

PLANNING AND IMPLEMENTING A WELDING
ROBOT IN A JOB SHOP

by

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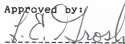
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TABLE OF CONTENTS

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LIST OF FIGURES	11
LIST OF TABLES	111
ACKNOWLEDGEMENTS	1v
CHAPTER I	1
INTRODUCTION	1
CHAPTER II	5
GAS METAL ARC WELDING	5
ARC WELDING ROBOT	8
CHAPTER III	12
FEASIBILITY ANALYSIS	12
DATA & OPERATIONAL ANALYSIS	23
CHAPTER IV	26
SELECTION & ECONOMIC ANALYSIS	26
ROBOT SPECIFICATIONS	33
ECONOMIC ANALYSIS	39
CHAPTER V	45
ROBOT SAFETY	45
MAINTENANCE OF ROBOT	53
TRAINING THE WORKFORCE	54
SOCIAL & ECONOMIC ASPECTS	57
CONCLUSIONS	61
REFERENCES	63
APPENDIX	64

LIST OF FIGURES

Figure

1	Different Manufacturing Methods for Different Volumes.	4
2	Main Product Families of Balderson Inc.	4
3	Different Components of GMAW Welding.	6
4	Layout of a Typical Welding Booth at Balderson Inc.	6
5	Arc Welding Robot System.	9
6 & 7	Carrying Heavy Welding Guns in Difficult Positions.	15
8 to 10	Different Part Positions Increase Set-Up Times.	16
11 & 12	Robot Can Weld in Horizontal & Vertical Positions with Equal Ease.	18
13	Hourly Cost of Robot and U.S. Labor.	22
14	Bucket & Blade Families have apprx 1200" Weld.	22

LIST OF TABLES

Table

1	Data & Operational Analysis.	24
2	Specifications of the Welding Robot for Balderson Inc.	34
3	Comparison of Application Features for Different Models.	37

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CHAPTER - I

INTRODUCTION

The priorities of present American manufacturing executives include product quality, high performance, on time delivery and low price of the manufactured products. Historically, automation has helped industries achieve these goals. Today automation in the United States is being seen in an even wider context - to increase competitive advantage.

Robotics is a form of automation that is becoming extremely popular due to their cost effectiveness at medium production volumes as shown in Figure 1. The population of robots in the United States is expected to increase by four times as compared to only a two fold increase in Japan during this decade (see Appendix 1).

Installation of robots in areas such as spot welding and painting may level off due to lower purchases by the automobile industry. Robot application to hazardous processes like arc welding are expected to increase [1]. Significant development of technology has helped in overcoming technical and economic problems encountered in applying robots to arc welding.

The purpose of this report is to describe the logical approaches required to plan and implement a welding robot into the Wamego plant of Balderson Inc. This robot would be used to fabricate components like buckets, blades, snow plows etc as shown in Figure 2. The analysis was divided into four phases: familiarization, feasibility analysis, selection and economic analysis, and the discussion of implementation issues.

The familiarization phase consisted of getting familiarized with Balderson company and the technology currently being used. Acquiring sufficient knowledge of robotic technology was also included in this stage.

Feasibility analysis involved surveying the plant to identify potential application area. Technical and non-economic criteria were established. Data and operational analysis was carried out to determine if a robot could be justified.

Selection and economic analysis consisted of choosing a robot from many models available in the market. Economic evaluation to determine the pay back period and cash flows were determined.

Implementation issues such as installation, training requirements, maintenance and optimization procedures for the proper use of robots were studied at the end of the analysis.

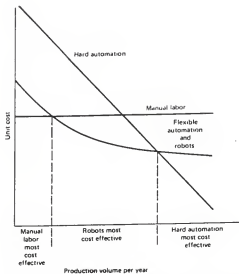


FIGURE 1. DIFFERENT MANUFACTURING METHODS FOR DIFFERENT VOLUMES
(REF: HANDBOOK OF INDUSTRIAL ROBOTICS, S.NOF)

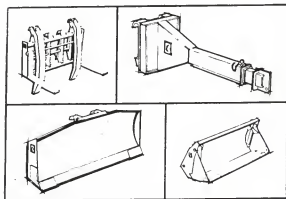


FIGURE 2. MAIN PRODUCT FAMILIES OF BALDERSON INC.

CHAPTER - II

In this chapter a brief introduction to Gas metal arc welding, and the features of a welding robot is made. The company profile of Balderson Inc. is provided in Appendix 2.

GAS METAL ARC WELDING PROCESS (GMAW)

Balderson Inc. use gas metal arc welding process for their operations. GMAW is one of the most popular semi-automatic welding methods today. Gas metal arc welding involves the use of a welding wire made of the same or similar metals as the parts being joined. The welding wire serves as an electrode in the arc-welding process. The wire is continuously fed from a coil and contributes to the molten metal pool used in the fusion process. Inert gases such as argon are used to surround the immediate vicinity of the welding arc to protect the fused surfaces from oxidation. Figure 3 shows the different components of GMAW and Figure 4 shows a typical welding booth at Balderson Inc.

There are two types of weld wires in use: solid wire and flux cored wire. Both of these have their own advantages and disadvantages.

Solid wire emits less smoke than flux cored

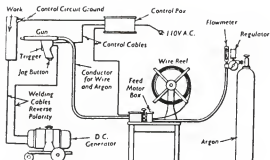


FIGURE 3. DIFFERENT COMPONENTS OF GHAW WELDING

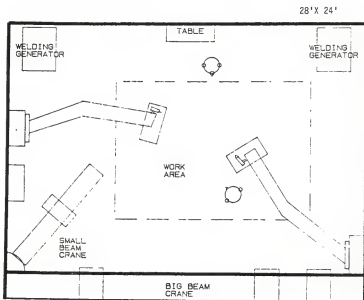


FIGURE 4. LAYOUT OF A TYPICAL WELDING BOOTH AT BALDERSON INC.

wire. The disadvantage of the solid wire is the poor quality of weldment when the welding process is done vertically. At high currents, an unequal length and profile of the weld is produced due to the flow of the weld pool. This problem largely discourages free-position welding.

The advantage of the flux cored wire is its ability to facilitate free-position welding. The flux cored wire consists of a tubular sheath filled with mixture of mineral flux and iron powder. This flux produces a slag which covers and holds the weld bead in position during solidification. Apart from this, flux cored wire allows higher deposition rates with wider joint tolerances and facilitates the production of superior quality welds [2]. The main disadvantage of its use is its high generation of fumes. This problem can be severe when the iron to be welded is not cleaned sufficiently or when ventilation is restricted.

At the present time manual welders at Balderson refuse to use cored wire because of the suspected health hazards [3]. Balderson welders use solid wire exclusively in their welding operations.

ARC WELDING ROBOT

A complete arc welding robotic system (robot cell) includes the robot, its controls, suitable grippers for the work, fixtures and the welding equipment as shown in Figure 5. An industrial robot that performs arc welding must possess certain features and capabilities like the following:

WORK ENVELOPE: The robots work envelope must be large enough for the sizes of the components to be welded. A sufficient allowance is also required for the manipulation of the welding torch. Six degrees of freedom is generally advised for arc welding robots.

CONTROL SYSTEM: Programming modes for a welding controller include speed and position settings, arc voltage, wire-feed speed and pulsing data and other operating parameters. Continuous path control is required for arc welding. The robot must also be capable of a smooth continuous motion in order to maintain uniformity of the welding seam. In addition, the welding cycle requires a dwell at the beginning of the movement in order to establish the welding puddle, and a dwell at the end of the movement to terminate the weld.

Data & Operational Analysis

Welding Parameter	Manual Welding	Robot Welding
Weld speed	30 cms.p.m. (12 i.p.m.)	44 cms.p.m.* (17 i.p.m.)
Set-up time	2 hr 30 min	1 hr 15 min
Weld time	3 hr 30 min	1 hr 45 min
Arc-on time	1 hr 15 min	1 hr 15 min
Total time	6 hours	3 hours
Man power	4 welders	2 operators

* Minimum for an arc welding robot

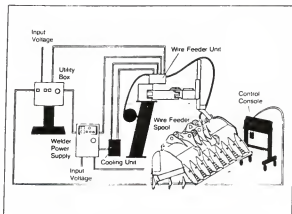


FIGURE 5. ARC WELDING ROBOT SYSTEM

PROGRAMMING: Programming the robot for continuous arc welding must be considered carefully. To facilitate the input of the program for welding paths with irregular shapes, it is convenient to use the walkthrough teaching method in which the robot wrist is physically moved through its motion path. For straight welding paths, the robot should possess the capability for linear interpolation between two points in space.

A floppy diskette system is required for downloading the taught programs and for program backup and storage.

Since the components made by Balderson are huge and heavy, they are brought to the welding fixture by overhead cranes. A welding fixture will be required to position the component accurately. Two fixtures would be desirable in the cell so that the robot can perform its welding cycle on one part while the operator unloads the previously welded assembly and loads the component for the next cycle. The robot would begin its cycle by making tack welds at critical locations along the joint. The tacks fewer than the number used for manual welding, prevent distortion from welding heat. Robot can also be programmed to weld in different locations sequentially to avoid warping of the plates. The robot will have a

programmable 'home feature' which enables the user to define any point as the home position and thus allow for greater flexibility in the placement of parts within the cell.

The various features described above assume that the components are fairly uniform. Accordingly, the robot would be able to repeat the programmed motion path for each set of components to produce welded assemblies with great consistency. If such assumptions are found to be invalid, then the robots can be equipped with smart sensor systems to track the welding path during the process and compensate for irregularities in the path. These vision based sensors find deviations and provide real time adaptive control for the welding torch (See Appendix 3).

CHAPTER - III

FEASIBILITY ANALYSIS

In this chapter the problems with the present method of welding and the advantages of using a robot are studied. Data analysis to justify the robot is also made.

At the beginning of this report it was said that automation is indeed a solution to many of the demands of the present industry. Many manufacturing firms have enthusiastically embraced factory automation in the machine shop. However the weld shop often sits at the back of the plant doing its thing manually, like the blacksmithy from which it descended. Welding too can profit and prosper from automation. While many engineers are aware of the potential areas of robot applications, few of them have attempted to make an organized study.

Balderson Inc. has a sophisticated 'fabrication shop' housing horizontal boring machines, N.C. flame cutting machines etc. Their welding operations, however, are done by manual arc welding process. The main problems with the present manual welding process are its inherent hazardous work environment and low productivity. Thus after surveying the plant, welding

was identified as a potential area for the application of a robot. The characteristics of the present method that would make the robot application practical and economically feasible are as follows:

HAZARDOUS WORK ENVIRONMENT:

A hazardous work environment is one of the major reasons for robot selection. In manual arc welding, the operator is protected from fumes and gases by a welding shield, safety gloves and apron. But these devices do not provide enough protection. The problem is severe under the following situations:

- Cold weather conditions when aisle-way doors are closed.
- Uncleaned, rusted steel plates are welded.
- Flux cored wire is used as the electrode.

Some of the effects of long term exposure to arc welding fumes are:

- Fumes and gases can be dangerous to health.
- Discomfort such as dizziness, nausea, dryness or irritation of nose, throat or eyes.
- Chronic exposure can lead to siderosis (iron deposits in lungs) and infection of pulmonary functions.

- Arc rays (ultra-violet radiations) can injure eyes and skin.
- Electric shock can kill.

LOW PRODUCTIVITY:

The productivity of a manual arc-welding operation is characteristically quite low. The productivity is often measured by the "arc-on" time (proportion of time during which the welder is actually welding). Typical values of arc-on time are as low as 30% in batch-production. The reasons for low productivity are:

High fatigue factor: The hand-eye coordination required in a generally uncomfortable working environment tends to be tiring. Figures 6 and 7 show an example of situations where an operator is carrying a heavy welding gun in uncomfortable positions.

Large set-up times: Usually large set-up times are required when heavy structures are welded. Balderson allocates about 40% of the total production time for setting up the component. Figures 8 through 10 show the different part positions for the final assembly welding of buckets indicating the cause for high set up time.



FIGURES 6 & 7. CARRYING HEAVY WELDING GUNS IN DIFFICULT POSITIONS



FIGURES 8 through 10. DIFFERENT PART POSITIONS INCREASE SET-UP TIMES

A hazardous working environment and low productivity are the main criteria considered to justify the use of a robot at Balderson. The advantages of replacing the present manual operation with a robot are:

BETTER WORKING CONDITIONS:

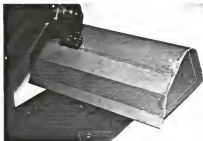
Better working conditions result from removing the human operator from an uncomfortable, fatiguing, and potentially dangerous work situation.

HIGHER PRODUCTIVITY:

With a robot welding, arc-on time can be increased to as high as 80%. The reasons for this are:

Elimination of the fatigue factor: A robot can continue to operate during the entire shift without the need for periodic rest breaks.

Reduced set up times: A robot can weld at more joints in the same setting when compared to a human welder. Since a robot is unaffected by fumes, the use of flux cored wire is possible. This facilitates welding in vertical and horizontal positions with equal ease as shown in Figures 11 and 12. The final result is the reduction in set up times. Flux cored wire also increases the quality of the weldment and deposition



FIGURES 11 & 12. ROBOT CAN WELD IN HORIZONTAL & VERTICAL POSITIONS WITH EQUAL EASE

rate. In addition to these benefits, welding robots in general have the following advantages:

REDUCED LABOR COSTS:

Figure 13 shows that direct labor hourly costs have risen exponentially over the last two decades and are expected to continue to increase even more sharply. The availability of skilled welders is also decreasing. Good specification and code welders are in short supply as the younger generation isn't interested in a welding career [4]. Hiring and training welders is becoming very expensive. Other labor costs are worker compensation claims. Hazards such as heat and stress are thought to impair health and represent the fastest growing category of worker compensation claims [5].

In contrast to the above, robot hourly costs have remained relatively constant. An important factor in this phenomenon is the fact that production and operation costs of robots decrease with the increase in robot population. Replacement of workers in hazardous positions through robotization cuts the medical care premium also by reducing the number of workers to be insured.

BETTER QUALITY OF THE PRODUCT:

The use of a robot improves manufacturing quality due to the following reasons: Better parts quality going into the operation at the robot cell result in better outgoing quality. Also improved quality in the welding results from the capability of the robot to perform the welding cycle with greater accuracy and repeatability than its human counterpart. This translates into a more consistent welding seam, one that is free of the start-and-stop buildup of filler metal in the seam that is characteristic of many welds accomplished by human welders.

REDUCED INVENTORY:

The design and installation of a robot forces the user to consider such issues as the delivery of materials to the cell, the methods required to perform the welding process, the design of the fixtures, and the problems of production and inventory control related to the operation of the cell. Typically these issues are not adequately addressed when the company relies on human welding.

Having established some of the advantages of a robot over manual operations the next step is to carry out data and operational analysis. This involves identifying the parts, production volume, the work station (a particular stage of manufacturing process) etc. which are suitable for introducing a robot.

When identifying these factors at Balderson, the following criteria were set:

- The operation should involve simple and straight welds.
- Components should have similarities in design.
- Cycle time should be at least 10 seconds.
- There should be sufficient volume of production.

Preliminary study showed that the bucket and the blade family of components satisfied the above requirements (See Figure 14). The bucket family was considered for further study because of its larger quantity of production. The manual operation data were gathered from the company. The data pertaining to robot operation have been assumed based on predetermined robot cycle times and other references [1].

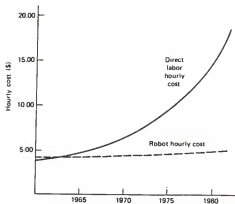


FIGURE 13. HOURLY COST OF ROBOT & U.S. LABOR (REF:2)

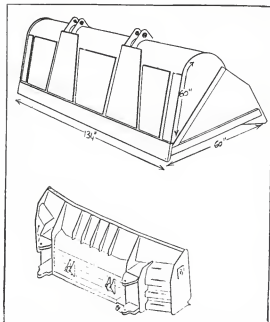


FIGURE 14. BUCKET & BLADE FAMILIES HAVE APPRX 1200" WELD

DATA & OPERATIONAL ANALYSIS

Balderson manufactures buckets in varying types and sizes. These include general buckets, coal buckets, woodchip buckets, side dump buckets etc. These buckets are attached to various models of Caterpillar wheel loaders, track-type loaders and hydraulic excavators.

For estimation purposes an average size of the bucket was considered. Table 1 shows the summary of data and operational analysis.

A final assembly welding station was considered suitable for robot operation due to the following reasons:

- straight and simple welds would reduce the structural complexity of the robot and simplify the necessary motion path.
- the long welds measuring about 350 cms (140") would increase robot arc-on time and minimize set up times.
- an average weldment of about 3050 cms (1200") per component and a volume of production of 1000 components per year would insure a 80% utilization of the robot.

Component : Coal Bucket (Part # 6845C1)
 Weld station : Final assembly

TABLE 1. Data & Operational Analysis

WELDING PARAMETER	MANUAL WELDING	ROBOT WELDING
Weld speed	30 cms.p.m. (12 l.p.m.)	44 cms.p.m.* (17 l.p.m.)
Set-up time	2 hr 30 min	1 hr 15 min
Weld time	3 hr 30 min	1 hr 45 min
Arc-on time	1 hr 15 min	1 hr 15 min
Total time	6 hours	3 hours
Man power	4 welders	2 operators

* Optimum value. Increasing welding speed to a very high level requires changes in welding parameters. This will make torch location very critical [2].

The above analysis showed that there will be annual savings equivalent to the wages of two welders. This indicates that the area identified is an attractive candidate for the application of robot.

Thus for Balderson it is technically feasible to introduce robot. The next phase of this project consisted of selecting a suitable robot and carrying out a detailed economic analysis.

CHAPTER -IV

SELECTION & ECONOMIC ANALYSIS

The process of selecting a robot for an application is an important activity. If the wrong robot is chosen it will be an expensive mistake, not only in terms of cost but also in terms of wasted time and effort. The purpose of this chapter is to convert the information gathered during the earlier analysis into a form that can be used to select a robot and also carry out an economic analysis.

Robot specifications usually contain the following types of information:

Number of Axes: In practice, most robots have between three and six axes (five being average). Not all axes may be servo controlled.

Configuration of the axes: There are different types of configurations like linear, circular, articulated. These have to be selected depending on the application.

Speed of movement of each axis: This is always expressed in either degrees/sec or meter/sec. It is often necessary to translate degrees into a linear measure in order to relate it to a process requirement.

Where many axes move simultaneously it is difficult to calculate the precise transit time between two points. The problem here is to account for the time it takes for acceleration and deceleration of the manipulator within a particular motion. In practice if times are critical they will be measured manually. Sometimes robot software contains linear and circular interpolation facilities.

Range of movement of each axis: This is quite simply how far an axis will move either in degrees or in meters.

Working volume of the robot: Since robots have many axes, the working volumes often have many convolutions. This is particularly true of robots with all radial movements. Since the work to be completed on an application has to reside within this working volume it must be accurately described.

Accuracy and repeatability of a robot: The accuracy and repeatability of a robot are always measured at a predetermined point at or near the end of the robot manipulator. The accuracy of the robot relates to the robot's ability to return to a taught position after programming, measured at the end of the axis, within its working volume. Repeatability is a measure of

the robots consistency and accuracy over a period of time. These terms are often interchanged but repeatability is always a better indication of the stability of the robot system.

Weight of the system: This is of importance where floor loading is critical.

Load capacity of the system: This is a practical limit placed by the design of the robot mechanism and the control circuits on the tool mounting plate. Often it is expressed by manufacturers in terms of moment. Sometimes it is quoted as a total load capacity including the weight of the gripper measured at the gripper-arm interface. Exceeding capacity usually causes a downgrade of the accuracy and repeatability figures.

Motional power source: There are three types of robot motivational sources: pneumatic, hydraulic and electric. Robots tend to only have one type of motivational source. The main reason for this is an engineering one, in that it is simpler to design an all-electric machine, an all-hydraulic machine or an all-pneumatic machine. Each motional power type has particular advantages and disadvantages. Pneumatic drive is generally reserved for smaller robots that possess

fewer degrees of freedom. These robots are often limited to simple "pick-and-place" operations with fast cycles. Pneumatic power can be readily adapted to the actuation of piston devices to provide translational movement of sliding joints. It can also be used to operate rotary actuators for rotational joints. Electric drive systems do not generally provide as much speed or power as hydraulic systems. However, the accuracy and repeatability of electric drive robots are usually better. Consequently, electric robots tend to be compact, requiring less floor space, and their applications tend toward more precise work. The cost of an electric motor is much more proportional to its size whereas hydraulic drive system is somewhat less dependent on its size. It should be noted that there is a trend in design of industrial robots toward all electric drives, and away from hydraulic robots.

Type of memory storage: There are two types of memory associated with the robot control computers: volatile and non-volatile. Volatile memory (RAM) is memory which is erased when the robot system is powered down or when an emergency power-cut occurs. Non-volatile memory (ROM) is not erased on power down. All robot systems have both volatile and non-volatile memory, but

have different functions. The non-volatile memory keeps all of the information about how the system works and what jobs have been taught. The volatile memory is where calculations are done and the system is controlled.

The size of the memory: The size of the memory has a direct relationship to the performance of a robot system. Again the difference between volatile and non-volatile memory is important. The larger the volatile memory, the more sophisticated the software can be. The more sophisticated the software, the better the control and the more extensive the features such as the linear interpolation can be. The larger the non-volatile memory the greater the number of jobs that can be held. Often non-volatile memory can be extended by the use of disk storage or magnetic-tape storage. In this case, the size of the fixed non-volatile memory is only important in that it limits the size of the program that can be taught.

Power requirements: This is usually expressed in kilovolt amps and relates to the power used by the robot. Where the robot is used with other equipment this must be determined separately.

Maximum operating temperature: This determines the temperature at which a robot's performance begins to

seriously deteriorate.

Maximum operating humidity: This determines the level of humidity at which the electrics and mechanics of a system begin to malfunction.

Number of interface channels: No robot works in isolation and the number of interface channels, both input and output, can greatly limit the flexibility of the system.

Methods of programming the robot: Robot programming is accomplished in two ways: Leadthrough methods and textual methods. The leadthrough methods require the programmer to move the manipulator through the desired motion path and that the path be committed to memory by the robot controller. There are two types of leadthrough programming: Powered leadthrough and manual leadthrough. The powered leadthrough method makes use of a teach pendant to control the various motors and to power drive the robot arm and wrist through a series of points in space. Each point is recorded into memory for subsequent playback during the work cycle. The manual leadthrough method, also called the 'walkthrough' method, is more readily used for continuous path programming where the motion cycle involves smooth complex curvilinear movements of the

robot arm. In the manual leadthrough method, the programmer physically grasps the robot arm and manually moves it through the desired motion cycle. A teach button is often located near the wrist of the robot which is depressed during those movements of the manipulator that will become part of the programmed cycle. This allows the programmer the ability to make extraneous moves of the arm without their being included in the final program. The control systems for both leadthrough procedures operate in either teach mode or run mode. The teach mode is used to program the robot and the run mode is used to execute the program.

Safety features: The laws which relate to the safety of manufacturing equipment quite clearly expect equipment to be fail safe. This is particularly important during the teaching phase of using robots as man and machine work in close proximity. Any emergency should leave the robot in a state that presents no threat to anyone standing nearby. Also, it should be possible to interface safety interlocks that enable the robot system to be put into a safe state in the event of unexpected occurrences. Safety features are discussed in detail in the Chapter V.

Software adaptability: As a general concept software adaptability is usually recognized by the ease with which programming changes can be made. As a feature it is important in batch work where continuous change occurs.

SPECIFICATIONS OF ROBOT AT BALDERSON INC.

The robot for the application at Balderson must have an appropriate combination of the technical features that have been discussed so far. To make the final selection of the robot, the guidelines set by Groover [6] are useful.

The procedure consists of preparing a detailed listing of the technical features as shown in Table 2 and comparing these features against the specifications of the alternative models under categories: "must" and "desirable". The "must" features are ones that must be satisfied by the robot. If any of the candidates do not satisfy the "must" features, then the model is excluded from further consideration.

Table 2. Specifications of the welding robot for Balderson Inc.

1.	Number of axes (servo controlled)	6
2.	Type of movement of axis	Articulated
3.	Speed of movement (tool center point)	1000 mm/sec (25"/sec) appr.
4.	Range of movement of axis: X axis	>2500 mm (100")
	Y axis	> 900 mm (60")
	Z axis	> 900 mm (60")
5.	Work volume required	X axis 6250 mm Y axis 2500 mm Z axis 2500 mm
6.	Accuracy/Repeatability (per cycle)	+ 0.25 mm (0.010")
7.	Weight of the system (robot)	around 1500 kg (3300 lbs)
8.	Load capacity of the system	around 25 kg (55 lbs)
9.	Motional power source	All electrical *
10.	Type of memory (should be extendable)	around 20 k **
11.	Power requirements	460 v.3 phase, 60 Hz
12.	Maximum operating temperature	4 to 48 C ° (40 to 120 F)
13.	Type of interface channels	around 20
14.	Method of teaching	Walkthrough and teach pendant with option for offline program

- * Since they are comparatively more accurate & compact than hydraulic system
- ** This is equivalent to 500 data points which should be sufficient for welding components like buckets. It is possible to extend this capacity, if required, by extending the RAM pack or by linking the controller to the larger computer available in the company.

The "desirable" features are ones that are not necessarily required to accomplish the application but would be highly beneficial during installation and/or operation. The specifications of each robot candidate would be compared to each of the desirable features, and a rating score would be assigned to the candidate to indicate how well the robot satisfies the particular feature. There may be differences in relative importance among the various features, and this would be taken into account by giving each feature a maximum possible point score. Determination of the rating score for the different robot models in each feature category would be a judgement call.

For Balderson, the features are divided into two categories: "must" and "desirable" according to the Groover's suggested procedure as shown in Table 3. The must features were considered essential for the welding application. It turned out that two of the models being considered have only five axes, whereas six axes were considered a requirement. This number is influenced by the characteristics of the job and the motion capabilities required at the manipulator. Therefore the models from Westinghouse and Hitachi were eliminated from further consideration.

The desirable features were each evaluated as to its relative importance by giving it a possible range of point score values. Judgement has been made to determine how each of the remaining four models can be rated for the given feature. It should be noted that some of the desirable features listed in the form included non-technical considerations as well as technical considerations. Based on the total of the point scores, the Cincinnati Milacron T3 646 model has been selected as the most suitable robot. Copies of the brochures of the robots are enclosed at Appendix 4.

Table 3. Comparison of application features for different models.

Technical Feature		Robot Model Candidates				
"Must" features	Cincinnati T3 846	GMF S-200	Yasakawa L-15	ESAB LK	Westing RWL 008	Hitachi
Continuous path	OK	OK	OK	OK	OK	OK
6 axes	OK	OK	OK	OK	X	X
Ease of programming	OK	OK	OK	OK	OK	OK
"Desirable" features (min:0 max:5)	Weight	Cincinnati T3 846	GMF S-200	Yasakawa L-15	ESAB LK	
Work volume	A=3	A*4=12	A*4=12	A*2= 6	A*1= 3	
Repeatability	A=3	A*3= 9	A*1= 3	A*2= 6	A*4=12	
Evaluation of vendor	B=2	B*4= 8	B*4= 8	B*3= 6	B*4= 8	
Controls	C=1	C*4= 4	C*5= 5	C*3= 3	C*3= 3	
Welding interface	C=1	C*4= 4	C*4= 4	C*4= 4	C*5= 5	
Low Price	C=1	C*4= 4	C*4= 4	C*5= 5	C*5= 5	
		41	36	30	38	

Close to the heels of Cincinnati Milacron T3 646 are Esab LK robot and GMF S-200 robot. Esab has a better welding interface, better repeatability and lower cost. GMF has good vendor assistance and service facilities. However both Esab and GMF robots do not have good reachability. It is possible to use them with tracks to increase the reachability but that would increase the cost and complexity of installation of the robot.

ECONOMIC ANALYSIS

The cost data required to perform the economic analysis of a robot project can be divided into two types: investment costs and operating costs. The investment costs include the purchase cost of the robot and the engineering costs associated with its installation. The operating costs include the cost of labor needed to operate the robot, maintenance costs, and other expenses associated with the robot. For the economic analysis, it is often convenient to identify the cost savings that will result from the use of a robot.

Weld process economics study for Balderson

The cost of welding consists of direct labor, supplies and overhead. To understand the impact of robotic welding, a comparison between manual and robotic welding costs are made. Each major cost is examined and ballpark estimates are determined to justify the investment.

The supplies used at Balderson for the welding operation are 052 (1.1 mm) diameter MIG wire and 85 Ar 15 Co2 gas.

Weld Wire

The utilization of robotic welding will increase the cost of weld wire. There are two reasons for this increase. The first is that tighter control of wire cast, diameter, helix, and new spooling techniques is required for proper system operation. The second is that the current low volume of wire production for robotic welding has not attracted sufficient competition or resource commitment in the wire industry.

The increase in wire cost can soon be recovered due to higher system uptime, eliminated patching and higher transfer efficiencies.

Welding Gas

The robot very accurately controls the torch so splattering with lower cost gas will be less than currently achieved manually. Gas cost is a function of flow volume and deposition rate. Higher deposition results in the reduction of the gas volume required per unit weight of the wire deposited.

Many welding robots have shown as much as 65% gas savings due to more wire deposition per cubic meter of gas. A robot can weld at as high as 90 cm/min (35"/min).

The increase in the cost of welding wire and decrease in the cost of gas can be considered to balance each other [7]. Therefore the labor cost savings is given highest priority in the economic analysis.

Labor cost

The elimination of direct labor during weld deposition is a key factor in reducing welding cost.

According to the data given in Table 1, the robot is expected to replace about four welders with two operators (semi-skilled welders trained to do programming).

This would result in annual savings of wages as follows:

Approximate wages of 4 welders	\$ 100,000
Approximate wages of 2 operators	\$ 40,000
Savings in labor cost	\$ 60,000

Payback method

The total investment in a Cincinnati Milacron's T3 646 robot including installation, programming, fixtures and training would be about \$ 150,000. The total operating costs (maintenance, utilities etc) are expected to be \$ 10,000 per year and the anticipated revenue of \$ 60,000/year is expected from savings in manpower.

The net annual cash flow for the project is:

$$\text{\$ } 60,000 - \text{\$ } 10,000 = \text{\$ } 50,000/\text{year}$$

$$\text{Therefore the payback period} = \frac{150,000}{50,000} = 3 \text{ years}$$

Since the payback method ignores the time value of money, the equivalent uniform annual cost method is also employed for economic analysis.

Equivalent Uniform Annual Cost Method

To begin with, it is assumed that a 25% MARR (minimum attractive rate-of-return) is acceptable to Balderson. The robot project can be expected to have a 7 year service life [6]. We have the initial investment of \$ 150,000, and annual savings of \$ 60,000 and an annual operating cost of \$ 10,000.

The initial investment (\$ 150,000) is converted into its equivalent uniform annual cash value using the capital recovery factor from the table of interest factors. Therefore the sum of cash flows would be figured as follows:

$$\begin{aligned} \text{Annual cost} &= - 150,000 * (A/P, 25\%, 7) + 60,000 - 10,000 \\ &= - 150,000 * (0.31634) + 50,000 \\ &= + \$2549 \end{aligned}$$

Since the resulting uniform annual cost value is positive, this robot project would be a good investment with a 25% MARR.

Return on Investment (ROI)

The return on investment method determines the rate of return for the proposed investment of robot. This rate of return can be compared with the company's minimum attractive rate of return to decide whether the investment is justified.

We have,

$$\text{Annual cost} = -150,000 * (A/P, 1, 7) + 60,000 - 10,000 = 0$$

$$\text{Therefore, } (A/P, 1, 7) = \frac{50,000}{150,000} = 0.33$$

Looking through the interest factor tables for a match of the A/P factor for $n = 7$ years, we find the rate of return is between 25% to 30% which can be considered very good.

In addition to labor, equipment and other sources of costs that are readily quantifiable in a robotics application project, there are other possible

sources of costs and savings that are more difficult to quantify and evaluate. They include such factors as improvements in the working conditions of the operators and inventory savings. While these factors cannot be easily quantified into costs and savings, they should be considered in the overall strategy for implementing a robot.

The robot requires fixtures, tooling, takes time for programming, and needs more precise joint preparation and fitup than manual welding does. However a robot increases arc-on time, uses less floor space, and decreases use of safety apparatus like shoes, gloves and masks.

CHAPTER - V

IMPLEMENTATION ISSUES

In this report recommendations to deal with management-oriented issues like safety, training, and maintenance are discussed.

Robot safety

Robot safety should be a major consideration in any new robot installation. Individuals designing and installing a new robot system should look at all the available safety options which will protect both workers and robots and which will prevent damage to the workstation where the robot is placed. A little time in the initial analysis can save a great deal of time and money later on.

The analysis should consider both hardware and software needs to insure that all the safety options have been explored. Robots, because of their unique characteristics and flexibility in design, demand safety considerations and safety planning methods which differ somewhat from those for humans.

Certain dangerous situations in arc welding could be avoided with adequate safety planning. The situations include the following:

- The robot appears 'dead' but may actually be awaiting input signals at which time it would begin to move without warning.

- Any number of occurrences, either within the robot or in its environment, may cause sudden unprogrammed moves.

- Improperly trained personnel may produce unprogrammed moves.

- The welding robot may initiate an unshielded arc. Workers accustomed to seeing a human welder drop his face shield before striking the arc receive no similar warning.

- Unless the robot is programmed offline, the programmer must work within the work area, a potentially hazardous area.

There are several areas where safety considerations can be built into a robotics project. These are the hardware options found in the components of a robotic system and the software options of the microcontroller program that help drive the entire system.

Software protection guards against improper operation of the robot at an inappropriate time. The use of redundant systems is the best protection option. A

redundant system unit turns itself off when subsystems are not in agreement with the information being exchanged in the software. This redundancy feature can be used in both a double redundant or even a triple redundant system in which there is an additional check to make sure that the information exchanged through the software is appropriate for the action to be performed. The types of software checks that are available are redundancy checks, parity bits, check sums, error detecting or error correcting codes, error messages, and interrupt messages.

There are also options that are built into the computer's software systems in which, if a signal is not properly received from a sending unit, the entire system will shut down. This process is called a software time-out option. For example, if a robot manipulator does not receive a command signal, the computer controller can, within milliseconds bring the entire robot to a halt. Manual intervention would be required to reset the system. If there are problems in the data communication lines or basic software and a lengthy time delay occurs during which the robot servo motors receive no appropriate signal, the entire system would shut down rather than allow the robot to react to inappropriate

signals. This would also insure that if the computer system is having a problem such as a loop, or is in an interrupted state, or has encountered a hardware failure, the entire robot system would immediately shut down.

Other types of software controlling options for robot safety include an emergency response by the system if inappropriate arm velocities are received. With this option, if the robot were swinging outside the prescribed velocities, the entire system would shut down to insure safety for individuals who might be in the vicinity of the robot, and for individuals or machines in other areas.

There are also options on arm limitations so that the travel of a manipulator arm outside of a prescribed range will shut down the system. Proper travel limits are maintained and the arm does not have a chance to build up velocity.

Other types of software control features can be used in the robotics system, including external sensors that would immediately halt a robot system by sending a signal to the computer to shut down the entire system. One example of this type of system might be a sensor that monitors the working range of a manipulator arm so

that if individuals cross a sonic or electric eye beam, the entire system shuts down. This would ensure the safety of the machine and any worker walking within the travel trajectory of the manipulator arm. The sensors are not very expensive.

There should be adequate amounts of hardware options so that if an emergency stop is necessary, the human operator should be within an easy reach of the dead-man switch. When the operator assigned to a work station is not available, the emergency stop switch should be adequately marked so that any worker can shut it down. There should also be an emergency stop switch located on the teach pendant.

The most common approach is to construct a physical barrier around the periphery of the robot cell. The periphery of the robot cell must be defined to be outside the farthest reach of the robot in all directions with end effector attached to the wrist. The workcell would also include any equipment in the cell which operates with the robot. The barrier should not be designed only for the programmed work cycle envelop because a malfunction of the controller may cause the robot to follow a trajectory different from its normal program. The barrier has the effect of preventing human

intruders from entering the vicinity of the robot while it is operating. The barrier often consists of a fence with a gate for access to the workcell. The gate is equipped with an interlock device so that the work cycle is interrupted when the gate is open. A positive restart procedure is designed into the cell for resumption of the cycle, rather than using the gate closure for restarting. Other possible physical barriers include safety rails and chains, although these are not as effective as a full fence.

Other hardware safety support systems are signs and painted stripes on the floor. Although these will not restrict individuals from coming into a specific area, they can be used as a secondary, informational support tool. The use of flashing lights on machines can also be used as a secondary warning device. Red lights on the manipulator system themselves can be used to grab the attention of workers before they walk into the travel path of a robot arm.

One extreme hazard of computer equipment is in the area of Radio Frequency Interference (RFI). Radio frequency interference can cause the computer system controlling a robotic unit to operate improperly. Any transmitting devices such as walkie-talkies or beepers

should not be used near a robot system under computer control.

RFI can "bleed over" from alternating and direct power supplies utilized in the robotic system. It is important that RFI be adequately accounted for in the workplace and that the computer controller for the robot system and data communication cabling be adequately shielded.

High power lines of alternating or direct current should be checked for RFI, especially where powerlines run through a plant.

Electric components of the entire robot system should be adequately grounded. Recommendations made by the vendor for the proper grounding requirements of the system must be strictly followed. Improper grounding will not only affect the performance of the system but may also damage its electrical components.

When a major power failure hits the plant, the robot system should be brought back into production independent of the power which is used to turn on in the plant. This method of restart insures that the operator can initiate a warm rather than a cold startup of the robot system. A warm start is one in which the robot has been working for sometime and does not have to go

through a full range of movements to get up to operating speed, starting at below-normal temperatures of the servo motors. A cold start is one where the robot system has been completely turned off, power is initially applied, and the robot has to go through a number of different warmup operations to insure that all the components are operating at their proper speeds and temperature ranges.

The second component of protection on the electrical power supply is called a "dropout" protector. "Dropout" occurs when a powerline voltage drops below its normal operating range; Dropouts occur when power levels become inadequate due to the excessive energy demand of the plant's functioning equipment, all of them operating at the same time. Because of overloading, the main plant circuitry does not have adequate power to serve all the devices, including the robot system. A "dropout" can damage the robot system because inadequate power strains the robot servo motors.

A power regulator can assure that appropriate power is being fed into the robot system or shut it down if the voltage is too low.

Maintenance of robots

Robots are sophisticated electronic/mechanical systems whose reliability is generally good. Nevertheless, the complexity of these machines means that occasional equipment failures do occur and periodic maintenance is required.

Maintenance requirements are determined by the type of robot and its specific use. The single most important factor affecting both the need for maintenance and the provision of maintenance is its power system. All robots will require attention to mechanical parts, including cleaning to remove abrasive or corrosive agents, lubricating, attending to seals and replacing protective accessories. For example, a typical electrically driven industrial robot requires weekly lubrication of its guide posts to ensure proper operation. In addition, all parts must be inspected regularly for wear.

When robot systems malfunction, the causes of the malfunction can be many and varied, but by and large they manifest themselves in relatively few ways. The singlemost significant feature of any malfunction in a robot system is erratic behavior, or simply unexpected movements. These may be grouped as minor deviations from

the taught path of operation, and major deviations from the taught path of operation.

To a trained technician the significance of these symptoms is great. Minor deviations or erratic movements are indicative of a system that is going out of alignment, rather like a car that is in need of tuning. The remedy for this kind of problem is simply to realign the control system and to check the mechanical integrity of the system (e.g. tighten loose bearings, check for worn components or couplings etc.). If neglected it is possible these minor problems may result in major deviations. So regular maintenance is absolutely essential.

Training the workforce

The range of skills required will vary greatly depending on who is involved. By and large the greatest demand for new skills will be among the people directly involved with the new system: operators, technicians, foremen, and supervisors. At the operator level the skills required to use the robot system are evident. They will need to know how to stop and start the robot system in both normal and emergency situations. If the robot has to be programmed by the operator then he must

be given complete training. Indeed this is not a daunting prospect as the majority of robot systems are designed for ease of use. Beyond these operational skills is safety training, and this is particularly important when operators come close to the robot.

Operational skills will be greatly enhanced through practice, and any training course must have plenty of 'hands-on' experience. Usually initial training is done off-site and it is well to allow adequate time after on-site installations for more practice before serious production begins. The majority of robot users find that it takes about two months before operators are fully competent, by which time the robot system will already be in use. It is wise to insure that as many operators as possible are trained to use the robot system, as this reduces the company's vulnerability to sickness and labor turnover.

The level of management immediately above the operators must also be thoroughly familiar with the robot system and know as much as the operators. This is essential if their authority is not to be undermined and their control of work people and work process supported. Beyond the basic skill level needed to operate the system the foremen or supervisors must be aware of the

performance parameters of the system. This will enable them to monitor the quality and output of the system and where necessary feed information back into the manufacturing system about the product or process design. As with the operators, the training of foremen or supervisors should be a combination of on-the-job and off-the-job experience.

The training required by middle and senior managers is of a more conceptual nature. Since the role of these managers is to plan and implement change in the company it is clear that their training should begin before the decision to use robots is made. This training should continue throughout the introduction of the new robot systems.

Last and by no means least is the training of the company's technicians. The training of these people must be conditional upon the level of skill and education of the existing maintenance people. Those who have a background in maintaining electrical and electronic systems will probably find little difficulty in coping with the maintenance of robot systems. However, the same will not necessarily be true of the maintenance technician who has only experience in maintaining mechanical systems. Assuming that the right

people are available, nearly all the training for maintenance will be done off-site. This training will include fault-diagnoses training for each part of the robot system. The technician should be provided with all the documentation and circuits to keep the robot system going. It is also usually necessary to buy special tools and spares to ensure that the training can be put to use in the factory.

Fortunately the majority of robot systems can be repaired in a straightforward way with replacement of electrical or mechanical components and complete printed circuit boards. Complex system problems usually require the attention of an expert from the robot system supplier. Some companies who are not concerned with a fast response time often subcontract all maintenance to the system suppliers.

Social and Economic aspects

Even though the robot economics clearly proposes labor displacement as the central benefit, many companies retain displaced workers and depend upon normal attrition to balance out the work force [6]. In their study of the human resource implications of robotics, Hunt and Hunt concluded that the main issue of

the robotic revolution is skill-twist and not job elimination. Robots are only one of several change agents in the work environment. Concurrent advances in product design, metal cutting, metal forming, finishing, assembly, and inspection under the control of computers will also modify the type of skills needed to work in the 'factory of the future'.

The United States is not confronting radical technological changes for the first time. Robots should not be given the credit or blame for initiating these changes. This does not make the potential problems associated with the introduction of robots less important, or less urgent. It does not mean that the need to cope with technological change is continuing. Resistance to the use of robots would not affect the likelihood of having a surplus of people whose skills are no longer needed while there is a simultaneous shortage of people with the skills required to develop and support the new technologies. Both mismatches are potentially troublesome.

Experience from a long history of technological innovation in the U.S. economy suggest that the rate of robot introduction, as well as the social impacts of their use, will depend on factors beyond the control of

individual firms. More emphasis must be put on the development and exploitation of new and evolving technologies to replace those mature and declining methods to manufacture standardized products. In an advanced industrial economy, standardized products must be replaced by new types of products produced in the batch mode. This implies a continuing rapid rate of technological innovation in both the product and its production techniques. Otherwise loss of these industries to overseas platforms with lower material and labor cost would follow.

Robots will contribute importantly to the material well-being of mankind without painful dislocation of individual workers. Robots will shoulder more and more drudgery of the world's work so that human beings can have more and more time to take care of its creative and joyous aspects.

EFFECT OF ROBOT ON LABOR AT BALDERSON INC.

The workers at Balderson Inc. have adopted a position that generally promotes the introduction of new technologies. At the same time the workers expect certain benefits in return. The following guidelines are suggested for the successful introduction of the robot:

Sufficient notice must be given to those workers who are likely to be displaced due to the introduction of robot.

The robot should be introduced in such a way as to cause the least amount of displacement. Normal attrition, increased production and job promotion of the workers are some of the means of achieving this goal.

Existing workers should be trained to operate the robot.

CONCLUSIONS

The purpose of this report is to describe the logical approach required to plan for and implement a welding robot into the Wamego plant of Balderson Inc. The analysis was divided into four phases: familiarization, feasibility analysis, selection and economic analysis, and the discussion of implementation issues.

The familiarization phase consisted of getting familiarized with the Balderson company and the technology currently being used. Acquiring sufficient knowledge of robotic technology was also included in this stage.

Feasibility analysis involved surveying the plant to identify potential application area. Technical and non-economic criteria were established. Data and operational analysis was carried out to determine if a robot could be justified.

Selection and economic analysis consisted of choosing a robot from the many models available in the market. After a robot was chosen, economic evaluation was used to determine the feasibility of this project.

Implementation issues such as installation, training requirements, maintenance and optimization

procedures for the proper use of robots are discussed at the end of the analysis.

This study showed that a robot will alleviate problems of an inherently hazardous work environment and low productivity associated with the present method of manual welding. Data analysis showed that the Bucket and Blade families of components of Balderson Inc. were ideally suited for robotic welding. Assuming an annual production volume of 1000 buckets, the robot would be utilized 80% of the time for a two shift operation. Cincinnati Milacron's T3 646 robot, Esab's LK robot and GMF's S-200 robot were selected as ideal candidates. Economic analysis showed an investment of \$ 150,000 for this project would have a pay back period of 3 years with an ROI of 25-30%.

While improvement in working conditions and increased throughput do produce some savings, labor displacement is the central benefit of this project. Productivity that can be achieved without displacement, however, is the most socially acceptable. The impact of labor displacement should be moderated by adopting strategies like natural attrition, increased production or job enhancement.

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FORECASTED GROWTH OF ANNUAL ROBOT PRODUCTION IN UNITS

FORECASTED GROWTH	1985	1995
WORLD	52,000-56,000	130,000-140,000
JAPAN	31,000	57,500
UNITED STATES	7,700	31,300
WEST GERMANY	5,000	12,000
UNITED KINGDOM	3,000	21,500
SWEDEN	2,300	5,500
ITALY	1,250	3,500
NORWAY	1,000	2,000
FRANCE	1,000	2,800

REF: Handbook of Industrial Robotics (1985), Shimon Nof

BALDERSON INC., WAMEGO, KANSAS, U.S.A.

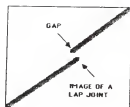
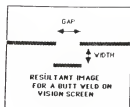
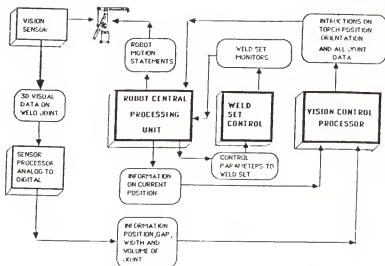
Balderson Inc. is an auxiliary equipment manufacturer for Caterpillar Tractor Co. They have been producing job matched attachments for Caterpillar machines for over 50 years. The company has another plant at Jacksonville, Florida. Balderson products are marketed through a wide network of Caterpillar dealers. Their products are focused on six prime markets: agriculture, construction, industrial, logging, mining, and petroleum. The product line at the Wamego plant is comprised of four major families: blades, buckets, couplers, and snow removal attachments as shown in Figure 2. There are nearly 40 variations within this product range. Sometimes job orders like 'Snorkel' ladders are also taken up to fully utilize available manufacturing resources during lean periods.

The company employs about 175 people at the Wamego plant. About 120 people are employed in the manufacturing departments and about 55 in the commercial and administrative department.

Company history

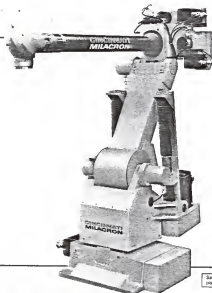
In 1914 the Balderson family moved its business from Louisville to Wamego in Kansas. Neil Balderson and his father, John, became partners in blacksmithing which

was the traditional business of the family. When John died in 1920, Neil began to see more and more of the farmers around Wamego investing in those "new-fangled" automobiles and in more complicated farm machinery. Accurately sensing this turn of events, Neil cut down on the blacksmithing part of the business and went in for welding and iron work, changing the name to Balderson Welding Shop. Neil's son, Willard, who attended Kansas State college of Engineering during late 1920s, joined the business at this time as a welder. A big switch was made from shoeing horses and working early day farm equipment to the manufacturing of snow plows. Neil generously gave much of the credit to Ira Taylor, former Pottawatomie County Engineer and first maintenance engineer of the then infant Kansas State Highway Department. Taylor asked Balderson to rebuild and repair some old snow plows for the State. The state liked the rebuilds, and Balderson was in the snow plow business. In 1930 he started building plows of his own design, selling them locally. With two helpers, Neil and Willard built about ten plows a year in their small shop. In 1935 Balderson was recognized by Caterpillar Tractor Co. as their auxiliary equipment manufacturer. Today Balderson Inc. have been rated as outstanding steel fabricators.



CINCINNATI
MILACRON

T3646

Industrial
RobotFor Long Reach
Process Applications

Safety equipment may have been removed or updated to comply with the product and must be in place prior to operation.

**The Long Reach Process Robot
With 50lb Load Capacity****For Versatility**

The electric T3 646 robot has been designed specifically for process applications. It combines all the control and programming power of Cincinnati Milacron's new ACRAMATIC Version 5 control with a slim dexterous robot arm.

Its payload of 50 lb combined with its velocity of up to 40 ips and its tremendous working volume make it ideal for all types of process applications ranging from sealant dispensing to light machining. Its slim forearm and in-line three roll wrist make it highly suitable for working in confined areas.

**Brushless Servo Drives—
Absolute Positioning****For Speed and Precision**

Each axis is driven by its own state of the art brushless motor and servo drive. These drive systems provide the speed, torque and response necessary for precise control of end effector motion.

Dual resolver feedback devices on each axis measure absolute position and eliminate the need to re-align the robot to a "home" position, even if control power is lost.

All axes are equipped with brakes which maintain arm position when power is removed. This feature, together with crad power removal, allows the robot to shut off automatically after a designated amount of idle time and to restart at the same point in the cycle when required.

Unique Mechanical Arm Design**Optimizes Work Envelope and
Minimizes Power Requirements**

The four bar linkage design of the arm provides an optimum work envelope for both horizontal and vertical motion. The mechanical axis drive systems incorporate ball screws for the shoulder and elbow, an anti-backlash gearbox for the base and new drive roll wrist and rear gear box design. A counterbalance system is built into the shoulder axis that minimizes the machine power consumption.

Advanced Robot Control**For Programming Power and
Teaching Simplicity**

Milacron's new ACRAMATIC Version 5 Robot Control, utilizing 80186/8087 microprocessors, is user friendly. The robot may be taught on-line with the aid of the teach pendant, or offline with the aid of Milacron's Robot Offline Programming System (ROPS).

Controlled Path Motion coordinates all six axes of the robot to move the Tool Center Point from one point to the next at the desired velocity. The paths between points may be straight lines or arcs of circles when utilizing the optional Circular Path Control feature. The Tool Center Point is defined by the operator, and may be changed at will throughout the program. Floating point arithmetic ensures optimum smoothness and precision of path motion. Program and system data are stored on a 3.5 inch floppy disk. An optional MS-DOS®

file management system is available. The standard disk drive and an optional second disk drive are located in the cabinet with access through an auxiliary door. Over 10,000 points may be stored using the additional memory option.

The T3 646 robot may be interfaced with a variety of peripheral devices, ranging from simple binary switches to intelligent sensors and remote data bases, through its Version 5 control. Communications may range from simple AC or DC binary signals to the more sophisticated serial CDCMP based communications (RS232C, RS422). Analog voltage outputs may be used as control signals for peripheral equipment and extra fully proportional servo axes are supported by the control. A 10 Megabit Backplane solution for MAP 2.1 is also available.

Integrated Application Systems**For Process Applications**

Cincinnati Milacron has designed complete process application systems for easy integration into new or existing manufacturing facilities.

The ACRAFLOW mastic dispensing system, comprising a servo-controlled metering unit and the necessary controls ready to connect to a mastic supply system, will apply mastic in a controlled manner. The bead/spray width can be initially defined and will then be maintained regardless of robot speed. The dispensing control is completely housed inside the robot control cabinet allowing maximum use of floor space.

The ACRA ARC robotic arc welding system has been developed over the years to satisfy customer requirements. This system interfaces the weld power supply, wire feeder, positioning tables and associated hardware with the robot to provide total process control. Use of the optional MILATAC™ seam tracking system serves to further enhance welding operations.

Cincinnati Milacron will design and implement other completely integrated application systems utilizing the versatile T3 646 Industrial Robot. The resources and experience gained by over 100 years of service to industry can be applied to the design of robotic solutions to manufacturing problems.

Full Milacron Support

For Full Confidence and Satisfaction

Feasibility studies, systems design, communications packages, tooling, on-site project coordination, training, service... Cincinnati Milacron's full range of engineering support is available with every T3 646 Robot.

To Learn More... Whatever your application or production problem, we can help you find a productive, profitable solution. Contact us at Cincinnati Milacron Marketing Co., Industrial Robot Division, 4701 Marburg Avenue, Cincinnati, Ohio 45209. Phone (513) 841-6200.

All illustrations and specifications contained in this literature are based on the latest product information available at the time of publication. The right is reserved to make changes at any time without notice or process, materials, equipment, specifications and models, and to discontinue models.

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*MS DOS is a trademark of Microsoft Corporation

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SPECIFICATIONS

Load Capacity

Load 250 mm (10 in) out and 125 mm (5 in)

from tool mounting plate

22 kg (50 lb)

Number of axes, configuration, servo system, control type

Number of served axes

6

Configuration

Articulated

Drive System

Brushless motors

Position feedback

Brushless resolver absolute

Control type

Controlled path at Tool Center Point

Positioning Repeatability

Repeatability, in cycle

±0.25 mm (±0.010 in)

Angular range of motion, velocity

Base

Range

Velocity

Shoulder

±150 to +150 deg

90 deg/sec

Elbow

±45 to +55 deg*

150 deg/sec

Pitch/Yaw relative to forearm

±60 to +150 deg*

120 deg/sec

Roll relative to wrist

±115 to +115 deg

320 deg/sec

Roll

±450 to +450 deg

560 deg/sec

Reach, path velocity and acceleration

Horizontal reach to tool mounting plate

2600 mm (102 in)

Horizontal range of wrist center

1525 mm (60 in)

Vertical range of wrist center

2700 mm (106 in)

Nominal velocity of TCP

1015 mm/s (40 in/s)

Horizontal acceleration of TCP

0.2g

Wrist torque capability

Roll 1

35 N·m (640 lb·in)

Roll 2

75 N·m (1620 lb·in)

Roll 3

25 N·m (550 lb·in)

Memory capacity, I/O contacts

Data size/Number of data points

17 k bytes/500**

Number of program sequences

256

Number of input contacts/Maximum optional

16/64

Number of output contacts/Maximum optional

16/64

Floor space, weight

Robot

0.8 m³ (8.3 HP)

1500 kg (3300 lb)

Control

1.0 m³ (11.1 HP)

840 kg (1850 lb)

Ambient temperature, power

Ambient temperature (air conditioner included)

5 to 50°C (40 to 120 °F)

Power requirement

480 volt, 3ø, 60 Hz

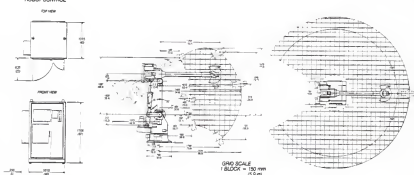
Power Rating

10 kVA

*Additional angular constant: 60 deg (yellow angle) = shoulder angle; 150 deg

**Additional memory available: over 10,000 points

ROBOT CONTROL



CINCINNATI MILACRON YOUR COMPETITIVE ADVANTAGE.

Printed in U.S.A.

S-200



BASIC DESCRIPTION

The GMF Model S-200 is a six-axis simultaneously controlled, articulated coordinate, electro-mechanically operated robot.

S-200 features include:

- 6 axes of motion
- 15kg (33 lbs) payload.
- Path accuracy: $\pm 1.0\text{mm}$ ($\pm 0.040''$) at 500mm/sec. & $\pm 2.0\text{mm}$ ($\pm 0.080''$) at 1000mm/sec
- Path repeatability: $\pm 0.5\text{mm}$ ($\pm 0.020''$) at 500mm/sec. & $\pm 1.0\text{mm}$ ($\pm 0.040''$) at 1000mm/sec
- 270° base rotation
- 1440mm (56.7") reach motion
- 2123mm (83.6") vertical motion
- 1200mm/s (47in/s) max. sealing speed
- Slender arm design
- Analog output signal proportional to tool tip velocity.

S-200 applications:

- Sealing
- Material handling
- Deburring
- Parts transfer
- Machine loading/unloading

MECHANICAL FEATURES

Model S-200 employs heavy-duty machine tool-type construction throughout and is built to operate in the most severe plant environments.

Design features include

- Massive cast iron mounting base.
- Cycloidal drive in base axis
- Anti-friction ball screw drive in waist and shoulder axes
- Sealed for life bearings on all critical rotating switches for overtravel protection
- Accordian-type protective covers for ball screws
- Compact in-line wrist.

- Dust-proof maintenance access covers
- Sealed electrical connections through each housing
- Industrial electrical cabinets

DRIVE FEATURES

Each axis motion (1, 2, 3, 4, 5, 6) is driven by state-of-the-art AC drives offering

- Fast acceleration and deceleration.
- Absolute encoders
- Precision position
- No brush maintenance.
- Long service life.
- World renowned dependability of FANUC servo drives

DRIVE DESCRIPTION

The base rotation utilizes a planetary gear reducer on the cycloidal drive to offer greater rigidity than harmonic drives with reduced backlash.

The waist bend (2) servo motor drives a precision ball screw and nut. The ball nut is attached to the (2) axis housing supported by precision bearings. An electro-magnetic

brake is attached to the end of the ball screw.

The shoulder bend (3) servo motor drives a precision ball screw and nut. The ball nut is attached to the (3) axis lower arm. The (3) axis arm is attached to a vertical connecting arm which pivots in the waist axis housing. An electro-magnetic brake is attached to the end of the ball

screw.

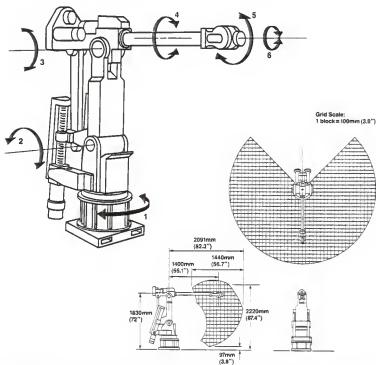
Arm roll (4) servo motor drives a harmonic reducer. An electro-magnetic brake is attached to the input of the harmonic reducer. The output of the harmonic reducer drives a set of precision gears to rotate the arm.

Wrist pitch (5) servo motor drives a harmonic reducer. An electro-

magnetic brake is attached to the input of the harmonic reducer. The output of the harmonic reducer drives a set of precision gears to rotate a set of bevel gears at the end of the robot arm. A precision set of bevel gears rotates the wrist.

Wrist roll (6) servo motor drives a harmonic reducer to rotate the wrist.

DIMENSIONS



CAPACITIES

Load capacity 15kg (33 lbs.) at wrist mounting surface at maximum speed and extension

Approximate weight
Mechanical unit=580kg
(1 276 lbs.)

AXIS

DESCRIPTION

RANGE

SPEED

(1)	Base rotation	270°	90° per sec
(2)	Waist bend	95°	72° per sec
(3)	Shoulder bend	95°	72° per sec
(4)	Arm roll	480°	240° per sec
(5)	Wrist pitch	240°	240° per sec
(6)	Wrist roll	540°	300° per sec

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PLANNING AND IMPLEMENTING A WELDING
ROBOT IN A JOB SHOP

by

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AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

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ABSTRACT

The purpose of this report is to describe the logical approach required to plan for and implement a welding robot into the Wamego plant of Balderson Inc. The analysis was divided into four phases: familiarization, feasibility analysis, selection and economic analysis, and the discussion of implementation issues.

This study showed that a robot will alleviate problems of an inherently hazardous work environment and low productivity associated with the present method of manual welding. Data analysis showed that the Bucket and Blade families of components of Balderson Inc. were ideally suited for robotic welding. Assuming an annual production volume of 1000 buckets, the robot would be utilized 80% of the time for a two shift operation. Cincinnati Milacron's T3 646 robot, Esab's LK robot and GMF's S-200 robot were selected as ideal candidates. Economic analysis showed an investment of \$ 150,000 for this project would have a pay back period of 3 years with an ROI of 25-30%.