onload station. The onload operators control the movement of the transport system on their side semi-automatically, to give freedom for planning as well as to keep humans in charge of the operation. On the robot production side, one robot operator controls the robots. He can also control the transport system. Here, the operation is foreseen to be carried out more or less completely automatically, but the operator has full access to override and re-select movement patterns and sequencing of the robots by using manual override functions within the logistics system.

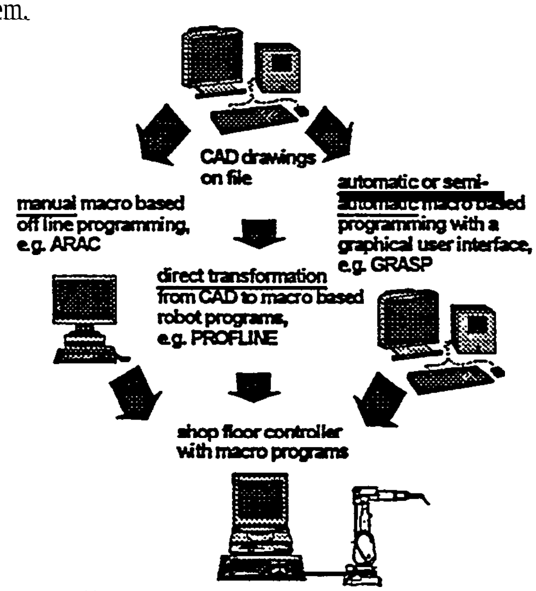


Figure 6. Off-line programming strategies.

Loading stations. Plates are loaded onto the pallets by use of the shop crane. Profiles are brought to the onload area in specially designed racks for easy access and pick-up. According to marked lines on the plates, the two operators mount profiles on the plates and tack-weld them manually. These tasks are performed using the stiffener mounting gantries each having a magnet manipulator, anchoring magnets and hydraulic actuators to press the profiles tightly down to the plate prior to tack welding. When one pallet is filled up with objects, it is released and automatically taken over by the robot systems.

Robot Welding Gantries The programs for the robot processing are, of course, already present and ready in the robot computer system, since the integrated system has created them automatically beforehand. When the robot operator enters the section identity for the objects that are located on the pallets, the robots will automatically activate the corresponding program and start executing it. Durning execution, the robot computer system will constantly monitor the operations and give report messages to the operator. These messages are also stored on a file for later evaluation and report generation. If, for instance, the wire-drum becomes empty, or another incident occurs requiring operator interference, the robots stop their actions, store where they are in space and in the task before moving to a safe position.Then the operator can refill or make adjustments and immediately initiate the process from where it was halted.

Out-loading Station When the pallet is completely processed by the robots, it is transported further to the outload buffer or the outload station, which is located at the infeed side of the line. Here, the orload operators empty the pallets by use of the same shop crane as for onload and move the webs or components over to the next transport medium. The pallets remain on the conveyor system, and continue their circulation around the system.

PROMISING TECHNOLOGY DEVELOPMENTS

This section will give the reader insight into some of the more premising technologies which will emerge in the near future and which will be of great advantage for robot production technology. STEP, neutral robot programming languages and standard robot macro libraries are discussed. The standard graphical file format IGES is also included for completeness, even though IGES is already an established ANSI standard.

Graphic File Formats and Product Modelling

As the computer hardware has become more complex, the complexity of the software has also increased. This has resulted in a growing variety of different CAD systems representing information in different ways. During the past years, several representation formats for data have been proposed, but, so far, none have fulfilled all the requirements for a streamlined CAD data exchange process. No formats have been able to represent geometrical data along with product information in an acceptable manner, though several formats have proven to be useful.

The IGES was developed for allowing data exchange between two independent CAD systems by use of a neutral file format. The conversion to or from the neutral format, is done by use of pre-/post-processors within the CAD systems. The latest IGES version 5.1 (IGES 1991), defines a file structure format, a language format, and the representation of geometrical, topological and non-geometric product data in these formats. Earlier. IGES versions had the disadvantage of producing a large amount of data or not being able to represent solids. These problems have been dealt with in the latest versions. There were also problems using the standard, as the pre/post-processor vendors tried to maintain proprietary rights. Due to its features, IGES has become a commonly used representation for information exchange. It is also important to mention that IGES has been a base for several other interface standards, e.g. PDES (Product Data Exchange Specification) and STEP.

The PDDI (Product Definition Data Interface) is design oriented and deals with product models. The purpose of the PDDI was to be an interface between the CAD and the CAM system. The work with PDDI was, however, merely conceptual research activities and the results were used for development of the PDES. The reason for making the PDES, was to make an interface which permits the exchange of data of the entire product development and production cycle. The PDES may be looked upon as an expansion of IGES, with organization and technological data added. Regarding functionality, PDES will contain IGES version 4.0. Thus, software for converting IGES into PDES will exist. In particular, PDES uses the formal language EXPRESS for modelling product information

STEP is an ISO activity to develop a new engineering product data exchange standard, ISO 10303. When completed, STEP will cover all aspects of a product's life cycle and all industries. STEP is based on a combination of several other common standards, such as IGES, PDDI, SET etc. It should be mentioned that STEP is not a graphics standard, but a data exchange standard, see also (Owens 1993).

To define the normative part of all information models in STEP, the formal product modelling language EXPRESS is used. EXPRESS is a product modelling language, based on entity relationship attribute models. EXPRESS has two forms; EXPRESS-G as graphical form and EXPRESS-I as instance form. EXPRESS has the advantage of being both human and computer readable.

So far it is mainly the car industry that has a STEP application protocol more or less finished for use, but the work to complete a protocol for the ship industry is already started. It is the authors' opinion that implementation of such will be of great advantage for the automation process occuring in the world's shipyards. This is due to a more streamline integration, allowing more product related data to b transferred the the CAD system, and further t production with a minimum of human interaction

Neutral Robot Languages

There exist several different national an international standards for a neutral robot languag IRDATA (Internal Robot Data), ICR (Intermedia Code for Robots), IRL (Intermediate Robot Languag and PLR (Programming Language for Robots) are th names of some of the established or suggeste standards for neutral robot languages and robot contr codes.

IRDATA has official status in Germany as a VI **(the German association of engineers) guideline f** robot control code, and it will be implemented as German DIN standard in the near future. ICR can b looked upon as a successor of IRDATA The work o ICR has mainly been undertaken by France an Germany. ICR has been proposed as an ISO standar but this was rejected by the ISO working group. PLR a German attempt to create a higher level robo language. The term higher level reflects a Pascal-lik syntax in contrast to the more assembly level whic ICR and IRDATA operate with. IRL is, like PLR, neutral robot. program language with a Pascal-lik syntax. IRL offers the general functionality of a hig level programming language allowing interaction wi external devices. Multi-robot handling multi-taskin and support for off-line robot programming are als among the features of IRL. Portability is, of course, o of the main targets with a neutral language such a IRL. IRL has been suggested to CEN as a proposal f a European standard, (DIN 66312 1993).

The introduction of a working neutral rob programming language will have numerous effect First, the costs of creating robot programming softwa will be dramatically reduced since the only differen from one vendor to another will be the man-machi interface. The resulting robot control code will be in standard format portable to any robot which accep standard robot control code. Post-processors from th standard control code to the proprietary control co will soon be introduced on the market. However, it is long way from the current status of standardize neutral robot programming to a functioning industr accepted standard. Ad hoc standards or proprietar but open normal robot programming formats a probably the solution for today's demand for a neutr robot programming language.

Open Standard Robot Macro Library

Presently, there is no international work on standardization of robot macros. The introduction of a standard open robot macro library written in a neutral robot programming language would be of great interest for the shipbuilding industry. The potential number of licenses sold would ensure that the price level of robot macros would drop dramatically. However, a number of problems must be solved. First and foremost the neutral robot programming language must become a working standard before the industry will risk committing itself to an open macro library.

SUMMARY

We have presented the current level of robot technology in the shipbuilding environment}

A case study of a modern computerized and robot based web and component line is included in this text to present the "state of the art" in robotized production in the shipbuilding environment,

A survey of the most relevant technologies with respect to robot production in the shipbuilding industry is also included.

REFERENCES

DIN 66312 document. 'Intermediate Robot Language", (1993).

ISO 6582 "Shipbuilding-Numerical control of machines - ESSI format". First edition 1983-04-01. Ref. No. ISO 6582-1983(E).

Owen J. ,(1993), "STEP - an introduction", ISBN 1-874728-04-6, Information Geometers, UK.

Rembold U., B.O. Nnaji and A. Storr, (1993), "Computer Integrated Manufacturing and Engineering", ISBN 0-201-56541-2, Addison-Wesley, UK.

"The Initial Graphics Exchange Specification (IGES) Version 5.1.",. (1991). National Computer Graphics Association, Administrator, IGES/PDES Organisation, Fairfax, VA 22031, USA.

Additional copies of this report can be obtained from the
National Shipbuilding Research and Documentation Center:

http://www.nsnet.com/docctr/

Documentation Center
The University of Michigan
Transportation Research Institute
Marine Systems Division
2901 Baxter Road
Ann Arbor, MI 48109-2150

Phone: 734-763-2465
Fax: 734-936-1081
E-mail: Doc.Center@umich.edu