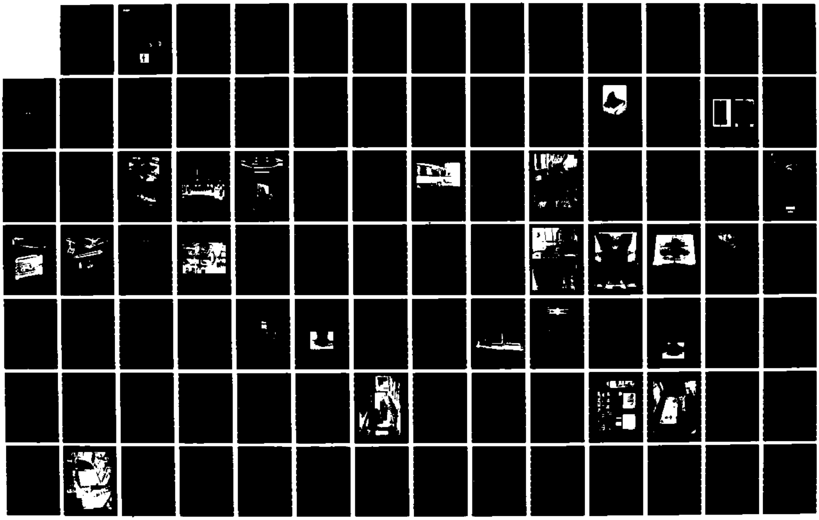
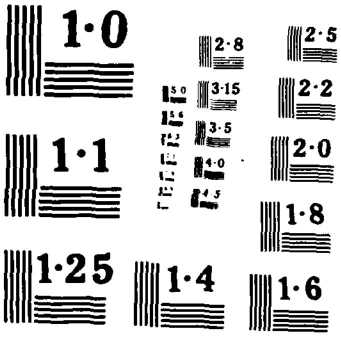
AD-A170 149 ASSESSMENT OF ELECTRON BEAM WELDING IN SHIPYARD CONSTRUCTION(U) AMERICAN WELDING INST LOUISVILLE TN J C DANKO DEC 85 AWI-CR-86-002 NB84RAC45137 1/3

UNCLASSIFIED F/G 13/8 NL




1·0
2·8
2·5
3·15
2·2
3·5
1·1
2·0
4·0
1·8
1·25
1·4
1·6

(12)

AWI CR-86-002
NBS CONTRACT NB84RAC45137

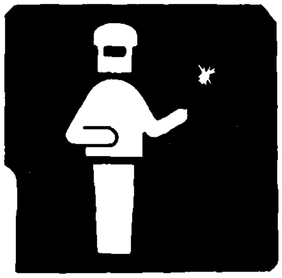
AD-A170 149

ASSESSMENT OF ELECTRON BEAM WELDING IN SHIPYARD CONSTRUCTION

DECEMBER 1985

DTIC
ELECTE
JUL 25 1986
S D
D

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited



AMERICAN WELDING INSTITUTE

86 7 1 100

AWI CR-86-002
NBS CONTRACT NB84RAC45137

ASSESSMENT OF ELECTRON BEAM WELDING IN SHIPYARD CONSTRUCTION

DECEMBER 1985

PREPARED FOR
U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
325 BROADWAY
BOULDER, COLORADO 80303
CONTRACTING OFFICER'S TECHNICAL REPRESENTATIVE
RICHARD P. REED

PREPARED BY
H. D. DORTCH
CHICAGO BRIDGE & IRON COMPANY
HOUSTON, TEXAS 77240

EDITED BY
JOSEPH C. DANKO

AMERICAN WELDING INSTITUTE
NEW TOPSIDE ROAD
ROUTE 4, BOX 90
LOUISVILLE, TN 37777

NOTICE

This report was prepared by the American Welding Institute (AWI) for the United States Government. Neither the United States Government, nor any agency thereof, nor any of their employees, nor AWI, members of AWI, nor any person acting on behalf of AWI: (a) makes any warranty, express or implied, with respect to the use of any information, apparatus, method, or process disclosed in this report of that such use may not infringe privately owned rights; or (b) assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method, or process disclosed in this report.

TABLE OF CONTENTS

LIST OF FIGURES

PAGE

LIST OF TABLES

PAGE

ABSTRACT

With the advancement of modern day high-energy welding technology, electron beam (EB) welding shows promise for application to specialized areas of welding fabrication in the shipbuilding industry. The findings of this report indicate that EB welding can be compared to the conventional methods of welding in the shipbuilding industry and be feasible as a long term investment. With the present day state-of-the-art minicomputers and automatic tracking systems, EB welding could be readily adapted to production line fabrication such as is required for the flat panel and T-stiffener to panel assembly areas.

INTRODUCTION

The purpose of this report is to assess the feasibility of applying a high energy beam welding process such as electron beam welding to the shipbuilding industry. With the advantages of EB welding being deep penetration and high travel speeds with minimal distortion, the shipyard would be able to apply this process to increase both productivity and decrease cost, when compared to conventional welding processes.

To pinpoint the specialized areas where EB welding could be applied, field trips were made to preselected shipyards. The fabrication areas which showed application for EB welding were: 1) flat panel/deck fabrication, 2) T-stiffener to panel assembly, 3) pipe welding and 4) T-stiffener web to flange welding.

Each fabrication area and the method of EB welding most likely to be adapted was analyzed. Due to the size limitations of the shipyard assemblies to be EB welded, the three following concepts appear to be the most feasible: 1) mobile or sliding seal EB welding, 2) non-vacuum EB welding and 3) large chamber EB welding.

Each concept would have a certain advantage if applied to that specific fabrication area in the shipyard.

As part of the study for this report, a survey was taken of the domestic electron beam manufacturers and the users of the equipment they produce. The EB manufacturers which the data was received from are 1) Leybold Heraeus Vacuum Systems, 2) Sciaky Bros. and 3) MG Industries - Steigerwald Systems.

An economic cost comparison between welding a 1 inch and 1-1/2 inch thick panel assembly with the automatic submerged arc process and the electron beam process was presented With the task manhours included, EB welding showed an 31% cost savings for the 1 inch thick panel assembly and a 43% cost savings for the 1-1/2 inch thick panel assembly as compared with two sided submerged arc welding process. Capital costs of equipment were not included.

Other areas of electron beam welding such as metallurgical and mechanical properties of EB welded shipbuilding steels, defects and the safety considerations of EB welding are also discussed in this report.

Fundamentals of the Electron Beam Welding Process

Electron beam welding is a high energy fusion process that is accomplished by bombarding the joint to be welded with a concentrated beam of electrons that have been accelerated to a velocity about 2/3 the speed of light. As the electrons impact the material, they give up their kinetic energy in the form of heat which inturn causes localized vaporization. The reaction force from the vapor produces the presence of a local molten area beneath the vapor. This process continues until the desired depth of the "keyhole" as shown in Figure 1, is achieved. The depth of the weld is determined by the power input and the speed at which the beam is moved along the joint. When the beam moves forward, it heats more strongly the leading surface of the cavity and the molten metal is thrown back behind the beam exposing a solid surface which inturn is melted and the molten metal passes to the rear and solidifies thus forming a weld with deep narrow sides.

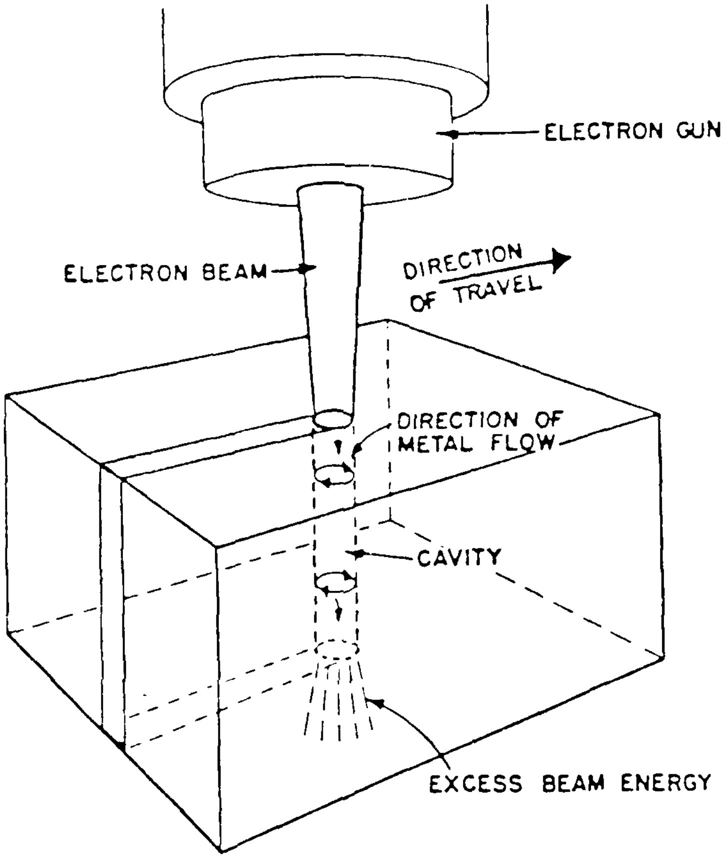


FIGURE 1 REPRESENTATION OF THE MECHANISM OF FULL THICKNESS PENETRATION ELECTRON BEAM WELDING

The beam of electrons is generated in an electron gun by heating a negatively charged emitting material to its thermonic emission temperature range. In this event, free electrons are "boiled off" this emitter and are given speed and direction by their attraction to a positively charged anode. A precisely contoured electrode surrounding the emitter electrostatically shapes the electrons into a beam.

In a diode (cathode anode) electron gun, the beam shaping electrode and the emitter are both at the same electrical potential and together are referred to as the cathode.

In a triode (cathode-grid-anode) electron gun, the emitter is at one potential and the beam shaping electrode can be biased to a slightly more negative potential to control the beam current. For this case, the emitter is referred to as the cathode and the shaping electrode is called the bias electrode or grid cup.

A magnetic focusing lens is used to reduce the diameter of the electron beam and focus the stream of electrons down to the concentrated beam that contacts the work surface. Also a magnetic deflection coil can be used to "bend" the beam thus providing a means for moving the focused beam spot to the desired point of contact. The auxiliary mechanical and electrical components in conjunction with the electron beam gun are commonly called the electron beam gun column assembly. Figure 2 illustrates the main elements of the electron beam gun column.

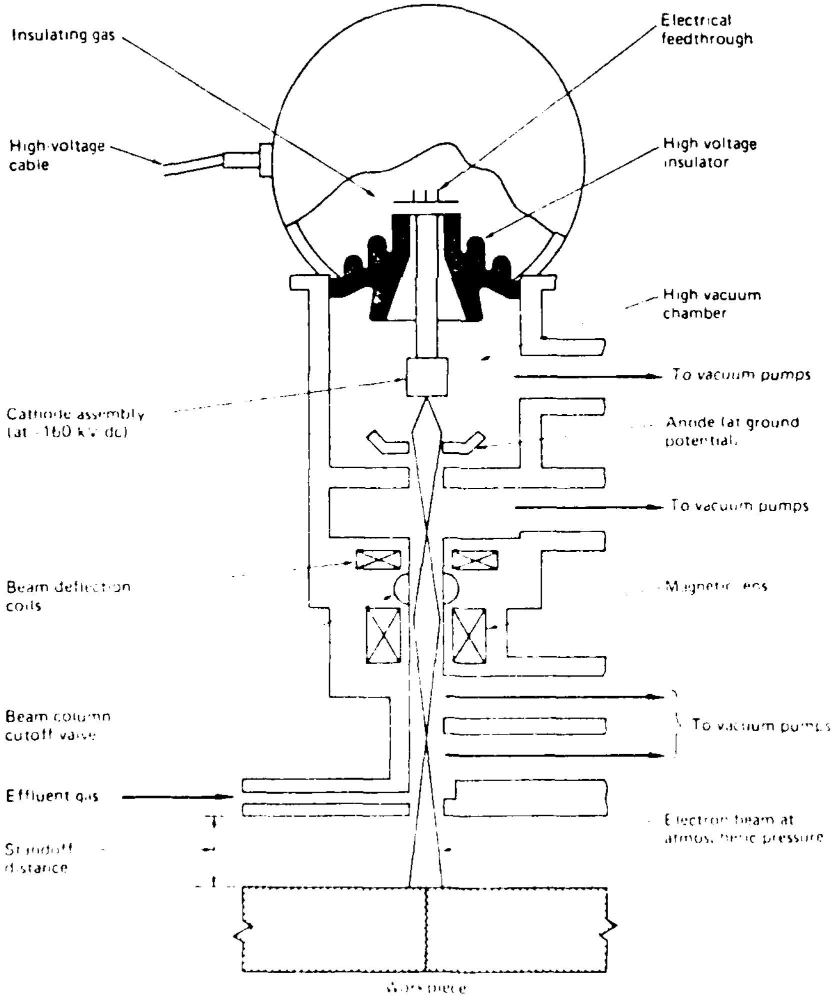


FIGURE 2 MAIN ELEMENTS OF THE ELECTRON BEAM GUN COLUMN

Depending upon the required capabilities of the electron gun, it can be designed by the manufacturer to achieve various accelerating voltage levels. If the gun is designed to operate in the 60KV range, it is considered low voltage. If operation is in the 150KV range it is considered high voltage. The main advantage of using an electron beam gun with high voltage capabilities is the longer gun-to-work distances possible and the high power spot densities at low beam currents which results in lower emission and longer filament life.

The essential variables which control the desired weld result of EB welding are the accelerating voltage (kinetic energy of the electrons), the beam current (number of electrons per second), the travel speed, beam spot size and the standoff distance between the gun assembly and the workpiece. Increasing the accelerating voltage or the beam current or decreasing the travel speed without changing any other penetrameters will increase the penetration depth of the beam.

The beam spot size which is focused on the workpiece is determined by the gun and electron optics used, the focusing current, the standoff distance between the gun assembly and the workpiece, the accelerating voltage and the beam current. By changing any of these variables to increase beam spot size will in effect reduce depth of penetration and increase weld width if the welding speed is left unchanged. The normal beam spot diameter used for EB welding varies from 0.005 to 0.050 in. depending upon the power used.

The power density of the electron beam is in the range of 10^4 to 10^7 watts/cm^2 which results in deeper penetration and higher welding speeds as compared with conventional welding processes.

The electron beam gun is normally isolated from the welding chamber through the use of valves. This would allow the gun to be maintained in a vacuum in the order of 1×10^{-4} torr (high vacuum) while the welding chamber can be vented to atmosphere to allow access to the chamber when welding is not taking place. The high level of vacuum on the gun is required to maintain the gun component cleanliness, prevent oxidation and to prevent arcing between the electrodes at various potentials. It is beneficial to have the welding chamber vacuum at the same degree of vacuum to minimize the scattering of the beam electrons from collisions with residual air molecules inside the welding chamber during welding.[1]

EB Welding can be classified into three distinct modes of welding depending upon the operating pressure at the workpiece. 1) High vacuum (EBW-HV), where the workpiece is in an ambient pressure ranging from 10^{-6} to 10^{-3} torr* 2) medium vacuum (EBW-MV), where the workpiece is in a vacuum ranging from 10^{-3} to 25 torr 3) non-vacuum (EBW-NV), where the workpiece is welded at atmospheric pressure in air or in a protective gas coverage such as Helium or Argon. In all cases, the electron beam gun must be held at a pressure of 10^{-4} torr or less for stable and efficient operation.

High vacuum and medium vacuum welding are done inside a vacuum chamber. The medium vacuum welding retains most of the advantages of high vacuum welding but due to the shorter pumpdown time (especially in large chambers), capabilities are improved. Performance production test have shown that relatively narrow EB welds can be completed at chamber pressures of 25 microns and still be acceptable. If the chamber pressure becomes excessive the beam scatters and the working distance from the gun has to be decreased significantly to produce a narrow weld. Figure 3 shows the effect of welding chamber pressure on penetration and weld shape.

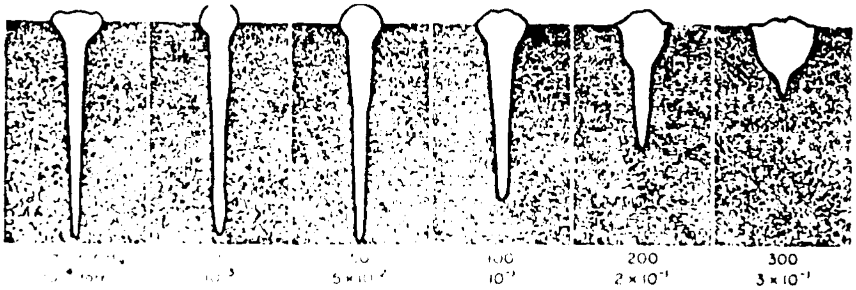


FIGURE 3 EFFECT OF WELDING CHAMBER PRESSURE ON PENETRATION AND WELD SHAPE

A comparison of various vacuum levels will help the understanding of the interaction between "hard" and "soft" vacuum levels. For chamber pressures normally utilized for EB welding, the number of gas molecules present in a cube 0.001 inches on a side (volume - 10^{-6} cubic inches) and a relative frequency of molecular collisions is as follows:

---

* A torr is the term for a pressure of one millimeter of mercury. One standard atmosphere can be expressed as 760 torr or 760 mm of mercury.

Pressure Torr (micron)	Number of Molecules	Relative Number of Collisions
10^{-5} (0.01)	5800	1
10^{-3} (1.0)	580,000	100
10^{-1} (100)	58,000,000	10,000
760 (760,000)(1 atm)	4.4×10^{10}	100,000,000

From this data, it can be seen that at 10^{-3} torr or higher vacuum levels, the scattering of the electron beam becomes a significant factor.

When welding any material, the possibility of contamination at a specific vacuum level is of concern. The total contamination of air (total concentrations of gasses present) is proportional to pressure as follows:

Pressure, Torr (microns)	Gas Concentration ppm
10^{-5} (0.001)	0.001
10^{-3} (1.0)	1.3
10^{-1} (100)	132
4×10^{-1} (400)	500

The conclusion can be drawn that in the soft vacuum range, the concentration of gasses will be less than that of welding grade shielding gasses.

With medium vacuum welding, the beam is generated in high vacuum and then projected into the welding chamber operating at higher pressure. This is accomplished through a special orifice that is large enough to pass the beam but too small to allow significant back diffusion of gases into the gun chamber.

In non-vacuum electron beam welding, the beam is generated in high vacuum and then projected through a series of differently pumped orifices.

Later in the report, an in-depth analysis of each mode of EB welding and how it could be applied to the shipbuilding industry will be presented.

The Electron Beam Gun

In general, most of the electron beam guns for welding used today are comprised of the components as shown in Figure 4. The anode is part of the gun itself and is at the same potential as the workpiece. This gun is commonly referred to as "self-accelerated". The beam of the self - accelerated gun converges to a point as it passes through the anode, and then becomes slightly divergent so that it can be influenced by an electromagnetic field and focused on the workpiece. The electromagnetic lens for this reason is located a short distance below the anode. Its focusing capability is a function of the beam accelerating voltage, the beam diameter, the lens design, and the electromagnetic coil current.

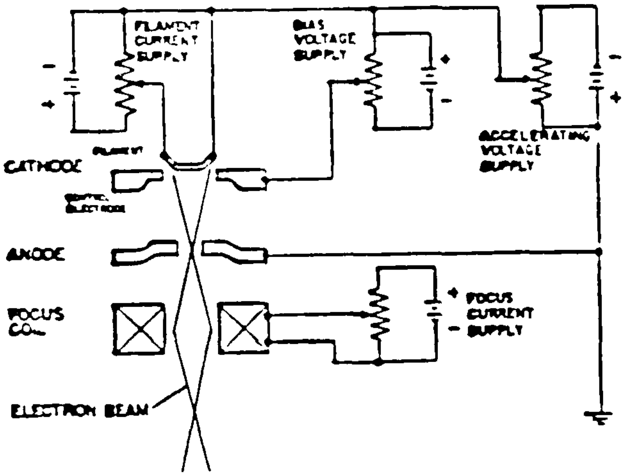


FIGURE 4 TRIODE ELECTRON BEAM GUN AND ASSOCIATED ELECTRICAL SUPPLIES

The focus of the beam has a direct relation to the beam spot size. The beam spot size is critical to the characteristics of the EB weld. Sharp focus of the beam will produce a narrow, parallel sided weld geometry because the effective beam power density will be at a maximum. Defocusing the beam, either by overfocusing or by underfocusing will increase the effective beam diameter and then inturn reduce the beam power density. This will tend to produce a shallow or Vee shaped weld bead geometry. These conditions are illustrated in Figure 5.

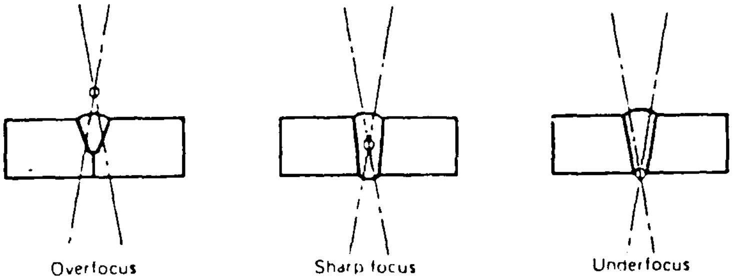


FIGURE 5 EFFECT OF ELECTRON BEAM FOCUSING ON WELD BEAD GEOMETRY

The beam can be oscillated by means of magnetic deflection coils and controls. The coils are positioned below the electromagnetic focusing lens where they can deflect the beam from its normal axis position. Simultaneous use of two sets of deflection coils allows the formation of circular or elliptical patterns on the workpiece. The size and shape of the deflections is set by the magnitude and phase relationships of the signals fed to the coils. Oscillation of the beam is primarily used to stabilize the weld pool prior to its solidification behind the keyhole. Certain oscillation patterns will tend to reduce the chance of porosity in the weld.

The filament in the gun can be heated indirectly or heated directly by another electron source. The filament temperature may be kept in a range where the beam current is a function of filament temperature (as shown in Figure 6). In this case the gun is referred to as operating "temperature limited". If the filament temperature is operated high enough (beyond the knee of the curve as in Figure 6), the beam current is not a function of filament temperature then the gun is said to operate "space-charge-limited".

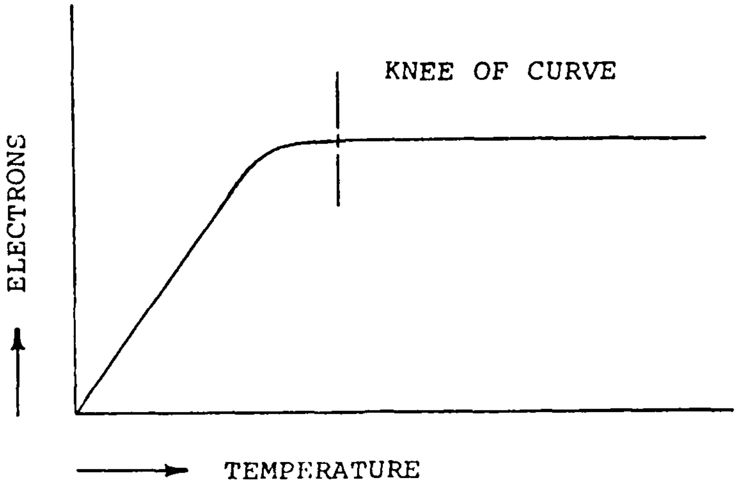


FIGURE 6 ELECTRON BEAM CURRENT AS A FUNCTION OF FILAMENT TEMPERATURE

In general, most EB welding guns are operated space-charge-limited. In this condition, the beam current produced at any accelerating voltage is proportional to the 3/2 power of the accelerating voltage ($I=KV^{3/2}$), where the constant of proportionality, K, is a function of gun geometry.

For an electron gun to deliver the required power and power density for producing a weld, several factors such as design, component configuration, emitter characteristics, total power capabilities, and focusing capabilities have to be considered. Each electron gun and system design has a specific characteristic in terms of capabilities and requirements. It may require a modest amount of parameter development work to simply take parameters from one type of system design to another. Weld parameters are not interchangeable between different designs, such as is the case in many arc welding techniques.

EB Gun Power Supplies

The power supply of an EB welding machine produces the high voltage power necessary for the gun and the auxiliary power for the emitter and beam control.

The main high voltage power source and auxiliary power units are usually placed together in a tank filled with a high purity, electrical grade transformer oil which acts as a heat sink for the electrical components. The main high voltage power source converts the three phase line power into high voltage DC power for the electron beam.

Directly heated emitters are typically ribbon or wire hairpin shaped filaments. Ribbon filaments are usually used on power supplies rated for higher currents and lower voltages (typically 30 to 70A at 5 to 10V) since they provide a larger emitting area than a wire type filament.

Vacuum Pumping Systems

The vacuum system for an EB gun chamber normally consists of a mechanical roughing pump and a oil diffusion pump. The mechanical roughing pump is usually a mechanical piston or a vane type which takes the chamber pressure from 1 atmosphere down to about 0.1 torr. The diffusion pump is used in conjunction with the mechanical pump and it will take the pressure on down to 10^{-4} torr or lower. A combination diffusion and mechanical pumping system is shown in Figure 7.

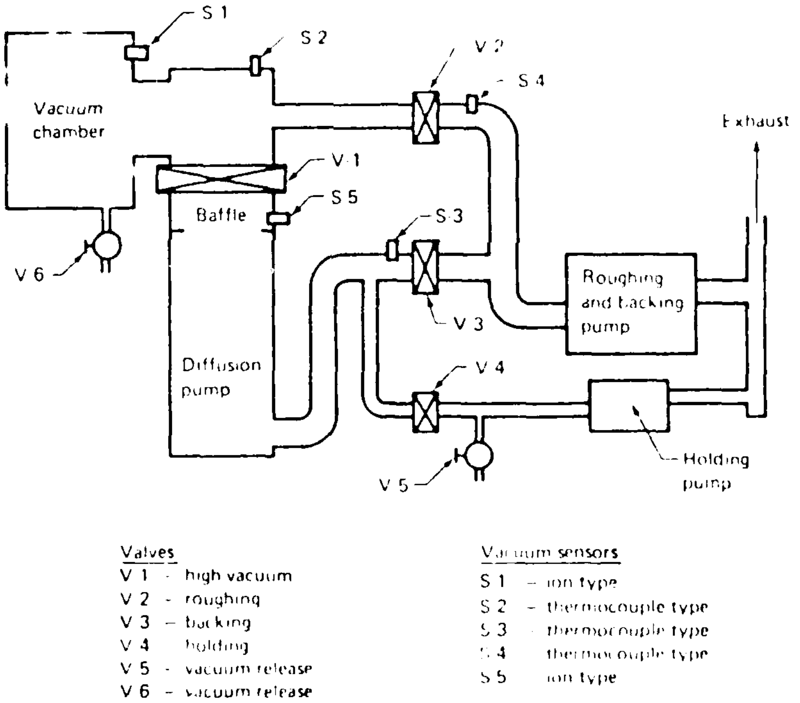


FIGURE 7 SCHEMATIC LAYOUT OF A TYPICAL VACUUM PUMPING SYSTEM

The roughing and diffusion pumping cycles are normally controlled by automatic sequencing vacuum values to prevent an accidental pressure increase in the chamber.

Since the size of the vacuum chambers available range from a few cubic inches to several thousand cubic feet the evacuation period in which it is possible to attain welding pressure varies. The pumpdown time of a chamber is dependent on the pumping systems capacity as well as the volume in the chamber to be evacuated.

Seam Tracking Methods

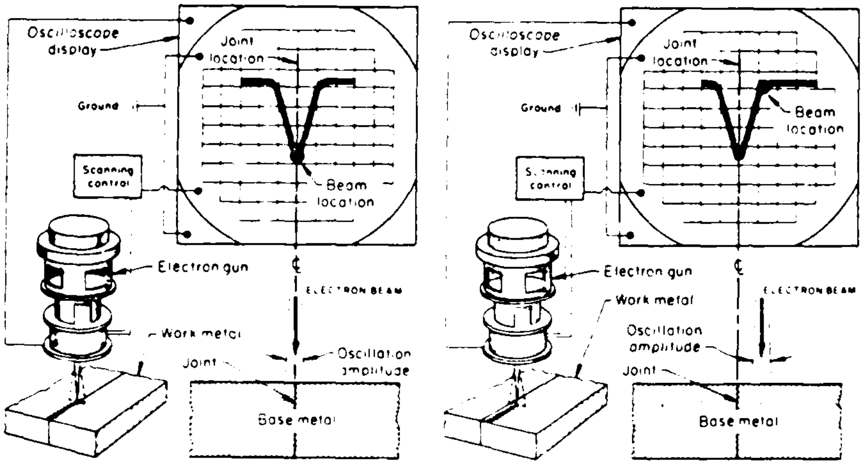
The high travel speeds at which EB welding is normally accomplished and the relatively small size of the beam spot (usually 0.020 to 0.060 in.) requires that the weld seam tracking mechanisms be controlled accurately throughout the EB weld operation.

Seam tracking is accomplished by scanning the weld seam by either optical, electronic or x-ray sensoring methods.

The optical method uses a low power beam telescopically sighted inside the chamber. This in conjunction with internal lighting and mirrors provides a line of sight co-axial with the beam path. The optical method is not very practical for long welding operations due to the metal vapors generated and deposited on the optical surfaces.

The electronic method uses a low powered beam that scans the weld seam and displays the beam to weld seam relationship on an oscilloscope. The low powered beam oscillates transversely across the seam at 60 HZ. The amplitude of the oscillation is transmitted back by reflected electrons and the surrounding area of the workpiece on either side of the seam as well as the seam itself is displayed on the oscilloscope.

When the beam is centered, it would show a condition as illustrated in Figure 8a. The V represents the joint with the beam spot centered in the middle. The two horizontal arms at the top of the beam indicate the adjacent workpiece surfaces. the relative height of the horizontal arms would give the mismatch of the abutting surfaces in thousandths of an inch. If the beam were positioned slightly to the right of the weld seam a condition as shown in 8b would be displayed.



(a) Electronic scanning setup, beam on joint (b) Electronic scanning setup, beam displaced to right of joint

FIGURE 8 ILLUSTRATION OF RECORD AND PLAYBACK ELECTRONIC SCANNING

From the oscilloscope display, the operator could tell the exact location of the electron beam in relation to the weld seam. With the use of computerized numerical control systems, the information received from the electronic seam tracking device can be automatically recorded and "digitized" on a scan pass. With the joint information recorded, the seam can be welded on the second pass using playback programmed control.

A recently devised method of seam tracking incorporates the scanning, the correction of the seam deviation, and the welding into a simultaneous operation by the use of a closed loop controller. This is accomplished by the electron beam determining measurement values by scanning ahead for an extremely short time, and with a preselected frequency, recording these values, and relaying this information back for the weld contour directly in front of the welding position. Similar to the record and playback method of digitizing the seam, this "real time" tracking method operates on the principle of reflected electrons, using the electron beam at reduced power as the measuring tool. The beam is deflected transversely across the welding seam of the workpiece. The difference between the electron reflection intensity at the seam and at the adjacent solid material provides the measurement values for the weld seam coordinates. Figure 9 shows the basic principle of how this method of seam tracking works.

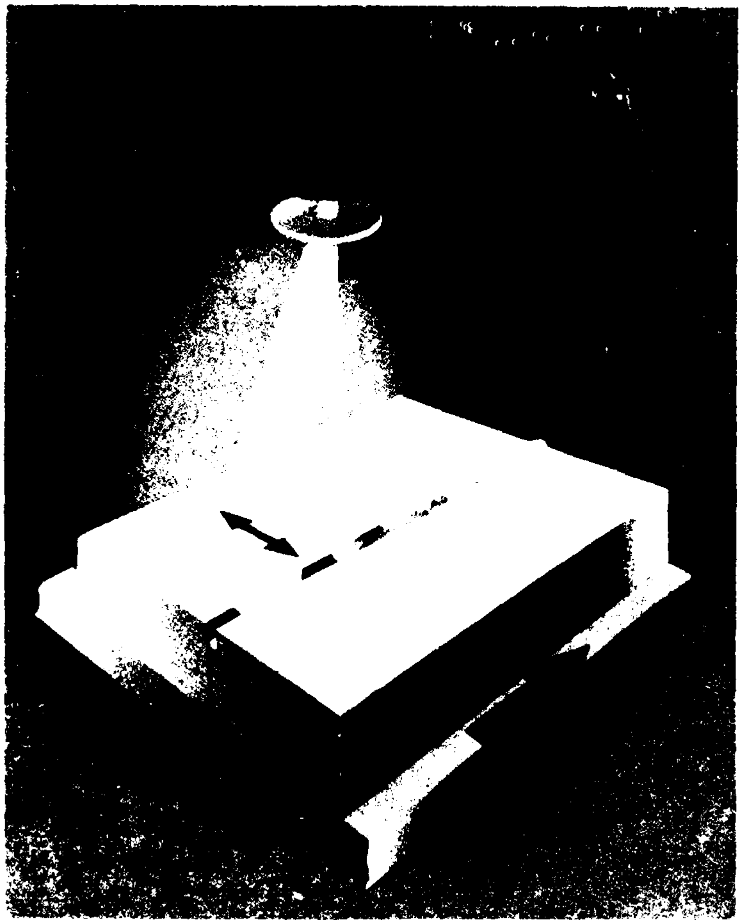


FIGURE 9 REAL TIME SEAM TRACKER SIMULTANEOUSLY DIGITIZING AND WELDING

The x-ray sensor method of seam tracking relies on the periodic high speed scanning of the weld seam ahead of the welding pool by the full power electron beam and sensoring the x-radiation being generated by the beam impact on the workpiece surface by the means of an x-ray detector. The difference of x-ray emission of the gap and the solid surface creates a signal which can be used for tracking the weld seam. When using filler wire feed systems this signal can also be used to measure the weld seam gap and directly regulate the wire feed speed to accommodate for variations in the gap width.

The different EB tracking systems available are also listed in this report under the EB manufacturers section.

There would be several advantages of applying electron beam welding to the shipbuilding industry as compared to the presently used conventional means of welding.

1. The ship building industry, like most industries, is concerned with maintaining a high productivity level while minimizing manhour cost. The electron beam process, due to its high power density, can obtain high welding speeds in combination with deep penetration depths. This ability to attain an extremely high weld depth to width ratio permits single pass welding of joints that would normally require multipass arc welds. Figure 10 shows a comparison of a typical weld zone of a narrow gap submerged metal arc weld versus EB weld.

2. Due to the low heat input, the EB weld is used to produce a narrow, parallel fusion zone which is just wide enough to ensure that the weld joint is completely welded but with minimal energy expenditure.

3. Normally no filler comsumables would be required, since EB welding consists of fusing the two parent metal plate edges together to form an autogenous weld. Normally the edge preparation required for EB welding is a simple square butt edge prep. Considering the amount of consumables used for welding heavy panel plates together, this would be a substantial savings factor.

4. Since EB welding produces a narrow, parallel sided weld, less distortion and shrinkage result as compared with other conventional means of welding. With the EB weld, the weld metal is essentially parallel sided except where the electron beam first impinges on the top surface of the abutted members. Contraction of the metal during cooling is fairly uniform through the joint. When the weld metal has a characteristic V shape, as in arc welding, there is significant warpage from unequal thermal contraction across the joint. This is illustrated in Figure 11.

5. High vacuum [illegible] partial vacuum electron beam welding normally takes place inside a vacuum chamber which minimizes contamination to the weld metal of undesirable atmospheric elements such as oxygen, nitrogen and hydrogen. These elements can lower the notch toughness and corrosion resistance of some weld metal.

6. Preheating of high strength steel is often not required.

7. Accurate control of the electron beam has always permitted a high degree of reliability and reproducible welding. The incorporation of modern day minicomputers and microprocessors offers additional control of the welding conditions.

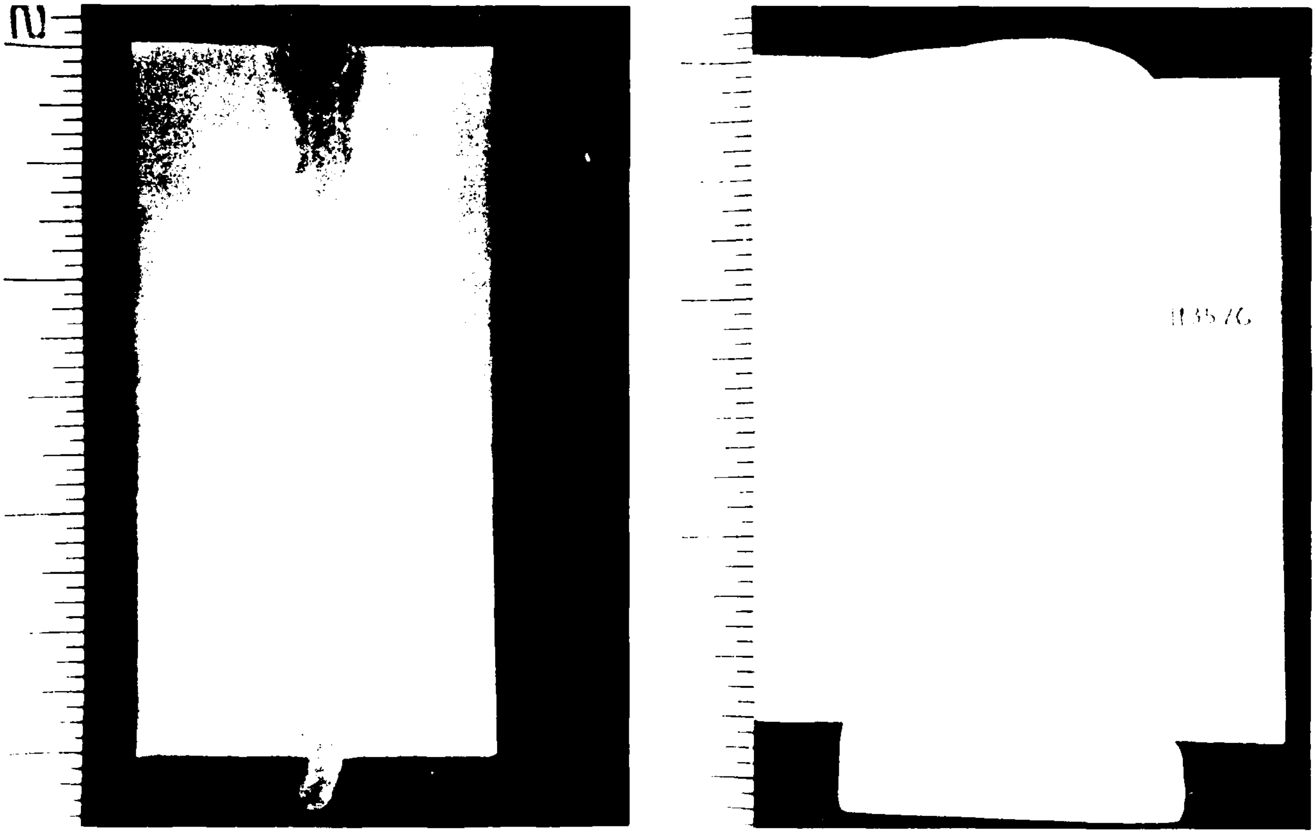


FIGURE 10 COMPARISON OF ELECTRON BEAM WELD (LEFT) AND NARROW GAP SUBMERGED ARC WELD (RIGHT) ON 3 INCH THICK CARBON STEEL

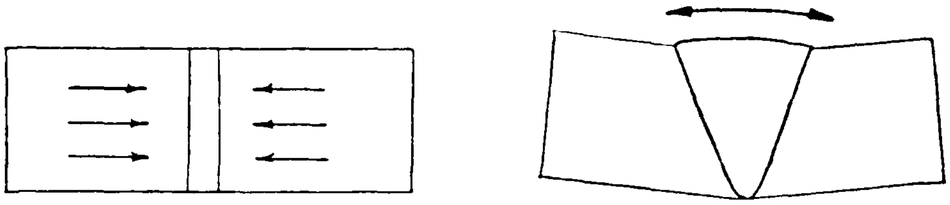


FIGURE 11 EB WELD SHRINKAGE VS. CONVENTIONAL ARC WELDING SHRINKAGE

Even though the EB Welding process has several advantages, it also has a few disadvantages which will need to be considered.

1) Electron beam welds are normally made in a vacuum chamber unless special equipment such as a local vacuum or non-vacuum set-up is used. The cost of a chamber and the time required to pump down the chamber could be considered a disadvantage. With the high capacity cryogenic and large diffusion pumps available on the market today, one could minimize pump down time.

2) The high initial cost of the EB gun with the vacuum chamber can be a relatively high capital outlay at first. Factors which would offset this would be the savings cost of no filler metal additions and no preheat gas.

3) Normally the plate edges have to be machined to a square butt edge prep to hold the maximum joint gap to within 1% or less of the total plate thickness. This is to minimize weld undercutting and solidification cracks from occurring. If filler metal is added, then a larger gap could be tolerated (up to 3% of plate thickness or 0.050 in., whichever is less).

4) X-rays are generated from the bombardment of the plate with electrons. Protective lead shielding would be required around the gun casing when EB takes place outside of a chamber such as when non vacuum EB welding is performed.

5) Plate surfaces should be free from scale and grease otherwise this could be a source of porosity. Normally, the plate edges are cleaned with an acetone solvent before EB welding occurs.

6) Residual magnetism in the plate could bend the beam enough to miss the weld seam. Protective measure such as demagnetizing the plates or placing a tube shielding around the beam are sometimes necessary to avoid this occurrence.

Industrial Users of Electron Beam Equipment

Over the last 25 years since EB welding was first introduced on a commercial basis to industry, it has found its niche in many specialized areas of welding. Originally, the EB process was adapted to the nuclear component and aerospace industries where the choice was largely based on technical reasons associated with material weldability and control of distortion rather than the welding cost, but over the last few years, realization that EB welding is a fast joining process has lead to its use in mass production industries where its speed as well as control of distortion are considered as important factors.

Today, the EB welding process is used on a very wide range of items, from welding the wing center sections of fighter jet aircraft to welding bimetallic saw blades together to achieve a longer cutting life.

The main users of worldwide industrial EB equipment with their application can be categorized as in Table 1.

Low Power EBW

Automotive equipment	Engine valves, Gear and shafts, Flywheels, manifolds, Ball joints, Torque converters, Catalytic converters
Nuclear power equipment	Fuel elements, Pipes
Aircraft	Turbine parts, Valves, Gears, Housing, Engine parts, Wing panel sections
Electronic equipment	Micro relays, Micro modules, Line printers
Chemical equipment	Pipe and flanges, Heat exchangers, Vessels
Others	General machine parts, Tools

High Power EBW

Pressure vessels	Bodies, Stub tubes, Nozzles, LNG tanks
General machinery	Large size gear units, Various cylinders, Valves
Nuclear power equipment	Nuclear reactors, Casing, Supporting structures
Heavy duty electric equipment	Turbines, Generator parts
Others	Various large scale structures

TABLE 1

One of the major aircraft manufacturer's, Grumman Aircraft, has been involved in the application of EB welding technology since 1961 when the capability of the process to produce high quality welds in a variety of materials was demonstrated. Developmental work in the application of EB welding of titanium alloys led to the actual implementation in the fabrication of F-14 wing center sections and wing planks. The success of that effort culminated in a Grumman commitment to the application of EB welding to aaerospace manufacturing. The extensive 80,000 Ft^2 EB welding facility that was set up at their Bethpage, N.Y. facility proved to be a significant factor in the award of the multibillion dollar F-14 program. Since 1969, Grumman has been EB welding F-14 wing center sections and wing panels on a production basis. Each section alone contains more than 170 feet of EB welds. The F-14 and wing center section shown are in Figures 12 and 13.

The long assemblies of the F-14 are welded in the clamshell chamber shown in Figure 14. The clamshell chamber measures 32 ft. long x 10.5 ft. wide x 8 ft. tall.

The aircraft and aerospace industry also uses EB welding on jet engine construction and load bearing structural members such as:

(1) Jet turbine stator and rotors
(2) Undercarriage shock struts
(3) Rocket combustion chambers
(4) Fuel tanks and pumps
(5) Load bearing structures of rocket stages

The major automotive manufacturers, such as GM and Ford, use the EB welding process to produce items such as automotive steering column jackets, catalytic converters, housing and transmission gear assemblies, die cast aluminum manifolds, and torque converters. The automotive industry uses both vacuum and nonvacuum systems. Figures 15 & 16 shows a catalytic converter and the nonvacuum system that welds the thin layers of the stainless steel together with speeds of 20 ft./min.

In Japan, electron beam welding is used quite extensively in the nuclear industry for welding core barrels and core internals for nuclear power plants. Mitsubishi Industries utilizes a 100KW EB gun inside a 280 meters^3 vacuum chamber for this purpose. They are able to weld components up to 100 mm in thickness in a single pass with high travel speeds and low resultant distortion. A schematic of their EB set up is shown in Figure 17.

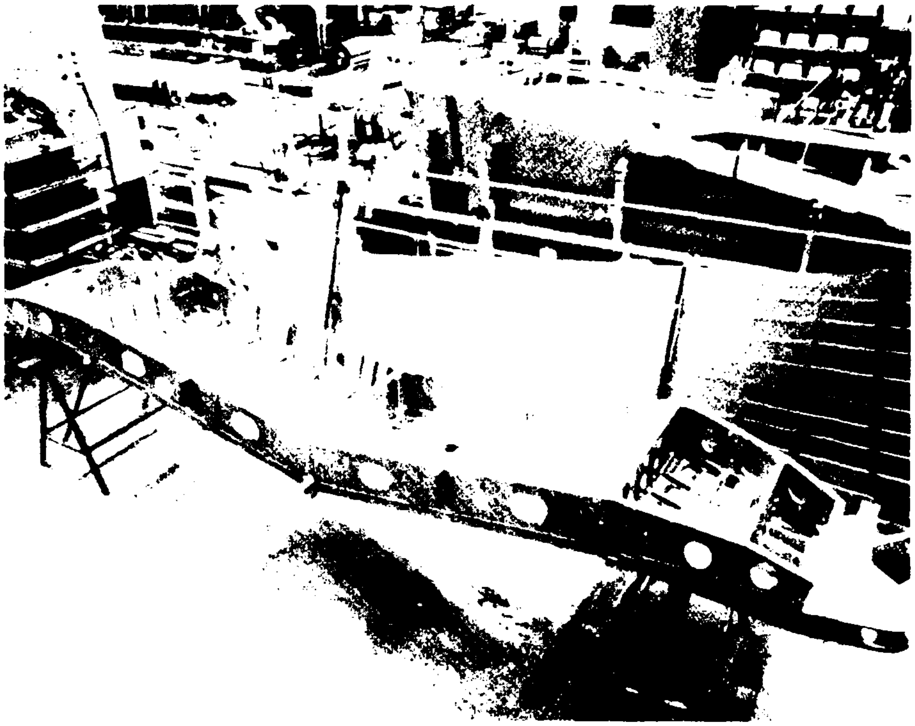


FIGURE 12 F-14 WING CENTER SECTION PREPARED FOR EB WELDING OF TOP COVERS

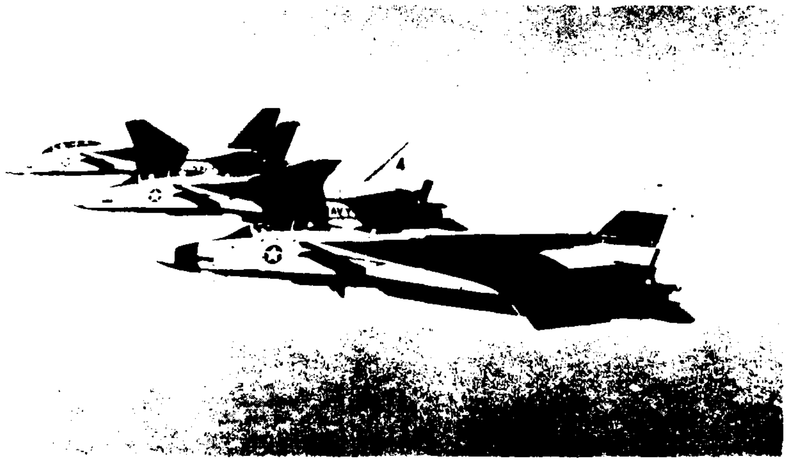


FIGURE 13 THE F-14 WING CENTER SECTION AND WING PANELS ARE WELDED WITH EB

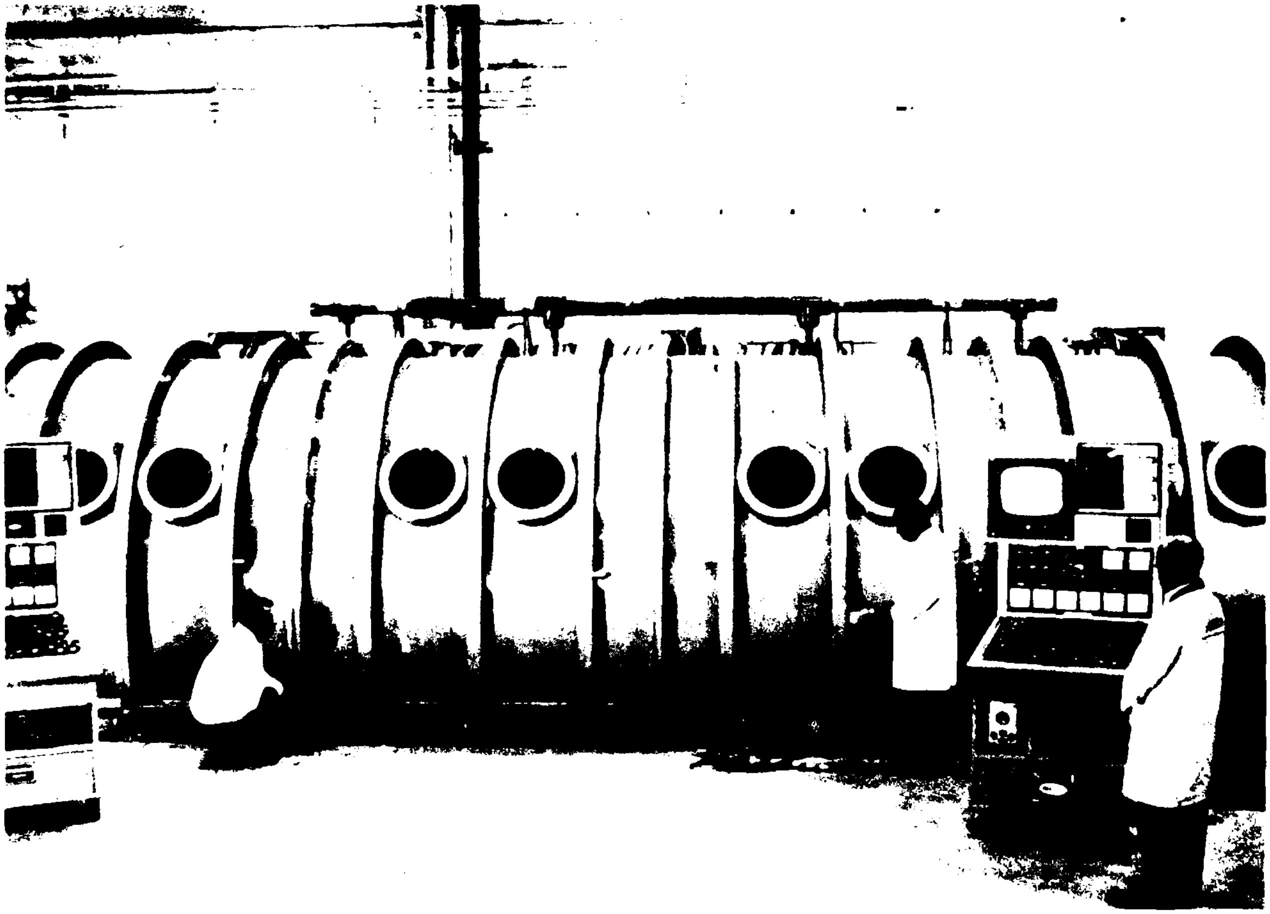


FIGURE 14 GRUMMAN AIRCRAFT CLAMSHELL CHAMBER FOR WELDING F-14 WING CENTER SECTIONS

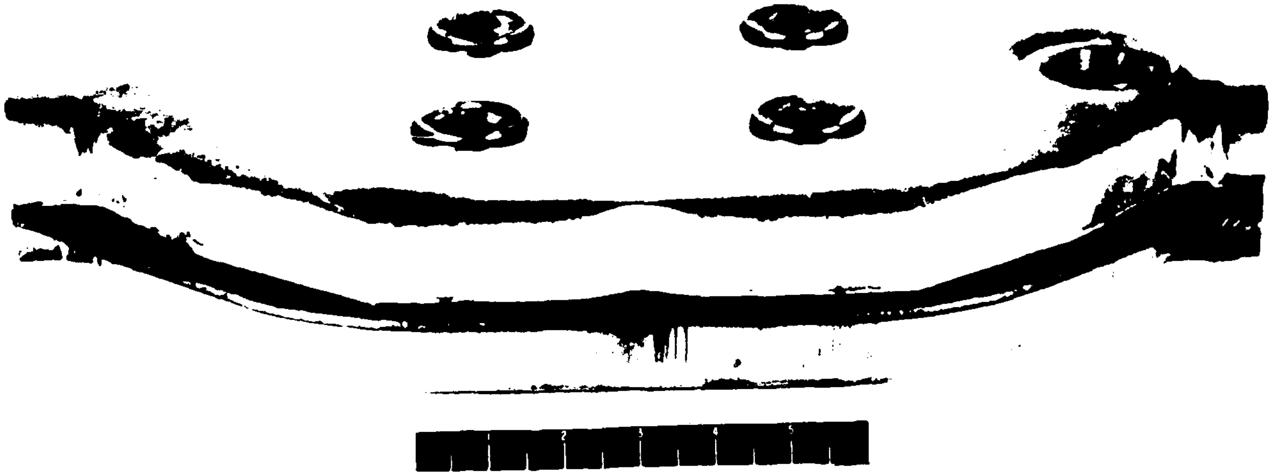


FIGURE 15 CATALYTIC CONVERTER WITH HALF COMPONENTS WELDED TOGETHER

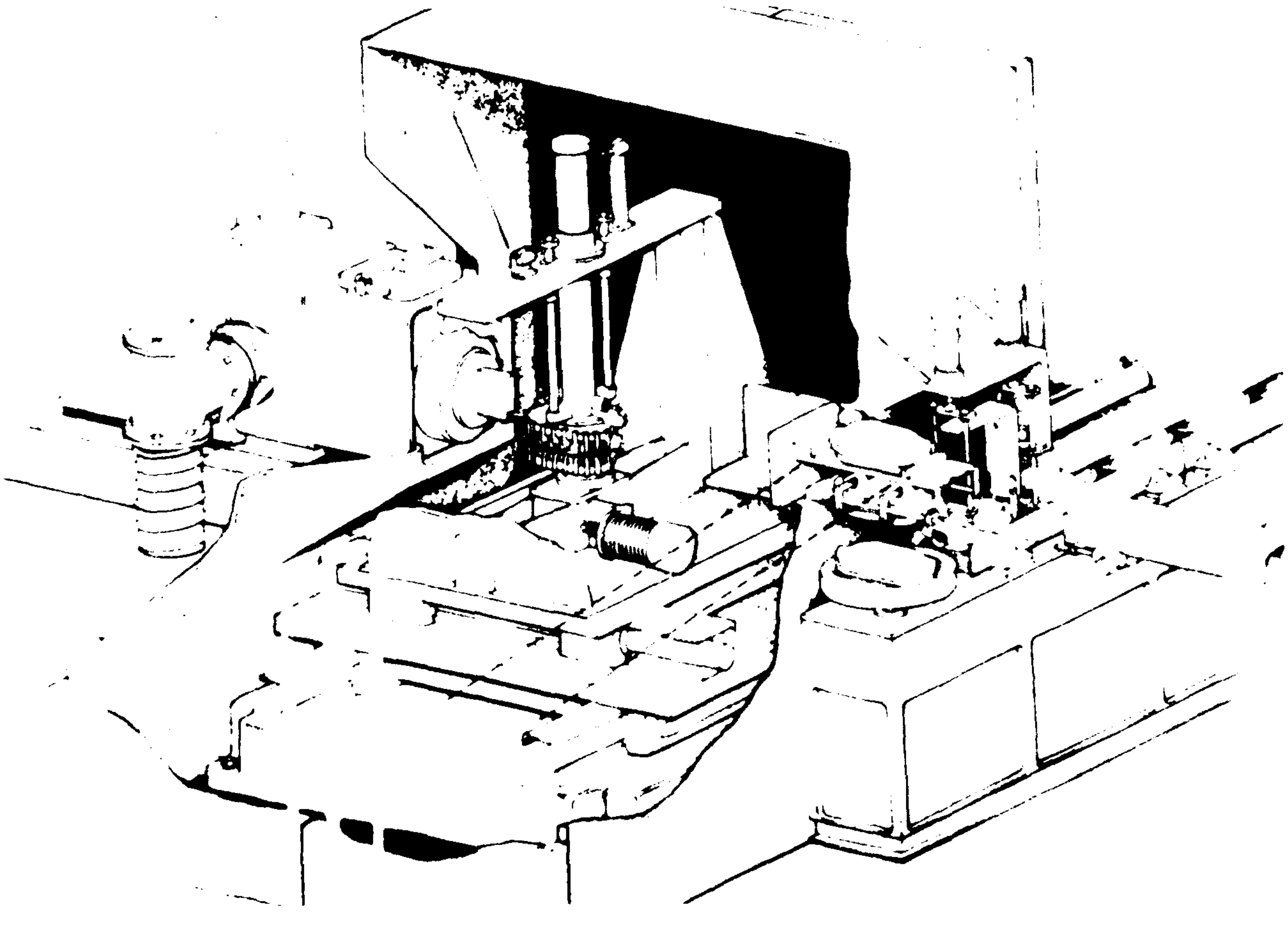


FIGURE 16 NONVACUUM EB WELDING SYSTEM USED BY AUTOMOTIVE INDUSTRY ON CATALYTIC CONVERTERS

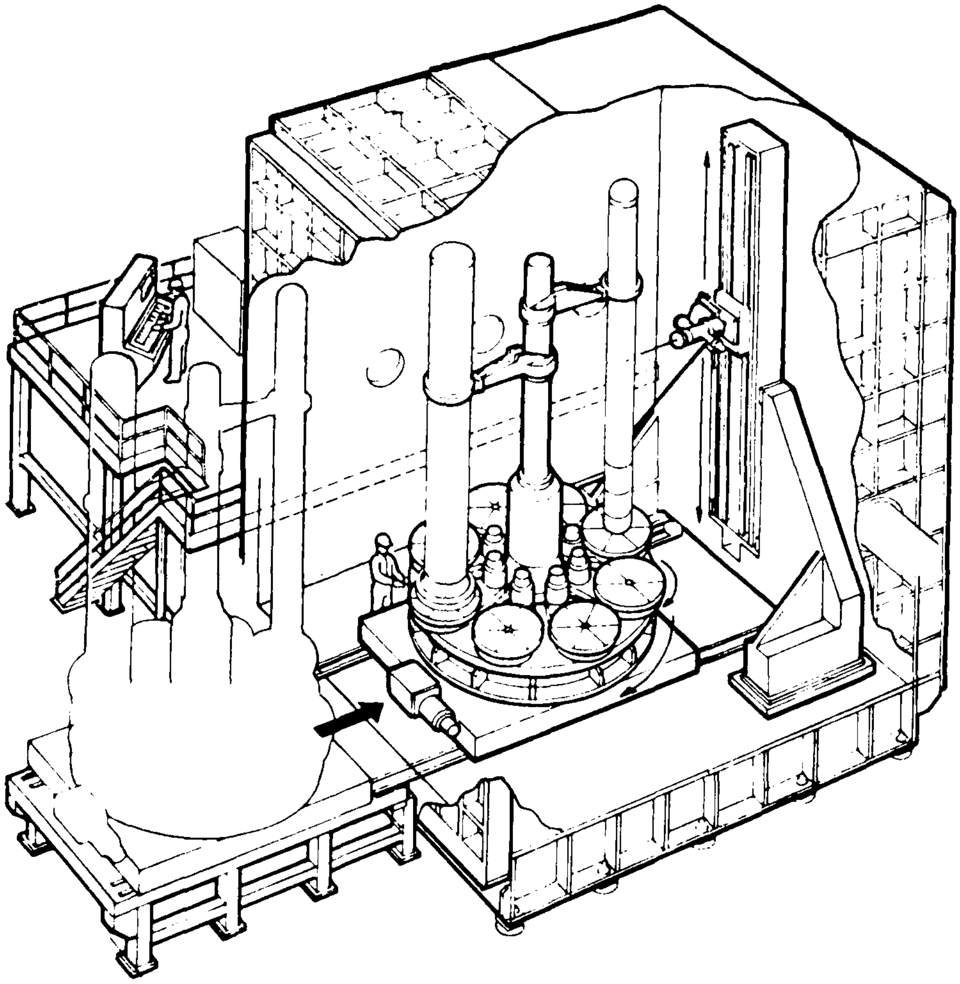


FIGURE 17 SCHEMETIC OF MITSUBISHI INDUSTRIES 280 METER^3 CHAMBER FOR WELDING NUCLEAR INDUSTRY COMPONENTS

SUMMARY OF SHIPYARD VISITS

As part of the study for this report, field trips were made to three selected shipyards to identify possible cost effective applications of EB welding equipment to specific areas of ship fabrication. The three shipyards visited for this study were:

1) Ingalls Shipyard, Pascagoula, Miss.
2) Newport News Shipyard and Drydock, Newport News, Va.
3) Norfolk Shipyard, Norfolk, Va.

For these visits, the main points of interest in each shipyard for applying EB welding were 1) the panel line fabrication area, 2) the T-stiffener to panel assembly and 3) pipe fabrication area.

Ingalls Shipyard

The Ingalls Shipyard panel line fabrication was typical for the industry with the plates being descaled first in a wheelabrator with subsequent beveling of the plate edges by conventional burning methods. The panel plates (normally 10 ft. width x 25 ft. length) were fit-up with the use of an electro-magnetic hold-down bed the length of the plate. Panel plates were fit-up into assemblies 50 ft. x 50 ft. The seams were tack welded, then they proceeded to the next station where the longitudinal and transverse seams were welded with the downflat automatic submerged arc welding process from two separate traveling bridges (See Figure 18 for a typical bridge welding head arrangement). Panel plate edges 5/8 in. thick or less were square butt detail and plates thicker than 5/8 in. had a 45° included bevel. Panel plates were welded from one side then the entire assembly was flipped by an overhead crane and the backside of the weld seams were completed with the sub-arc process after being semi-automatically flame or arc gouged.

The Ingalls Shipyard used mainly three groups of materials for the fabrication of panel section, 1) structural carbon steel material with 50-60 KSI tensile strength (A36 typically), 2) high tensile strength material in the range of 80-100 KSI (HY80-100) and 3) high strength low alloy material (A710 Gr. A with sulfur 0.010% maximum). Material used was dependent on the design criteria of the ship hull in that area. Sometimes various strength levels of plate material were used in a panel assembly with thickness ranging from 1/4 in. to 1-1/4 in.

After the panel plate butt seam welding was accomplished, the plates were moved to the fabrication area where longitudinal and transverse T-stiffeners were fillet welded to the panel sections with the semi-automated flux core arc process. Fit-up of the

FIGURE 18 A TYPICAL TRANSVERSING BRIDGE SET-UP WITH DOWNFLAT AUTOMATIC SUBMERGED ARC PROCESS WELDING BUTT SEAMS OF PANEL OR DECK PLATES IN SHIPYARD

T-stiffeners to the panel plate assembly was achieved with the aid of mechanical and hydraulic fit-up equipment. It was noted that internal piping required for a typical surface ship varied from 2 in. to 10 in. diameter. Most of the welding observed on the larger pipe diameters was performed with the pulsed gas metal arc or the flux core arc process. The small diameter pipe joints were being welded with the TIG process.

Newport News

The Newport News Shipyard panel line and T-stiffener to panel plate assembly area had a similar layout, but due to the size of the ships (mainly aircraft carriers) fabricated there, the panel and deck plates were thicker, usually in the range of 1/2 inch to 2 inches. Panel and deck plate assemblies were normally comprised of 4 plates - 10 ft. x 40 ft. length resulting in an assembly 40 ft. x 40 ft. Depending upon thickness, panel and deck plate edge preparation was normally double bevel prep burned by oxy-fuel systems with Numerical Control capabilities. The variations in the panel plate gap width appeared to be between a tight fit to about 1/8 inch.

The longitudinal T-stiffeners were fit to the panel plates by hydraulic hold-down ram equipment mounted on a transversing bridge. The fit-up procedure was followed by dual headed submerged arc welding of fillet welds on each side of the T-stiffener similar to Figures 19 and 20.

The Newport News Shipyard used mainly higher strength materials such as HY 80-100 or A710 for the panel/deck assembly of the aircraft carriers.

Norfolk Shipyard

On visiting the Norfolk Shipyard, it was discovered that they deal primarily with the repair and modification of existing surface effect ships. It was observed that there wasn't an assembly type fabrication facility of panel or deck plates to warrant adaptation of a high density welding process such as EB welding. There were specialized items such as pipe welding or catapult cover repair welding which could be readily EB welded, but it was felt that the initial high capital cost of this equipment would not be justifiable unless several thousand of these components were welded on a regular basis.

As was mentioned, the fabrication areas in the shipyard that showed the most economic advantage of applying EB welding were 1) panel/deck line assembly, 2) T-stiffener to panel weld area and 3) piping.

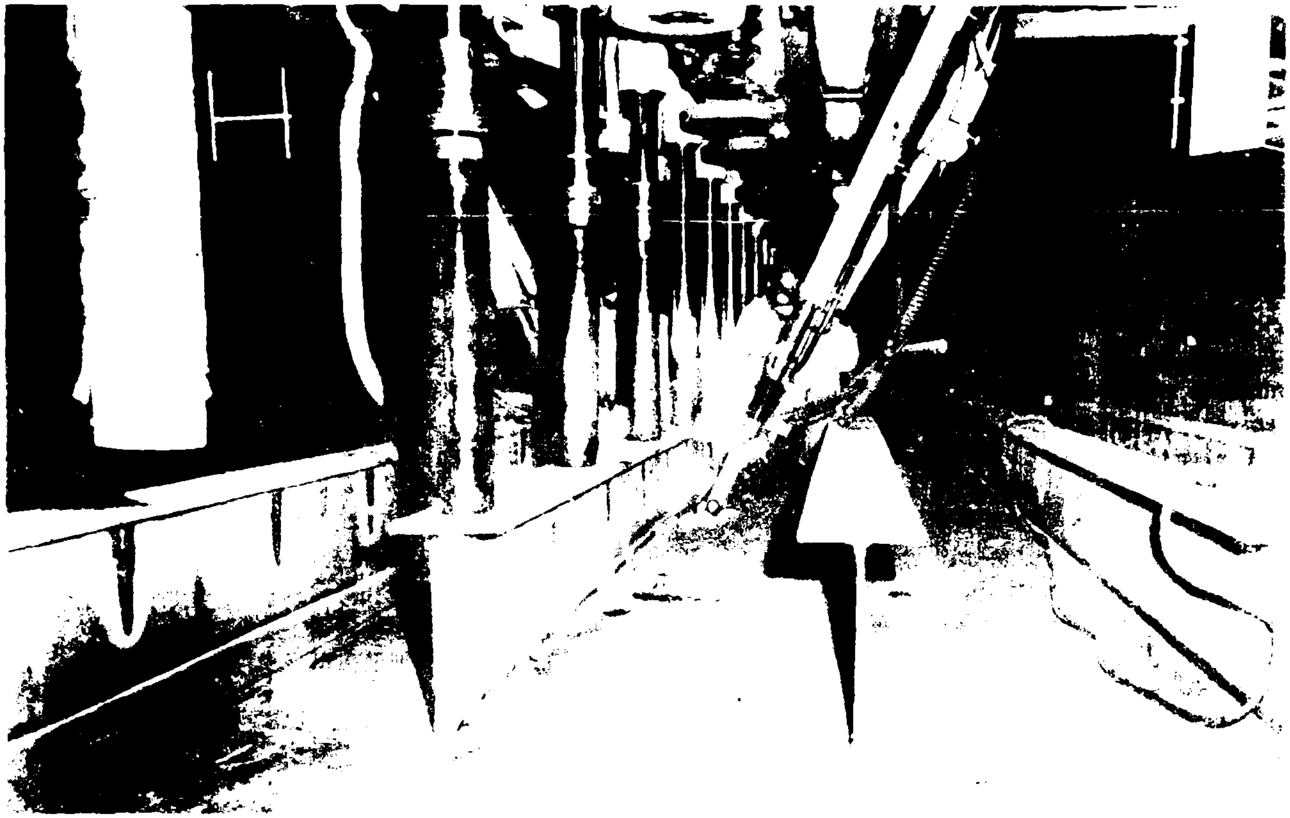
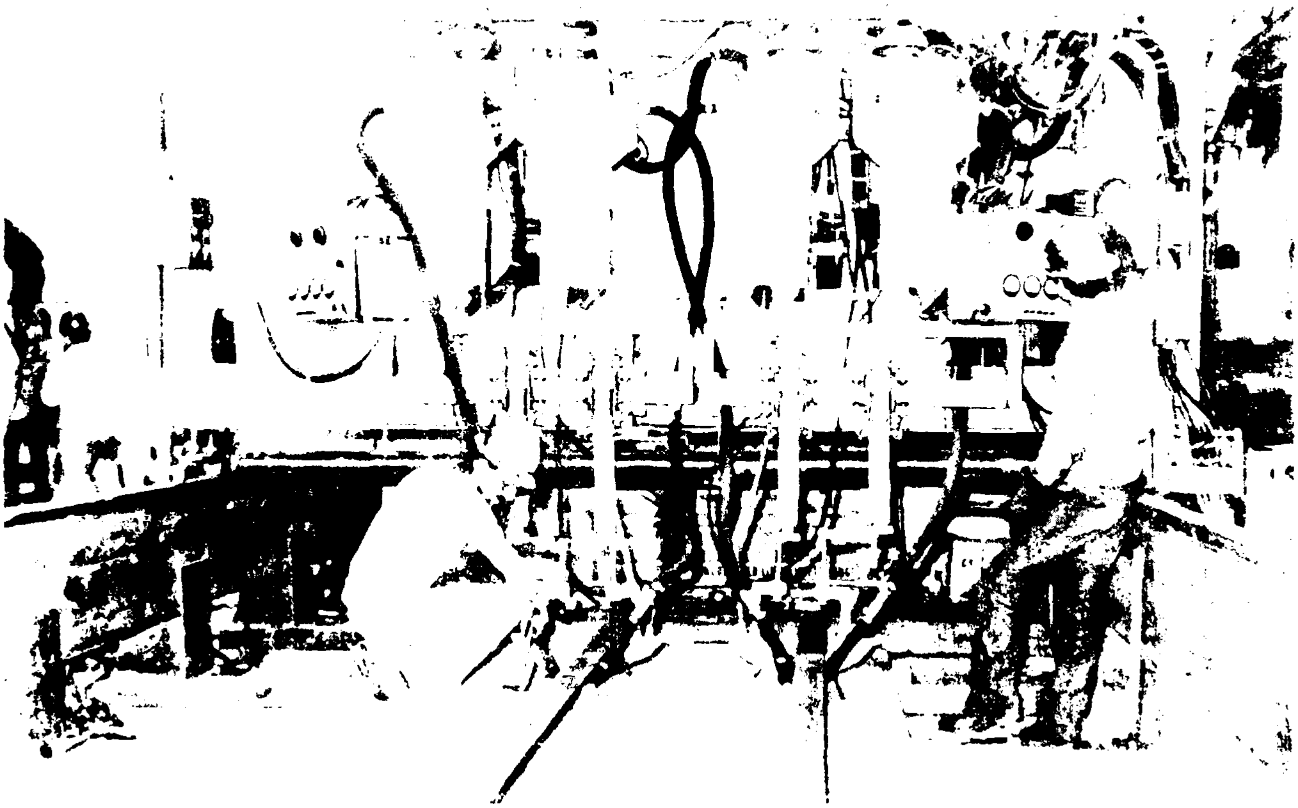


FIGURE 19 A TYPICAL HYDRAULIC HOLDDOWN RAM SET-UP WITH DUAL HEAD SUBMERGED ARC WELDING OF T-STIFFENER TO PANEL FILLET WELDS



[illegible] HEAD SUBMERGED [illegible]
[illegible] WELDS

Other areas such as bulkhead and superstructure assembly were analyzed, but due to the complexity of shapes and the size of the EB gun, it was decided these fabrication areas would not be readily adaptable to this method of welding.

A fourth electron beam application identified during the shipyard visits is the fabrication of T-stiffeners. Due to the inavailability of T-stiffeners, the shipyards are frequently forced to buy I-beams and cut off one flange to get the desired dimensions. This results in wasted material and extra manhour cost. It was also noted that high strength T-stiffeners (80 KSI) can normally only be purchased in a maximum of 8 ft. lengths so the shipyard is required to make several butt splices to obtain the 40 ft. lengths for the longitudinal T-stiffeners for each panel assembly. EB welding would appear to be ideally suited to this application since it can be readily automated and has the penetrating capabilities to weld heavy flange to web plate with minimum distortion.

CONCEPTS OF EB EQUIPMENT DESIGNS APPLICABLE TO THE SHIPBUILDING INDUSTRY

There are three basic designs of electron beam equipment today that would be feasibly adaptable to these fabrication areas. These designs could be categorized as:

1) mobile vacuum or sliding seal EB welding; where the EB gun, mounted on a track, moves across the weld seam. A partial vacuum is maintained at the point of welding by sliding seals
2) non-vacuum or "open air" EB welding which takes place under atmospheric conditions
3) large vacuum chamber EB welding.

Each of the three different EB welding concepts would have certain advantages and disadvantages when applied to the specified fabrication areas in the shipbuilding industry. A brief description of each concept will be presented with the visualized method of application.

MOBILE OR SLIDING SEAL EB WELDING

This design has the main advantage of eliminating the bulky vacuum chamber which the workpiece is normally placed inside thus minimizing the pumpdown to only the time required to evacuate the local chamber.

The EB manufacturers that have successfully designed and adapted this technique to welding flat plate surfaces such as would be required for the welding of panel or deck plates are 1) Sciaky Bros., Inc., Chicago, Ill. and 2) MG Industries - Steigerwald Systems, Menomonee Falls, Wisc.

Sciaky Design

The Sciaky design is operated on the principle as shown in Figures 21 and 22. The EB gun (I) travels along a track mounted on the plate. A vacuum is produced in the main and counter chambers (J and C) in the range of 10^{-2} to 10^{-3} torrs. Seals are located at the bottom of the housing to provide adequate tightness against the plate surface (A). The top plate of chamber (D) has a longitudinal "Vee" notch (E) where a special silicon seal is fitted to allow for the carriage to travel forward yet maintain an adequate seal for welding. To avoid the electron beam striking the silicon seal (F), rollers are used during travel to lift the "Vee" seal ahead of the carriage and move it laterally away from the notch and replace it in the slot at the back of the carriage. The electron beam thus penetrates the joint (B) and produces a full penetration weld in plate (A) as the carriage moves forward.

The prototype (30 KW unit, 60 KV/500ma) of this design was built by Sciaky at their Vitry, France location. It has dimensions of 4145mm by 806mm with a maximum longitudinal travel of gun carriage of 2.5 meters. Typical welding speeds varied from 0.05 to 1 meter/minute, dependent on plate thickness and weld parameters used. Welding has been accomplished on 15-50mm thick steel at speeds up to 40 cm/minute.

The gun has a traversing motion tolerance of ±5mm to allow for lateral travel of the beam while tracking the plate seam. A seam tracking device could be incorporated in order to automatically position the beam transversally with respect to the weld seam. Weld seam viewing is performed by using optics integral with the carriage and a TV monitoring system. The main and counter chambers utilized two roughing pumps of 350 and $40m^3$/hr. respectively. The gun requires a roughing pump of $40m^3$/hr. and a diffusion pump of 1200 l/sec.[2]

A filler wire feed system would be adaptable to the carriage for weld joints with a gap up to 1mm. The Sciaky local vacuum equipment has been used on various research projects. For instance, Grumman Aircraft Corp. used this concept on the welding of 1/4, 1/2, 3/4 and 1 inch thick HY130 steel alloy plate under Naval Ship Research and Development Contract No. N61533-75-M-4468 in 1976.[3]

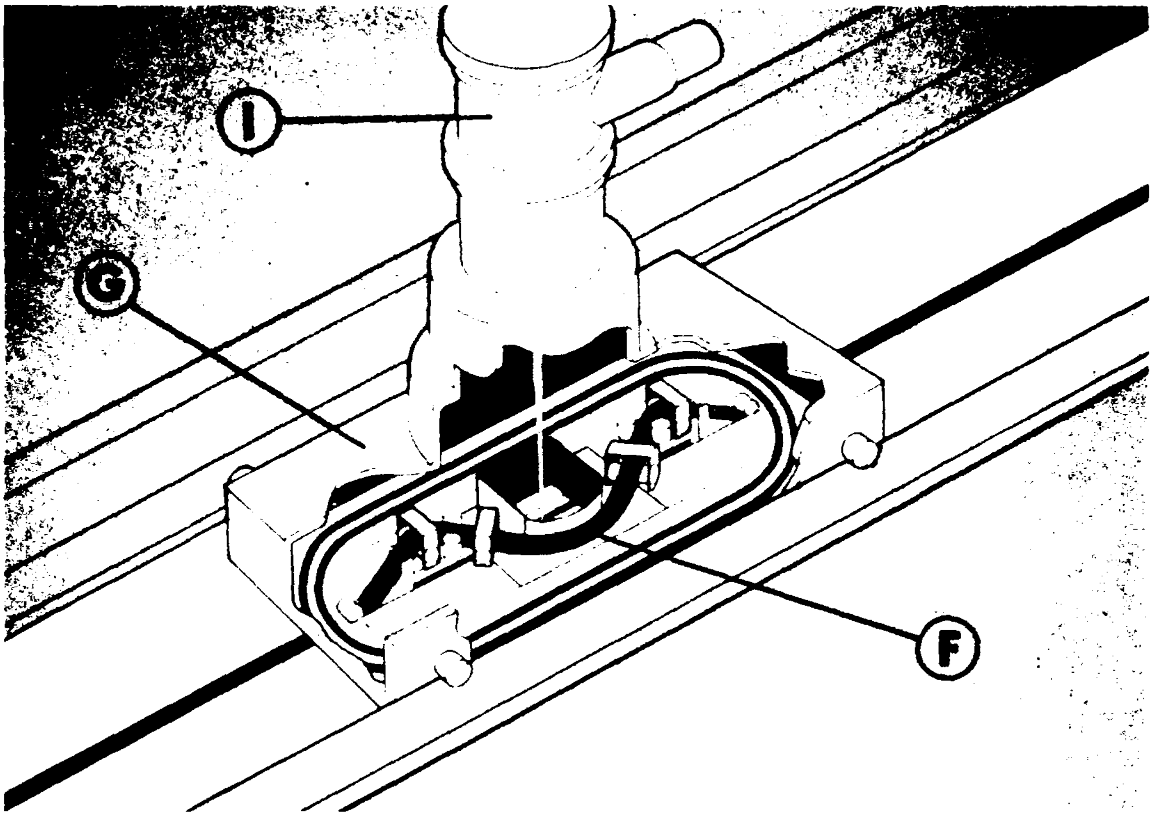


FIGURE 21 SKETCH OF SCIAKY CARRIAGE AND ELECTRON GUN

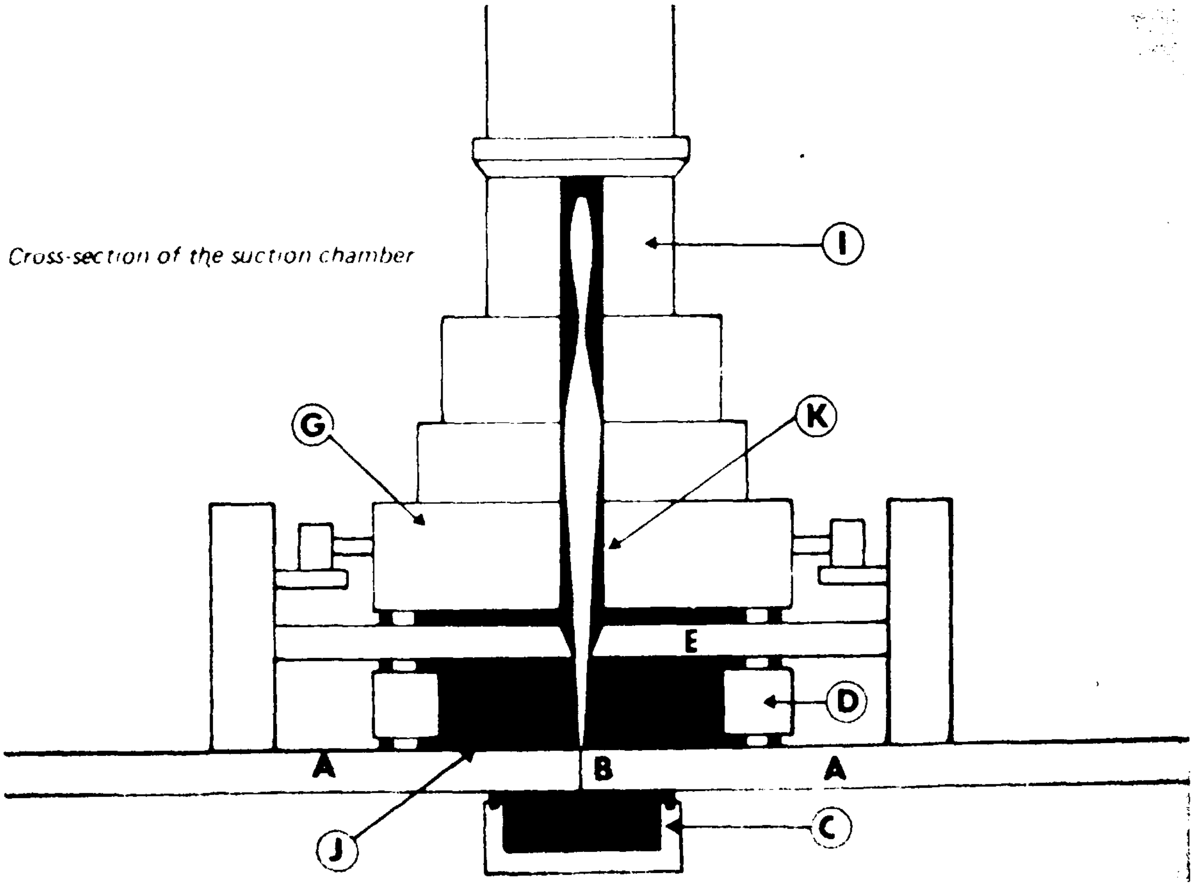
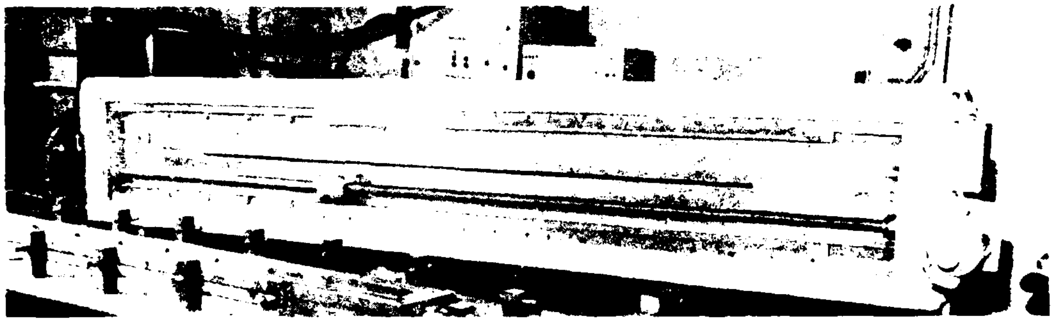


FIGURE 22 CROSS-SECTION OF THE SUCTION CHAMBER



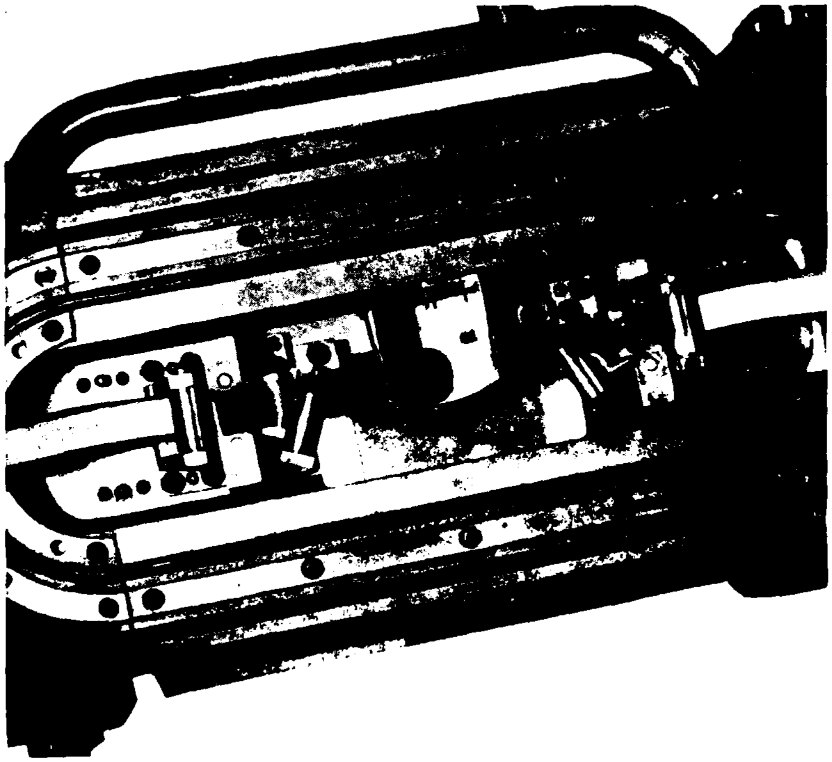


FIGURE 23 SCIAKY MOBILE VACUUM EB WELDER CARRIAGE (above) AND LOCAL CHAMBER (below)

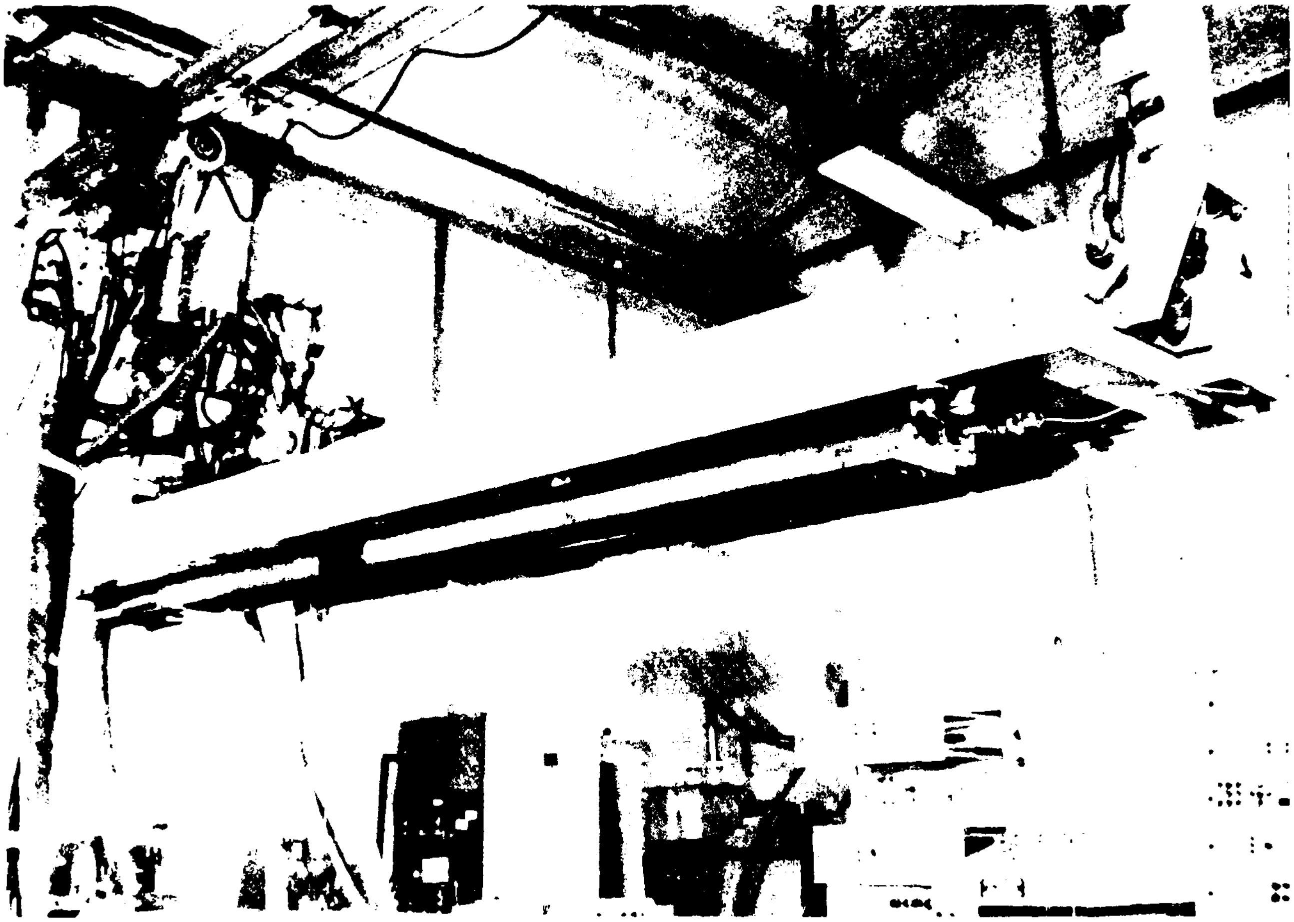


FIGURE 24 SCIAKY MOBILE VACUUM EB WELDER

Steigerwald Design

The Steigerwald design is not based on the conventional tight sealing system, but rather to reduce the pressure by gas flow systems inside ring shaped pressure stages surrounding the welding area.

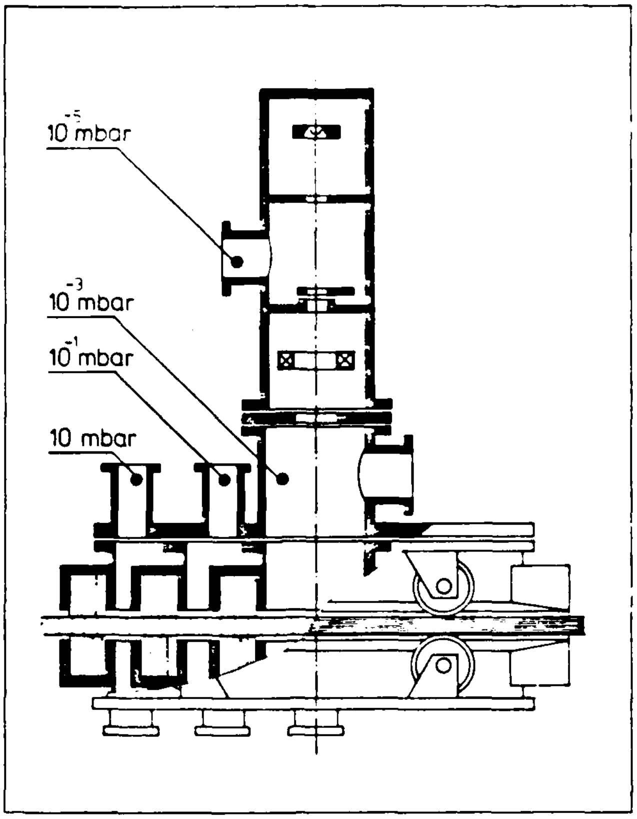


FIGURE 25 CROSS-SECTION OF STEIGERWALD MOBILE VACUUM SYSTEM

Shown in Figure 25, this pressure "step down" is performed essentially by the first pressure staging so that the inner sealing sections can be built by using sealing material such as ceramic wool. This is the main reason why it is not necessary that the separating elements between each pressure stage form closed rings or be leak tight around the vacuum area. With this design it is possible for the seals to pass over the weld bead buildup as well as the high temperatures of the welded seam without destroying the seal material. Plates as thick as 60mm have been successfully welded by this design without defects. Filler wire additions were used on plates with gaps up to 2mm. The filler wire is fed to the welding pool behind the beam under an inclination of 20° to the beam axis. As shown in Figure 26 to avoid defects, the distance X between filler wire and beam must be kept constant.[4]

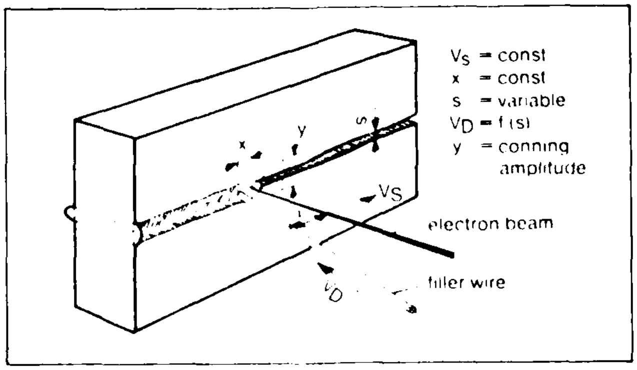


FIGURE 26 EB-WELDING WITH FILLER WIRE

As can be seen with the Steigerwald design (See Figure 27), it also requires that a local mobile vacuum system be applied to the backside of the weld seam. Both chambers move along the joint synchronously guided by a carriage system mounted on rails.

The necessary vacuum of 10^{-2} torr for welding is reached in about 5 minutes pumping time. The weld seam is observed by a TV monitor and seam tracking is by an automatic guidance system.

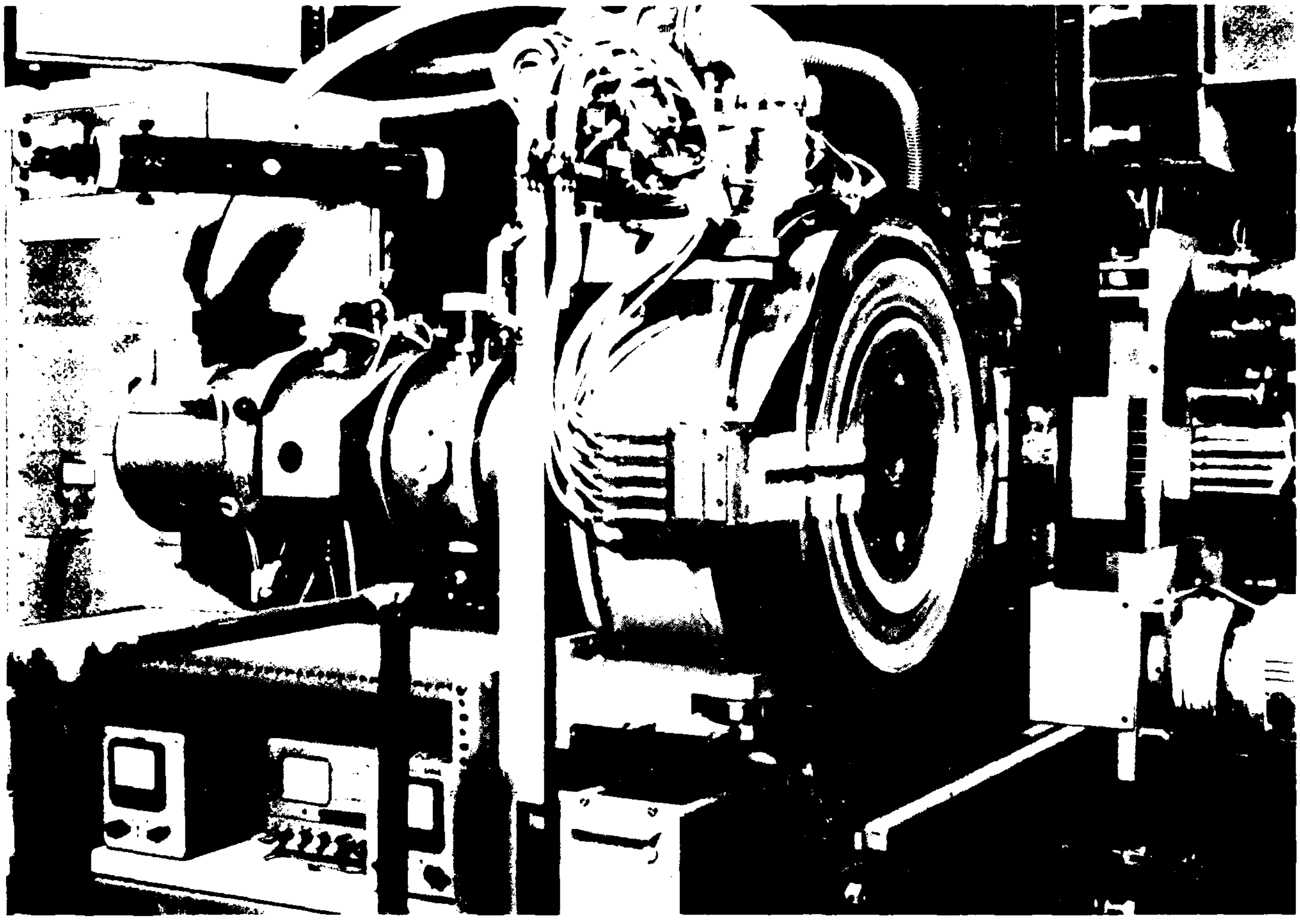


FIGURE 27 STEIGERWALD MOBILE VACUUM SYSTEM

Even though the illustrations of the equipment are in the horizontal position, weld tests have been also performed successfully with the gun in the vertical position and the plate in the downflat position, as would be necessary for welding panel plate assemblies.

Japan Steel Works and Nippon Kokan presently have the Steigerwald local vacuum equipment adapted to specific in-production requirements.

Both the Steigerwald and Scaiky local vacuum designs require that "run-off" tabs be welded at the ends of the plate to allow for support of the gun and sealing equipment after completion of the weld seam.

NON-VACUUM (ATMOSPHERIC) EB WELDING

Non-vacuum EB welding equipment maintains the electron gun at hard vacuum (1 x 10^{-4} torr) but the workpiece is at atmospheric pressure (760 torr). The electron beam travels through several orifices which are divided into successive but distinct pumping chambers. Each chamber is maintained at a progressively lower vacuum until the beam reaches atmospheric pressure at the column outlet. See Figure 28 for a typical NVEB gun/column assembly.

The main advantage of using NVEB welding over hard or partial vacuum EB welding is the higher production rates while incurring lower costs, since no vacuum chamber is required for the work and time is not consumed in pumpdown prior to welding. Also the chamber size is not a limiting factor.[5]

These advantages are gained at the expense of reduced weld penetration and working distance (the separation between the electron beam exit nozzle and the workpiece being welded). This in turn limits the maximum thickness of material that can be welded.

The working distance is limited in NVEB welding (usually 3/8 to 7/8 in.) because of the power density of the beam being gradually diminished by the scattering effect from collisions with air or unless a less dense gas such as helium is used as a transmitting medium then the working distance may be increased to as much as 2 inches.[6] An effluent gas such as helium would need to be used as a gas coverage for the beam to acquire the maximum penetrating deeps capable of the NVEB. Typical flow rates of helium gas coverage are about 100 ft^3/hr. As much as 2/3 of the gas could be recovered if a recovery system were adapted to the nozzle area.

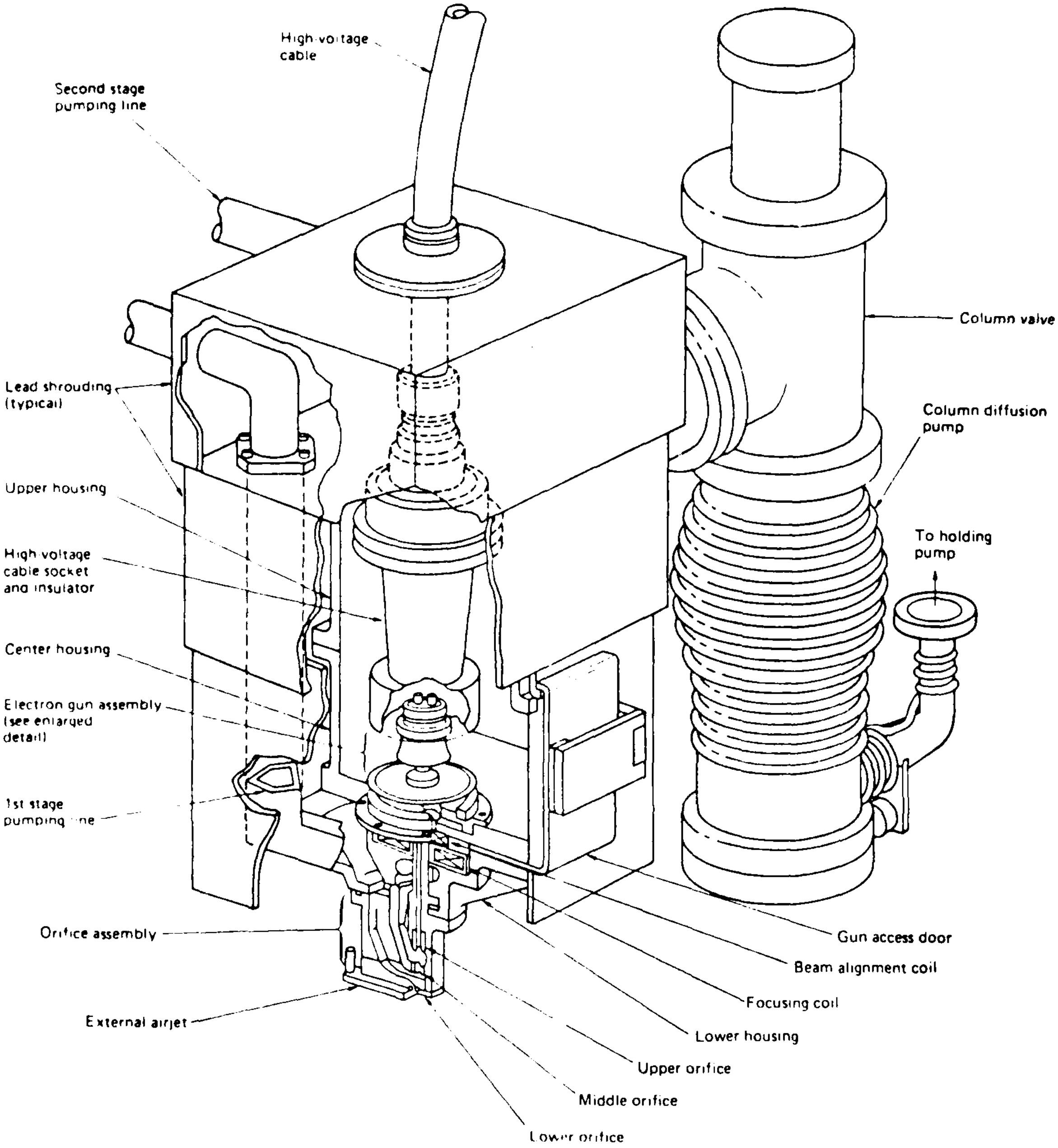
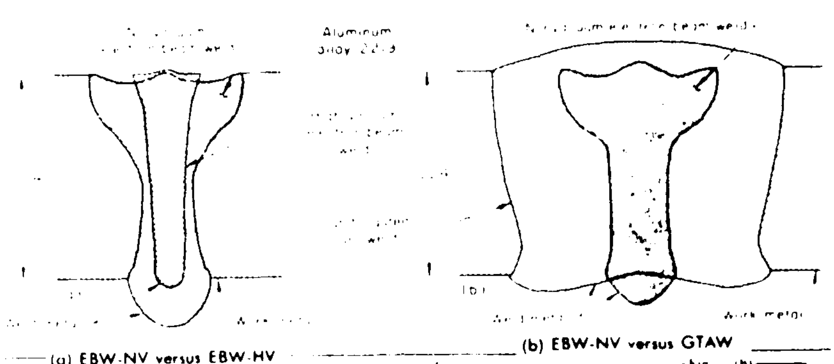


FIGURE 28 TYPICAL NON-VACUUM GUN/COLUMN ASSEMBLY

Due to the scattering effect of the NV electron beam, a wider weld and diffusion zone may result giving an appearance similar but less narrow than a gas tungsten arc weld (See Figure 29). Slightly more distortion would result from a NV weld as compared to a high or partial vacuum weld.



(a) EBW-NV versus EBW-HV

(b) EBW-NV versus GTAW

Welding conditions	Fig. (a) High-vacuum EBW	Fig. (a) Nonvacuum EBW	Fig. (b) GTAW	Fig. (b) Nonvacuum EBW
Voltage, kV	150	140	13 V	140
Current, mA	20	30	270 A	20
Welding speed, in./min	100	100	20	50
Welding energy, kJ/in.	1.8	2.5	10.5	3.36

FIGURE 29 COMPARISON OF FULL-PENETRATION WELDS MADE BY VARIOUS PROCESSES

Beam power level is a major factor in determining maximum penetration depth as shown in Figures 30 and 31. Power levels from 3 to 36 KW are shown with depth of weld penetration and welding speed as the dependent and independent variables respectively. High penetration depths of 1.5 inch (3.8cm) are attainable in carbon steels with 36 KW at a welding speed of 24 ipm (1.0 cm/sec).[7]

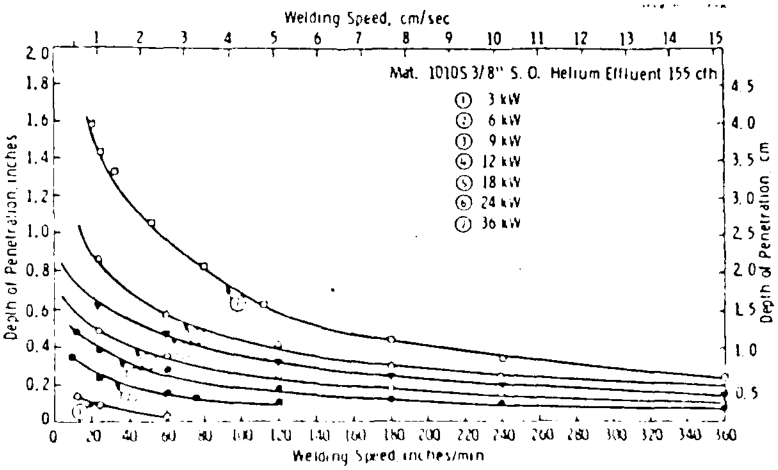


FIGURE 30 NVEB DEPTH OF PENETRATION VS. WELDING SPEED AT SELECTED POWER LEVELS. MATERIAL 1010 CARBON STEEL, 3/8" STANDOFF, HELIUM GAS EFFLUENT. (WESTINGHOUSE DATA)

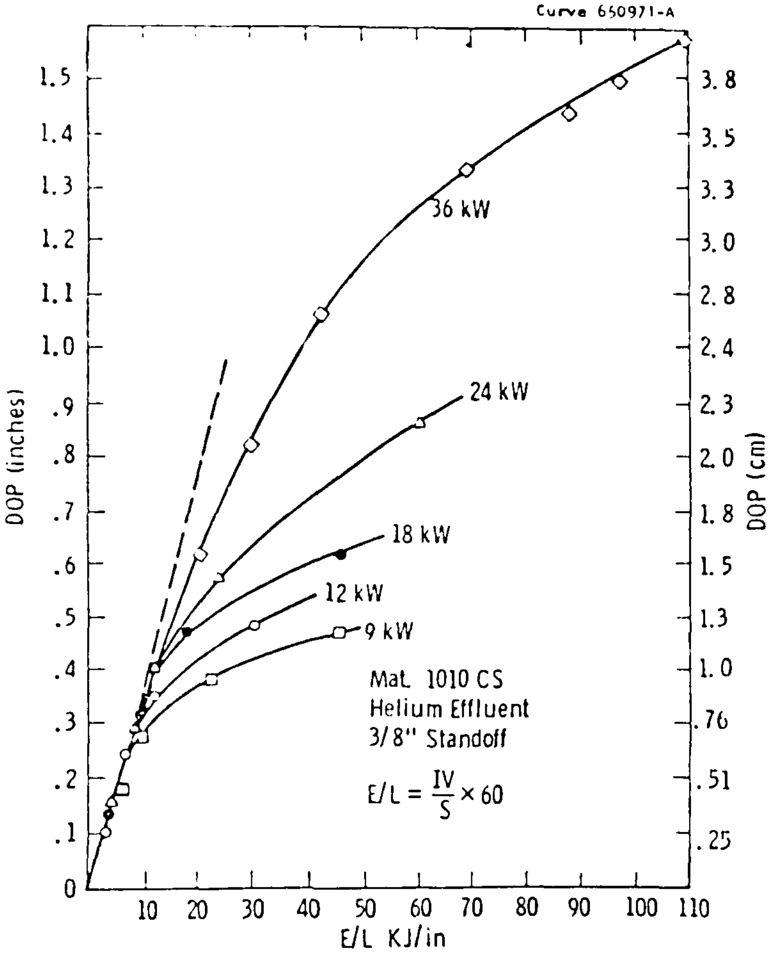


FIGURE 31 NVEBW DEPTH OF PENETRATION VS. BEAM ENERGY INPUT/UNIT LENGTH OF WELD. MATERIAL 1010 CARBON STEEL, 3/8" STAND-OFF, HELIUM GAS EFFLUENT. (WESTINGHOUSE DATA)

Filler metal is not ordinarily required for NVEB welding except where necessary because of poor fit-up, for weld reinforcement to produce desired weld metal properties or to avoid cracking.

Most materials that can be conventionally welded can be NVEB welded. No test data was available on the mechanical properties of NVEB welds performed on typical shipbuilding steels.

The manufacturer of NVEB welding equipment in the U.S. is Leybold-Heraeus Vacuum Systems, Enfield, Conn.

LARGE VACUUM CHAMBER EB WELDING

The method of electron beam welding most commonly used is placing the workpiece inside a chamber and having the electron gun mounted either externally or internally to the chamber. Placement of the gun is usually dependent on the size of the chamber and the adaptation of the workpiece to be welded.

Chambers of the intermediate or smaller size are the most common but in specialized condition, large chambers have been designed and built such as the chamber (See Figures 32 and 33) for Mitsubishi industries of Japan for welding of the core barrels and internal components of nuclear reactors and the large clamshell chamber built for Grumman Aircraft welding of F-14 wing panel sections. (See Section 1)

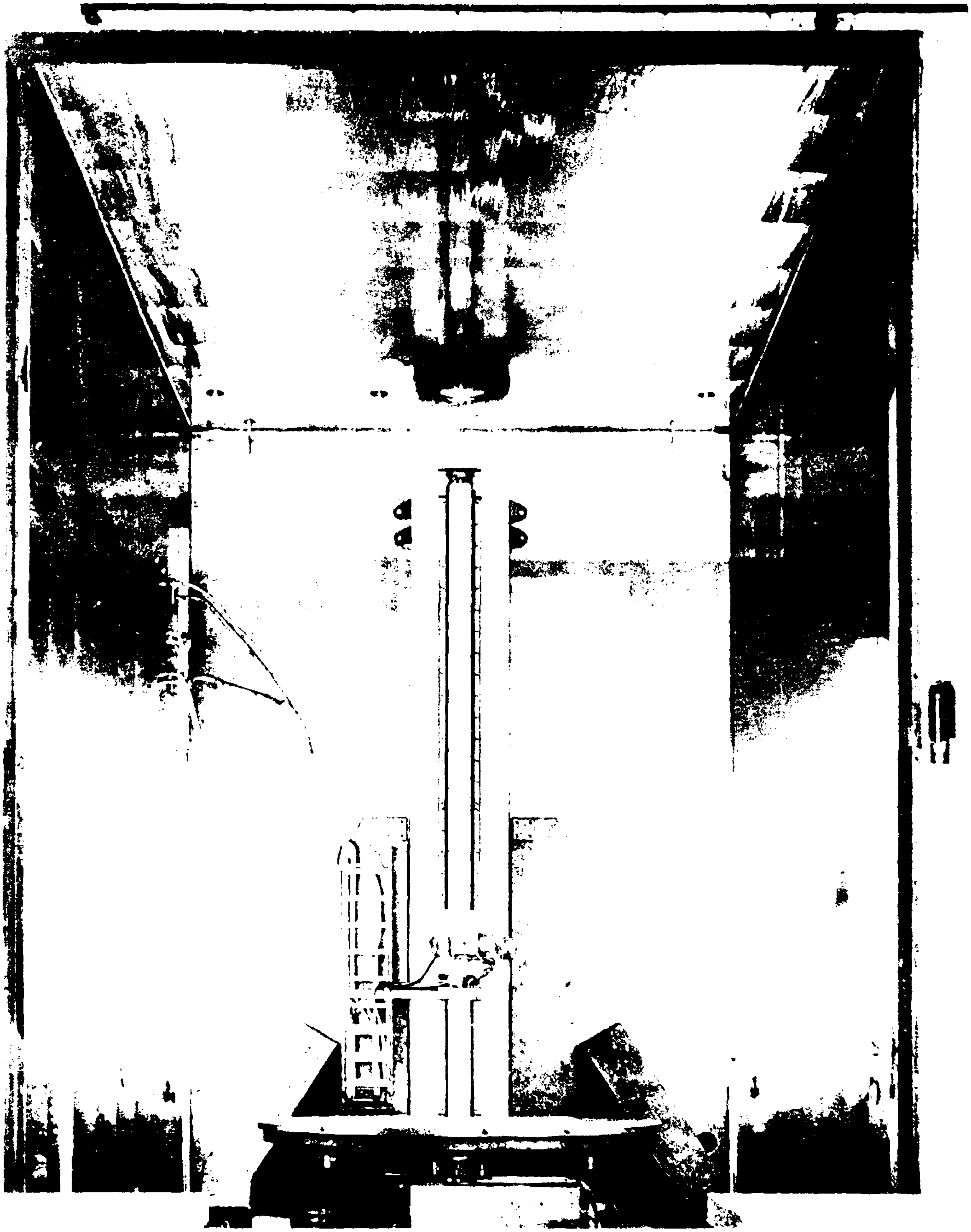
For many applications, it has been preferable to have the large chamber with a mobile internal gun which can be moved to several welding sites on a component inside the chamber such as would be necessary for welding of the longitudinal seams of panel plate assemblies or welding of multiple fillet welds of T-stiffeners to panel plate assemblies in the shipbuilding industry.

A disadvantage of having the internal gun has been the requirement to pump the chamber to the same operating pressure as the electron gun (i.e., 10^4 torr). One method to overcome this problem has been to adapt a local turbo-molecular pump to the gun chamber, so the high vacuum is maintained on the gun while a lower vacuum can be used inside the chamber thus minimizing the pumpdown time required.

One of the main disadvantages of a large chamber in the past, has been the pumpdown time to evacuate the chamber before welding pressures could be attained. But with the vacuum systems available today, it is possible to evacuate even large chambers such as the Mitsubishi Industries chamber (volume 7560 ft^3 = $280m^3$) in only 20 minutes (10^{4} torr vacuum).

Welding in a high or partial vacuum atmosphere inside a chamber not only increases the penetration depth of the electron beam, but it also yields a cleaner weld, since there are minimal residual contaminants remaining in a vacuum of this level. The chamber also acts as a shielding for the x-rays that are generated as the electrons impact the workpiece. Ordinarily, no additional shielding is required on a chamber when the gun is internally mounted. The mobile vacuum or non-vacuum EB welding equipment which normally has the electron gun exposed usually requires at least a 1/4 inch thick lead shield around the gun and workpiece to lower the x-rays to an acceptable level to meet industrial safety standards.

FIGURE 32 MITSUBISHI EB WELDER
(Exterior View)



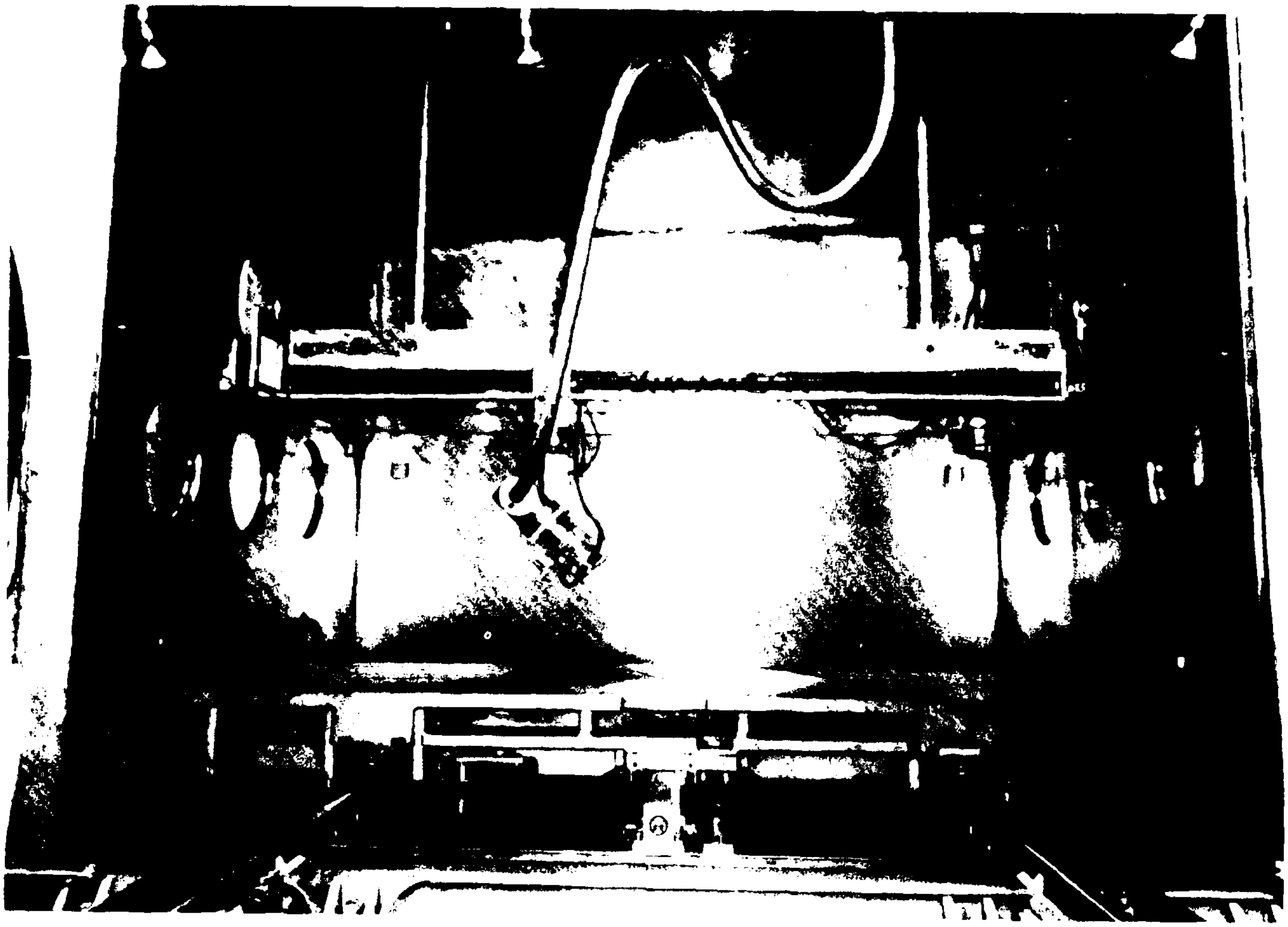


Figure 34 Typical vacuum chamber arrangement with internally mounted gun. Added features of a vacuum chamber are motorized doors for easy access and viewing ports to allow inspection of the chamber interior by the operator.

Most large chambers designed today are equipped with computer controlled feedback servo-mechanisms which can control the beampower and size as well as the gun or work travel to within a few thousandths of an inch. The adaptability of these feedback systems would minimize the risk of missing a weld seam from improper beam setting.

Figure 35 Gun carriage mechanisms can be automated to provide motion in the major axis and the gun may be manually rotated ±90° to provide various angles of incidence between the electron beam and the piecepart.

Various types of travel mechanisms of rigid construction can be adapted to a vacuum chamber set-up. Runout tolerances of approximately 0.001 in per foot can be obtained, but this is usually dependent on the manufacturing tolerances and the accuracy of the workpiece fit-up. One of the main features of a vacuum chamber over either mobile vacuum welding or non-vacuum welding is the extra ruggedness and less risk of damaging the gun mechanisms since the workpiece would be passing through the chamber rather than the gun/mobile chamber moving to the weld seam.

The following three major manufacturers of electron beam welding equipment in the U.S. have the capabilities to design and fabricate large vacuum chamber and electron beam gun systems: 1) Leybold-Heraeus Vacuum Systems, 2) Sciaky Bros. and 3) Steigerwald Systems - MG Industries.

ADAPTABILITY OF EB WELDING EQUIPMENT TO THE SHIPBUILDING INDUSTRY

As was mentioned earlier in this report there are four fabrication areas in the shipyard where EB systems could feasibly be adapted to increase productivity over the presently used conventional methods of welding. These areas are:

1) panel/deck fabrication
2) T-stiffener to panel assembly
3) pipe welding
4) T-stiffener web to flange welding

Each fabrication area will be analyzed and how it is envisioned that method of EB welding could be applied.

FLAT PANEL/DECK FABRICATION

Either the mobile vacuum chamber, non vacuum, or the large chamber EB welding concepts could be adapted to this fabrication area.

The mobile vacuum EB welding equipment (Sciaky and Steigerwald designs) could be modified to fit into the shipyard environment of welding panel/deck plates. Both designs have the capability of using electron guns with sufficient power levels to penetrate and weld the normal panel plate thickness ranges (1/4 to 2 in.) seen in most surface-effect shipyards. It was suggested by the EB manufacturers consulted that the power level of 40-60 KW would be suited for welding of plates in this thickness range. The length of the panel/deck weld seams (40 to 50 ft. normally) would require that the specific design be developed to accommodate seam tracking and maintaining a consistent vacuum over the entire length of the seam.

In past studies by varius users of mobile or sliding seal EB equipment, they discovered that the local chambers have to be pumped rapidly to exhaust the metal vapors emitted during welding, otherwise arc-outs of the beam regularly occurred. The high production and quality requirements of the shipyard industry may require that more development work be accomplished on these designs to overcome this problem.

With the gap tolerances of the square butt edge prep necessary for electron beam welding (less than 1% of the plate thickness), the shipyard would have to decide if their manufacturing tolerances of plate edge preparation could be controlled this accurately with machining or if filler metal would need to be added. With filler metal additions, a gap of up to 3% of the plate thickness would probably be acceptable. Both the Sciaky and Steigerwald mobile vacuum designs have filler metal addition capabilities.

The shipyard would also need to evaluate their present fit-up methods. The tight gap tolerance requirement for EB welding would necessitate a better quality assurance method for guaranteeing proper fit-up before welding commences or excessive repairs would result.

Since the electron gun is exposed during welding with the mobile and non-vacuum concepts, the welding equipment would have to be covered with adequate lead shielding to decrease the x-ray emission to an acceptable industrial safety level.

The non-vacuum EB welding system would be somewhat limited to only shipyards that weld between 1/4 to 1-1/4 in. panel plates. The present power level of 36 kw for the NVEB equipment is restricting but there are more powerful units being developed which should show promise for welding plates thicker than 1-1/4 in.

Both mobile and non-vacuum EB systems could be adapted to the panel line with a traversing bridge welding concept, very similar to what is presently used for production welding with automatic submerged arc welding equipment. Figures 36 and 37 show the conceptual layout for the adaptation of the mobile and non-vacuum systems to the panel line fabrication area. The assembly line method of EB welding the panel plates would effectively blend into the present methods of fabrication for the shipbuilding industry.

The large chamber EB welding concept would readily adapt to the panel/deck fab area.

For large chamber EB welding to be economically competitive with automatic subarc welding, the chamber would have to large enough to accommodate a panel plate assembly (4 plates - 10 ft. x 40 ft.) inside for each pumpdown. If the inside dimensions of the chamber were 45 ft. L x 45 ft. W x 5 ft. H, it would have a volume of 10,125 ft^3 (375 M^3) or about 33% more volume than the Mitsubishi chamber in Japan.

If similar evacuation systems were used on this chamber, approximate pumpdown time would be 30 minutes. One of the main considerations of a chamber this size and shape would be designing it with sufficient external stiffening to minimize deflection due to external air loading. This deflection must be

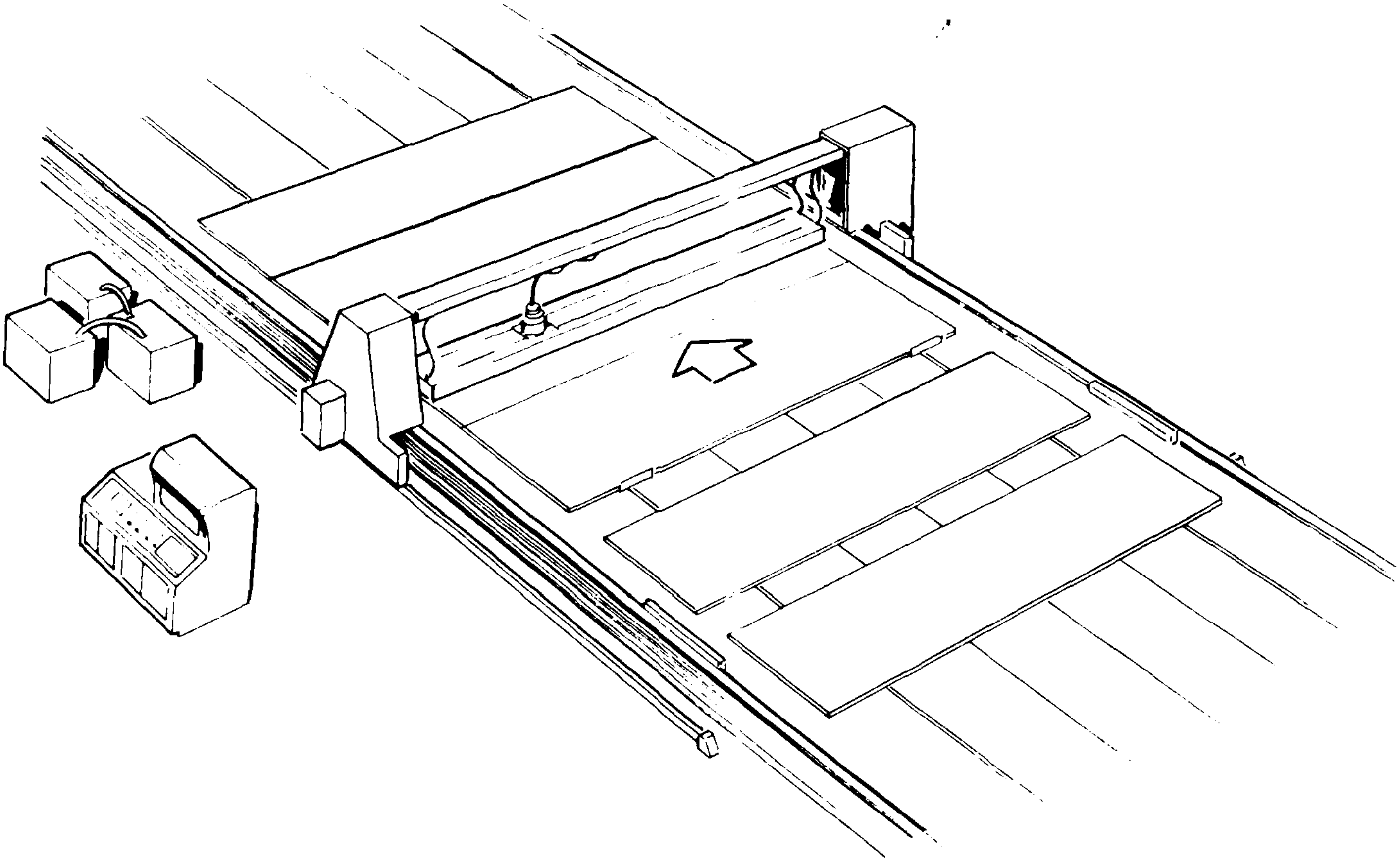


FIGURE 36 **MOBILE OR SLIDING SEAL EB WELDING FLAT PANEL LINE FABRICATION**

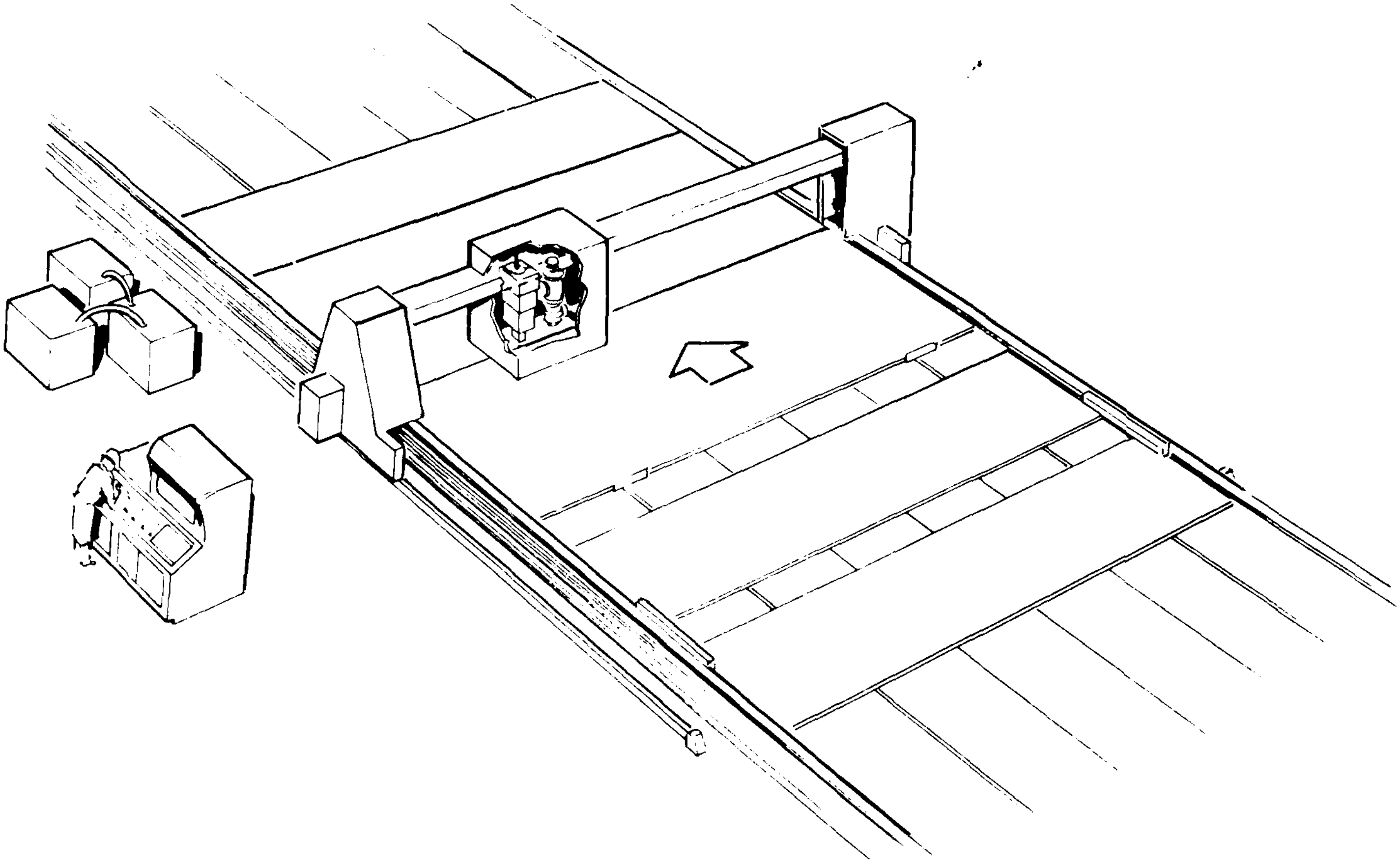


FIGURE 37 **NON-VACUUM EB WELDING FLAT PANEL LINE FABRICATION**

kept adequately low if there is to be good mechanical alignment of the electron beam path and the weld seam, since the vacuum chamber acts as the mounting surface for the work piece and the gun transport systems.

The other major factor of a vacuum chamber this size would be the cost. Estimated prices of a chamber this size with EB and vacuum systems may cost as much as $5 million. Of course, this would also be partly dependent upon the power rating of the gun and the pumping systems adapted, but these would be a relatively low percentage in the overall cost as compared to the vacuum chamber. This $5 miilion dollar cost would also cover the expense of run out systems, internal tracking mechanisms, and the erection cost of the chamber at site.

With a chamber this large, an internally mounted gun would be the most advantageous to increase productivity and give greater welding flexibility. The addition of computer control systems over the EB welding functions as well as the gun carriage travel mechanisms would provide a complete hardware and software package to monitor quality assurance in each EB welded seam.

Figure 38 shows the conceptual layout for the adaptation of a large vacuum chamber with EB welding systems to panel line fabrication. The large chamber could be set-up in an assembly line method if motorized doors were placed on the front and backside of the chamber to allow for continuous line travel of the panel plates.

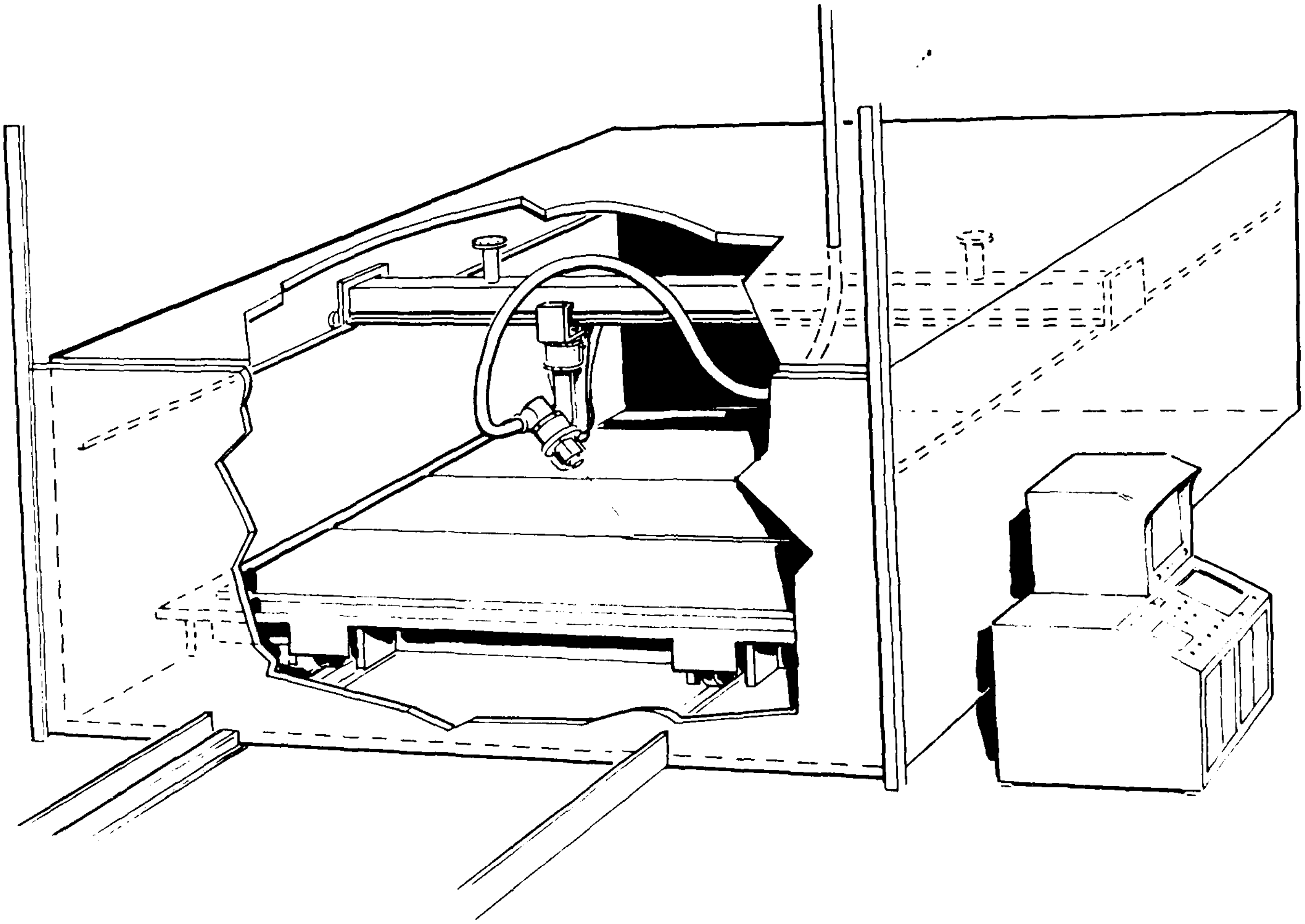


FIGURE 38 **LARGE CHAMBER EB WELDING FLAT PANEL LINE FABRICATION**

T STIFFENERS TO FLAT PANEL FABRICATION

The fillet welds required on each side of the longitudinal T stiffeners that run the length of the panel plates could be EB welded in the large vacuum chamber concept.

From previous development test performed by DTNSRDC for Contract No. N00600 77-C 1554 and report SME 81/35, T stiffener to panel, partial penetration fillet welds were welded in a vacuum chamber with the EB gun angled at 45° to the plane of the panel with no filler wire additions.[8,9] All fillet welds were examined by mag particle and flourescent penetrant testing and found to be acceptable. The configuration and layout of the T-stiffener and panel plates used in these reports are shown in Figures 40 and 41. A typical cross section of the fillet is shown in Figure 39.

The shipyards visited for the study of this report used T stiffeners with varying thickness, some with webs as thick as 1.0 in. Further tests should be proposed on Tee configuration welds of plates with this thickness to ensure that solidification cracking would not be a problem.

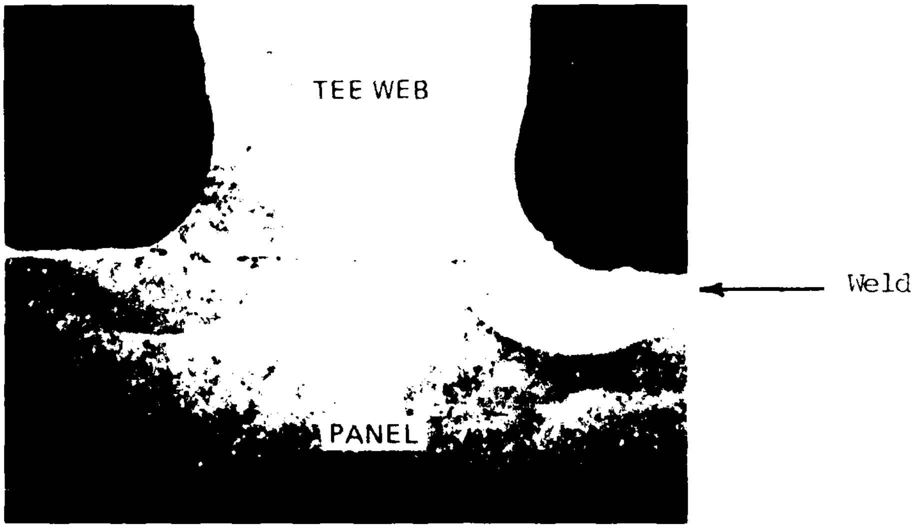


FIGURE 39 FILLET WELD TECHNIQUE 10X

Mobile vacuum chamber and non-vacuum EB welding has not been tested on T-stiffener to panel plate fillet welding. Each of these methods of welding are not readily adaptable for this application due to the configuration. The mobile vacuum needs a flat welding surface to form a vacuum and NVEB welding has a very short working distance and limited penetrating capabilities. The wide dispersion of the NV electron beam could possibly cause undercutting in the tee web unless filler metal was added.

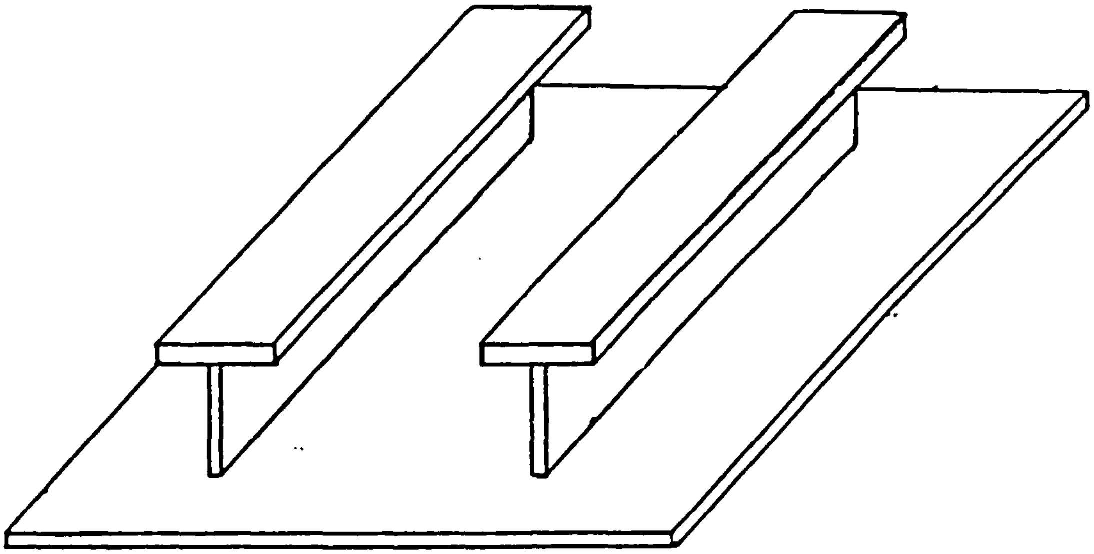


FIGURE 40 T-STIFFENER TO PANEL CONFIGURATION

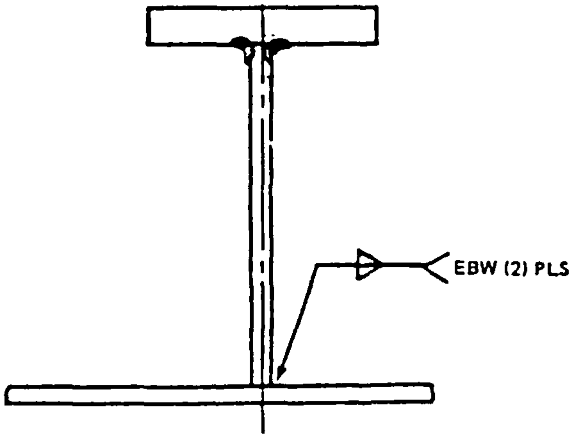


FIGURE 41 T-STIFFENER TO PANEL ASSEMBLY - EB FILLET WELDED

PIPE WELDING

EB welding has been shown to be an economical and effective method of joining pipe joints. The most recent application has been in the welding of pipeline in the J position from a pipe laying barge.[10] Total (French Petroleum Co.) and La Soudure Autogene Grancaise (SAF) have designed and built a local chamber (shown in Figure 42) which creates a vacuum around the pipe seam to be welded. The equipment can weld 24 in. diameter pipe, 1 1/4 in. thick, automatically in only 3 minutes. The vacuum chamber is separated into an inner and outer section. The inner section houses the EB gun and the operating electronics under vacuum. The outer section is maintained at atmospheric pressure until the weld is to be made, then it is pumped down in about 3 minutes.

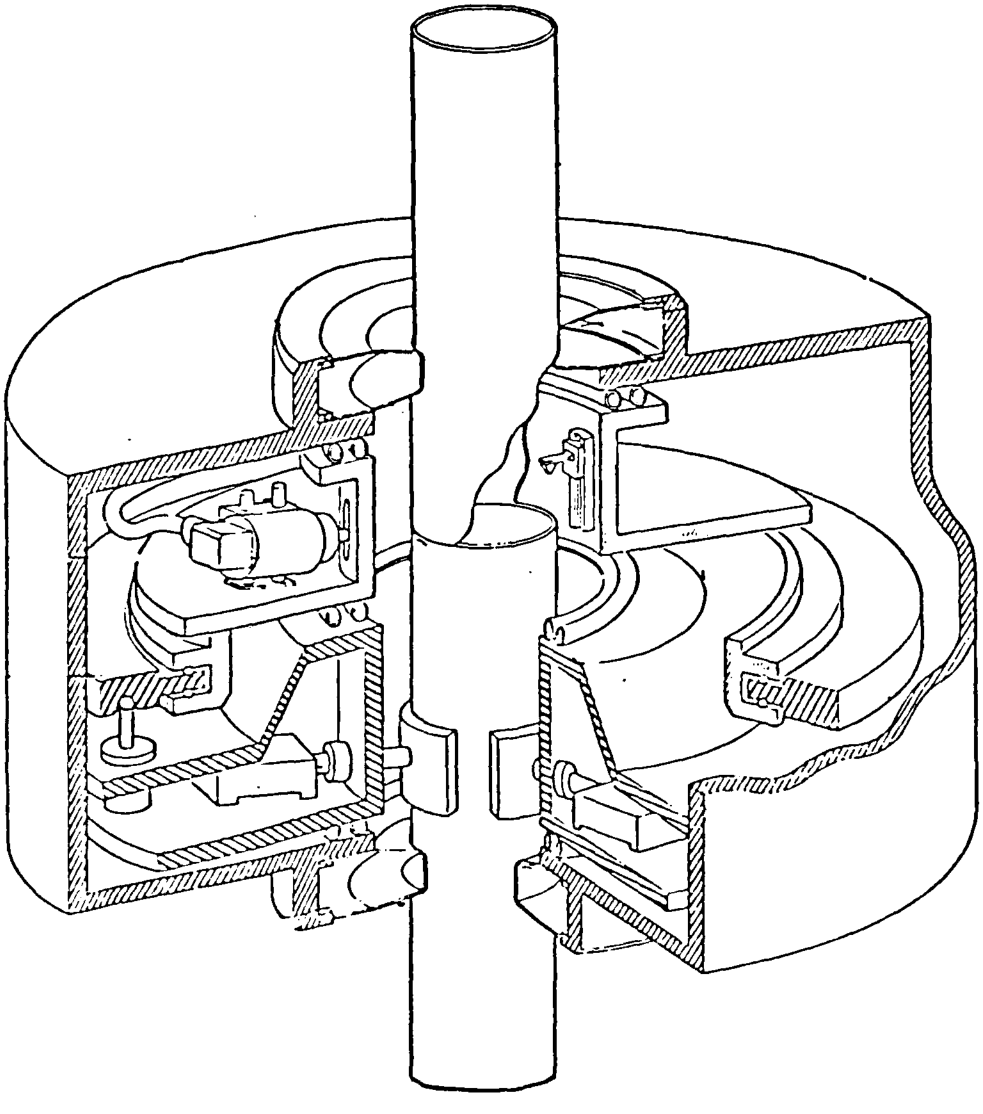


FIGURE 42 EXTERNAL EB SET-UP FOR WELDING PIPE JOINTS

This EB pipe welding equipment has made over 1200 welds on 12 different types of materials with successful results.

Another design (Sciaky) for pipe welding is where the EB gun is positioned inside the pipe to create a local vacuum chamber. (See Figures 43 and 44)[11] The local vacuum chamber is integrated into the gun support, travel and centering mechanisms. Two inflatable seals are located on the ends of the pipe to allow pumping the inside to a soft vacuum (10^{-3} to 10^{-2} torr). The EB gun is maintained at a hard vacuum (10^{-5} to 10^{-4} torr) by a turbomolecular pump. On the outside of the pipe seam is a counter chamber (See Figures 44 and 45) which holds the stopping bar for the excess beam current. The counter chamber stays at a soft vacuum level.

This design can weld pipe with a minimum diameter of 10 in. (250mm) and a maximum of 30 in. (750mm).

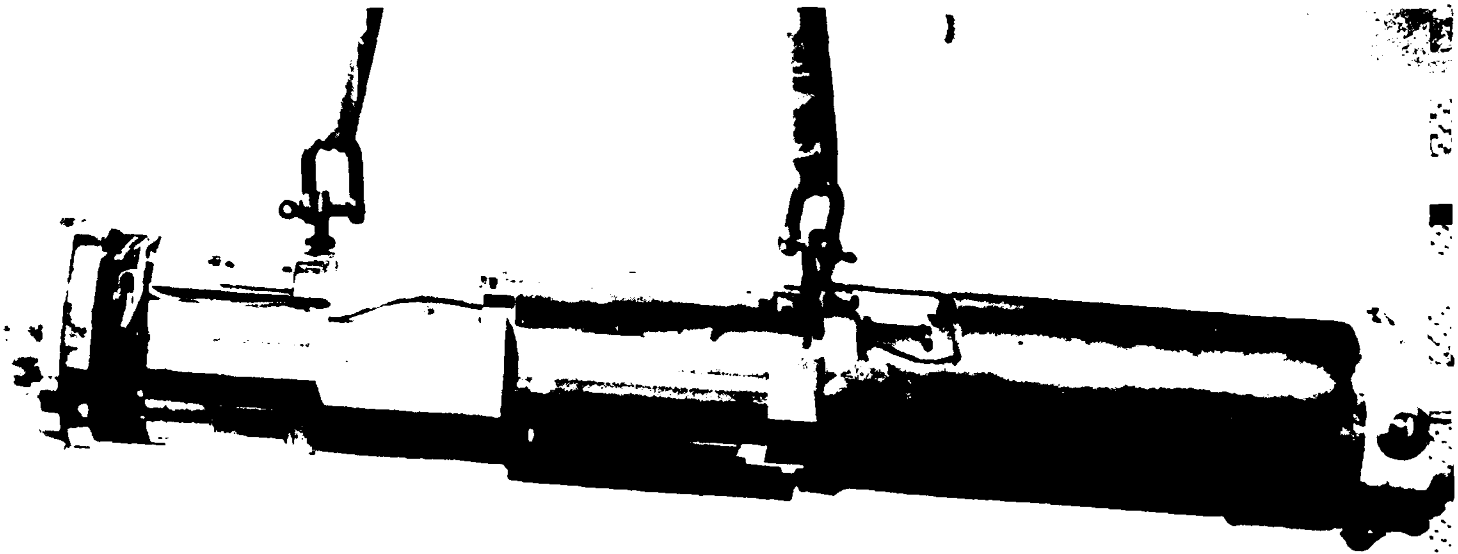


FIGURE 43 INTERNAL EB GUN SET-UP FOR WELDING PIPE JOINTS

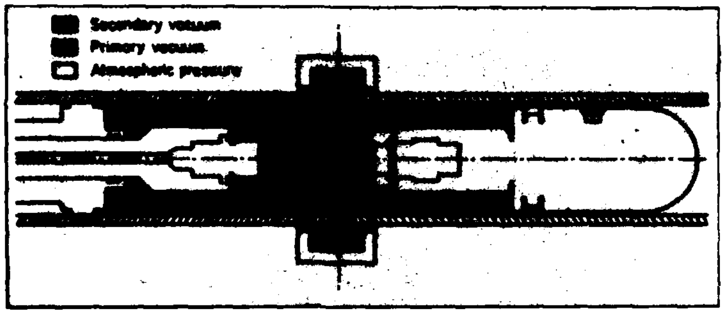


FIGURE 44 SCHEMATIC PRESENTATION OF INTERNAL CHAMBER FOR EB PIPE WELDING. 1-ELECTRON GUN; 2-COUNTER CHAMBER; 3-TURBO-MOLECULAR PUMP; 4-INFLATABLE SEALS. DARK SHADED AREA: SECONDARY VACUUM; LIGHT SHADED AREA: PRIMARY VACUUM

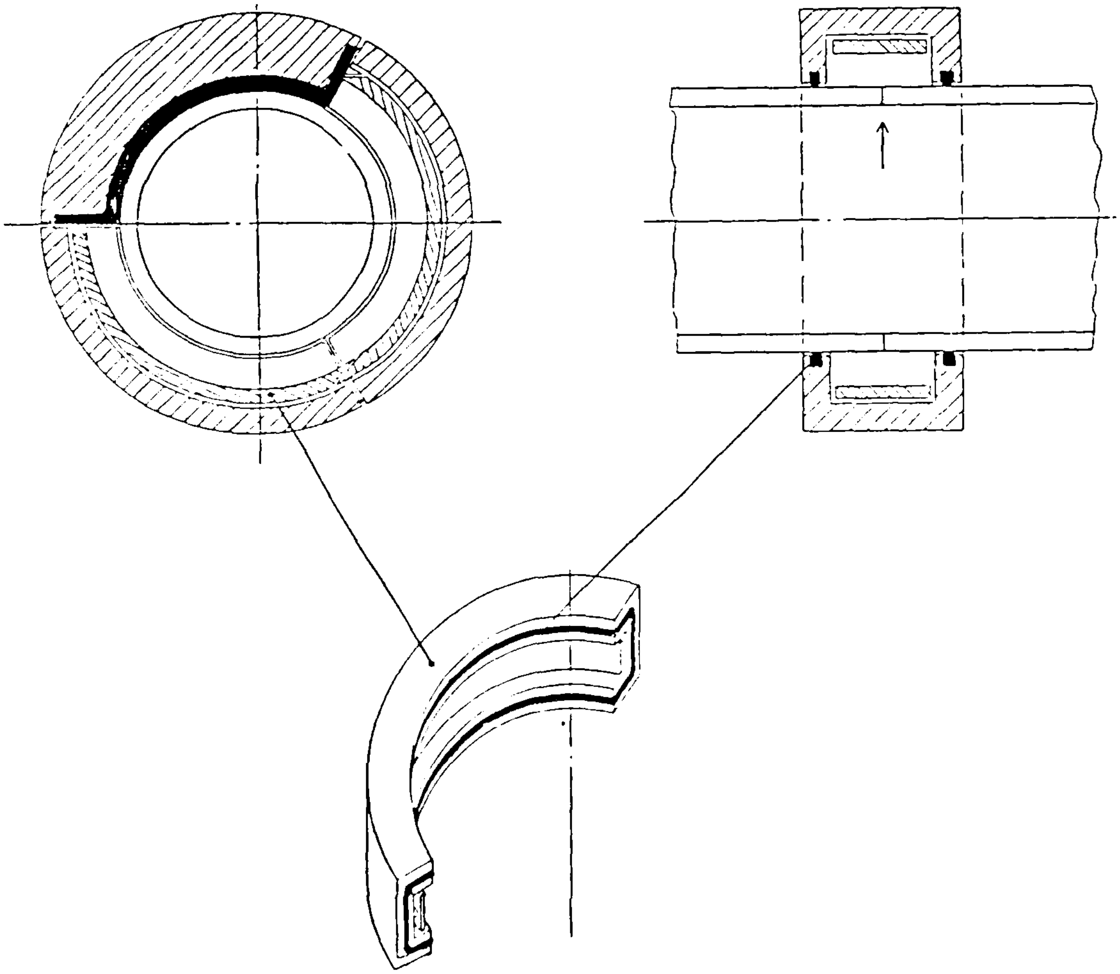


FIGURE 45 SCHEMATIC PRESENTATION OF COUNTER CHAMBER WITH SPECIAL SEALS

With the thousands of pipewelds required for each ship, the application of EB welding would appear to be very feasible for the shipyard industry. Since the pipe spooling area could be located in an isolated section of the fabrication facility, it would be ideal for a controlled environment for the EB welding systems. In a temperature and humidity regulated atmosphere the EB computer systems would have better reliability.

Piping also has the advantage of having commercially available machining units on the market that could machine the square butt edge preparation to the necessary tolerances for EB welding. The units are relatively inexpensive and could be set up in a pipe spooling operation. The cost for machining the square butt edge preparation on a pipe should be comparable to conventional flame cutting techniques.

The adaption of the presently available EB pipe welding equipment to the various diameters of pipe in shipbuilding (2 in. to 20 in.) would require some development work in the form of seal modifications and holding fixtures.

T STIFFENER WEB TO FLANGE WELDS

Since the shipyards have been unable to order high strength T stiffeners (80 ksi yield strength material) from the steel mills, they have been forced to fabricate the webs and flanges from flat plate material. This results in each shipyard cutting plate with a shear and welding the longitudinal fillet welds and butt splices of each web to flange member. This has resulted in a time consuming operation.

EB welding test performed by Grumman Aerospace Corp. for the Navy have proven that web and flange members can be welded together in a practical and feasible method.[8] Plate thickness of 3/4 in. and 1 in. Hy 80 material was used for the web and flange members. (See Figure 46) The 25 ft. length tees were welded in a vacuum chamber with the longitudinal seam welded in the horizontal position and the butt splices made in the vertical position. Except for a few instances of the electron beam missing the weld seam, the welds were found to be sound by radiographic and ultrasonic testing. A typical T-stiffener web to flange EB weld cross section is shown in Figure 47.

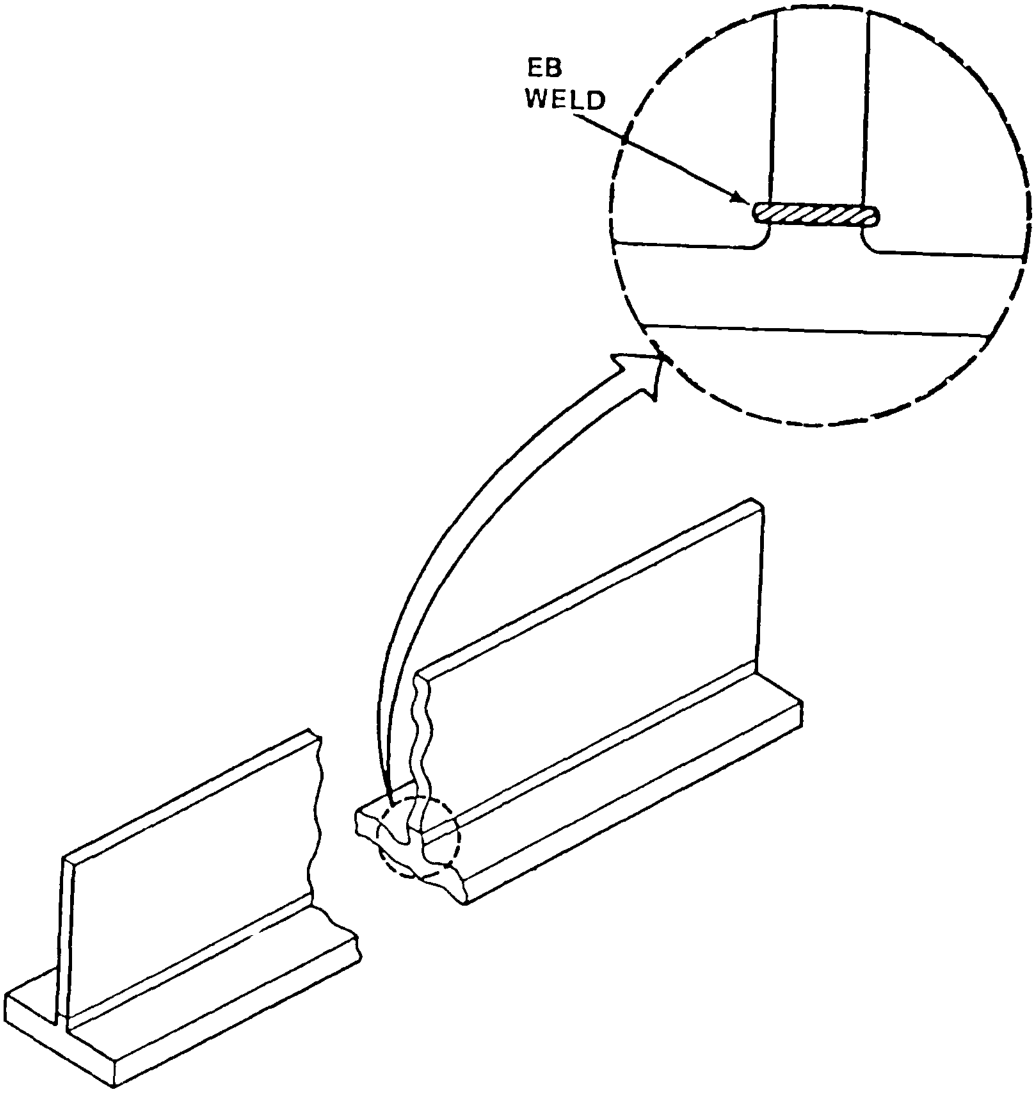


FIGURE 46 JOINING T-STIFFENER FLANGE TO WEB WITH EB

FIGURE 47 TYPICAL T-STIFFENER CROSS-SECTION
OF WEB TO FLANGE EB WELD

To obtain sound EB welds, Grumman found that the following was necessary for the preweld operation:

1) The face, root and interface areas of each web and flange member should be disc sanded along its entire length.

2) Each web and flange member had to be magnetically degaussed to minimize beam deflection.

3) Because the welding was performed without preheat, relatively slow speeds and high heat inputs were necessary to prevent cracking.

4) Oscillation of the electron beam reduced or eliminated porosity in the weld.

After welding of the T stiffener, it was found that the Hy 80 EB welds exhibited relatively high hardness values in the weld and HAZ. A post weld heat treat of one (1) hour at 1200° F was found to lower the weld/HAZ hardness to an acceptable level while maintaining satisfactory toughness and ductility.

Since the shipyards do not post weld heat treat the T-stiffener web to flange welds for normal fabrication practice, other high strength materials such as A710 Grade A should be considered instead of HY80 material for EB welding. The mechanical properties of A710 Gr. A material appear to be better in the as-welded condition after EB welding (refer to data in Section 5) than HY80.

In general, these considerations would need to be applied to the shipbuilding industries method of fabricating panel, stiffener and pipe components if electron beam welding were used.

1) Plate or pipe edges should be machined with a tight fitting gap.

2) Plates should be checked for contaminants on surfaces that would increase pumpdown time of the vacuum chamber.

3) Plate or pipe edges would have to cleaned with solvent cleaner and visually checked before welding to avoid defects.

4) In order to prevent missing the weld seam due to beam deflection from residual magnetism, the plates would probably have to be demagnetized by an effective degaussing technique. The plates would probably have a relatively high level of magnetism since the plates are handled by DC electro magnets in the shipyard.

4) (cont'd)

Several techniques for demagnetizing are available, such as a reversing DC magnetic system where terminals are connected at diagonals to the plate and 4000-5000 amps of DC current is passed through for 4-5 minutes. The terminals are reversed and the procedure is repeated. Another method would be a magnetic stepdown chamber where the plates are passed through a chamber wrapped with coils every 4 or 5 ft. An alternating pulse would be used and the amplitude of the current would be tapered off at the end of the plate.[27]

Either method would be acceptable for stepping down the residual magnetism in the plate. Typical cost of this demag setup would be about $30,000.

Another technique for reducing the beam deflection is by shielding the beam with a screening pipe that covers the beam from the electron gun to the work. Tests have shown that plates with high magnetism can be successfully welded with only the use of a screening pipe and no demagnetization of the plate.[12] This may be the most cost effective method of overcoming the residual magnetism in the plates before they are EB welded.

5) Certain components of the EB set-up (computer control cabinet, servo cabinet and the power distribution cabinet) should be housed in a regulated environment which is relatively dust and humidity free, to maintain the reliability of the electrical components. Downtime due to shorts or electrical component failure can be troublesome and labor intensive to troubleshoot.

6) Specially trained operators and maintenance technicians would have to be trained to correctly operate and service the equipment.

EQUIPMENT PROCESS SURVEY

As part of the study for this report, a survey was taken of the domestic electron beam manufacturers and the equipment they produce. The EB manufacturers which the data was received from are 1) Leybold Heraeus Vacuum Systems, 2) Sciaky Bros. and 3) MG Industries - Steigerwald Systems.

Each manufacturer has a complete range of options available from high and low voltage EB guns to small and large chambers. The power rating of the EB guns and the size of the chambers available vary, due to the requirements of the material thickness and the component size of the customer purchasing the equipment.

Table 2 shows the options available from each of the three manufacturers. Each manufacturer has the capabilities to design a large chamber system to meet the requirements of the shipbuilding industry. The final cost of the EB system would be dependent on the options that are required by the individual shipyard.

	High Voltage Gun	Low Voltage Gun	High Vacuum Chambers	Partial Vacuum Chambers	Mechanical Pumping System	Oil Diffusion Pumping System	Cryogenic Pumping System	Computer Numerical Control	Digitizing Seam Tracking	X-Ray Tracking Sensor	Real Time Tracking	Gun Servo Mechanism (x,y,z coordinates)	Transporter Run-Out System	Wire Feed Systems	Optical Viewers (TV Monitor)	Computer Feed Back Printer	Non Vacuum System Capabilities	Sliding Seal Equipment Capabilities	Design Capabilities of Large Chamber
Leybold-Heraeus	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X		X
Sciaky	X	X	X	X	X	X	X	X	X			X	X	X	X	X		X	X
MG Industries-Steigerwald Systems	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X		X	X

X - Option Available from Manufacturer

TABLE 2

Each EB manufacturer has completed a questionnaire that describes areas such as EB models available, delivery time, equipment reliability, etc.

Also attached to each EB manufacturer questionnaire is an appendix (submitted by the manufacturer) which gives the technical data of their equipment. The appendices are as follows:

1)	Leybold-Heraeus	Appendix A
2)	Sciaky	Appendix B
3)	MG Industries - Steigerwald Systems	Appendix C

Each manufacturer provides for supervision of installation of any EB equipment as an integral part of the equipment sale. A service representative would be available to provide on-site technical advise and check on the erection, assembly, sequence of work and pre-operational testing of the EB equipment purchased. However, the overall responsibility for the work performed during installation and construction would remain with the purchaser and the purchaser would be responsible for the supervision of workmen and the quality of workmanship.

Each manufacturer conducts training programs covering the design and operation of the equipment they supply. It is recommended by the manufacturer that the maintenance personnel and equipment operators obtain proper classroom training prior to operation of the equipment.

Several electron beam equipment users were surveyed and the data that was collected is shown on the EB applicators questionnaire form located behind the Manufacturers section.

LEYBOLD HERAEUS VACUUM
SYSTEMS, INC.

ELECTRON BEAM MANUFACTURER SOURCE QUESTIONNAIRE

1. Company Name: Leybold-Heraeus Vacuum Systems Inc.
2. Address: 120 Post Road, Enfield, CT 06082
3. Telephone: (203) 741 2281
4. U.S. Representative: --
5. E.B. Models Available (High, Partial and No-Vacuum Systems):
   - Model: High and low voltage, high and partial vacuum models; high voltage, non-vacuum models.
   - Output Rating (KW): High and partial vacuum models, up to 60kW; non-vacuum models, up to 40kW.
   - Status: All of the above, standardly available models.
   - Development: ---
   - Commercial: --
6. Delivery Time: 6 to 18 months, depending on type and complexity of total system ordered.
7. Number of Electron Beam Units Supplied: Approximately 1000 systems, to date.
   - Customer Name: Wide variety of both domestic and international aerospace, automotive, nuclear, job shop, etc. customers (P&WA, GE, GM, FORD, DOE, etc., etc.).
   - Address: --
8. Electron Beam Budgetary Costs ($) or ($/KW): $400,000 to $1,600,000, approx. range of total system costs, depending on size and sophistication of total system ordered.
9. Electron Beam Equipment Reliability:
   - Uptime (hr/wk): 90 to 100%, AVG. uptime percentage, for high vac. systems being operated 1 to 2 shifts per day 5 to 6 days per week; 70 to 90% for partial and non-vacuum systems being cperated 2 to 3 shifts per day - 6 to 7 days per week.

9. (continued)

   - Repair Time (hr): 1/2 hr. (AVG.) for normal repairs, 4 hrs. (AVG.) for abnormal repairs.

10. Available Service Program: Full service and spare part support available, for both scheduled and unscheduled types of required service assistance.

11. On-Site Maintenance Skill Requirements: Same as required for other similar type, industrial style/CNC machine tools.

12. Electron Beam Fact Sheets:

    - EB Unit Dimensions: Systems available vary widely in size covering a range of from very small
    - Weight: to very large
    - Performance:
    - Consumables (Cooling Water, Gas, Cover, etc.): ----
    - Critical Component(s) (Cathode, Filament, etc.): --
    - Operating Cost ($/hr): From $0.05 to $0.95 per hour, total operating costs, per kW of delivered beam power; range dependent on whether system employed in a lab environment or production environment.
    - Electrical Requirements: 460V/3 phase; kVA draw depends on system size and complexity - and spans a range of from 40 to 18-kVA.

13. Welding Experience Data (Power, Welding Speed, Heat Input, Weld thickness) with:

    - AISI 1018: 4.75 inch penetration (bead on plate), at 10 ipm, using 30 kW.
    - HY 80: 1 inch penetration (butt weld), 20 ipm, using 5.7kW.
    - ASTM A302B: 2 inch penetration (butt weld with backup), 17 ipm, using 22kW.
    - 304 St. Stl.: 5 inch penetration (bead on plate), at 5 ipm, using 25kW.
    - AA 1100 Al: 5 inch penetration (bead on plate), at 10 ipm, using 25kW.

13. (continued)

- AA 5083 Al: 4 inch penetration (butt weld), at 10 ipm, using 19.5kW.
- 6AL-4V Titanium: 5 inch penetration (bead on plate), at 5 ipm, using 30 kW.
- OFHC Copper: 2 inch penetration (bead on plate), at 18 ipm, using 25kW.

Above are just a few examples of the various EB welding investigations that LHVS has conducted.

14. Safety Considerations (OSHA): OSHA specified personnel safety requirements covered by system design considerations.

15. Literature furnished by Leybold-Heraeus is included in Appendix A of Section 11 of this report.

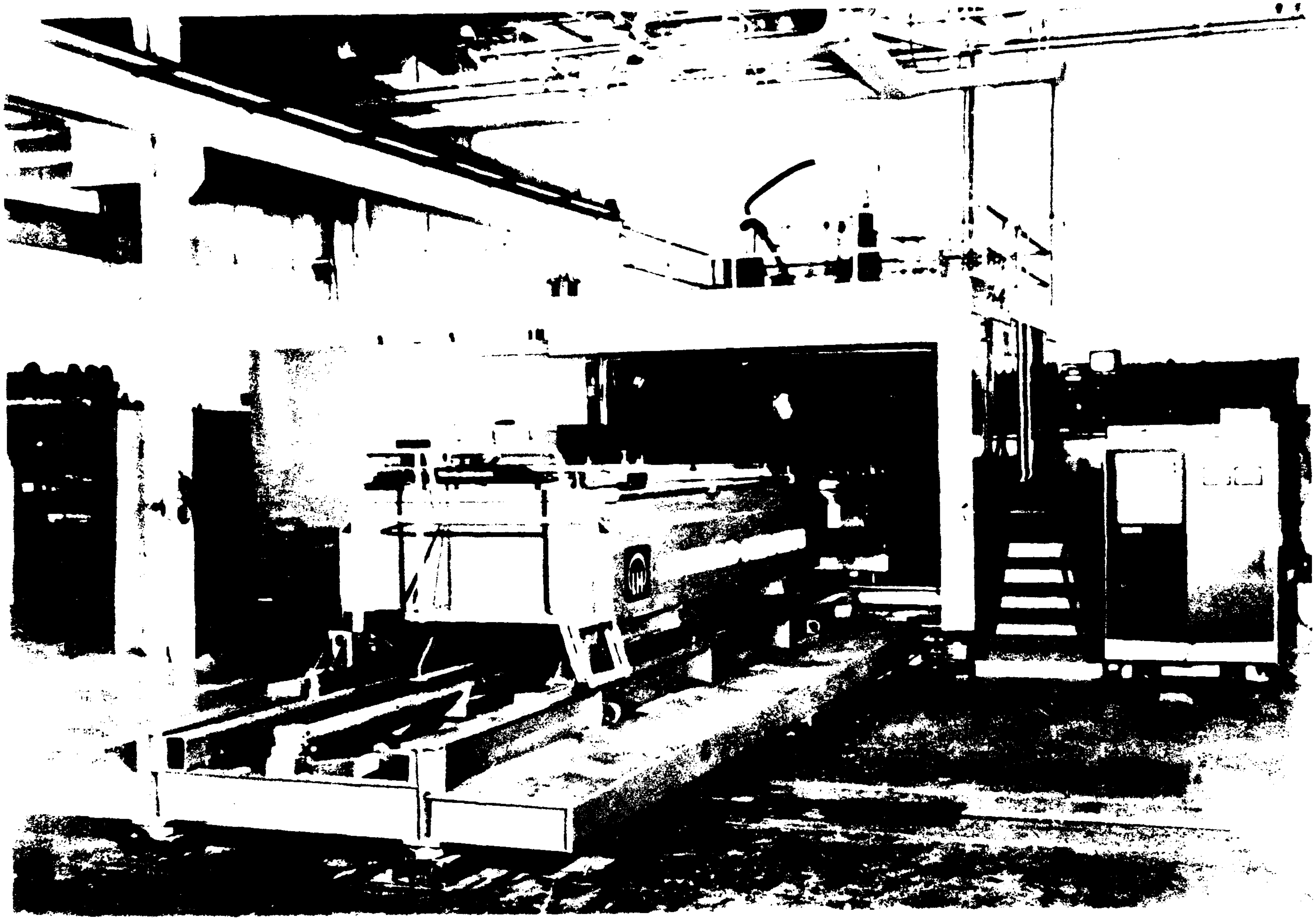


FIGURE 48 LEYBOLD HERAEUS EBW 36000
60 KW MACHINE

SCIAKY BROS.

ELECTRON BEAM MANUFACTURER SOURCE QUESTIONNAIRE

1. Company Name: Sciaky Bros., Inc.
2. Address: 4915 W. 67th Street - Chicago, Illinois 60638
3. Telephone: (312) 594-3800
4. U.S. Representative: Sciaky Sales Organization
5. E.B. Models Available (High, Partial and No-Vacuum Systems)
    - Model: High Vacuum (VX) - Partial Vacuum (CV)
    - Output Rating (KW): 7.5/15/30/42 KW
    - Status: Fully available as 60 KV equipment
    - Development: 150 KW/100 ma (high voltage equipment)
    - Commercial: Fully Automated Welding System with CNC Control.
6. Delivery Time: 30-50 weeks depending upon machine type
7. Number of Electron Beam Units Supplied: Over 500 units
    - Customer Name: All major aerospace/automotive/nuclear/drilling and mining/and job shop customers.
    - Address:
8. Electron Beam Budgetary Costs ($) or ($/KW): $300,000 to $2,000,000
9. Electron Beam Equipment Reliability:
    - Uptime (hr/wk): 75% to 80% up time
    - Repair Time (hr.): Varies depending upon problem
10. Available Service Program: Service response within 24 hours
11. On-Site Maintenance Skill Requirements: Normal mechanical and electrical skills

12. Electron Beam Fact Sheets:

- EB Unit Dimensions: Std. Mach. - Approx. 18' x 22' x 10' (floor space)
- Weight: 20,000 to 50,000 lbs.
- Performance: Excellent - full CNC control with diagnostics and monitoring
- Consumables (Cooling Water, Gas Cover, etc.):
  Cooling water - 10 GPM
  Cover Gas - None required
- Critical Component(s) (Cathode, Filament, etc.):
  Filament (consumable 20 hrs) $7.00
- Operating Cost ($/hr): Approx. 4-5 dollars per hour (nominal)
- Electrical Requirements: 480 volt/60 cycle/3 phase/300 amp.

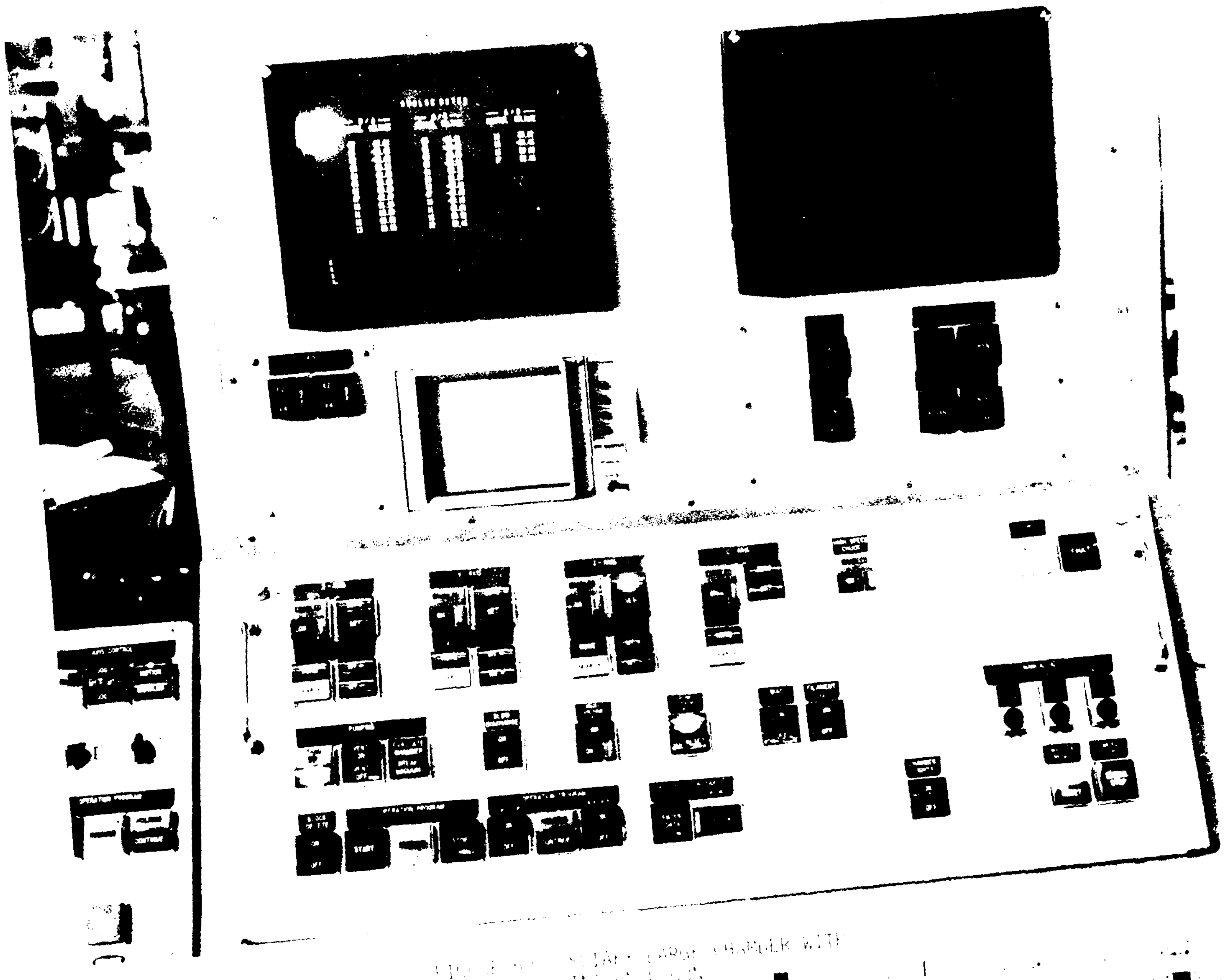
13. Welding Experience Data (Power, Welding Speed, Heat Input, Weld thickness with:

- Carbon Grade Structural Steel: ---
- HSLA Steel Grade A710: ---
  Grade E633: --
- HY80, HY 100: --
- Al, Ti, Other Alloys: ---

Experience on several grades of Carbon Steel, Stainless, Aluminum and Titanium Alloys.

14. Safety Considerations (OSHA): Meets all local and government safety requirements

15. Literature furnished by Sciaky Bros., Inc. is included in Appendix B of Section 11 of this report.



[illegible] CHAMBER WITH
[illegible]

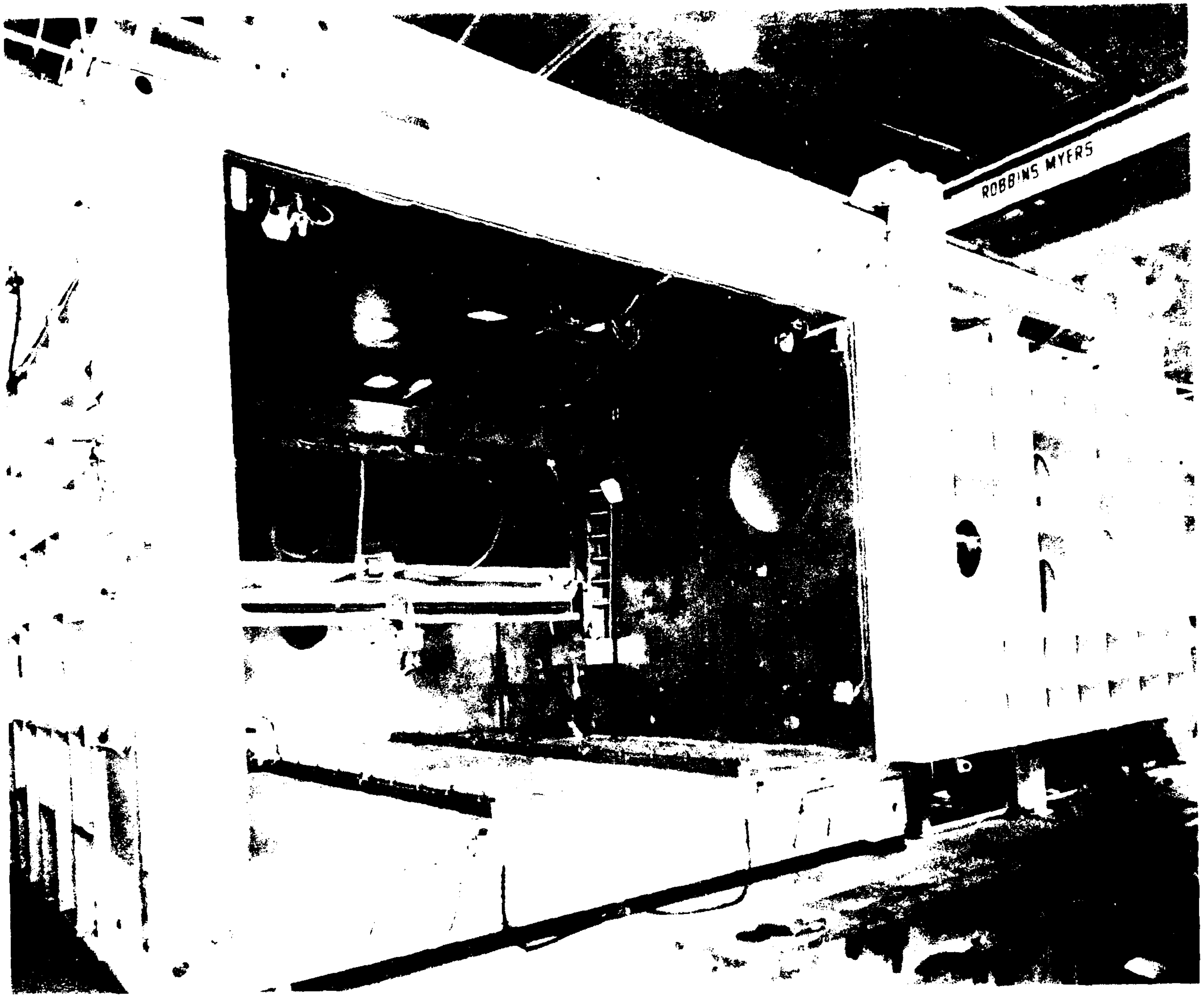


FIG. 49 SCIAKY MARK VII SERIES CONTROL PANEL

MG INDUSTRIES
STEIGERWALD SYSTEMS

ELECTRON BEAM MANUFACTURER SOURCE QUESTIONNAIRE

1. Company Name: MG Industries - Steigerwald Systems

2. Address: W141 N9427 Fountain Blvd.
Menomonee Falls, WI 53051

3. Telephone: (414) 255-5520

4. U.S. Representative: - Delaware Corp. - MFG. in Wisconsin

5. E.B. Models Available (High, Partial and No-Vacuum Systems)

. Model: All Sizes High, Partial - No Non-Vacuum

. Output Rating (KW): 3, 6, 8.5, 15, 30, 60 KW

. Status: All Mature, Operating in Production

. Development: New E.B. Perforator Under Devel.

. Commercial: New Systems and Modifications Constantly Coming Out

6. Delivery Time: 8-12 Months Standard - 12-15 Months for Special

7. Number of Electron Beam Units Supplied:
Hundreds - World-Wide

. Customer Name:

. Address:

8. Electron Beam Budgetary Costs ($) or ($/KW):
Systems Prices start at $275,000 and can go up to $3,000,000 + Each.

9. Electron Beam Equipment Reliability:

. Uptime (hr/wk): Documented 19 Hr/Day - Up Time

. Repair Time (hr): Question Unanswerable Without More Specific Data.

10. Available Service Program: All Types of Training & Assistance

11. On-Site Maintenance Skill Requirements:
Same as Required for Typical CNS Machining Center

12. Electron Beam Fact Sheets

Typical Only

- EB Unit Dimensions: Smallest 36"^{3} Largest 10 Ft.^{3}
- Weight: 14,000# to over 150,000#
- Performance: Foil Thickness to 17" Aluminum - 1 Pass
- Consumables (Cooling Water, Gas Cover, etc.):

. Filaments	Electricity - 480 V 3 Phase 100A
. No Gas	4 GPM - Water
	80 PSI - Air

- Critical Component(s) Primarily: Vacuum Seals, Gum Filament, Follow P/M Schedule
- Operating Cost ($ hr): Less than $12/Hr - Not Including Labor and Amortization.
- Electrical Requirements: Typical: 480V 30 100A

13. Welding Experience Data (Power, Welding Speed, Heat Input, Weld Thickness) with:

- Carbon Grade Structural Steel: 5" @ 15 IPM 10" @ 6 IPM
- HSLA Steel Grade A710: See our Data Sheet on Deep Weld of Cr/Moly Steel

  Grade E633:
- Hy80, Hy 100:
- Al, Ti, Other Alloys: - Up to 17" Aluminum

14. Safety Considerations (OSHA): Systems meet OSHA when they are shipped and leave the Manufacturer.

15. Submitted by MGI, Menomonee Falls, WI.

16. Literature furnished by MG Industries is included in Appendix C of Section 11 of this report.

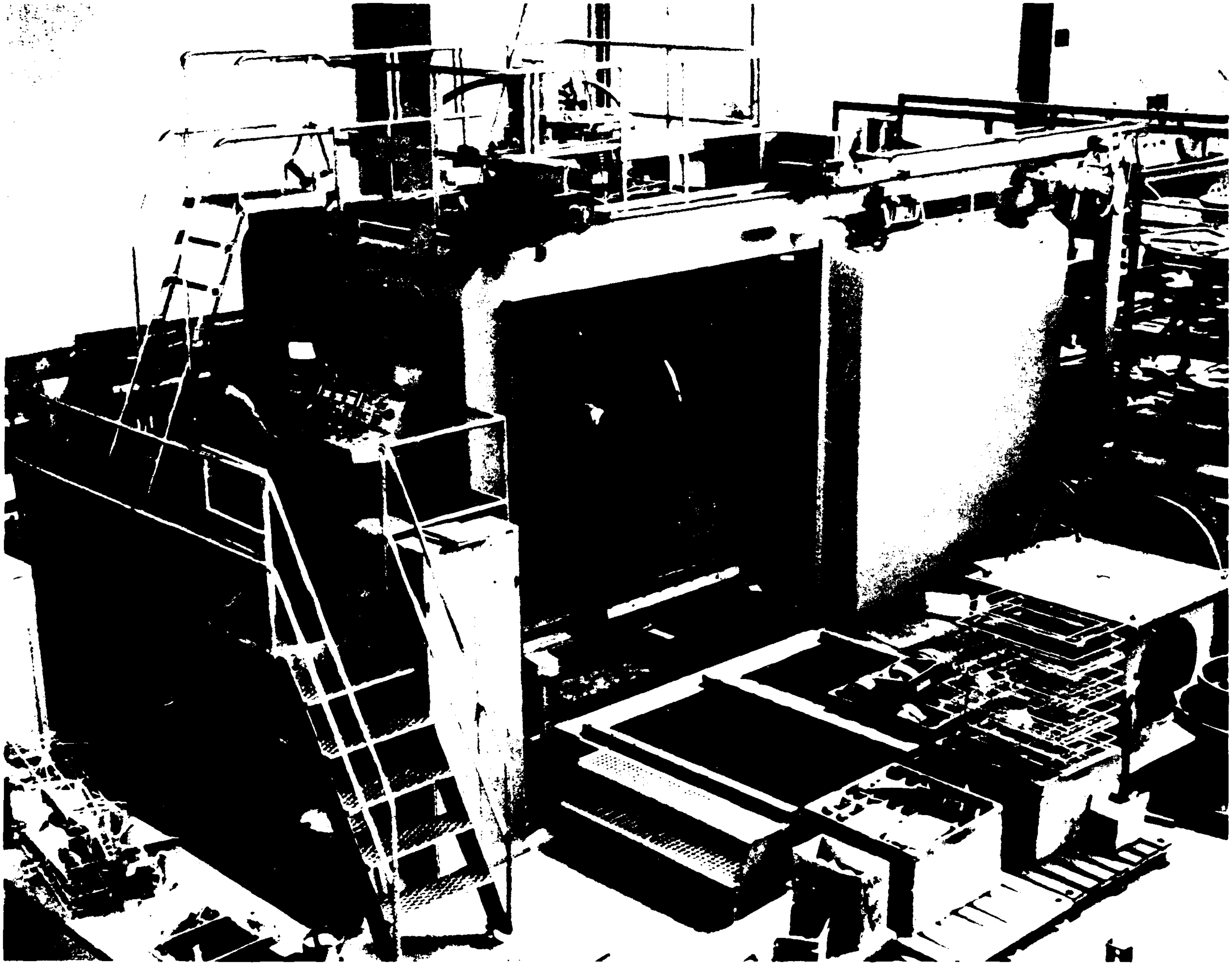


FIGURE 51   STEIGERWALD LARGE CHAMBER
W/EXTERNAL GUN

EB USERS APPLICATION QUESTIONNAIRES

ELECTRON BEAM APPLICATORS QUESTIONNAIRE

1. Applicators Name: American Saw Co.

2. Address: East Bedford, Mass.

3. Telephone: (413) 525-3961

4. Description of Electron Beam Welding Equipment:

- EB Manufacturer/Output Rating (KW): 1) 2 Steigerwald Units 8.5 KW (150 KV, 50 ma)
  2) 2 Leybold Heraeus 7.5KW

- Optional Subsystems (Computer, Printer, etc.): Struthers-Dunn Computer Systems

- Chamber Size: 36 in. x 23 in. x 30 in.

- High, Partial, or Non-Vacuum System: High vacuum systems

5. Critical Components: 1) filament (90-100 hrs) ($10)
   2) electrical components

6. Operating Cost ($/Hr): N/A

7. System Reliability: 20 hrs/day; 6 day/wk; 4.5 million feet of saw blades welded per month

- Uptime (Hr/Wk): 95% uptime, 2 hrs/wk maintenance
  2 hrs. maintenance 1 week

8. Welding Experience (Power, Welding Speed, Weld Thk.) with:

. Carbon Steel Structural Grade	
. HSLA Steel Grade A710:	high grade carbon steel
Grade E633:	M42
. HY 80, HY 100:	high carbon steel (0.020" - 0.125")
. Aluminum, Titanium Alloys:	

9. Number of Trained Operators: 1 operator each 12 hr. shift

- Level of Training: Medium
- Availability of Operators: N/A

- Experience:

10. Safety Precautions: Normal precautions of x-ray, etc.

ELECTRON BEAM APPLICATORS QUESTIONNAIRE

1. Applicators Name: Martin Marietta

2. Address: Oak Ridge, Tenn.

3. Telephone: (615) 574-4807

4. Description of Electron Beam Welding Equipment:

   . EB Manufacturer/Output Rating (KW): (1) Leybold Heraeus 15 KW Unit (150 KV, 100 ma)

   . Optional Subsystems (Computer, Printer, etc.): CNC Computer System (Allen Bradley)

   . Chamber Size: 56 in. x 40 in. x 36 in.

   . High, Partial, or Non-Vacuum System: High vacuum systems

5. Critical Components: 1) vacuum door seals
   2) filament

6. Operating Cost ($/Hr): N/A

7. System Reliability:

   . Uptime (Hr/Wk): 95% uptime, 2 hrs/wk maintenance

8. Welding Experience (Power, Welding Speed, Weld Thk.) with:

   . Carbon Steel Structural Grade

   . HSLA Steel Grade A710: 1) Carbon Steels (2-3")
   2) Aluminum
   Grade E633: 3) Low Alloy

   . HY 80, HY 100:

   . Aluminum, Titanium Alloys:

9. Number of Trained Operators: 3 operators

   . Level of Training: Moderate

   . Availability of Operators: N/A

   . Experience: N/A

10. Safety Precautions: Radiation Precautions

ELECTRON BEAM APPLICATORS QUESTIONNAIRE

1. Applicators Name: Ridge Tool Co.
2. Address: Cleveland, Ohio
3. Telephone: (216) 323-5581
4. Description of Electron Beam Welding Equipment:
   - EB Manufacturer/Output Rating (KW): (1) Leybold Heraeus 15 KW Unit
   - Optional Subsystems (Computer, Printer, etc.): Computer and Printer
   - Chamber Size: 52 in. x 36 in. x 30 in.
   - High, Partial, or Non-Vacuum System: High vacuum systems
5. Critical Components: computer, electrical problems
6. Operating Cost ($/Hr): N/A
7. System Reliability:
   - Uptime (Hr/Wk): 85% or better
8. Welding Experience (Power, Welding Speed, Weld Thk.) with:
   - Carbon Steel Structural Grade
   - HSLA Steel Grade A710: mostly carbon steels

     Grade E633:
   - HY 80, HY 100.
   - Aluminum, Titanium Alloys:
9. Number of Trained Operators: 5 operators
   - Level of Training: N/A
   - Availability of Operators: N/A
   - Experience: N/A
10. Safety Precautions: Radiation Safety

ELECTRON BEAM APPLICATORS QUESTIONNAIRE

1. Applicators Name: McDonald Douglas
2. Address: Titusville, Fla.
3. Telephone: (305) 268-7126
4. Description of Electron Beam Welding Equipment:
   - . EB Manufacturer/Output Rating (KW): (1) Steigerwald 30 KW Unit
   - . Optional Subsystems (Computer, Printer, etc.): Direct Numerical Control
   - . Chamber Size: 3 ft. x 6 ft. x 13 ft
   - . High, Partial, or Non-Vacuum System: High vacuum systems
5. Critical Components: 1) filament ($8-10) 40 hrs, 2) vacuum system seals 3) electrical components
6. Operating Cost ($/Hr): N/A
7. System Reliability:
   - . Uptime (Hr/Wk): 85% , 3 mhrs/wk maintenance
8. Welding Experience (Power, Welding Speed, Weld Thk.) with:
   - . Carbon Steel Structural Grade
   - . HSLA Steel Grade A710: Only 2219 Aluminum
     Grade E633:
   - . HY 80, HY 100:
   - . Aluminum, Titanium Alloys:
9. Number of Trained Operators: 3 operators
   - . Level of Training: N/A
   - . Availability of Operators: N/A
   - . Experience:
10. Safety Precautions: Precautionary measures for x-radiation

ELECTRON BEAM APPLICATORS QUESTIONNAIRE

1. Applicators Name: Aero Technical Services
2. Address: San Antonio, Texas
3. Telephone: (512) 333-6010
4. Description of Electron Beam Welding Equipment:
    - EB Manufacturer/Output Rating (KW): Sciaky 15 KW gun
      Steigerwald 6.5 KW gun
    - Optional Subsystems (Computer, Printer, etc.): Manual
    - Chamber Size: 62" x 92" x 108" Sciaky
      36" sq. 0 Steigerwald
    - High, Partial, or Non-Vacuum System: High Vacuum
5. Critical Components: Filament, cathode regularly
6. Operating Cost ($/Hr): $100/Hr. (includes labor)
7. System Reliability: Good
    - Uptime (Hr/Wk): 40 hrs/wk
      1-2 hrs./wk maintenance
8. Welding Experience (Power, Welding Speed, Weld Thk.) with:
    - Carbon Steel Structural Grade
    - HSLA Steel Grade A710: Some on all types of carbon
      Grade E633: stainless, aluminum,
      titanium alloys
    - HY 80, HY 100:
    - Aluminum, Titanium Alloys:
9. Number of Trained Operators: 2 Operators
    - Level of Training: High
    - Availability of Operators: N/A
    - Experience:
10. Safety Precautions: Electrical, radiation safety

ELECTRON BEAM APPLICATORS QUESTIONNAIRE

1. Applicators Name: Grumman Aircraft Corp.
2. Address: Bethpage, N.Y.
3. Telephone:
4. Description of Electron Beam Welding Equipment:
   - EB Manufacturer/Output Rating (KW): 2 guns 30 KW
     (60KV, 500ma)
   - Optional Subsystems (Computer, Printer, etc.):
     computer, printers
   - Chamber Size: Rectangular Chamber - 302 in. x 108 in. x 132 in.
     Clamshell Chamber - 388 in. x 126 in. x 96 in.
   - High, Partial, or Non-Vacuum System: High Vacuum
5. Critical Components: Filament, anode
6. Operating Cost ($/Hr): Not Available
7. System Reliability: Good
   - Uptime (Hr/Wk): 50 Hrs/Wk/Machine
     Maintenance 5 Hrs/Wk/Machine
8. Welding Experience (Power, Welding Speed, Weld Thk.) with:
   - Carbon Steel Structural Grade Various
   - HSLA Steel Grade A710: Titanium Alloys
     Grade E633: Copper, Aluminum
     Stainless Steel
   - HY 80, HY 100:
   - Aluminum, Titanium Alloys:
9. Number of Trained Operators: (3)
   - Level of Training: High to moderate
   - Availability of Operators: On Request
   - Experience: N/A
10. Safety Precautions: Electrical, radiation safety

ELECTRON BEAM APPLICATORS QUESTIONNAIRE

1. Applicators Name: McCay Tool & Engr. Co.
2. Address: 1449 West Lark, Fenton, Mo.
3. Telephone: (314) 677-3440
4. Description of Electron Beam Welding Equipment:
   - EB Manufacturer/Output Rating (KW): 15 KW Sciaky Gun
   - Optional Subsystems (Computer, Printer, etc.): Manual
   - Chamber Size:
   - High, Partial, or Non-Vacuum System: High Vacuum
5. Critical Components: Filament every 8 hrs., cathode annually
6. Operating Cost ($/Hr): $50/Hr. (includes labor)
7. System Reliability: Good
   - Uptime (Hr/Wk): 85% - 2 Hrs/Wk maintenance
8. Welding Experience (Power, Welding Speed, Weld Thk.) with:
   - Carbon Steel Structural Grade
   - HSLA Steel Grade A710:
     Grade E633: Only on Aluminum Alloys
   - HY 80, HY 100:
   - Aluminum, Titanium Alloys:
9. Number of Trained Operators: 1 Operator
   - Level of Training: High
   - Availability of Operators: N/A
   - Experience:
10. Safety Precautions: Electrical, radiation safety

ELECTRON BEAM APPLICATORS QUESTIONNAIRE

1. Applicators Name: TK International
2. Address: P.O. Box 45587
3. Telephone: (918) 628-0111
4. Description of Electron Beam Welding Equipment:
   - EB Manufacturer/Output Rating (KW): 30KW (60 KV, 500 ma)
   - Optional Subsystems (Computer, Printer, etc.): Manual Operations
   - Chamber Size: 2 chambers (62" x 55 x 55)
   - High, Partial, or Non-Vacuum System: High Vacuum
5. Critical Components: Filament, cathode regularly
6. Operating Cost ($/Hr): Quote basis only
7. System Reliability: Good
   - Uptime (Hr/Wk): 95%, (2-3 hrs/week maintenance)
8. Welding Experience (Power, Welding Speed, Weld Thk.) with:
   - Carbon Steel Structural Grade
   - HSLA Steel Grade A710:
     Grade E633: Carbon, stainless steel
   - HY 80, HY 100:
   - Aluminum, Titanium Alloys:
9. Number of Trained Operators: 5 Operators
   - Level of Training: High to Moderate
   - Availability of Operators: N/A
   - Experience:
10. Safety Precautions: Electrical, radiation safety

ELECTRON BEAM APPLICATORS QUESTIONNAIRE

1. Applicators Name: Aireseach Mfg. Co.

2. Address: 9851 Sepulveda Blvd.
   Los Angeles, Ca.

3. Telephone: (213) 512-5590

4. Description of Electron Beam Welding Equipment:

   . EB Manufacturer/Output Rating (KW): Sciaky 60 KV and 30 KV gun

   . Optional Subsystems (Computer, Printer, etc.): Computer, printer

   . Chamber Size: 50" x 30" x 42" and 68" x 68" x 78"

   . High, Partial, or Non-Vacuum System:

5. Critical Components: Filament every 4 hrs, anode and cathode annually

6. Operating Cost ($/Hr): $49/hr.

7. System Reliability: Good

   . Uptime (Hr/Wk): 95%, 2-3 hrs/week maintenance

8. Welding Experience (Power, Welding Speed, Weld Thk.) with:

   . Carbon Steel Structural Grade

   . HSLA Steel Grade A710:
   Grade E633: Titanium and Aluminum Alloys

   . HY 80, HY 100:

   . Aluminum, Titanium Alloys:

9. Number of Trained Operators: 6 Operators

   . Level of Training: High to Moderate

   . Availability of Operators: N/A

   . Experience:

10. Safety Precautions: Electrical, radiation safety

ELECTRON BEAM APPLICATORS QUESTIONNAIRE

1. Applicators Name: Kaiser Aerospace

2. Address: Irvine, California

3. Telephone: (213) 512-5590

4. Description of Electron Beam Welding Equipment:

   . EB Manufacturer/Output Rating (KW): Sciaky 30 KW gun

   . Optional Subsystems (Computer, Printer, etc.):
   Computer and printer

   . Chamber Size: 10 ft. x 4 ft. x 10 ft.

   . High, Partial, or Non-Vacuum System: High vacuum

5. Critical Components: N/A

6. Operating Cost ($/Hr): N/A

7. System Reliability:

   . Uptime (Hr/Wk): 88 - 90 Hrs/wk.
   15 hrs. maintenance/wk

8. Welding Experience (Power, Welding Speed, Weld Thk.) with:

   . Carbon Steel Structural Grade

   . HSLA Steel Grade A710:
   Grade E633: Some types of alloys

   . HY 80, HY 100:

   . Aluminum, Titanium Alloys:

9. Number of Trained Operators: N/A

   . Level of Training: N/A

   . Availability of Operators: N/A

   . Experience:

10. Safety Precautions: Electrical, radiation safety

ELECTRON BEAM APPLICATORS QUESTIONNAIRE

1. Applicators Name: EB Associates

2. Address: 166 North 121st Street
   Wauwautosa, Wisc.

3. Telephone:

4. Description of Electron Beam Welding Equipment:

   . EB Manufacturer/Output Rating (KW): Sciaky 30 KW gun

   . Optional Subsystems (Computer, Printer, etc.):
     N/A (manual systems)

   . Chamber Size: 30 in. x 50 in. x 42 in.

   . High, Partial, or Non-Vacuum System: High vacuum

5. Critical Components: Filament, anode, electrical components
   pump seals

6. Operating Cost ($/Hr): $100/hr (includes labor)
   Equipment cost $450,000

7. System Reliability: Good

   . Uptime (Hr/Wk): 40 hrs/week
     maintenance 3-4 hrs/week

8 Welding Experience (Power, Welding Speed, Weld Thk.) with:

   . Carbon Steel Structural Grade

   . HSLA Steel Grade A710: Job shop materials, high
     Grade E633: carbon steels, some
     stainless

   . HY 80, HY 100:

   . Aluminum, Titanium Alloys:

9. Number of Trained Operators: (3)

   . Level of Training: High to moderate experienced operators

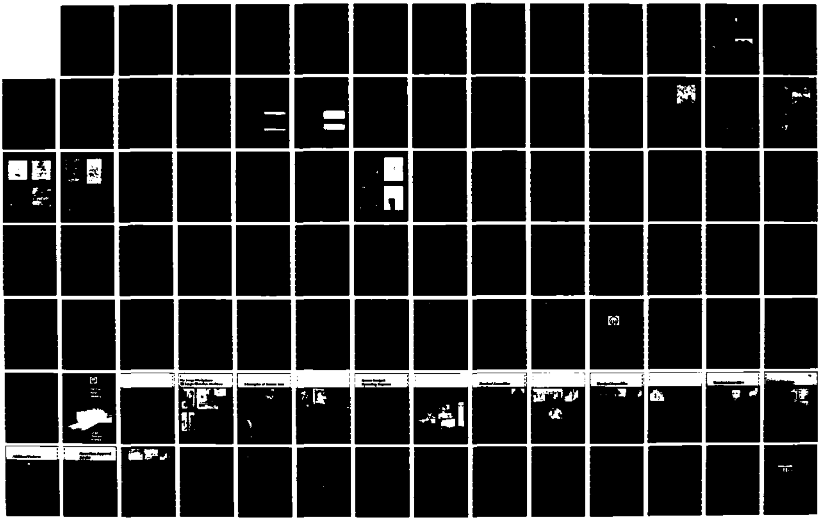
   . Availability of Operators: N/A

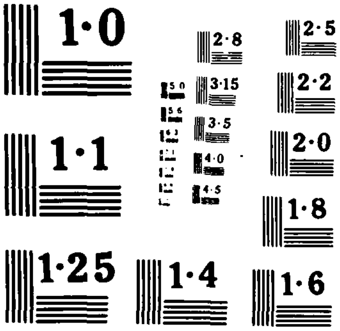
   . Experience:

10. Safety Precautions: Electrical, radiation safety

AD-A170 149 ASSESSMENT OF ELECTRON BEAM WELDING IN SHIPYARD 2/
CONSTRUCTION(U) AMERICAN WELDING INST LOUISVILLE TN
J C DANKO DEC 85 AWI-CR-86-002 N084RAC45137

UNCLASSIFIED F/G 13/8 NL




1·0
2·8
2·5
5·0
5·6
3·15
2·2
3·5
6·3
7·1
8·0
9·0
10·0
1·1
4·0
2·0
4·5
1·8
1·25
1·4
1·6

ELECTRON BEAM APPLICATORS QUESTIONNAIRE

1. Applicators Name: Globe Engineering Co.

2. Address: 1539 S. St. Paul Ave.
Wichita, Kansas

3. Telephone:

4. Description of Electron Beam Welding Equipment:

. EB Manufacturer/Output Rating (KW): Sciaky 30 KW gun

. Optional Subsystems (Computer, Printer, etc.):
N/A (manual systems)

. Chamber Size: 96 in. x 50 in. x 42 in.

. High, Partial, or Non-Vacuum System: High vacuum operation

5. Critical Components: Filament, anode, electrical components
pump seals

6. Operating Cost ($/Hr): $90/hr (approximate cost including labor)
Equipment cost $450,000

7. System Reliability: Good

. Uptime (Hr/Wk): 30 hrs/week
2 hrs. maintenance 1 week

8. Welding Experience (Power, Welding Speed, Weld Thk.) with:

. Carbon Steel Structural Grade

. HSLA Steel Grade A710: Welding mainly performed
Grade E633: on stainless steels and
some carbon steels

. HY 80, HY 100:

. Aluminum, Titanium Alloys:

9. Number of Trained Operators: (4)

. Level of Training: N/A

. Availability of Operators: For all shifts

. Experience: High to moderate experience

10. Safety Precautions: Electrical, radiation safety

METALLURGY AND MECHANICAL PROPERTIES OF EB WELDED STEELS COMMONLY USED IN THE SHIPBUILDING INDUSTRY

Since there are several different types and grades of materials used in the shipbuilding industry, this report has narrowed the area of interest to the metallurgical and mechanical properties of the following EB welds for these steels:

1) Low strength structural steels (60-70 ksi range)
2) High strength low alloy steels (A710 Grade A Class 3)
3) Hy 80-130 steels

EB welds are normally characterized as having a narrow parallel sided fusion zone with a narrow HAZ. This in general produces a weld geometry quite different from that obtained by conventional arc welding processes. The EB weld usually has low distortion due to the relatively low heat input compared to other arc welds.

Since EB welds are principally of an autogenous weld nature (ie., no filler metal), the weld metal microstructure and mechanical properties are mainly determined by the composition of the parent plate and the particular welding parameters chosen. The welding parameters are usually chosen to produce a particular weld bead shape (rounded top and bottom bead with no undercut) and to avoid weld defects such as porosity and cracks. The choice of welding conditions such as the welding speed and the weld width can substantially effect the solidification structure and the resultant mechanical properties of the resultant weld.[13]

From several investigations made by Russel et al[16] it has been shown that acceptable toughness valves can be obtained in EB welds although it is sometimes necessary to use preheat or postweld heat treatment. This is especially true if the carbon content of the material is relatively high (>0.24%). Heat input and cooling rates are also important factors in determining the weld toughness and has been discussed by several different authors.[14-16] Due to the fast cooling rate, EB weld metal has a tendency to exhibit lower impact strength levels than the HAZ. It has also been shown that welds with a relatively high width to depth ratio have a tendency for cracking especially if faster travel speeds than normal are used during welding.

LOW STRENGTH STRUCTURAL STEELS (60-70 KSI YIELD STRENGTH)

One of the more commonly used structural carbon steels used in the shipyard is DH36. For this report, the investigator was unable to locate any EB welded mechanical property data for either DH36 or its ASTM equivalent A36. This was also true for other shipyard types of carbon steel such as A575 (M1020).

Consideration should be made for future development of EB welded A36 material since metallurgical properties would vary for different materials and welding parameters utilized.

EB weld tests have been conducted by CBI on a comparable structural grade of carbon steel. The material used in this test was 3-3/8 inch thick SA516 Grade 70, Lukens fine line rolled plate, normalized at 1625/1675°F and air cooled. Initial parameter development welds were bead on plate in the horizontal position. The final horizontal parameters were run on a 32 inch long machined square butt joint with gaps varying from 0.001 to 0.008 inch and mismatch varying ±0.070". The welding parameters used on the plate were as follows:

	Full Penetration
Accelerating Voltage (KV)	85
Beam Current (ma)	350
Travel Speed (IPM)	4.5
Beam Focus (Amps-programmed)	4.08
Gun to Work (Inches)	22
Gun to Focal Point (Inches)	24-1/8
Oscillation Amplitude Horizontal Ellipse (Inches)	.085 x .052
Oscillation Frequency (Hertz)	100
Chamber Pressure (Microns)	3-10

These parameters produced a weld with a slightly convex bead with a narrow tapered meltzone with adequate reinforcement on both the entrance and exit sides of the beam. The entrance surface had very little undercut and required no cosmetic pass.

TESTING AND RESULTS

Testing was performed on specimens in the following manner.

1) Chemical Analysis

A chemical analysis was obtained on both the plate material and the weld metal. The results are shown in Table 3.

2) Tensile Tests

Four (4) reduced section tensile specimens were tested. In the as welded condition, the average ultimate tensile strength was 84.3 KSI, with 30% elongation. The failure location of all the specimens was in the plate.

SAMPLE	Cr	Ni	Mo	Mn	Si	Cu	Cb	C	S
Plate	0.22	0.21	0.06	1.03	0.21	0.17	0.003	0.262	0.007
Weld	0.21	0.21	0.05	0.99	0.21	0.17	0.002	0.241	0.007

SAMPLE	P	Co	Al	O	N				
Plate	0.005	0.020	0.029	0.0020	0.0138				
Weld	0.005	0.020	0.026	0.0029	0.0110				

TABLE 3 CHEMICAL ANALYSIS OF A516-70 PLATE EB WELD METAL

3) Side Bends Tests

Six (6) guided bend specimens each were tested in the as welded and all were acceptable.

4) Charpy V-Notch Impacts Tests

Charpy V-notch specimens were taken transverse to the rolling direction in the weld metal, heat affected zone, and plate at side one, 1/4 in. thickness, 1/2 in. thickness, 3/4 in. thickness and side 2. The test temperatures for the as-welded specimens were 0F, +20F, +60F and +120F. This data is shown in tabular form in Table 4 and graphic form in Figure 53.

5) Hardness Tests

A traverse Rockwell "B" and "C" hardness survey of cross section samples were performed. The results are shown graphically in Figure 52. The results are converted to Vickers Hardness Numbers for the graph.

6) Metallographic Examination

Photomicrographs (X100) of the base plate, heat affected zone, and weld metal are shown in Figures 57. A photomacrograh of the welded seam is also shown in Figure 57.

The microstructure of the A516 Gr. 70 base metal appeared to be a pearlite and ferrite structure. The HAZ appeared to be a banitic and martensitic structure. The weld metal microstructure was mainly a quenched martensitic structure.

7) Summary

The test results for EB welds of A516 Grade 70 material exhibit relatively poor toughness qualities in the as-welded condition. This is thought to be due to the high carbon content (0.26%) in the plate material. If A516 Grade 70 material were to be considered for application of EB welding in industry, the chemical composition would need to be modified (for example, lower the carbon content) to improve the toughness.

The toughness qualities of EB welded A516 Grade 70 material were also confirmed in the tests conducted by Arata et al.[17] They concluded that the toughness of steels with high carbon content (C 0.24%) is poor due to the formation of high carbon martensitic islands in the weld.

The wide scatter of the Charpy-V-Notch values for the A516 Gr. 70 weld metal in Figures 53 through 56 could be attributed to varying amounts of manganese (Mn) through the weld metal. Arata et al[28] have shown that due to the high vapor pressures of Mn there can be as much as a 20% loss of Mn on the surface sides ofthe EB weld metal.

Test Temp (°F)	CHARPY V-NOTCH ENERGY (Ft-Lbs)					
	LOCATION	Side 1	1/4 t	1/2 t	3/4 t	Side 2
0	WELD	10/ 7/ 9	5/ 9/ 9	6/ 9/ 18	12/ 9/ 14	9/ 6/ 7
	HAZ	21/ 13/ 12	65/ 40/ 12	65/ 17/ 30	12/ 47/ 11	124/ 68/119
	PLATE	56/ 62/ 55	51/ 55/ 51	62/ 47/ 38	56/ 52/ 40	48/ 47/ 36
+20	WELD	7/ 5/ 9	6/ 9/ 14	11/ 7/ 8	5/ 16/ 18	6/ 8/ 12
	HAZ	24/ 9/ 30	14/ 27/110	110/ 10/ 96	98/ 24/ 36	20/ 29/ 33
	PLATE	49/ 51/ 64	58/ 50/ 48	52/ 51/ 56	61/ 59/ 57	60/ 48/ 53
+60	WELD	13/ 16/ 11	25/ 21/ 15	18/ 12/ 27	16/ 24/ 13	16/ 16/ 20
	HAZ	30/ 23/ 26	104/116/ 30	82/120/ 22	124/ 29/ 37	120/123/ 19
	PLATE	85/ 76/ 73	80/ 80/ 70	79/ 67/ 78	68/ 79/ 80	81/ 60/ 73
+120	WELD	25/ 24/ 31	22/ 56/ 24	47/ 38/ 22	28/ 27/ 58	19/ 31/ 40
	HAZ	115/107/ 31	119/112/119	129/102/121	125/124/117	29/130/148
	PLATE	105/101/108	109/106/109	113/110/ 98	104/107/103	97/103/103

TABLE 4 CHARPY V-NOTCH IMPACT RESULTS FOR ELECTRON BEAM WELDED A516-70 MATERIAL - AS-WELDED

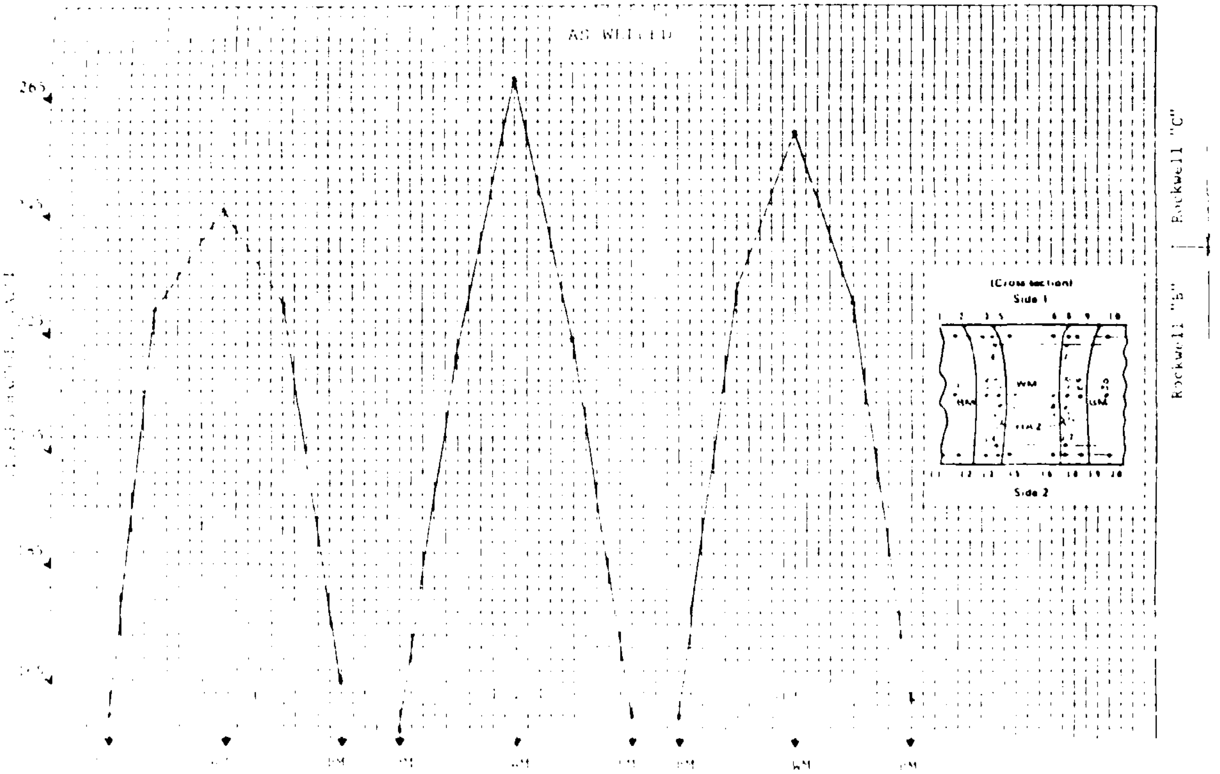


FIGURE 52 APPROXIMATE VICKERS TRAVERSE HARDNESS VALUES (FROM ROCKWELL "B" & "C") FOR ELECTRON BEAM WELDED A516-70 MATERIAL - AS-WELDED

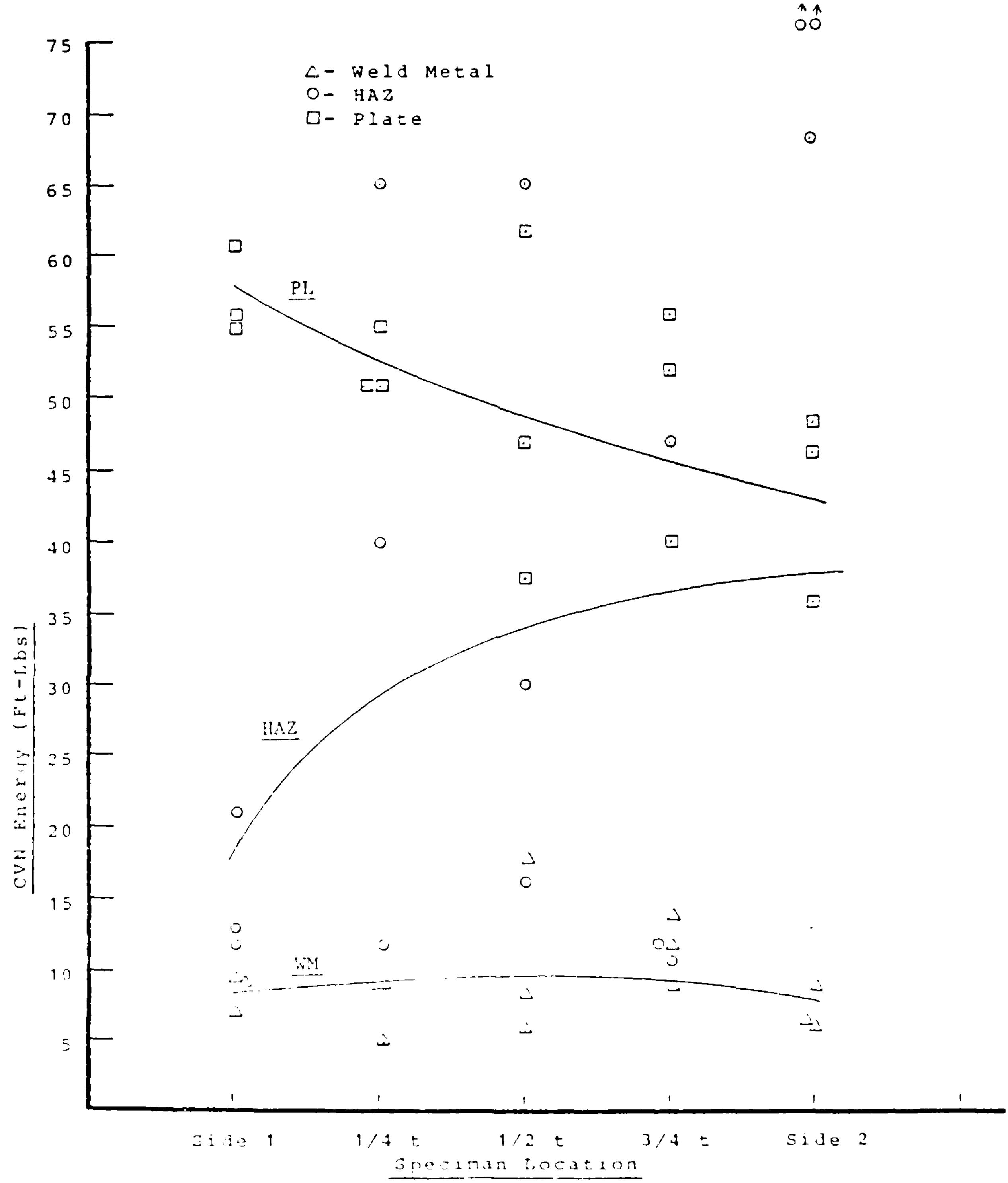


FIGURE 53 CHARPY V-NOTCH IMPACT RESULTS FOR ELECTRON BEAM WELDED A516-70 MATERIAL - AS-WELDED (TEST TEMP. 0°F)

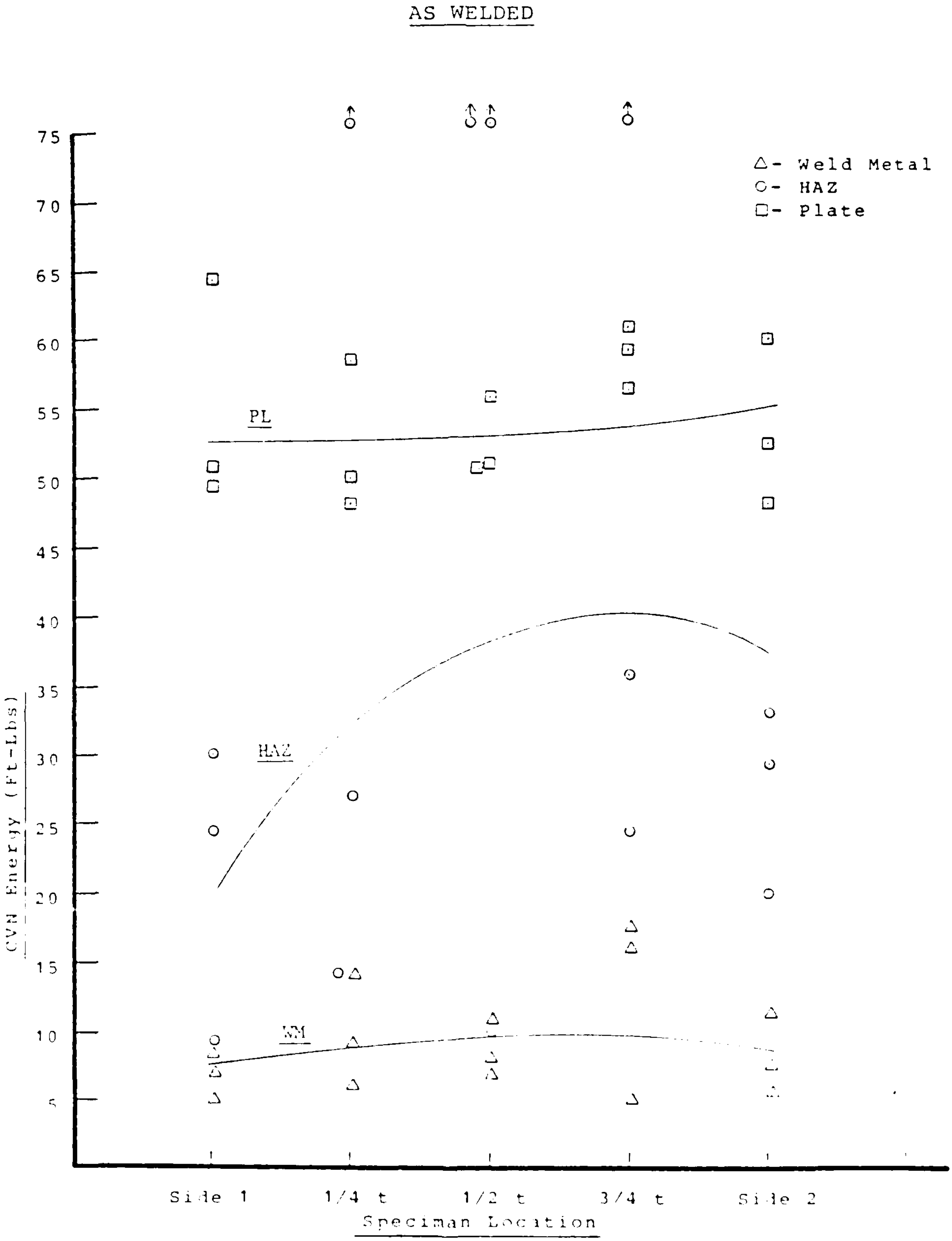


FIGURE 54 CHARPY V-NOTCH IMPACT RESULTS FOR ELECTRON BEAM WELDED A516-70 MATERIAL - AS-WELDED (TEST TEMP. +20°F)

AS WELDED

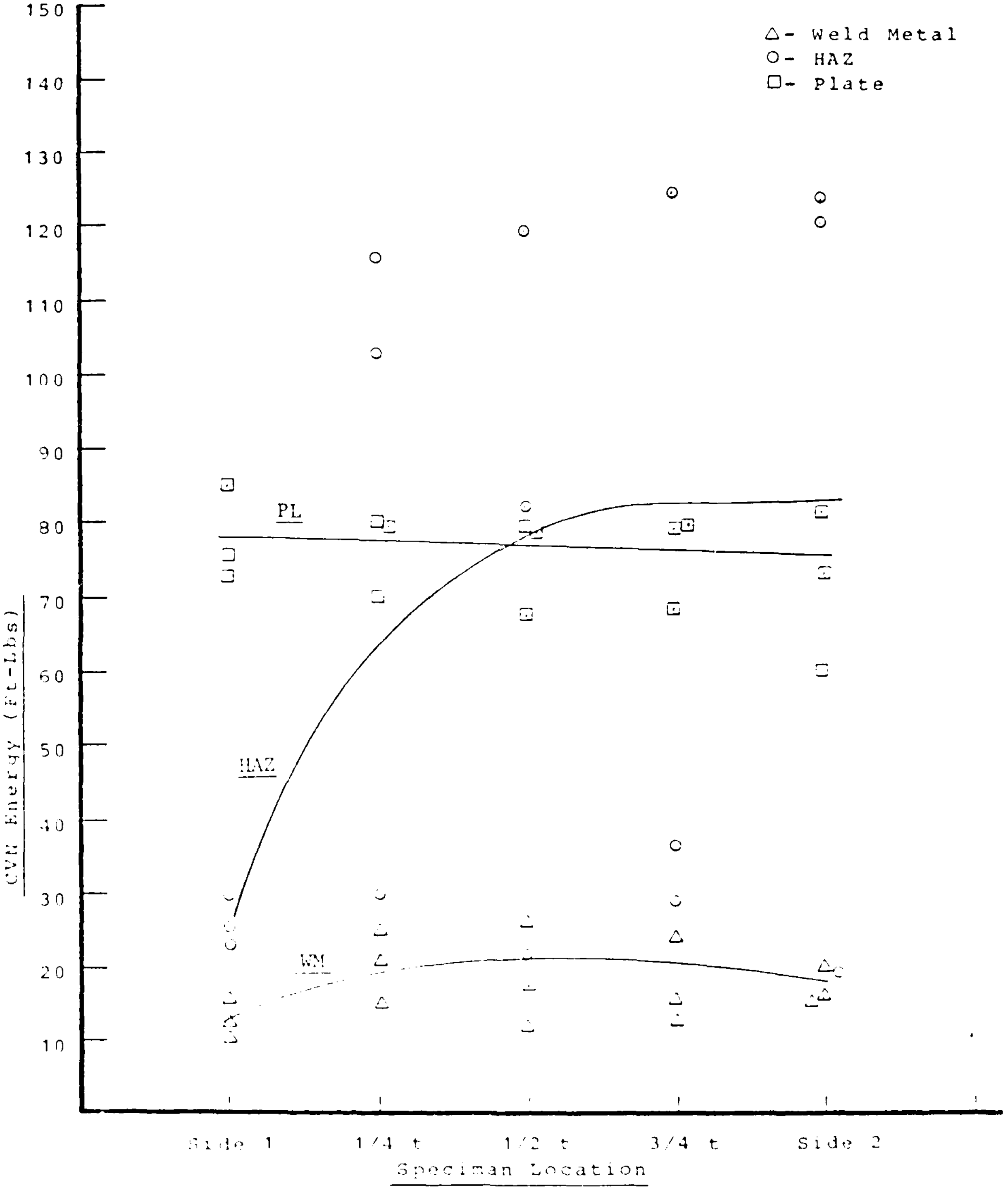


FIGURE 55 CHARPY V-NOTCH IMPACT RESULTS FOR ELECTRON BEAM WELDED A516-70 MATERIAL - AS-WELDED (TEST TEMP. +60°F)

AS WELDED

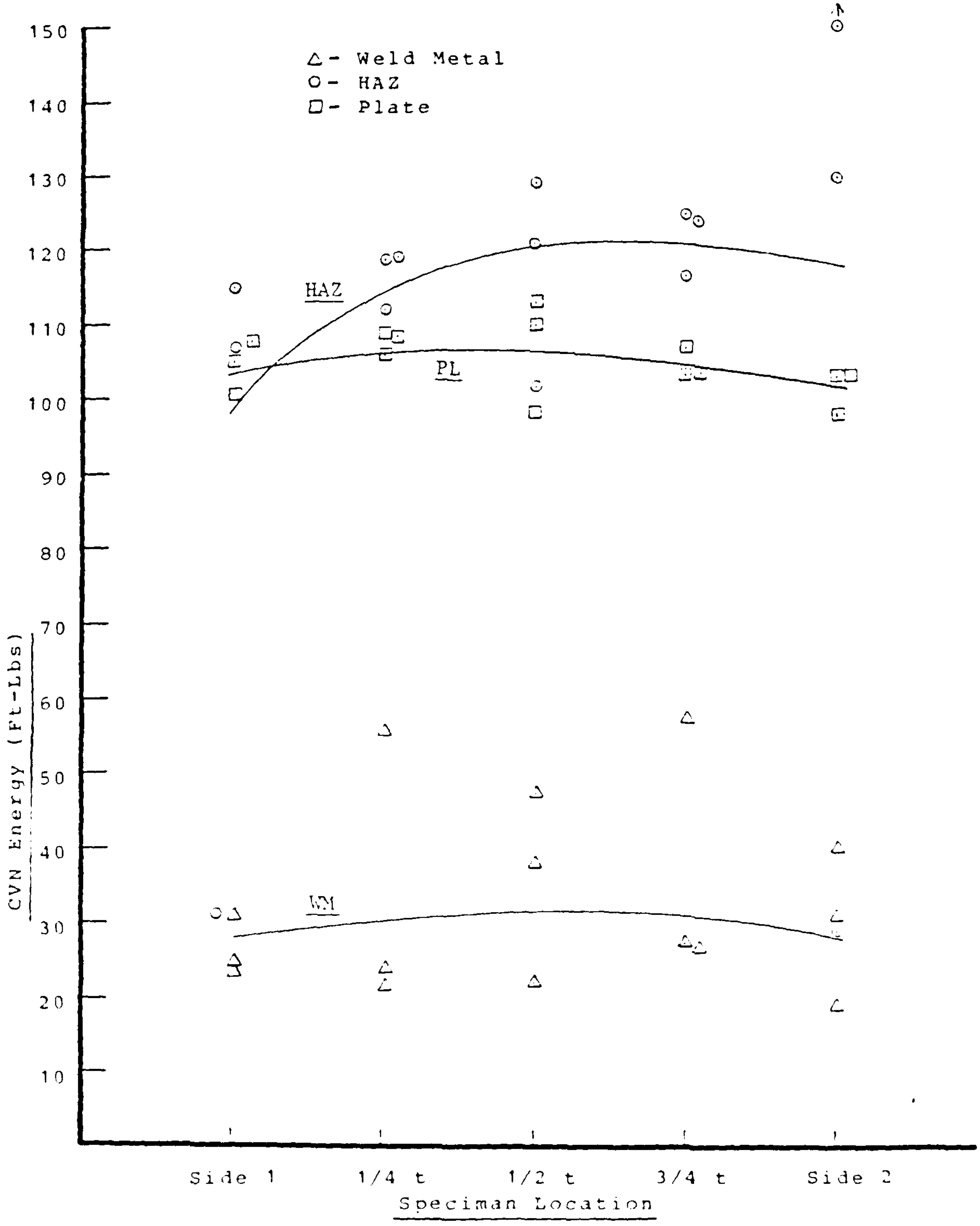
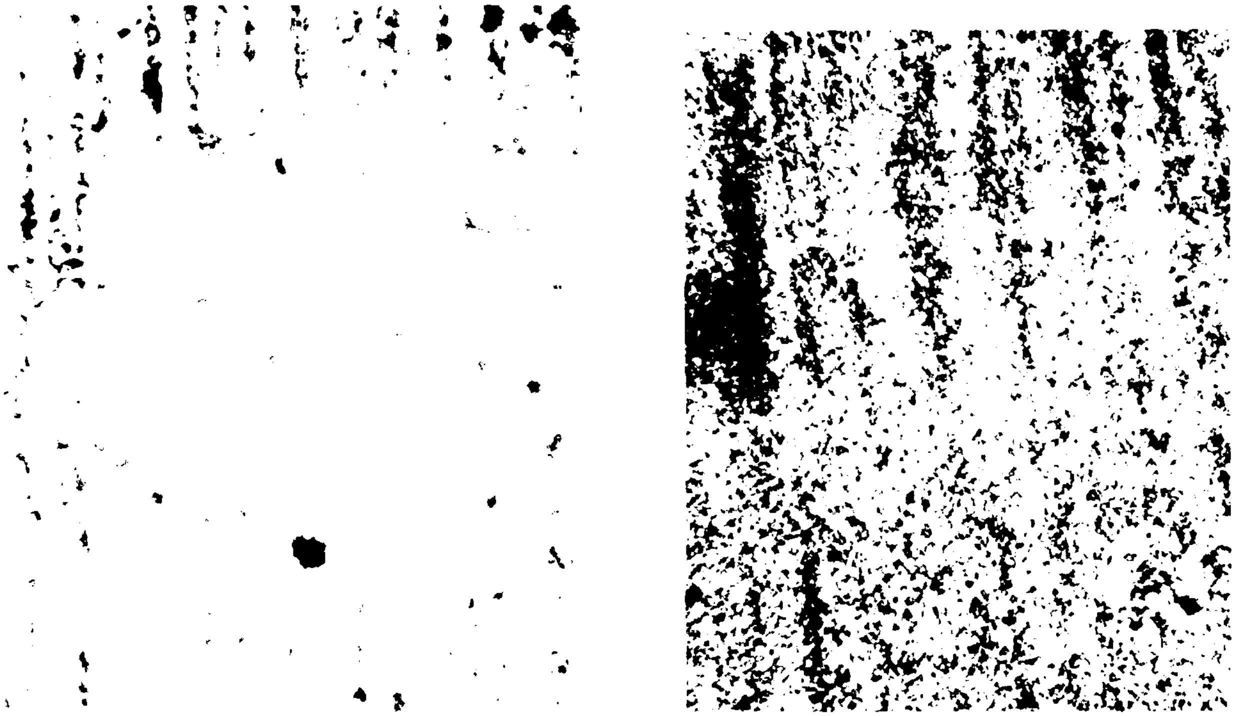
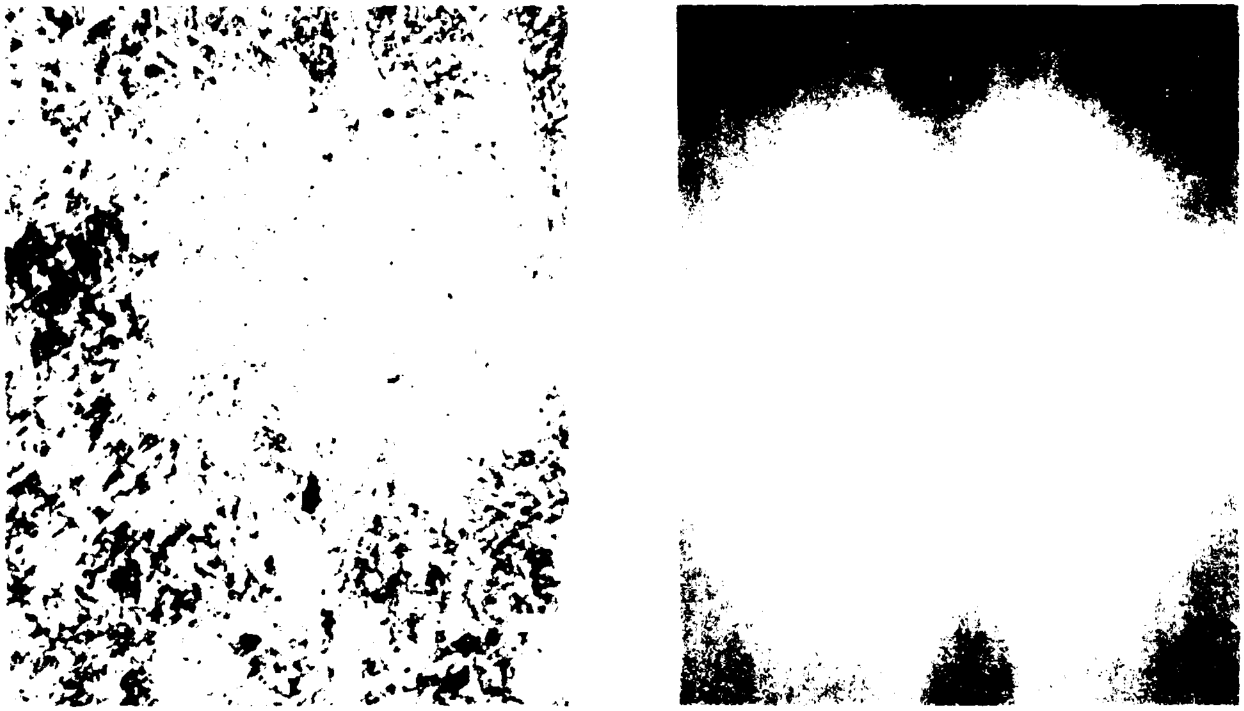


FIGURE 56 CHARPY V-NOTCH IMPACT RESULTS FOR ELECTRON BEAM WELDED A516-70 MATERIAL - AS-WELDED (TEST TEMP. +120°F)



Base Metal (X100)
(Nital etch)

HAZ (X100)
(Nital etch)



Weld Metal (X100)
(Nital etch)

X-Section
(Nital etch)

FIGURE 57 MACRO AND MICROGRAPHS OF 3-3/8" - A516-70 MATERIAL - AS-WELDED

HIGH STRENGTH LOW ALLOY STEEL (HSLA)

The EB weld toughness data available on HSLA (microalloyed) materials is very minimal. Evaluation tests have been conducted by Goldak and Bibby[18] on the EB welded properties of Nb microalloyed HSLA steels with favorable results.

In the study for this report, two (2) plates of HSLA material (A710 Grade A) were donated to CBI by Ingalls Shipyard, Pascagoula, Mississippi for EB welding and mechanical properties evaluation. The two (2) plates were 3/4 inch and 1/4 inch thick with the following plate chemistries in Table 5.

Plate	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Nb	V	Al
3/4 in.	.055	0.53	.003	.008	0.27	1.12	0.87	0.80	0.19	0.034	0.01	0.23
1/4 in.	.061	0.53	.004	.010	0.28	1.06	0.90	0.82	0.18	0.040	0.01	0.22

TABLE 5

The welds were made on machined square butt joints with a joint gap around 0.010 inch. The plates were welded in the horizontal position with the following parameters.

3/4 Inch A710 Grade A Plate (EB 1270)

Accelerating Voltage (KV)	75
Beam Current (ma)	100
Travel Speed (IPM)	8
Beam Focus (amps-programmed)	4.41
Gun to Work Distance (inches)	24.5
Oscillation Frequency (Hz)	400
Chamber Pressure (microns)	3-9

1/4 Inch A710 Grade A Plate (EB 1269)

Accelerating Voltage (KV)	75
Beam Current (ma)	46
Travel Speed (IPM)	20
Beam Focus (amps programmed)	4.45
Gun to Work Distance (inches)	24.5
Oscillation Frequency (Hz)	300
Chamber Pressure (microns)	3-10

MECHANICAL TESTING

1) Tensiles

Four (4) tensile specimens were tested; two for each thickness of plate. The 3/4 inch plate had an average ultimate tensile strength of 104.5 KSI and an average elongation of 16%. The 1/4 inch plate had average values of 99.5 KSI and 23% elongation. The failure of one of the 3/4 inch tensile specimens was in the weld metal. The other specimens failed in the plate. Examination of the specimen that failed in the weld metal indicated a defect of non-fusion.

2) Side Bends

Three (3) side bends were tested for the 3/4 inch plate and all were acceptable. A root and face bend were tested on the 1/4 inch plate with satisfactory results in Tables 6 and 7.

3) Charpy V-Notch Impacts

Charpy V notch specimens were taken transverse to the rolling direction in the weld metal, HAZ, and plate. The specimens were taken at 1/2 the plate thickness with the following results.

3/4 Inch A710 Grade A Plate

Notch Location	Test Temp. (°F)	Impact Value* (ft-lbs)
WM	32	45, 62, 180
WM	0	64, 38, 57
WM	-120	11, 9, 10
HAZ	32	83, 82, 80
HAZ	0	83, 78, 75
HAZ	-120	24, 21, 15
PL	32	73, 63, 66
PL	0	48, 38, 43
PL	-120	18, 24, 21

* denotes full size specimens

TABLE 6

1/4 Inch A710 Grade A Plate

Notch Location	Test Temp. (°F)	Impact Value** (ft-lbs)
WM	32	61, 41, 10
WM	0	10, 41, 55
WM	-120	6, 7, 6
HAZ	32	28, 31, 30
HAZ	0	33, 31, 33
HAZ	-120	24, 15, 14

**denotes 1/2 size specimens

TABLE 7

4) Hardness

A traverse Vickers Hardness Number survey was performed. The results are shown graphically in Figure 3B. The microhardness of the A710 base plate was approximately 240 VHN for the 3/4 inch plate and 225 VHN for the 1/4 inch A710 base plate. The fusion zone hardness was about 235 VHN for the 3/4 inch and the 1/4 inch A710 plate.

5) Metallographic Examination

Photomicrographs of the 3/4 inch base plate (200X), HAZ (200X), and weld metal (200X) are shown in Figure 4B. Photomicrographs of the 1/4 inch base plate (200X), HAZ (200X) and weld metal (200X) are shown in Figure 5B.

The microstructure of the A710 Grade A Class 3 base metal appeared to be a fine blocky ferrite with some small carbide aggregate regions located along the grain boundaries. The HAZ area was similar to the base plate microstructure except the blocky ferrite was more refined and the blocky ferrite was larger. The fusion zone was a mixture of acicular ferrite, and grain boundary ferrite.

SUMMARY

A 710 Grade A material is a low carbon (0.07 C max.) ferritic steel which achieves its high strength and toughness through microalloying with columbium to refine the grain size. Small amounts of copper, nickel, chromium and molybdenum contribute to strengthen and toughen by precipitation hardening.

The results of the mechanical testing and the microstructure observations indicate that A710 Grade A Class 3 material can be successfully electron beam welded with mechanical properties that are comparable to conventionally welded A710 or HY80. The CVN results indicate slightly lower impact values for the weld metal as compared to the base plate properties. The HAZ has slightly higher values than the base plate.

The hardness results indicate that A710 material, in the as-welded condition, does not exhibit the relatively high values in the heat affect zone which is characteristic of other EB welded high strength materials used in the shipbuilding industry, such as HY 80. This is thought to be due in part to the very low carbon content in A710 material.

CBI had insufficient A710 plate material and funds to perform a complete study of the EB welded mechanical properties of this material at various temperatures. It is recommend that future testing of this material be considered in light of the encouraging results from this preliminary study. It is felt that better mechanical properties than these test results may be possible from EB welds of A710 material if various heat inputs and travel speeds are tested to obtain the optimum range of the weld metal cooling rate.

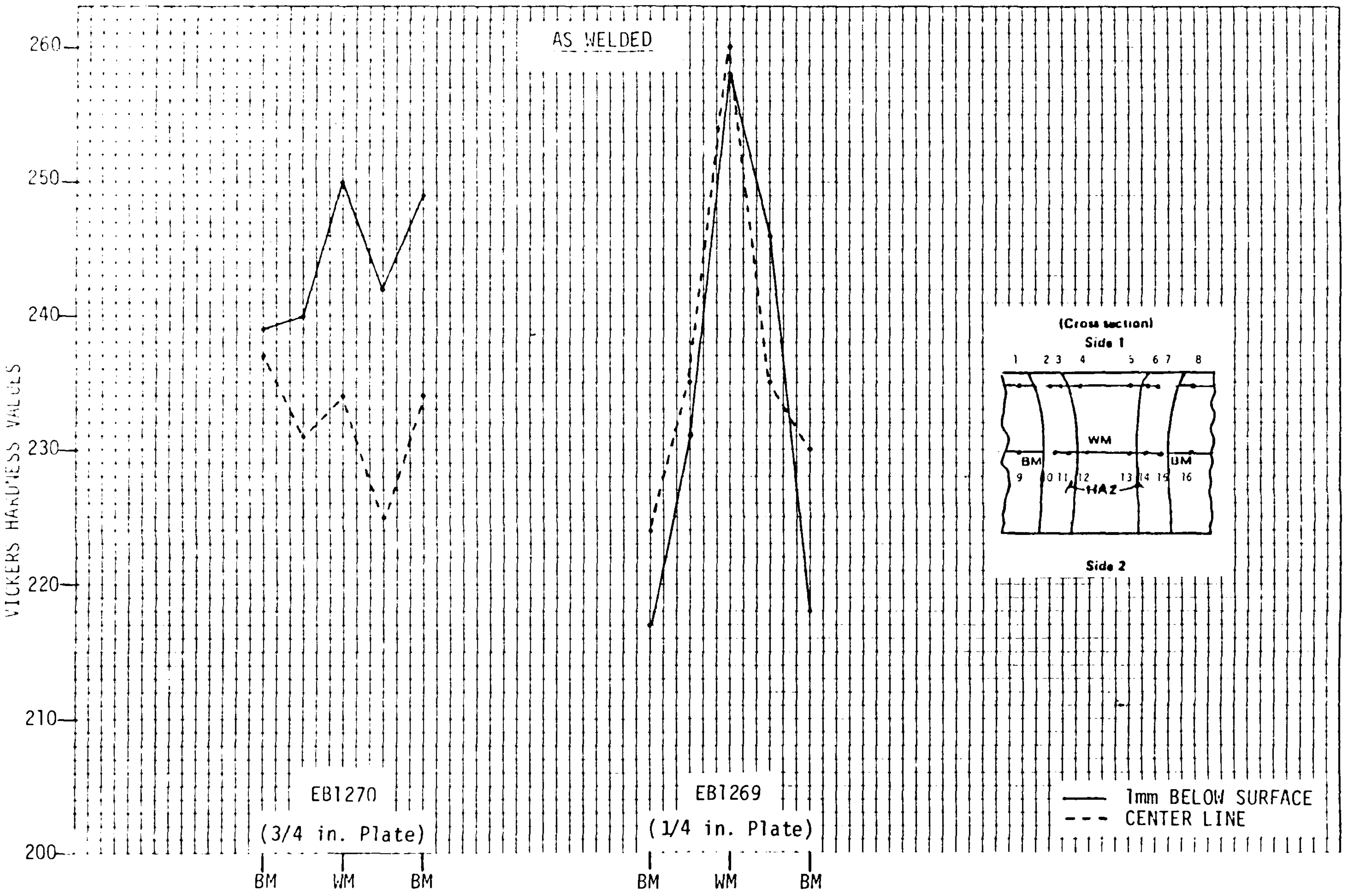
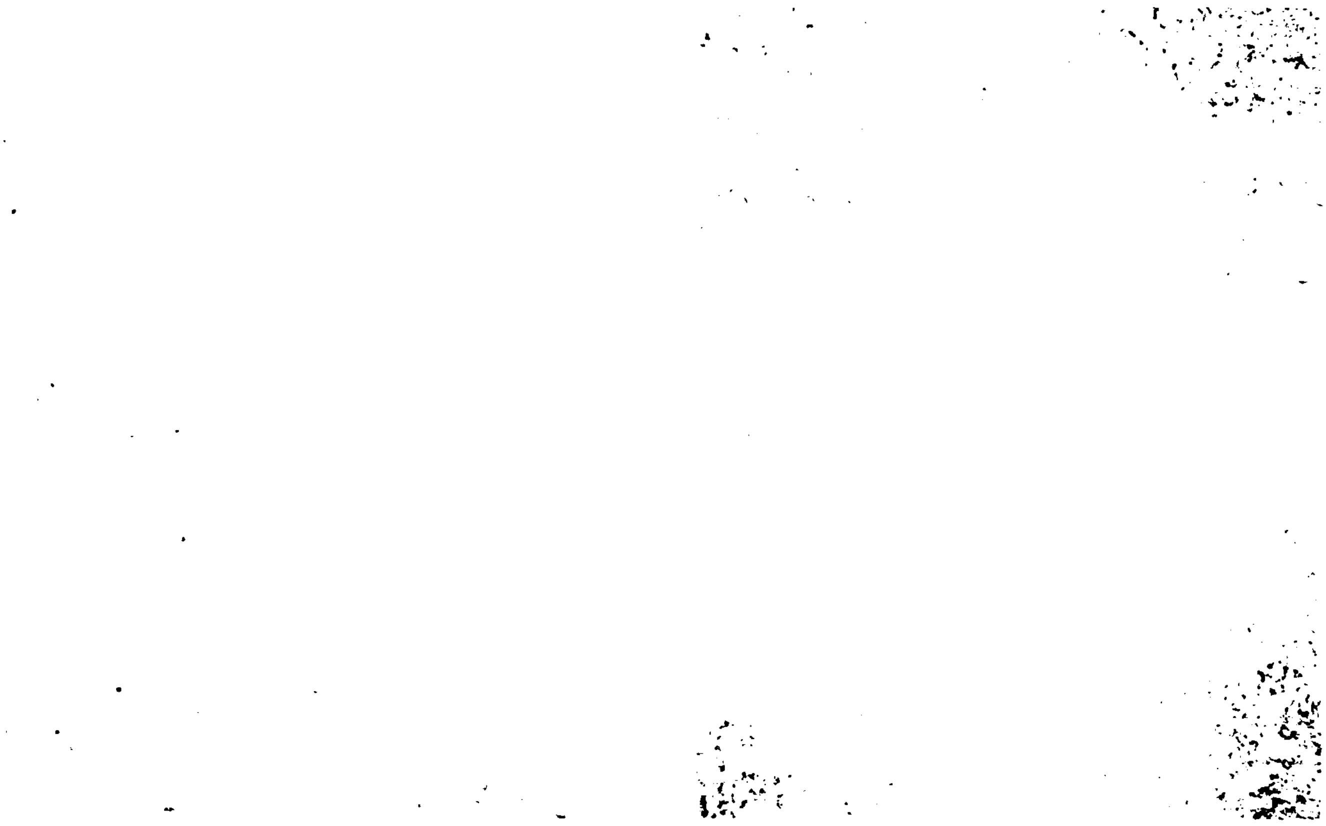
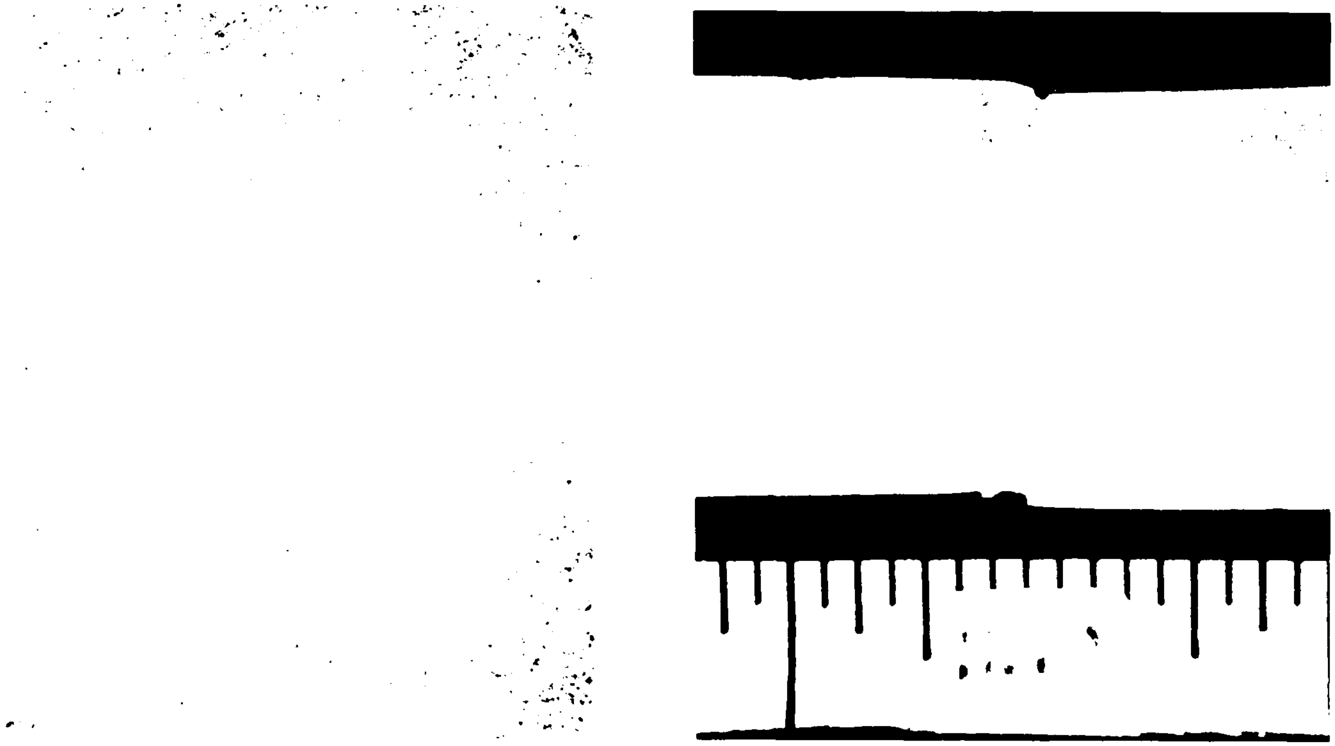


FIG. 58 APPROXIMATE VICKERS TRAVERSE HARDNESS VALUES FOR ELECTRON BEAM WELDED A710 GR. A MATERIAL - AS-WELDED



Base Metal (200X)
(Nital etch)

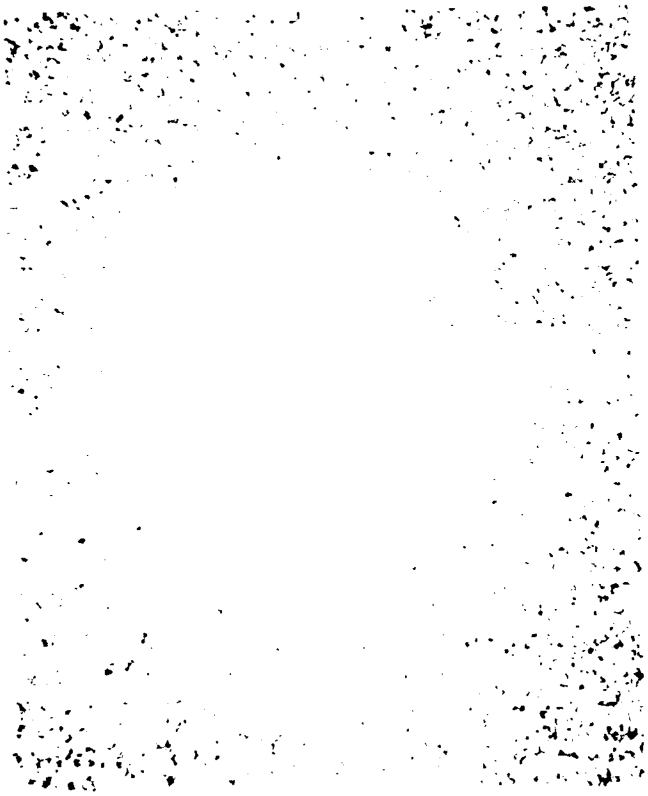
HAZ (200X)
(Nital etch)



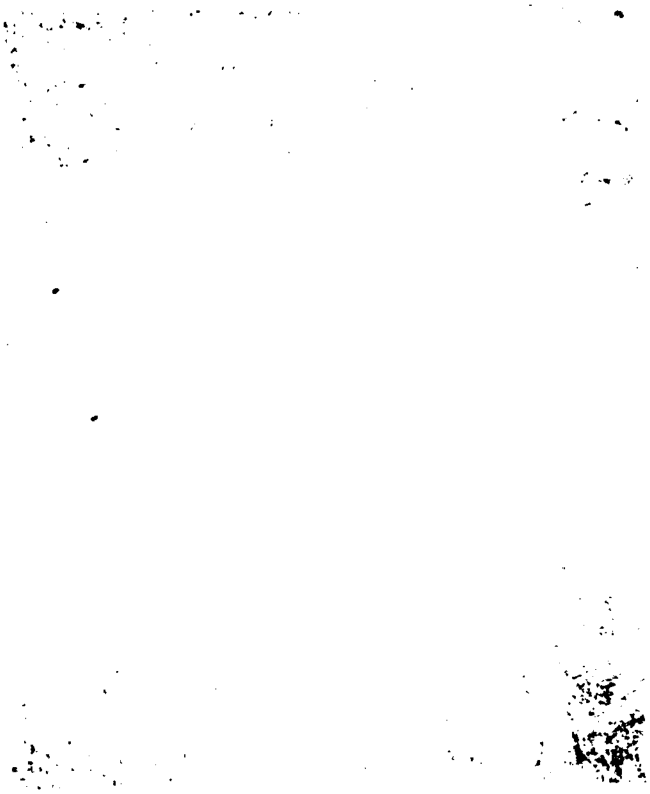
Weld Metal (200X)
(Nital etch)

X-Section
(Nital etch)

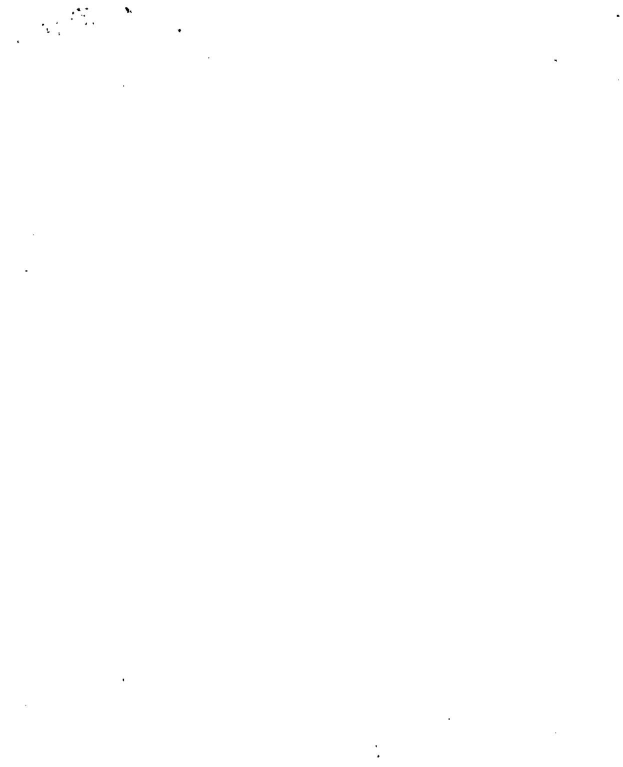
FIGURE 59 MACRO AND MICROGRAPHS OF 3/4" - A710 GRADE A MATERIAL - AS-WELDED



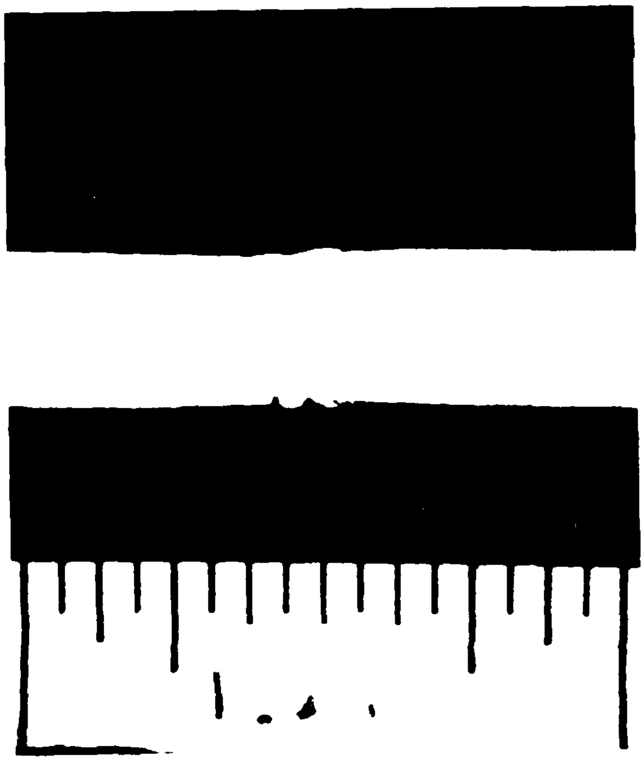
Base Metal (200X)
(Nital etch)



HAZ (200X)
(Nital etch)



Weld Metal (200X)
(Nital etch)



X-Section
(Nital etch)

FIGURE 60 MACRO AND MICROGRAPHS OF 1/4" - A710 GRADE A MATERIAL - AS-WELDED

HY80 - 130 HIGH STRENGTH CARBON STEELS

HY-80

Various development programs have evaluated the EB weldability and mechanical properties of HY 80 material, since it is used in the fabrication of steel tees for ships and submarines. Two reports by the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) SME-82/66 and SME-81/47, indicated that HY 80 EB welds had excellent tensile and dynamic fracture resistance properties.[19,20] The impact properties were satisfactory if adequate post weld heat treating techniques were used. Occasional low toughness values did occur in the centerline of the weld, but this was associated with the intermittently occurring growth of long parallel martensitic laths at the weld centerline.

Previous work by Grumman Aerospace Corporation indicated that HY 80 has a propensity for solidification cracking when EB weld speeds are greater than 7 IPM for 1 inch thick material.

The EB weld parameters and the mechanical test results for the DTNSRDC report SME-82/66 can be summarized accordingly.

ELECTRON BEAM WELDING PARAMETERS FOR ONE-INCH THICK HY-80 STEEL

Joint design	Square butt joint with no joint gap
Welding position	Horizontal
Preheat	None (ambient temperature, 70° F)
Beam voltage	36 kV
Beam current	250 mA
Welding speed	5 IPM
Linear heat input	108 KJ/in.
Beam oscillation frequency	50 Hz
Beam oscillation amplitude	3/64 in.
Absolute beam frequency	857 Hz/in. of weld length

PARAMETERS FOR COSMETIC SMOOTHING PASS

Specimen	Beam Voltage (kV)	Beam Current (mA)	Travel Speed (IPM)	Oscillation Amplitude (in.)	Frequency (Hz)
W823	36	75	5	3/64	50
W824	25	105	5	3/64	50
W825	25	105	5	3/64	50
W826	25	105	5	3/64	50

DTNSRDC tested the four (4) plates of 1 inch thick HY 80 material after they were radiographed and post weld heat treated for 4 hours at 1200° F.

The Rockwell Hardness testing of the specimens gave an average value of 25 R_c in the weld metal and 21 R_c in the HAZ.

The base plate mechanical properties they found are given in Table 8.

	Tensile Properties				Toughness Properties CVN	
Specimen	0.2% Y.S. (ksi)	U.T.S. (ksi)	Elong. in 4D (%)	R.A. (%)	Longitudinal -120° F (ft-lbs)	Transverse -120° F (ft-lbs)
B1	89.6	104.4	22	65	115.5/103.5/ 94.5	47.5/52.5/55.5
B2	91.7	105.9	24	74		

TABLE 8 BASE MECHANICAL PROPERTIES OF HY 80 PLATE

The transverse tensile test results of the EB welds are given in Table 9.

TRANSVERSE TENSILE PROPERTIES FROM ELECTRON BEAM
WELDED HY-80 STEEL

Specimen	0.2% Y.S. (ksi)	U.T.S. (ksi)	Elong. in 4D (%)	R.A. (%)
T1	88.0	104.0	20	65
T2	87.0	102.0	20	68

TABLE 9

The transverse Charpy V-Notch values of the weld metal and HAZ are summarized in Table 10.

Specimen	Notch Location*	Temperature (°F)	Transverse CVN (ft-lbs)
C1 thru C5	1	-60	10.5/12/21/6.5/16
C6 thru C10	1	0	90/39/38.5/22.5/51
C11 thru C15	2	-60	27.5/64.5/39/34/36.5
C16 thru C20	3	60	48/56.5/54.5/62.5/60

TABLE 10

*Location 1 - Centerline of weld
Location 2 - Fusion zone/HAZ interface
Location 3 - Center of HAZ

These values were for specimens that were stress relieved for 4 hours. When Charpy V-Notch specimens from an EB weld were heat treated for 1 hour as recommended by Grumman Aerospace, the result showed an increased toughness performance. The CVN values found are shown in Table 11.

CHARPY V NOTCH TOUGHNESS OF ELECTRON BEAM WELDS
WITH A ONE HOUR POST WELD HEAT TREATMENT

Specimen	Notch Location	Transverse CVN -60° F (ft-lb)
HT1-1	1	49.5
HT1-2	1	36.0
HT1-3	1	53.0
HT1-4	1	44.0

Location 1 - Centerline of Weld

TABLE 11

DTNSRDC performed explosion bulge test on three 1 inch thick EB welded HY-80 steel plates with good results. All of the specimens exhibited excellent dynamic fracture resistance. The data for the explosion bulge test is shown in Table 12.

DTNSRDC stated that the narrow range of fabrication parameters found to be acceptable indicated that qualification procedures based on specific welding and heat treating equipment would be required before EB welding technology could be implemented for navel ship construction.

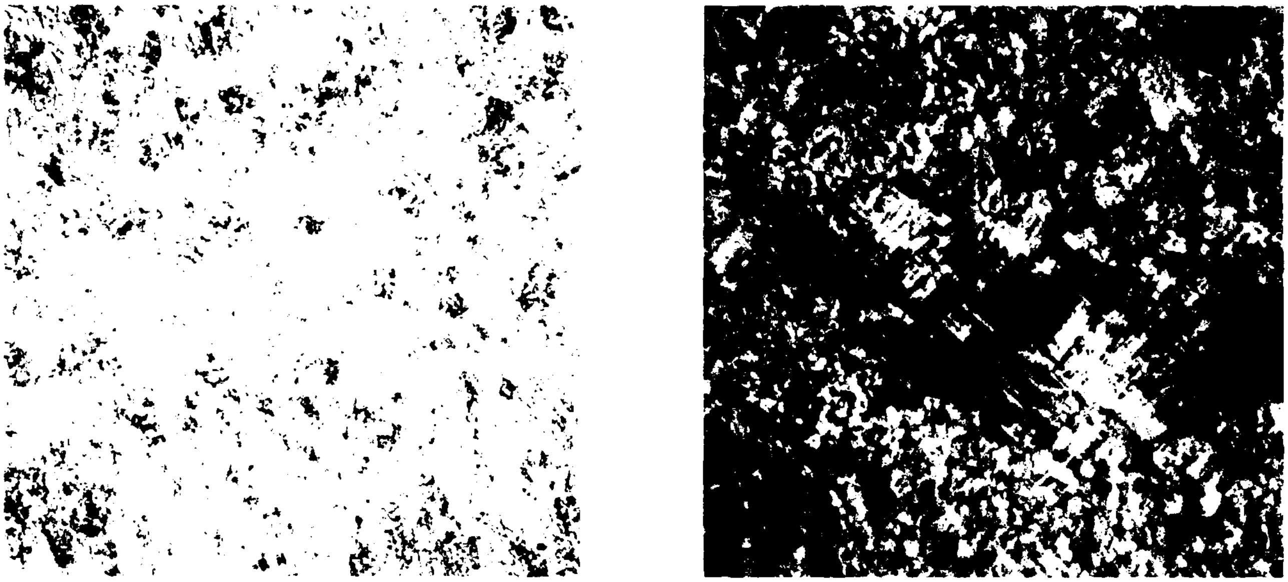
Plate No.	Type	Shot No.	Reduction in Thickness (%)		Depth of Bulge (in.)		Remarks
			Side A	Side B	Side A	Side B	
W824	CS	1	3.84	3.63	1.82	1.76	Three small cracks in starter bead.
		2	8.90	8.64	2.78	2.72	Previous cracks have widened slightly.
W825*	B	1	3.46	2.55	1.79	1.76	NVCT
		2	8.20	7.97	2.76	2.75	NVCT
		3	12.45	12.40	3.34	3.39	NVCT
		4	18.18	18.11	3.92	4.02	Five small shallow cracks in weld metal near center of plate.
W826**	B	1	3.76	3.15	1.80	1.74	NVCT
		2	8.81	7.97	2.73	2.70	NVCT
		3	13.47	12.89	3.37	3.35	NVCT
		4	19.70	19.20	3.93	4.00	NVCT

* Root side of weldment on tension side of plate.
** Face side of weldment on tension side of plate.

TABLE 12 SUMMARY OF EXPLOSION BULGE TEST RESULTS FROM ONE-INCH-THICK ELECTRON BEAM WELDED HY-80 STEEL PLATES

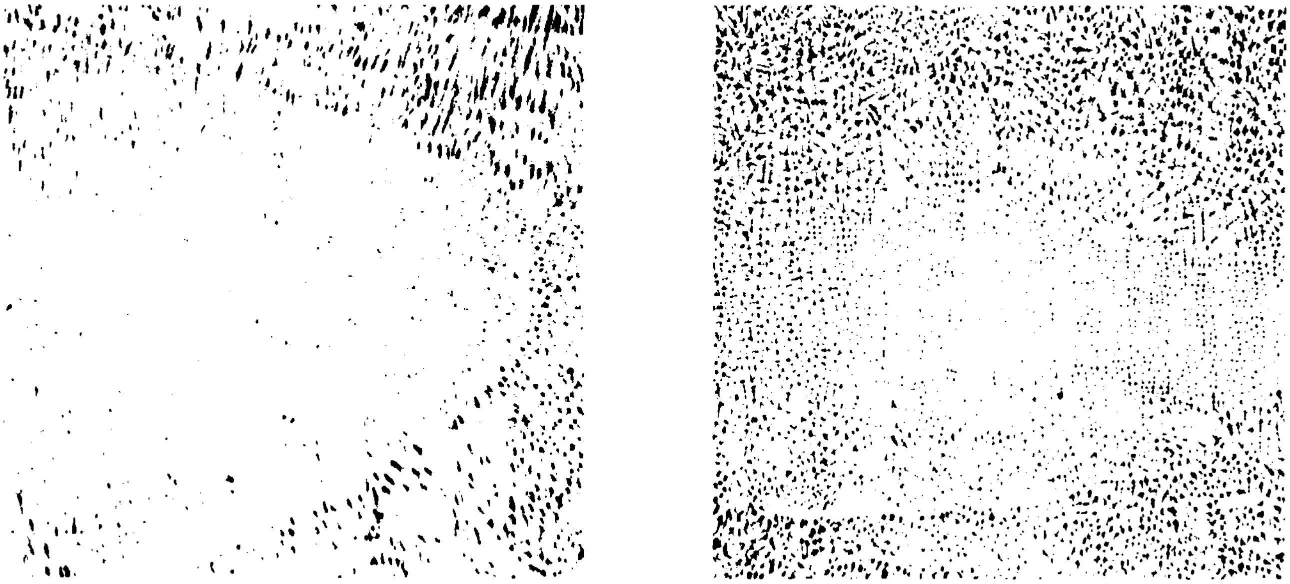
The general microstructures of the EB weld metal for HY80 steel are shown in Figure 61 through Figure 65.

DTNSRDC stated that the narrow range of fabrication parameters found to be acceptable indicated that qualification procedures based on specific welding and heat treating equipment would be required before EB welding technology could be implemented for naval ship construction.



(a) SPECIMEN S, NITAL ETCH
(100X)

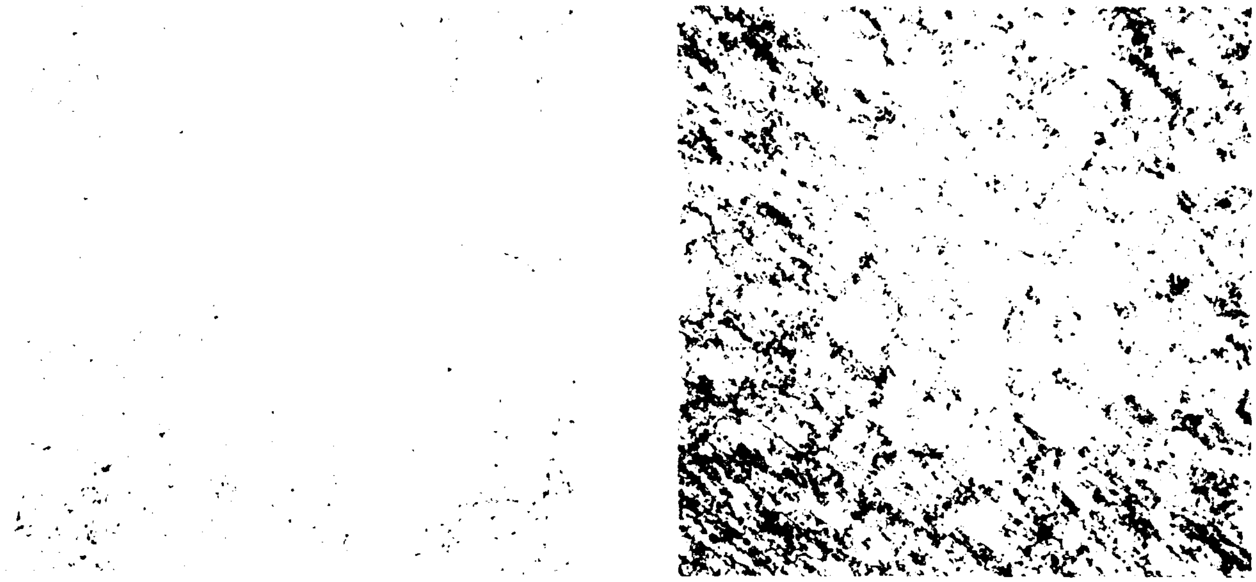
(b) SPECIMEN G, NITAL ETCH
(100X)



(c) SPECIMEN S, DENDRITE ETCH
(100X)

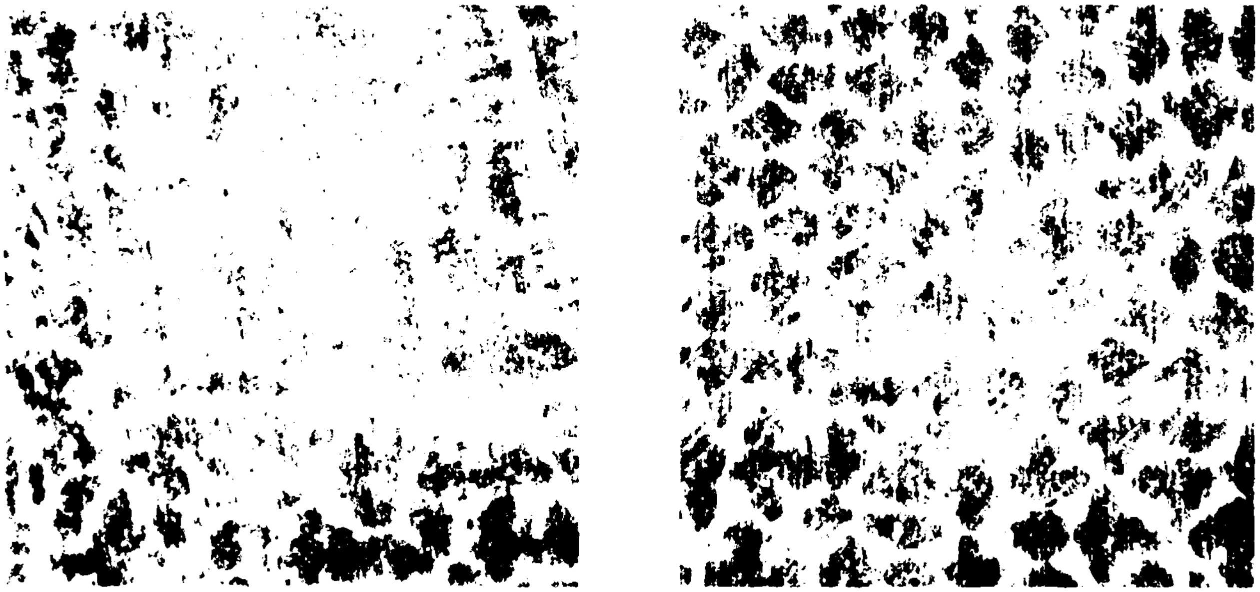
(d) SPECIMEN G, DENDRITE ETCH
(100X)

FIGURE 61 COMPARISON OF TRANSVERSE SECTION PHOTOMICROGRAPHS FROM WELD CENTERLINE OF HY-80 ELECTRON BEAM WELDMENTS



(a) SPECIMEN S, NITAL ETCH (100X)

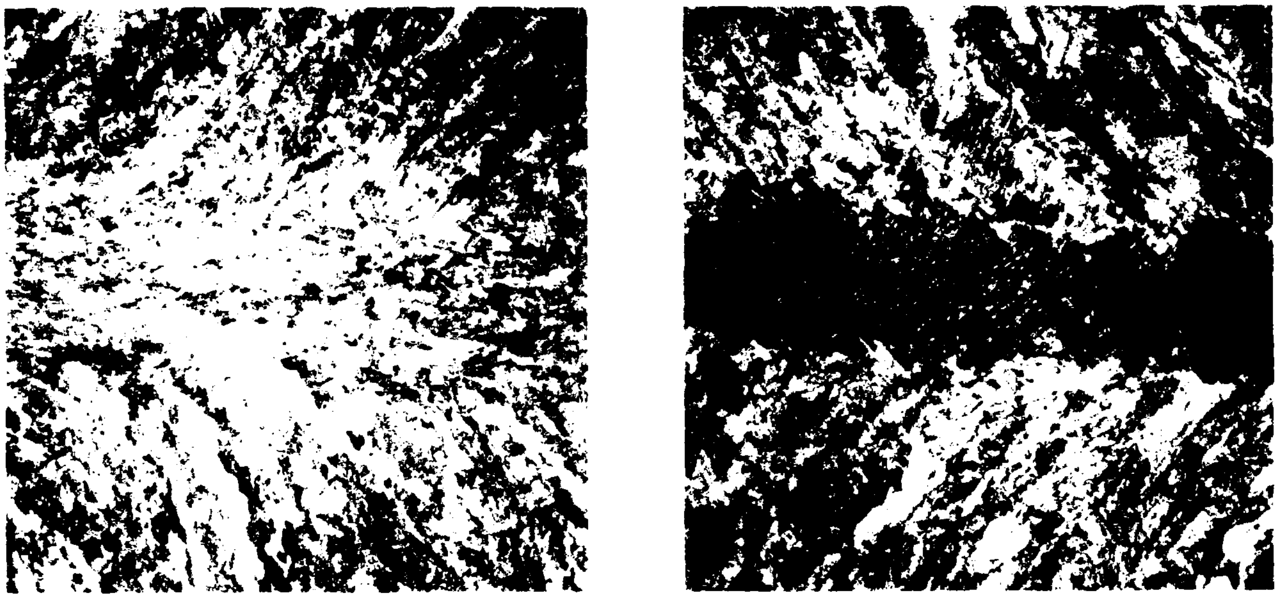
(b) SPECIMEN G, NITAL ETCH (100X)



(c) SPECIMEN S, DENDRITE ETCH (100X)

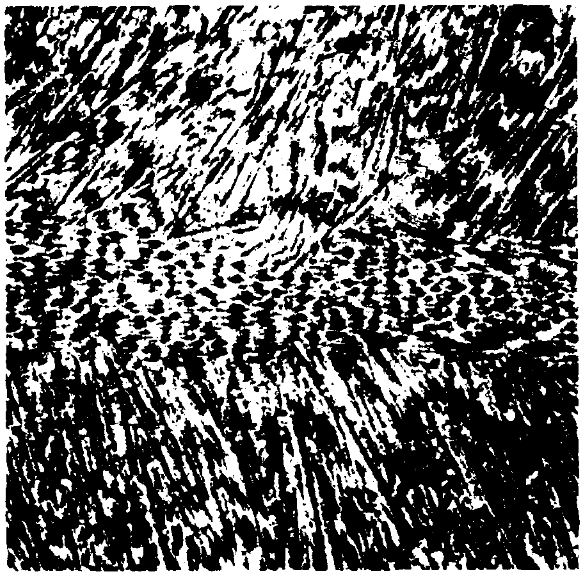
(d) SPECIMEN G, DENDRITE ETCH (100X)

FIGURE 62 COMPARISON OF TRANSVERSE SECTION PHOTOMACROGRAPHS FROM WELD CENTERLINE OF HY-80 ELECTRON BEAM WELDMENTS



(a) SPECIMEN S, NITAL ETCH (100X)

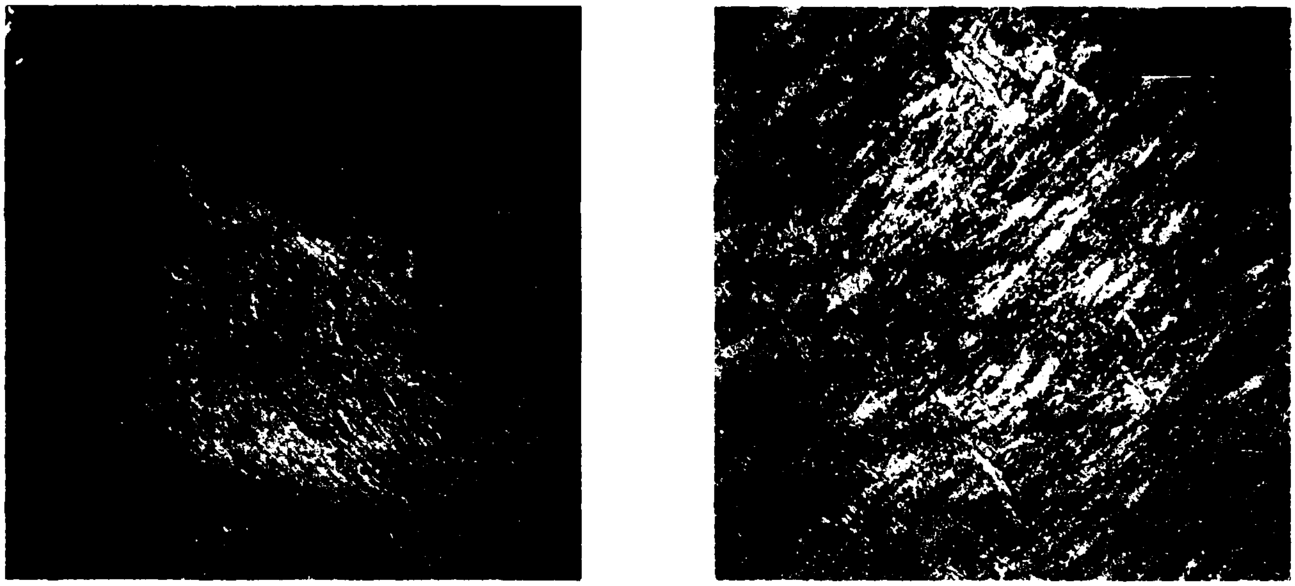
(b) SPECIMEN G, NITAL ETCH (100X)



(c) SPECIMEN S, DENDRITE ETCH (100X)

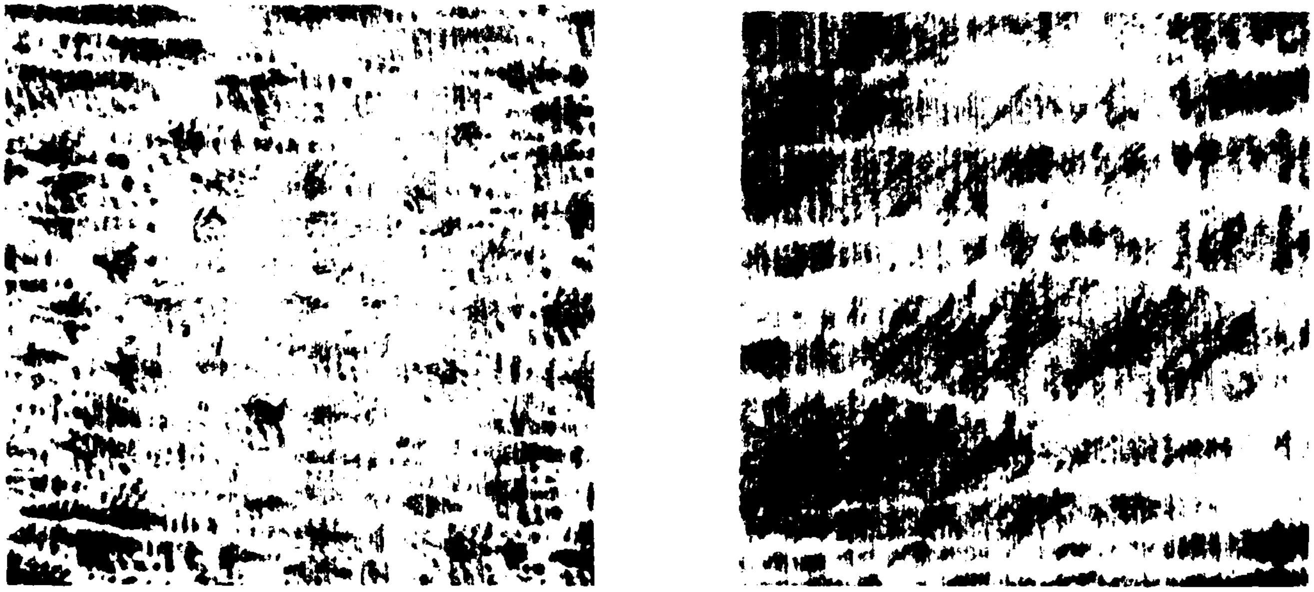
(d) SPECIMEN G, DENDRITE ETCH (100X)

FIGURE 63 COMPARISON OF PLAN SECTION PHOTOMACROGRAPHS FROM WELD CENTERLINE OF HY-80 ELECTRON BEAM WELDMENTS



(a) SPECIMEN S, NITAL ETCH
(100X)

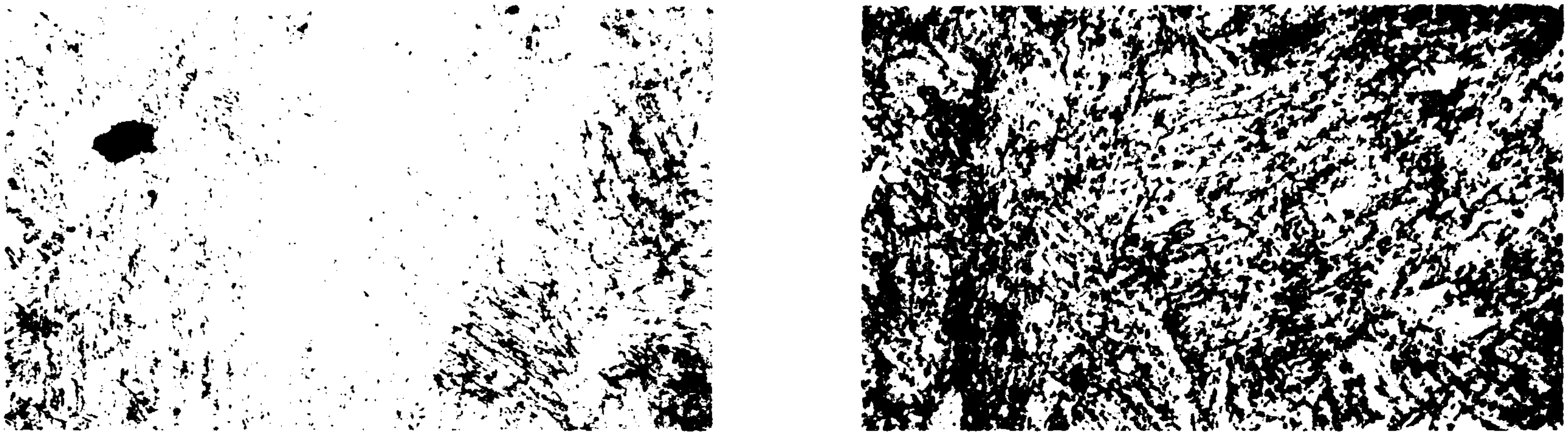
(b) SPECIMEN G, NITAL ETCH
(100X)



(c) SPECIMEN S, DENDRITE ETCH
(100X)

(d) SPECIMEN G, DENDRITE ETCH
(100X)

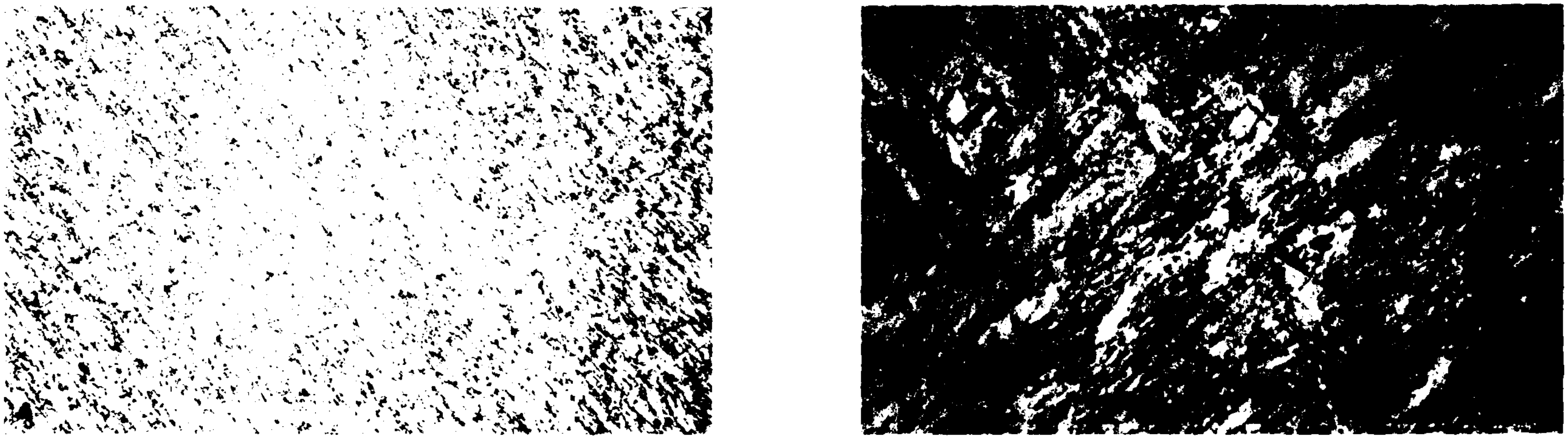
FIGURE 64 COMPARISON OF PLAN SECTION PHOTOMICROGRAPHS FROM WELD CENTERLINE OF HY-80 ELECTRON BEAM WELDMENTS



MAGNIFICATION 250x

MAGNIFICATION 1000x

(a) TPYICAL MICROSTRUCTURE OF WELD METAL



MAGNIFICATION 250x

MAGNIFICATION 1000x

(b) CENTERLINE MICROSTRUCTURE

FIGURE 65 COMPARISON OF CENTERLINE AND GENERAL MICROSTRUCTURE OF ELECTRON BEAM WELD METAL IN HY-80 STEEL

HY-100

CBI has performed electron beam qualification tests on 0.85 inch thick HY-100 (Lukens) material. The plate was water quenched from 1650° F and tempered at 1050° F (minimum). The parameter development welds were bead-on-plate in the horizontal position on a 36 inch long machined square butt joint. The gaps varied from 0.001 inch to 0.020 in no mismatch. The welding parameters used were as follows:

	Full Penetration	Cosmetic
Accelerating Voltage (KV)	75	70
Beam Current (ma)	115	30
Travel Speed (IPM)	8	18
Beam focus (Amps-programmed)	4.38	4.70
Gun to Work (Inches)	22	22
Gun to Focal Point (Inches)	24	22
Oscillation Amplitude (Inches-Dia)	.070	.070
Oscillation Frequency (Hertz)	400	400
Chamber Pressure (Microns)	3-6	3-6

These parameters produced a weld with a near parallel meltzone and adequate reinforcement on both the entrance and exit sides of the beam. Two cosmetic passes were run over the entrance surface to reduce some slight undercut.

TESTING AND RESULTS

Testing was performed on the specimens in the as-welded condition only.

1) Chemical Analysis

A chemical analysis was performed on the plate material only. The results are shown in Table 13.

C	Mn	P	S	Cu	Si	Ni	Cr	Mo	V	Ti
.17	.30	.010	.011	.15	.20	2.65	1.48	.44	.003	.003

TABLE 13 CHEMICAL ANALYSIS OF HY 100 PLATE

2) Tensile Test

Two reduced section tensile specimens were tested with the average ultimate tensile strength of 122 KSI with no apparent yield and 26.5% elongation. The location of failure of both specimens was in the plate.

3) Side Bends

Four guided bend specimens each were tested and all were acceptable.

4) Charpy V-Notch Impacts

The Charpy V-notch specimens were taken transverse to the rolling direction in the weld metal, fusion line, fusion line plus 1mm and fusion line plus 3mm at side one. Six specimens from each location were tested at a test temperature of -120F. This data is shown in tabular form in Table 14 and graphic form in Figure 66.

NOTCH LOCATION	CVN ENERGY (ft.-lbs.)
	HY 100
	Test Temperature -120°F
WELD METAL	11.5/9.0/11.5/10.0/8.5/9.5
FUSION LINE	17.0/10.0/9.5/13.5/11.5/105.0*
FUSION LINE + 1 mm	84.5/82.0/77.5/86.0/46.0/53.0
FUSION LINE + 3 mm	64.0/41.5/46.0/52.5/62.5/49.0

* Notch was along the face of the weld.

TABLE 14 CHARPY V-NOTCH IMPACT RESULTS FOR ELECTRON BEAM WELDED HY 100 MATERIAL - AS-WELDED

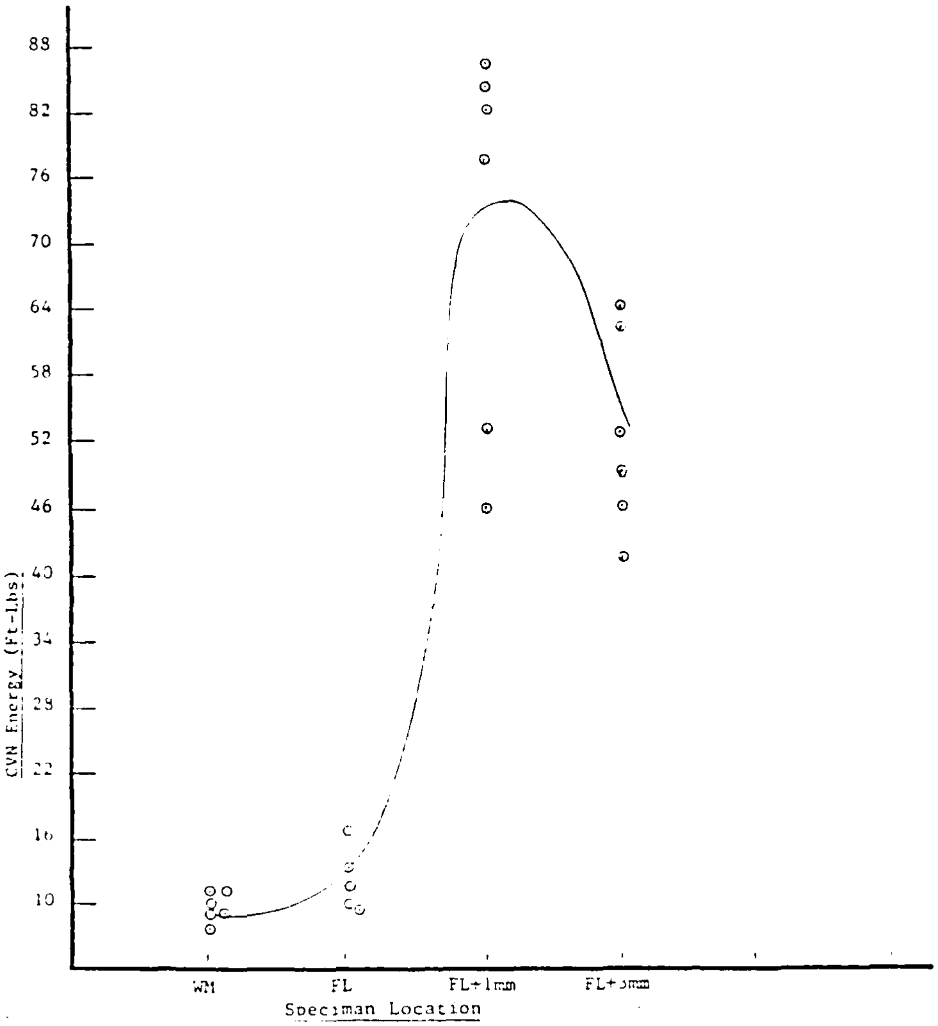


FIGURE 66 CHARPY V-NOTCH IMPACT RESULTS FOR ELECTRON BEAM WELDED HY-100 MATERIAL - AS-WELDED (TEST TEMP. -120° F)

5) Hardness

A traverse Rockwell "C" hardness survey of a cross section sample was performed. The results are shown graphically in Figure 67.

6) Metallographic Examination

Photomicrographs (x100) of the base metal, heat affected zone and weld metal along with a photomacrograph of the welded seam are shown in Figure 68.

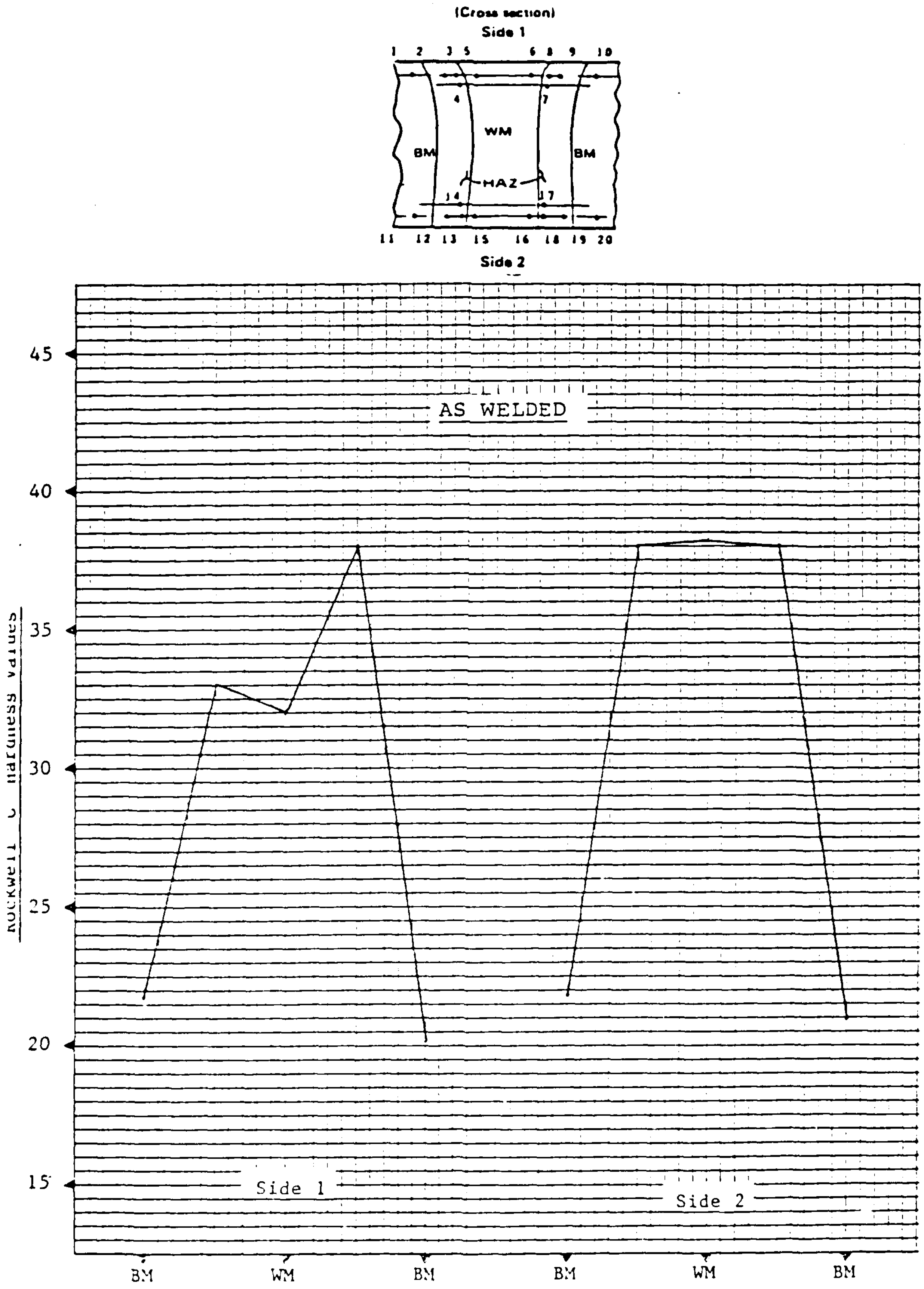
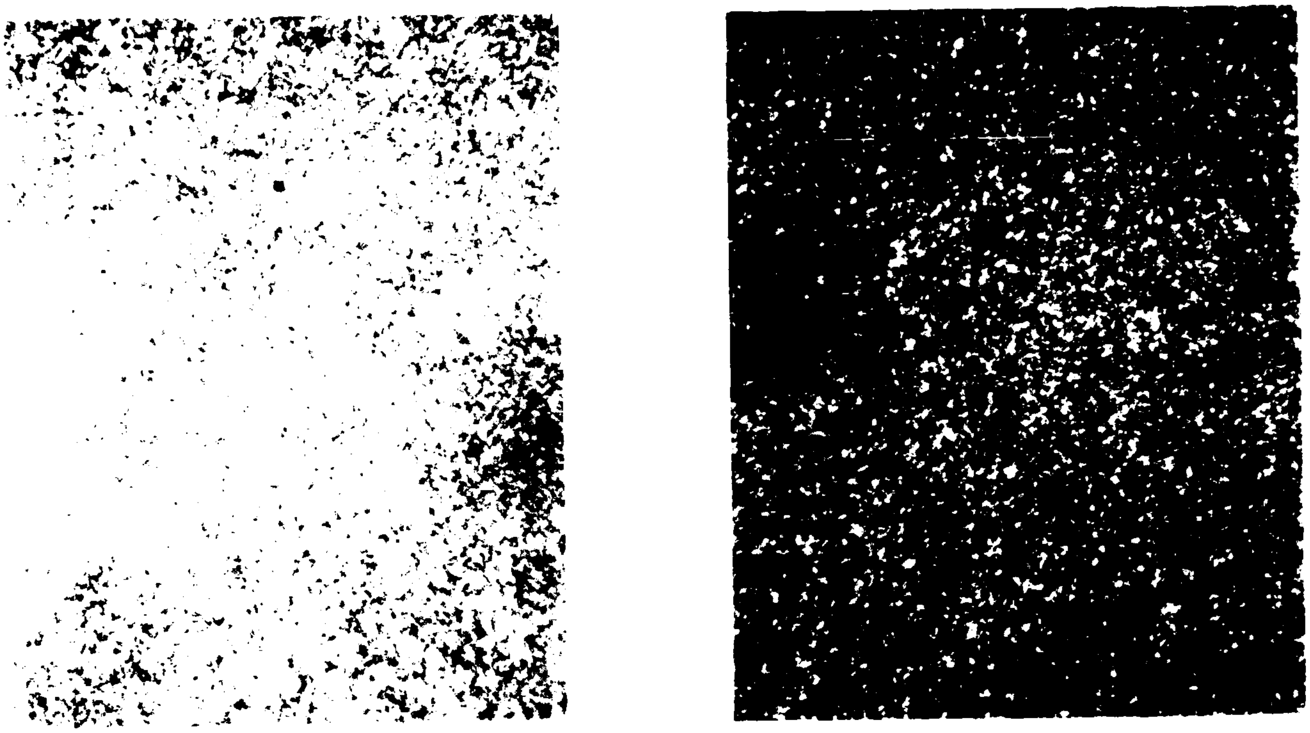
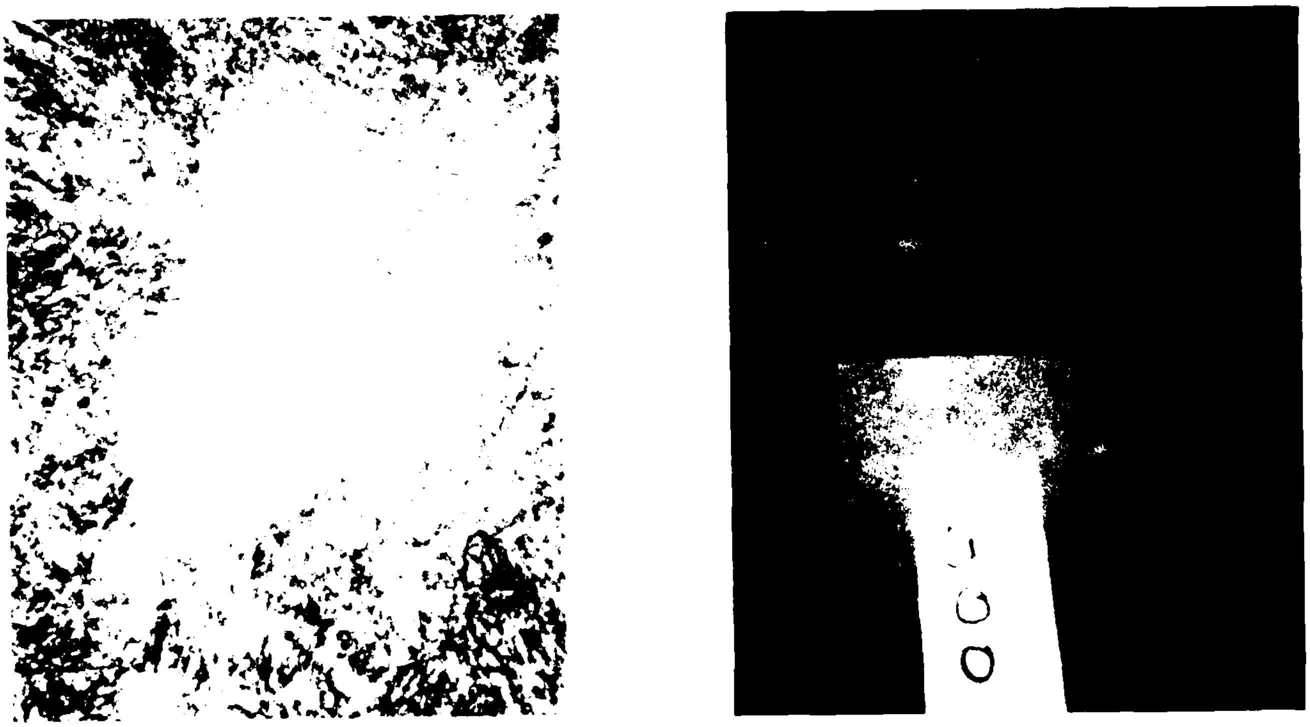


FIGURE 67 ROCKWELL "C" TRAVERSE HARDNESS VALUES FOR ELECTRON BEAM WELDED HY-100 MATERIAL - AS-WELDED



BASE METAL (X100) (NITAL ETCH)

H.A.Z. (X100) (NITAL ETCH)



WELD METAL (X100) (NITAL ETCH)

X-SECTION (NITAL ETCH)

FIGURE 68 MACRO AND MICROGRAPHS OF .85" - HY-100 MATERIAL - AS-WELDED

7) Summary

HY-100 weldments exhibit good tensile properties in the as-welded condition, but relatively low weld metal values (test temperatures of -120°F). The high as-welded hardness in both the fusion zone and near HAZ anticipated relatively poor impact strength for the HY-100 weld in the as-welded condition. The metallography of these structures appear to indicate a predominately martensitic zone. Post weld heat treating would have substantially reduced the relatively high local residual stresses inherent in EB welding and would have tempered the weld fusion zone and HAZ.

HY-130 STEEL

EB welding tests were conducted by Stoop and Metzbower[22] on 1/4 inch and 1/2 inch HY-130. They compared the EB weldmen's to comparable weldments made with the laser, SMA and GMA weld processes. The welding conditions that they used on the EB weldments of their tests are shown:

Welding Conditions of 1/4 Inch Thick
EB Weldments of HY-130 Steel

Joint	Square Butt
Position	Flat
Filler Metal	None
Amperage (Amps)	0.20 - 0.24
Voltage (Volts)	40,000
Passes	1
Travel Speed (mm/s)	21.2
Environment	High Vacuum
Preheat Temperature °C	None
Heat Input (KJ/mm)	0.38 - 0.51

Welding Conditions for 1/2 Inch Thick
EB Weldment of HY-130 Steel

Joint	Square Butt
Position	Flat
Filler Metal	None
Amperage (Amps)	0.20 - 0.24
Voltage (Volts)	40,000
Passes	1
Travel Speed (mm/s)	21.2
Environment	High Vacuum
Preheat Temperature °C	None
Heat Input (KJ/mm)	0.38 - 0.51

The weld metal and base metal chemistries of the plate used for these weldments are shown in Table 15 and 16.

	C	S	P	Mn	Ni	Cr	Mo	Si	V	Cu	Ti	Al
Plate	0.11	0.005	0.005	0.80	4.70	0.60	0.54	0.21	0.07	0.06	0.004	0.05
Weld	0.11	-	-	0.85	4.8	0.62	0.59	0.26	0.07	0.08	0.004	0.03

TABLE 15 BASE METAL AND WELD METAL CHEMISTRIES OF 1/4 INCH THICK HY-130 PLATE

	C	S	P	Mn	Ni	Cr	Mo	Si	V	Cu	Ti	Al
Plate	0.085	0.007	0.006	0.74	4.70	0.52	0.54	0.22	0.07	0.19	0.003	0.05
Weld	0.079	-	-	0.70	4.75	0.55	0.52	0.24	0.07	0.18	0.005	0.05

TABLE 16 BASE METAL AND WELD METAL CHEMISTRIES OF 1/2 INCH THICK HY-130 PLATE

Hardness traverses were made in the mid-thickness regions of the 1/4 inch and 1/2 inch plates. The values are plotted in Figure 69 and 70. The EB welds showed higher weld metal and HAZ values as compared to the SMA and GMA processes. The EB and laser welds were comparable.

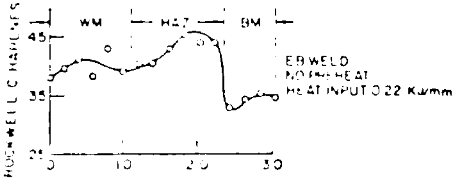


FIGURE 69 EB WELD HARDNESS OF 1/4 INCH HY 130 PLATE

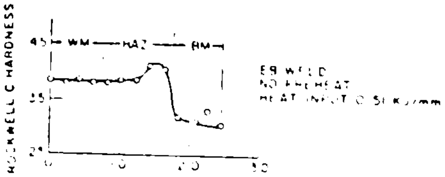


FIGURE 70 EB WELD HARDNESS OF 1/2 INCH HY 130 PLATE

The tensile data of the weldments of the 1/4 inch and 1/2 inch thick plate is shown in Table 17.

	Location	0.2% YS (KSI)	UTS (KSI)	% Elongation	RA %
1/4 In.	Base Metal	140.9	147.1	13.3	63.3
	Weld Metal	144.2	147.8	13.0	60.2
1/2 In.	Base Metal	133.4	139.1	20.5	72.7
	Weld	131.9	137.2	18.5	74.2

TABLE 17

Fracture energy data for the 1/4 inch and 1/2 inch thick plate and EB welds are compiled in Tables 7 and 8.

Location	Avg. DT Energy (ft-lb)	Rp (ft-lb) in. 5/2
Base Metal	391.0	437.1
Weld	308.0	344.3

TABLE 18 FRACTURE RESISTANCE DATA OF 1/4 IN. THICK HY-130 WELDMENTS

Location	Avg. DT Energy (ft-lb)	Rp (ft-lb) in. 5/2
Base Metal	804.0	899.0
Weld	610.0	682.0

TABLE 19 FRACTURE RESISTANCE DATA OF 1/2 IN. THICK HY-130 WELDMENTS

The microstructures of the HY-130 weld fusion zone and the HAZ were analyzed and compared. A hardness value was recorded for that area for correlation. This is shown in Table 20 and 21.

Weldment	Microstructure	Hardness, Rc	Grain Size	Location
		Weld Metal		
EB	Martensite + some Bainite	43.0	Medium-fine	0.8mm from center of weld
		Heat Affected Zone		
EB	Martensite + some Bainite	40.5	Medium	0.2
EB	Martensite + some Ferrite	45.5	Fine	0.8

TABLE 20 MICROSTRUCTURE, HARDNESS AND GRAIN SIZES OF 1/4 INCH THICK WELDMENTS OF HY-130 STEEL

Weldment	Microstructure	Hardness, Rc	Grain Size	Distance From Center of Weld, mm
		Weld Metal		
EB	Martensite + Bainite	37.5	Medium-fine	0.4
		Heat Affected Zone		
EB	Martensite + some Bainite	38.0	Medium	0.2
EB	Martensite + some Ferrite	41.0	Fine	0.8

TABLE 21 MICROSTRUCTURE, HARDNESS AND GRAIN SIZES OF 1/2 INCH THICK WELDMENTS OF HY-130 STEEL

SUMMARY OF HY-130 RESULTS

HY-130 EB weldments exhibited good tensile strengths, but relatively low fracture toughness. This was largely due to the formation of cold shuts (incomplete fusion) at the weld HAZ interface.

The EB weldments demonstrated high hardness values with steep hardness gradients but relatively fine grain structures in the weld and HAZ.

High cycle fatigue tests were performed by DTNSRDC for development project SME-81/35[9] on EB welded HY 130 stiffened panel sections. The EB welded assemblies exhibited high-cycle fatigue performance better than conventional GMAW or SMAW welds, but below the HY 130 base metal test results.

SUMMARY FOR EB WELDED MATERIALS FOR THE SHIPBUILDING INDUSTRY

In general, most of the carbon steels used in the shipyards could probably be EB welded. The resultant mechanical properties of the material would be dependent on the base plate composition and the welding parameters utilized for welding.

As shown in the test results for A516 Gr. 70 and the HY 80-130 EB welded materials, the relatively high carbon content in the base plate and the fast cooling rate resulted in low weld metal notch toughness values and high hardness values in the HAZ. Post weld heat treatment would be beneficial in lowering the high hardness values and improving the notch toughness properties.

Consideration should be made for the development of a special steel for EB welding in structural applications that would provide good mechanical properties in the as-welded condition. A 710 Grade A material shows promise for EB welding, but further development work would be recommended before test results could be conclusive.

Other materials used in the shipbuilding industry, such as titanium and aluminum, lend themselves quite readily to electron beam welding due to the inherent characteristic of the EB weld normally being completed in a controlled environment such as in a vacuum chamber. Several articles have been written on both titanium and aluminum EB welding.[23-25]

ECONOMIC COST ANALYSIS

The following is a cost comparison between a panel assembly (40 ft. x 40 ft.) (HSLA material) welded with the automatic submerged arc welding process from two sides and one side welding and a panel assembly welded with the electron beam process inside a large chamber. The welding of the T stiffeners will also be included in the cost comparison.

Typical weld details with welding manhour rates were taken from the Lincoln Electric Arc Welding Procedure Handbook 12th Edition. Other task manhours were estimated from shipyard and construction practices. Sub-arc weld consumable cost were based on using LA100 wire and 880M flux or equivalent.

As reflected in the following calculations, a 1 inch thick panel assembly (with stiffeners), EB welded, showed about a 31% cost savings and a 1 1/2 inch thick EB welded panel assembly reflected a 43% savings over the 2 sided submerged arc welded alternate. Capital cost of EB equipment were not included in this estimate.

A similar comparison of cost of EB welding of pipe cannot be made from published information available for preparation of this report. Costs for conventional arc welding are available in the literature. However, applications of EB welding to pipe have been made by private companies and cost information resulting from these applications has not been made available to the public.

SAW (2 Side Weld) 1" Thick Plate

TYPICAL DETAIL

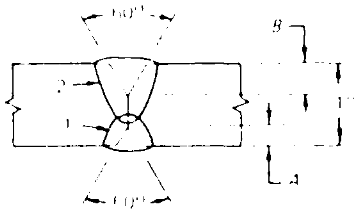


Plate Thickness (in.)	1	
Pass	1	2
Electrode Size	3/16	3/16
Current (amp) (DC+)	850	1000
Volts	35	36
Arc Speed (in./min)	13.5	17
Electrode Req'd. (lb/ft)	0.74	
Flux Req'd. (lb/ft)	0.64	0.36
Total Time (hr/ft of weld)	0.0266*	
Depth A (in.)	3/8	
Depth B (in.)	3/8	

*Expressed in arc time. Multiply by 1.53 to obtain operator efficiency of 65%.

	Per Seam (manhours)		Factor		Total Assembly (manhours)
1. Burning Plate Edge (w/grinding cleanup) (12 IPM burning travel speed) and handling	1.5	x	4	=	6.0
2. Fit-up, tacking, power brushing	1.0	x	3	=	3.0
3. Welding mhs (both sides) 026 mh/ft x 40 ft x 1.53	1.63	x	3	=	4.9
4. Semi-automatic seam arc gouging, grinding and flipping assembly	1.0	x	3	=	3.0
5. Visual Inspection	0.50	x	3	=	1.5
6. NDE (UT or RT 10% total weld footage) 12 ft x 0.25 mh/ft = 3.0	-		-		3.0
7. Repairs (10% of inspected footage) 1.2 ft x 1.0 mh = 1.2	-		-	-	1.2
					22.6

Labor Cost ($30/HR) = $678

Consumables:
Wire 0.74 lb/ft x 120 ft = 90 lbs @ $1.30/lb = $117.00
Flux 0.86 lb/ft x 120 ft = 103.2 lbs @ $0.50/lb = $ 51.60

SAW (2 Side Weld) 1-1/2" Thick Plate

TYPICAL DETAIL

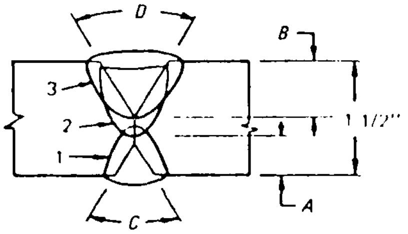


Plate Thickness (in.)	1-1/2		
Pass	1	2	3
Electrode Size	3/16	3/16	3/16
Current (amp) DC(+)	1000	1000	950
Volts	36	36	34
Arc Speed (in./min)	9	10	7
Electrode Req'd (lb/ft)	2.26		
Flux Req'd (lb/ft)	1.45 – 2.00		
Total Time (hr/ft of weld)	0.0708*		
Depth, A (in.)	1/2		
Depth, B (in.)	5/8		
Angle, C (deg)	70		
Angle, D (deg)	90		

*Expressed in arc time. Multiply by 1.53 to obtain operator efficiency of 65%.

	Per Seam (manhours)		Factor		Total Assembly (manhours)
1. Burning Plate Edge (w/grinding cleanup) (10 IPM burning travel speed) and handling	1.8	x	4	=	7.2
2. Fit-up, tacking, power brushing	1.1	x	3	=	3.3
3. Welding mhs (both sides) 0.0708 mh/ft x 40 ft x 1.53	4.3	x	3	=	12.9
4. Semi-automatic arc gouging, grinding and flipping	1.1	x	3	=	3.3
5. Visual Inspection	0.50	x	3	=	1.5
6. NDE (UT or RT 10% total weld footage) 12 ft x 0.25 mh/ft = 3.0	–		–		3.0

7. Repairs (10% of inspected footage) 1.2 ft x 1.0 mh	-	-	=	1.2
				32.4

Labor Cost ($30 HR) x 32.4 mh = $972

Consumables:
Wire 2.26 lbs/ft x 120 ft. = 271.2 lbs @ $1.30/lb = $352.56
Flux 2.0 lbs/ft x 120 ft. = 240 lbs @ $0.50/lb = $120.00

Welding of Longitudinal Stiffeners

(Assume 12 in. Web Spaced Every 4 ft., HSLA Material)

3/8 in. fillet required each side -
Welded with automatic sub-arc (Twin head single electrode per side)

	Per Stiffener (manhours)		Assembly (manhours)
1. Layout, fitting and tacking each T-stiffener on panel plate (Fit-up with hydraulic hold down equipment)	.65 x 9	=	5.85
2. Welding Fillets 0.035 mh/ft. x 40 ft.	1.4 x 9	=	12.6
3. Visual Inspection	.25 x 9	=	2.25
4. Repairs and Pickups	.25 x 9	=	2.25
			22.95

Labor Cost = 22.95 mh x $30 mh = $688.50

Consumables:

Wire = 40 ft. x 9 stiff. x 2 sides x .35 lb/ft. = 252 lbs.
Cost = 252 lbs x $1.30 lb = $327.60

Flux = 40 ft. x 9 stiff. x 2 sides x .40 lb/ft. = 288 lbs.
Cost = 288 lbs x $0.50 lb = $144.00

SAW (One Side Welding) 1" Thick Plate
(HSLA Material)

TYPICAL DETAIL

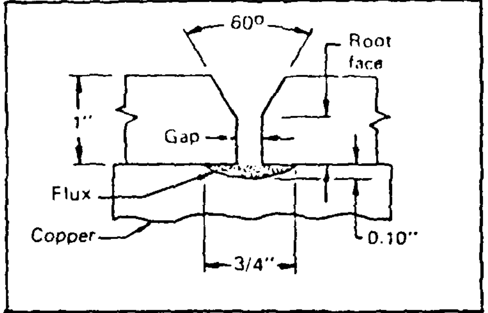


Plate Thickness (in.)	1
Pass	1 – 2
Electrode Size: Lead (No. 1)	3/16
Trail (No. 2)	3/16
Current (amp): Lead (No. 1) DC(+)	1000
Trail (No. 2) AC	800
Volts: Lead (No. 1)	34
Trail (No. 2)	41
Arc Speed (in./min)	17
Electrode Req'd (lb/ft)	1.48
Flux Req'd (lb/ft)	1.25 – 1.65
Total Time (hr/ft of weld)	0.0236*
Gap (in.)	3/16
Root face (in.)	1/2
Spacing, S (in.)	7/8
Electrode angle α (deg.)	12

*Expressed in arc time. Multiply by 1.53 to obtain operator efficiency of 65%.

	Per Seam (manhours)		Factor		Assembly (manhours)
1. Burn 40 ft. plate edges (w/grinding cleanup) (12 IPM burning travel speed) (dual burning heads)	1.5	x	4	=	6.0
2. Positioning plate in hold down bed (fit-up performed simultaneously by hydraulic ram)	.40	x	3	=	1.2
3. One side welding (pass 1-2) 0.0236 mh/ft. x 40 ft x 1.53 = 1.44	1.44	x	3	=	4.32
4. Visual Inspection	.25	x	3	=	0.75
5. NDE (UT or RT 10% total weld footage) 12 ft. x 0.25 mh/ft. = 3.0mh	–		–		3.0

6. Repairs (10% of inspected footage) 1.2 ft. x 1.0 mh = 1.2	-	-	=	1.20
TOTAL MHS				16.47

Labor Cost = 16.47 mh x $30 HR = $494.10

Consumables:

Wire = 1.48 lb/ft. x 40 ft. x 3 seams = 177.6 lbs.
Flux = 1.65 lb/ft. x 40 ft. x 3 seams = 198.0 lbs.

Cost of wire = 177.6 lbs x $1.30 = $230.88
Cost of flux = 198.0 lbs x $0.50 = $ 99.00

EB Weld (In Chamber)
1 in. Thk. Plate

Typical EB Weld Parameters

Beam Voltage - 75 KV
Beam Current - 125 ma
Weld Speed - 8 in/min.
Linear Heat - 70 KJ/in.
Gun to Work Distance - 24 in.

	Per Seam (manhours)		Factor		Assembly (manhours)
1) Plate handling and edge machining (by open face side planer) (including burning edges of 2 end plates)	3	x	3	=	9
2) Fit-up, tacking, cleaning (solvent)	1.25	x	3	=	3.75
3) Demagnetizing operation	.35	x	4	=	1.40
4) Pumpdown, set-up gun on seam, (assume real time tracking capabilities)	-		-		.75
5) Welding operation and travel time of gun to seam (8 IPM)	1.2	x	3	=	3.6
6) Visual Inspection by (TV monitor before release of vacuum in chamber)	0.50	x	3	=	1.5
7) NDE (UT 10% Total Weld Footage) 12 ft. x 0.25 = 3.0	-		-	=	3.0

8) Repairs (10% of inspected footage) - - = 1.2
1.2ft x 1.0 mh/ft = 1.2

Total 24.20

Labor Cost = 24.20 mhs x $30 HR = $726.00
No wire or flux cost required.

EB Weld (In Chamber)
1-1/2" Thk. Plate

Typical Weld Parameters

Beam Voltage - 80 KV
Beam Current - 240 ma
Weld Speed - 8 in/min.
Linear Heat Input - 144 KJ/In.
Gun to Work Distance - 24 in.

Cost would be the same as for 1 in. thick EB welded plate except edge prep machining would require an extra 1.0 mh per seam or 3.0 mh for assembly. Total = 27.20 mh

Labor Cost = 27.20 mhr x $30 HR = $816.00

No wire or flux cost required.

EB Weld (In Chamber)
Longitudinal Stiffeners

Typical weld parameters with gun angled at 45° to the horizontal plane of the panel. (Not full penetration)

Beam Voltage - 95 KV
Beam Current - 50 ma
Weld Speed - 18 IPM
Linear Heat Input - 14.3 KJ/In.
Gun to Work Distance - 24 in.

	Per Stiffener (manhours)		Factor		Assembly (manhours)
1) Fitting and tacking each T-stiffener (grinding and cleaning)	.85 mh	x	9	=	7.65

2) Rolling assembly into chamber and pumpdown	–				.75
3) Welding fillets (including time for moving and set-up of EB gun) 18 IPM x 40 ft. = .5 mh x 2 sides	1.0	x	9	=	9.0
4) Visual Inspection	.25	x	9	=	2.25
5) Repairs and Pickup	.25	x	9	=	2.25
					21.9

Labor Cost = 21.9 mh x $30 HR = $657.00

No wire or flux required.

Comparison of 1.0 in. thick sub-arc welded panel assembly with T stiffeners versus 1.0 thick EB welded panel assembly with T-stiffeners.

1 In. Thk. Panel Assembly Comparison

SAW PROCESS (2 Side Welding)

1) Panel = $678 (Labor) + $168.60 (Consumables) = $846.60
2) T-Stiffeners = $688.50 (Labor) + $471.60 (Consumables) = $1160.10
3) Total = $2006.70

EB PROCESS

1) Panel = $726.00 (Labor)
2) T Stiffeners = $657.00 (Labor)
3) Total = $1383.00

1-1/2 In. Thk. Panel Assembly Comparison

SAW PROCESS (2 Side Weld)

1) Panel = $972 (Labor) + $472.56 (Consumables) = $1444.56
2) T Stiffeners = $688.50 (Labor) + $471.60 (Consumables) = $1160.10
3) Total = $2604.66

EB PROCESS

1) Panel = $816.00 (Labor)
2) T-Stiffeners = $657.00 (Labor)
3) Total = $1473.00

As can be seen without the capitol and operating cost taken into consideration for a 1 inch thick panel assembly EB welding shows about a 31% cost savings and a 1-1/2 inch thick EB welded panel assembly reflects a 43% savings over the sub-arc welded alternate.

The one side submerged arc process was more efficient than the EB process but the limitations of the one side SAW process restricts its use to less than 1 inch due to distortion and other problems.

Large vacuum chamber EB welding would probably have a breakeven point somewhere less than 1 inch but its practicality would be for panel or deck assemblies that averaged 1 inch in thickness or greater.

The projected overall hourly operating cost of the EB set up would require that the capital cost of the equipment be included with the labor and consumable cost. If depreciation of the EB equipment were taken into consideration over a ten year period, the yearly hourly cost would be as follows:

1) Cost of equipment (chamber with dimentions 45 ft. L x 45 ft. W x 5 ft. H, gun, pumping systems, computer control systems) = $5 million or $500,000 per year.

2) Labor cost of 2 men for 1 year (assume 40 hr. shifts per week) = 2000 mh x 2 = 4000 mh x $30 = $120,000.

3) Operating hr. cost (estimated) for water, electricity, maintenance = $15/hr. or $30,000 per year.

4) Total Cost = $650,000/year
$650,000/2000 Hr. = $325 per hour direct cost

If another electron beam welding method were considered such as the mobile or the sliding seal concept, the cost of the EB gun with pumping and computer systems would cost an estimated $1.5 million. A tracking mechanism set-up for the equipment would cost another $0.5 million. Total cost of this concept would be about $3 million less than the large chamber concept.

While the projected capital costs of an EB welding system are high, they are comparable to installing a new arc welding system from scratch. For shipyards with submerged arc welding systems now in place, the price for modifications to improve the system would likely be in the range of $500,000 or less. However, if a completely new system were to be installed from scratch, it would could easily run $1 to $2 million. This would compare favorably with that of a sliding seal EB welding system. The largest handicap in deciding to install an EB welding system over a submerged arc system is the lack of experience in similar applications for the EB systems. This handicap will exist until a user is convinced EB system available are dependable and can produce on the basis estimated!

As can be seen, the large chamber concept does not appear as feasible due to high capitol cost, even though the state-of-the-art EB technology indicates the large chamber concept to be the most practical. The mobile or sliding seal concept is more feasible from an economic standpoint but further development work would be necessary before it could be applied on a production basis in the shipyard.

The cost effectiveness of EB welding could be increased if the nondestructive examination could be performed while the assembly is under vacuum inside the chamber. Once the vacuum is released, the repairs usually are made by manual welding methods. Also, if faster travel speeds could be developed, some welding time could be saved.

The welding of mild steels would not be as economically feasible due to the decreased cost of weld consumables as compared to high strength low alloy materials.

The task manhours for this cost comparison was derived from estimates given by individuals in the shipbuilding and construction industries. For the cost study to be more accurate, it would be necessary to perform a time study of the actual operations in the shipyard.

IN-PROCESS REPAIRS AND MONITORING TECHNIQUES

Electron beam welding is susceptible to the same types of weld defects that are commonly found in other fusion welding processes, with the exception of hydrogen induced cold cracking of carbon steel welds because normally there is no source of hydrogen in an autogenous electron beam weld. The main types of defects in EB welding are:

1) weld metal cracking from either solidification, liquation, and hot or cold cracking
2) lack of fusion or missed weld seam
3) lack of penetration
4) weld metal porosity
5) undercutting
6) underfill

Hot or cold cracks may occur in EB welds in alloys that are susceptible to these types of cracking. Hot cracking is usually intergranular and cold cracking is transgranular. Cold cracks form after solidification as a result of high internal stresses from thermal contraction of the metal during cooling. A crack starts at some point of stress concentration and propagates through the grains by cleavage.

Proper selection of the welding parameters will minimize the risk of cracking. If the travel speed is too high or the weld bead shape is too wide, cracking may occur. Also, lack of penetration may produce cracking in the weld metal since solidification stresses would not be distributed uniformly throughout the depth of the joint. Another type of discontinuity sometimes found in partial penetration welds is large voids at the bottom of the weld metal. Usually these voids will be aligned and appear as linear porosity rather than scattered porosity. When the weld just penetrates through the joint, root porosity will appear as underfill accompanied by spatter on the backside of the weld.

Cold cracking is related to the steel hardenability and weld hardness. Normally in high hardenable steels with a carbon content greater than 0.024%, cracking could occur unless a preheat of 300°-400°F is used.

Lack of fusion from missing the weld seam can occur since the narrow joint is a characteristic of the EB process. This defect is avoided by presetting machine parameters with accurate beam and joint alignment, either manually of by an automatic tracking system. A monitoring technique such as ultrasonic testing would be the only sure guarantee of having proper fusion in the weld seam.

Residual magnetism in the workpiece can sometimes be sufficient to cause beam deflection which results in a missed seam. Sometimes, precautions such as demagnetization of the plate or shielding the beam with a screening pipe may be necessary before welding.

Weld metal porosity is usually associated with the oxygen or nitrogen level in the steel and/or the heat input. If the oxygen and nitrogen content is higher than 60 and 70ppm, respectively, in the steel and the welding heat input is 15 KJ/cm or greater, porosity may occur.[26] The tolerance level of N_2 and O_2 decreases, with increasing weld depth. In general, a good quality vacuum degassed or silicon killed steel should be used when possible.

The addition of a filler metal containing a deoxidizer may be helpful in welding metals that are not completely deoxidized. Also, the use of a slower welding speed will provide time for gas to escape from the molten metal.

Preweld inspection and cleaning of plate surfaces would be essential to eliminate porosity caused by scale or grease. Power brushing or flapping followed by wiping with acetone or other cleaning solvent are recommended practices before the actual welding of components.

Undercutting is the grooves produced at the sides of the base metal where the weld metal does not flow evenly up to the edge of the base metal. Undercutting can result from too high travel speeds, improper or inadequate cleaning procedures and beam assemetry. Filler metal additions that reduce the surface tension will help minimize undercutting. Figure 71B represents undercutting of a weld.

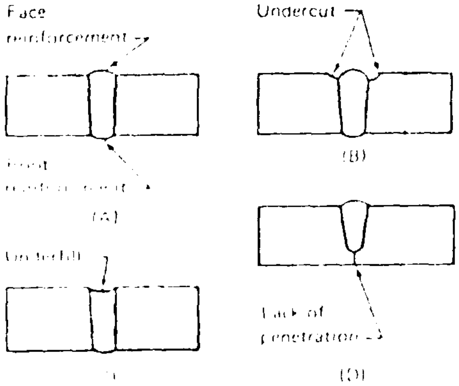


FIGURE 71 (A) SHOWS PROPER FACE AND ROOT REINFORCEMENT (B,C AND D) SHOW EB DEFECTS OF UNDERCUT, UNDERFILL, AND LACK OF PENETRATION

In thick plates (3 inches or thicker) the face and root surface shapes are dependent on the surface tension supporting the column of molten metal as it flows along the weld seam. At slow welding speeds the force of gravity will tend to give the weld a concave shape or cause underfill. This is illustrated in Figure 71C. A backup bar or welding in another position other than downflat will eliminate this condition.

The preferred method of making a repair in an EB weld would be to make a remelt pass through the original weld which contains the defect. This is accomplished by isolating the area with the defect and "sloping in" the beam current to make either a partial or full penetration weld through the defect then "sloping out" of the weld. If the "slope in" - "slope out" mode is performed correctly, the repaired area is indistinguishable from the remainder of the weld. Most of the EB equipment manufactured with CNC capabilities today has automatic programming of the function with slope times that can be varied from 1/2 to 10 secs. Figure 72 shows a schematic diagram of typical remelt EB pass of a defect.

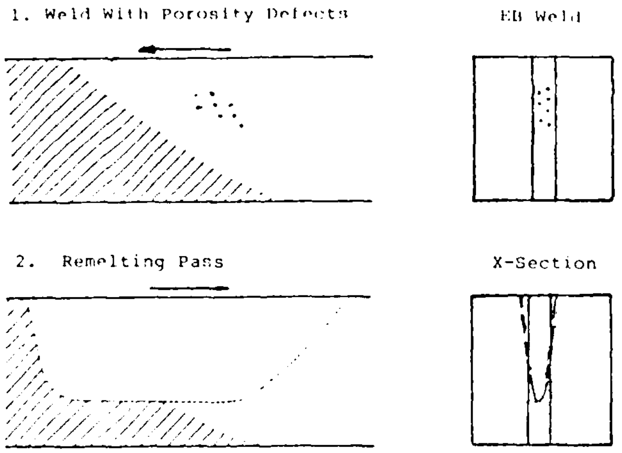


FIGURE 72 SCHEMATIC DIAGRAM OF POROSITY AND ADDITIONAL REMELT EB PASS

Depending upon requirements, the most common methods of inspection techniques for locating defects in EB welds are:

1) Visual
2) Radiograph
3) Ultrasonic
4) Liquid penetrant or mag particle
5) Etch inspection

Visual inspection is usually performed directly after welding inside the chamber by means of borescopes, fiber optics or TV monitor systems.

The shipbuilding industry, due to the tonnages of steel that pass through the panel and deck fab areas, would probably require on line monitoring with ultrasonic testing as well as in production visual inspection. A defect such as nonfusion from missing a seam would be detrimentally dangerous so monitoring the weld seam with 100% UT should be considered. A large immersion ultrasonic monitoring area directly behind the EB weld area, similar to the setup at Grumman Aircraft Facility, Bethpage, N.Y. may be a consideration.

EB welds can be effectively repaired with conventional fusion welding processes as well. Since set up time for EB welding of repairs can be substantially more involved because of relocating the weld seam, digitizing, pumpdown, etc., it might be more advantageous to make the repair with a conventional weld process depending upon the length of the defect and the plate thickness being welded.

Even though defects do occasionally occur in EB welds, repair welds are required no more often with EB welds than with the other conventional welding processes. It is essential that before EB production welding proceeds proper welding parameters be established by analysis of macrosections of sample welds and by nondestructive testing.

Due to the high degree of control of the EB welding process, it offers several long term advantages for producing consistent high level quality welds.

SAFETY CONSIDERATIONS FOR EB WELDING

Since electron beam welding uses a high energy beam of electrons to provide the thermal energy for welding, there are several safety precautions that need to be observed that are not normally necessary for other types of conventional welding.

The primary hazards associated with EB equipment and its use are electric shock, x-radiation, fumes and damaging visible radiation.

All electron beam welding machines operate with high voltage that can cause fatal injury. The manufacturers of EB equipment provide proper insulation, but all precautions should be followed by trained operators and technicians when servicing and troubleshooting the equipment.

Most of the x-rays in EB welding are produced from the high velocity electrons of the beam striking the workpiece. They are also generated when the beam strikes gas molecules or metal vapor in the gun column and work chamber. Underwriters and governmental regulations have established firm rules for the allowable exposure levels of radiation in industry. All EB equipment that is produced by the manufacturers meet these requirements when it leaves the factory. The user of the equipment is required to monitor and maintain the radiation exposure levels allowed by law.

Normally, the shielding provided by the steel walls of the chamber are adequate shielding but occasionally lead shielding is required around the gun. Lead glass windows are employed for the portholes of the chamber for viewing. In the case of nonvacuum or mobile vacuum systems, it is necessary to provide lead shielding around the machine to protect the operator. In addition to normal precautions, it is wise to post x-ray signs on the equipment to inform other personnel of the hazard. A radiation survey should be performed at the time the equipment is installed and at regular intervals afterwards.

It is doubtful if any air left in the high vacuum chamber would be sufficient to produce harmful gases, but when partial vacuum or nonvacuum welding is performed, these gases are evolved. Precautions such as adequate ventilation and proper exhausting techniques should be followed to provide a safe work area.

Viewing of the visible radiation generated by the welding process can be harmful to personnel eyesight. Proper safety precautions, such as eyeglasses or lead glass windows, should be employed when viewing the EB weld process.

CONCLUSIONS

- The domestic manufacturers of EB equipment have the capabilities to design EB systems for use in the shipbuilding industry. The EB manufacturers surveyed for this report are: 1) Leybold Heraeus Vacuum Systems, 2) Sciaky Bros. and 3) MG Industries - Steigerwald Systems.

- EB welding could be adapted to production line fabrication in the shipbuilding industry in the flat panel and T-stiffener to panel assembly area. The large vacuum chamber concept appears the most practical for the butt welds of the panel plates and the fillet welds of the T-stiffeners to panel plates, but due to the high capital cost of the large chamber, this concept may not be as economically feasible as the mobile or sliding seal or the non-vacuum concept of EB welding.

- EB welding could be feasibly adapted to pipe welding and T-stiffener web to flange welding in the shipyard, but future development work should be considered before application. Pipe welding with EB equipment is still in the development stage and has not been perfected, as yet, on a production basis.

- EB welding can be compared to the conventional methods of welding in the shipbuilding industry and be feasible as a long term investment. For EB welding to be justifiable in a shipyard, the savings of the welding manhours and the consumable costs would have to balance out the cost of the EB equipment.

- A study of some of the different types of materials used in the shipbuilding industry show they can be EB welded, but their resultant mechanical properties may vary depending upon the composition of the base material and the weld parameters selected.

- Preliminary EB weld tests on HSLA material, A710 Grade A, indicates it has better weld metal mechanical properties than HY 80 in the as-welded condition. HY-80 normally requires post weld heat treat to obtain reasonable mechanical properties after EB welding.

- A review of current non-destructive inspection practices indicates that ultrasonic inspection is the most favored method of examination of EB welds. Radiography can be used, but has been known to miss defects such as nonfusion where the electron beam did not fuse the parent metal to the weld metal.

- An economic cost comparison between welding a 1 inch and 1 1/2 inch thick panel assembly with the automatic submerged arc process and the electron beam process was presented. With the task manhours included, EB welding showed an 31% cost savings for the 1 inch thick panel assembly and a 34% cost savings for the 1-1/2 inch thick panel assembly as compared with two sided submerged arc welding process. Capital costs of equipment were not included.

RECOMMENDATIONS

- Consider the EB welding process with either a large vacuum chamber concept or mobile/sliding seal welding concept for use in the fabrication of future panel assemblies.
- Establish program to develop mobile or sliding seal EB welding equipment for production panel fabrication. Cost analysis indicates this method of EB welding may be more feasible from an economic standpoint.
- Establish a program to develop the most effective method of degaussing the panel plates before they are EB welded.
- Further development studies on the mechanical properties of EB welded steels used in shipbuilding such as DH36 and A710 Grade A material should be considered.
- A time study in a shipyard of the actual manhours involved with preparing and welding a panel assembly compared to the estimates made in this report.

REFERENCES

Appendix A - Manufacturer's Literature furnished by Leybold Heraeus

Appendix B - Manufacturer's Literature furnished by Sciaky Bros., Inc.

Appendix C - Manufacturer's Literature furnished by MG Industries

REFERENCES

1. Metzbower, E.A., et al "Electron Beam Welding", ASM Metals Handbook 9th Edition, Vol. 6, p. 609-646.
2. Sayegh, G., "Principles and Applications of an Electron Beam Welding Machine with Mobile Local Vacuum Chamber - Suction Cup or Ventouse Machine". Reprint of Sciaky Bros. Vitry France.
3. Ellison, H., "Sliding - Seal Electron Beam Welding of 1/4, 1/2, 3/4 and 1 Inch Thick HY 130 Steel Alloy Plate", Grumman Aerospace Corp., Bethpage, N.Y.
4. Steigerwald, K.H., et al "Electron Beam Welding of Large-Size Workpieces with Mobile Vacuum Unit Under Nearly Practical Conditions", Reprint of Messer Griesheim, Gmbh 9/81.
5. Gajdusek, E., "Advances in Non-Vacuum Electron Beam Technology", Welding Journal, July 1980.
6. Miska, K., "Non-Vacuum Electron Beam Welds - Many Metals, Sizes, Shapes", Materials Engineering, 6/75, p. 20-22.
7. Wells, J.M., "Considerations of Non-Vacuum Electron Beam Welding Capabilities and Applications", Electron and Ion Beam Science and Technology, 6th International Conference, p. 287-306.
8. Ellison, H., Payne, K., "Electron Beam Welding Technology for Ship Structures", April 1979, p. 26, Grumman Aerospace Report produced for official use only for DWTNSRDC.
9. Wong, R., Czysyca, E., "Electron Beam and Sliding Seal Electron Beam Welding of HY 130 Steel Panels", David Taylor Naval Ship Research and Development Center Report, August 1981.
10. Sivry, B., Connet, C., "Electron Beam Welding of J-Curve Pipelines", Offshore Technology Conference, 1980, Paper OTC 3746, p. 99-103.
11. Sayegh, G., Cazes, R., "The Possibilities for Use of Electron Beam Welding in Pipeline Welding in the J Position", 1979.
12. Kihara, H., et al "High Power Electron Beam Welding of Thick Steel Plates - Method for Eliminating Beam Deflection Caused by Residual Magnetism", Welding in the World, Vol. 22, No. 5/6, p. 126-134, 1984.

13. Elliott, S., "The Effect of Process Parameters on the Weld Metal Toughness of EB Welds in a Range of C and C-Mn Steels - A Preliminary Investigation", Welding Institute Res. Report, 169/1981, Dec. 1981.

14. Yada, H. and Nisida, S., "Study on Mechanical Properties of EB Welding Joints in Mild Steel", Advanced Welding Technology Proceedings 2nd International Symposium of the JWS Osaka, August 1975, paper 1-1(17)93-98.

15. Steffens, H.D. and Sepold, G. "Some Metallurgical Aspects of Welding Steel with High Intensity EB", Proceedings of 2nd EB Process Seminar, Frankford am Main, June 1972, paper 3e, Dayton, Ohio: Universal Technology Corporation.

16. Russell, J.D., et al "Electron Beam Welding of Structural Steels", Metal Construction and British Welding Journal, 6(19), p. 307-312.

17. Arata, Y., et al, "Mechanical Properties of Electron Beam Welds of Heavy Section Steel Plates", Transaction of JWRl, Oct. 1983.

18. Goldak, J., Bibby, M., "The Toughness of EB Welds in HSLA Steels", Proceedings of International Conference, Rome 1976, Amercian Society of Metals and Associaione Italiana de Metallurgia.

19. Wong, R., Brenna, R. "Static and Dynamic Properties of Electron Beam Welds in 1 Inch Thick HY 80 Steel", DTNSRDC Report, August 1982.

20. Wong, R., "Electron Beam Welding of HY 80 Steel Tees", DTNSRDC Report, September 1981.

21. Ellison, H., Payne, K., "Electron Beam Welding of HY 80 Steel for Submarine Applications", Technical Report 1187-77, Grumman Aerospace Corporation, January 1977.

22. Stoop, J., Metzbower, E.A., "A Metallurgical Characterization of HY 130 Steel Welds", Welding Journal Research Supplement, November 1978.

23. Nightingale, K.R., Scott, M.H., "Electron Beam Welding a Titanium Alloy Up to 50mm Thickness", The Welding Institute Research Bulletin, May 1980, p. 132-135.

24. Witt, R., et al, "Weldability and Quality of Titanium Alloy Weldments", Grumman Aerospace Corporation, Bethpage, N.Y., 1971.

25. Hardy, R., "High Cycle Fatigue Behaviour of 5086-H116 Aluminum Alloy Electron Beam Welds", WRC Bulletin 215, May 1976.

26. Arata, Y., et al "Mechanical Properties on Electron Beam Welds of Constructional High Tension Steels (Report V)", Transactions of JWRI, Vol. 5, No. 2, 1976.

27. Schroeder, K., Personal Communication, Magna-Flux Corporation, Chicago, Illinois, March 1985.

28. Arato, Y., et al, "Electron Beam Weldability of Heavy Section Steel Plates", IIW Document IX-1237-82, May 1982, p. 5.

29. James, Henry A., "Electron Beam Welding Equipment: Process Parameters, Limitations, and Controls", Presentation at Electron Beam Metallurgical Processing Seminar February 1971, Oakland, California.

30. Blakeley, P. Sanderson, "The Origin and Effects of Magnetic Fields in Electron Beam Welding", Welding Journal, January 1984, p. 42-49.

APPENDIX A

MANUFACTURER'S LITERATURE

FURNISHED BY

LEYBOLD HERAEUS

LEYBOLD·HERAEUS
VACUUM SYSTEMS INC.

EBL 79022

NON-VACUUM SYSTEMS DESCRIPTION

3.0 SPECIFICATION FOR LEYBOLD-HERAEUS NVW (17.5) -SPECIAL ELECTRON BEAM GENERATING SYSTEM

3.1 General Description

The Leybold-Heraeus NVW (17.5) Electron Beam Generating System is an extremely practical and efficient device that is designed for high production welding of metals in air at working distances (exit orifice to weld joint) ranging from 0.250 to 1.50 inches.

Work handling equipment, especially designed to customer requirements, is offered with the NVW system. In this way, customer requirements and variables such as part configuration, production rate, etc., can be satisfied by designing only the necessary work handling equipment. Every element of this system is carefully designed to allow maintenance-free, dependable operation in the conventional environment of the production plant. Because of these inherent features, the NVW system is especially suited for incorporation in assembly-line type or other mass-production facilities.

3.2 Detail Description

The NVW (17.5) electron beam generating system is completely self-contained and features modular construction. The modular subsystems include a welding column assembly (housing the electron gun and vacuum staging systems), an electrical control cabinet, a high voltage power supply, and a vacuum pumping system.

The welding column assembly is responsible for generating and directing the electron beam at the workpiece. The assembly can be mounted off a vertical or horizontal support member and connected through flexible vacuum hosing to the column vacuum system, and mated to a variety of specialized tooling packages. The beam's power and accelerating potential are supplied by the high voltage power supply. The vacuum environment necessary in the welding column is produced by a pressure staging arrangement provided by the vacuum pumping system. The electrical control cabinet maintains control

3.2 (continued)

over the entire system. It provides power and logic to the vacuum system, continuous adjustment and instrumentation of beam current and accelerating potential, workpiece cycle control, and other machine functional requirements. The subsystems can be positioned in a compact arrangement which still provides easy access to all subsystems.

The subassemblies and their major components are described in detail below.

3.3 Electron Gun and Column Assembly

Beam Generation

The patented Leybold-Heraeus telefocus electron gun is of the self-accelerated triode type. Electrons are emitted from a ribbon style filament, then collimated and accelerated by a potential field existing between the cathode and anode.

The electron beam generated by the gun is focused as it passes through an electro-magnetic lens located near the base of the gun column.

Beam Control

Control of beam power is obtained by setting a voltage level between cathode and anode, and selecting a voltage level between cathode and grid. Both beam current (i.e., mass-flow of electrons) and velocity are easily established. The operating accelerating potential is 175 kV.

Beam current is continuously variable over the range 0 to 100 milliamps by means of a control which allows fine-setting resolution over the full current range.

Upper Column

The upper column contains the electron gun assembly which is supported from the top of the upper housing. The filament is specially designed for stability, long life and fast replacement. The electron gun and insulator assembly is mechanically pre-aligned and locked by a partial turn of a locking ring. The exposed grid cup and filament assembly is provided with a quick-disconnect electrical connection, thereby facilitating replacement.

A side mounted column door provides access for filament and gun service thereby maintaining the critical mounting surfaces and spatial relationships of these components. Alignment of the electron bundle with the focus coil is readily accomplished electromagnetically via the alignment coil located below the anode.

Electrical Control Cabinet

All electrical circuit components, controls, indicators, instrumentation, low voltage power supplies, etc., are located in a completely self-contained cabinet. The electrical system is designed for compliance with applicable parts of EIA, NEMA, NMTBA and JIC electrical standards. Major components such as the magnetic-lens-regulated power supply, the high voltag and vacuum control modules, electrical control relays and voltage regulating transformers are located on panel mounted chassis or vertical panels for ease of maintenanc The typical controls and instrumentation present are:

Beam Current Milliammeter
Vacuum Level Meter
Beam Focus Control
Accelerating Potential Control
Filament Current Control
Vacuum Cycle Control

All controls and meters are machine tool type of high quality and accuracy.

High Voltage Power Supply

All power supplies operating at high voltage are packaged in separate, oil-filled, self-contained modules. Filament current, beam current and high voltage are adjustable from the control panel.

(a) The main high voltage supply provides beam currents of up to 100 mA at the fixed operating voltage of 175 kV. An electronically regulated motor generator set supplies variable voltage AC into the supply and allows independent control of output DC voltage from 0 to 230 kV (to "clear" gun). The set value of output voltage is regulated to ± 1% by means of the high response (1/4 second) regulating system.

(b) The filament power supply delivers the required DC power on a 100% duty cycle basis. Line regulation is ± 1% for 10% line voltage variations. Ripple is less than 3%. A filament temperature relaxation circuit is incorporated to extend filament life.

3.3 (continued)

A second additional relaxation is incorporated to assure that no beam may be generated during parts transfer.

Vacuum Staging System

A vacuum staging system is incorporated into the column for maintaining the electron gun in a high vacuum ($1\text{x}10^{-4}$ Torr region) environment with line-of-sight orifices open to atmospheric pressure. The high vacuum in the electron gun section of the column is maintained by a method designed to develop a pressure strata varying from atmosphere to a vacuum level of $1\text{x}10^{-4}$ Torr. The beam of electrons accelerated by the high voltage potential passes through the regions of varying pressure and into the atmosphere while retaining sufficient power density for effective electron beam welding.

Vacuum Pumping System

The vacuum pumping system functions to provide the proper operating pressure level for the electron gun. The system consists of a 2200 L/S oil diffusion pump in series with two 600 cfm blower-150 cfm mechanical pump combination. The diffusion pump provides the high vacuum in the electron gun region. The vacuum levels in the intermediate stages are provided by plumbing to the above pumps at discrete points. The mechanical pumps are mounted remotely to insure isolation of the electron gun column from the vibration generated by the pump. The necessary controls to operate the vacuum equipment are located in the control station.

3.4 Utility Requirements

Electrical	- 460/480 volts, 3 phase, 60 hertz, 400 amps.
*Water	- 1.5 gpm and 45 psi. (6 gpm during Faraday cup usage)
Air	- 75 to 110 psig, clean, dry, oiled - 1/2 inch ips connection.
Drain	- 2-inch ips is required to dispose of cooling water.
Exhaust	- 3-inch vent line is required for mechanical pumps. An externally exhausted vent line is also required for dispensing of welding vapors.
Operational Gases	- Dried and filtered air. Dry Helium.

LEYBOLD-HERAEUS

The EBW 36000-60/150 Electron Beam Welding System incorporates advanced machine design and construction technology, including a new type of vacuum pumping system, automatic weld path adjustment and pallet-shuttle part load/unload.

The new system will be used to weld large rotary parts from 30 to 108 in. diameter and weighing up to 10 tons. It will join an inner hub to an outer ring with two continuous weld paths with weld depths from 2½ to 4½ inches. The new EB welding system will produce, in less than 3 hours, the same part that previously took up to one week using the submerged arc welding process.

UNIQUE FEATURES OFFER MANY PRODUCTION BENEFITS

A fixed gun high-voltage electron beam welder with a chamber size of 192" x 84" x 132", the Leybold-Heraeus EB welder was specifically designed to make circumferential and linear welds on large heavy parts. With tooling the machine weighs over 70 tons.

The electron beam gun is rated for continuous duty at 60 Kw, double the power level of many other high voltage units operating in U.S. industry. It has a dual-lens arrangement that permits broad focal length range. The gun column has an integral tilt device that allows it to be positioned to ±35 degrees from the vertical, with 1/100 of a degree accuracy.

One of the system's most important features is Real Time Seam Tracking. Periodically during actual welding, the electron beam can automatically drop to a low power level and scan ahead of the weld spot to locate the seam. The beam then returns to the weld keyhole and resumes welding. A signal is sent to the CNC which then repositions the part for any position deviation due to thermal expansion or part run-out. Real Time Seam Tracking is accomplished in milliseconds without interruption of the welding process.

The vacuum chamber is constructed from 1 inch thick stainless steel and heavily ribbed to minimize chamber distortion during operation. A Leybold-Heraeus proprietary chamber design allows for machining of the guide rails in the chamber base to precise machine tool standards without later loss of precision due to distortion from structural welds in the chamber walls.

The vacuum pumping system is the first domestic application of its kind in the electron beam welding industry. Instead of conventional diffusion pumps, Leybold-Heraeus employs a cryogenic pump system on the machine. Compared to diffusion pumps, cryogenic pumps offer advantages such as elimination of part contamination from oil back streaming, elimination of reduced pumping speed during humid periods, and reduced energy consumption.

The machine is equipped with an Allen-Bradley 7320 CNC featuring special LH Executive software. All tooling motions, including the tilting column, vacuum pump sequences, and other routine machine functions are under CNC. Welding parameters, seam tracking and data logging are performed automatically. Provision is also made for manual control of the machine through the CNC.

MODULAR TOOLING SYSTEM PROVIDES PRECISE POSITIONING

The machine's tooling consists of X-axis and rotary tables inside the chamber, and a pallet-shuttle part load/unload system outside the chamber. The pallet and workpiece are loaded onto the rotary table, which sits on the X-axis table, by a unique airglide system consisting of an external loader/transporter mounted on a run-out system. The rotary table positions 50,000 lbs. to within .01 of a degree accuracy, and .001 degree repeatability. The X-axis table positions 65,000 lbs. to within ±.001 in./ft. with a maximum accumulated error of less than .005 in. with .001 in. repeatability. Together the X-axis and rotary tables provide highly accurate positioning of the part under the vertical electron beam for making rotary welds.

A separate Y-axis table, with the same accuracies, is also supplied. It can be mounted on the X-axis table after the rotary table has been removed. This allows for making linear welds in either the X- or Y-axis direction.

When the loader/transporter is removed from the run-out system base, the X-axis table can be driven out of the chamber onto the run-out base complete with its ballscrew and drive. This unique feature enables the tooling to be operated outside the chamber for setup and servicing.

LEYBOLD-HERAEUS
EBW 36000 - 60/150 Machine Specifications

Model No.	36000 150/60
Chamber Dimension (Interior)	192 x 132 x 84 inch
Chamber Volume	36,000 Liters
Chamber Weight, Empty	40 Tons
Loaded	80 Tons

Electron Beam Gun

Accelerating Voltage	0 - 175 Kv
Beam Current	0 - 400 mA
Maximum Continuous Power Output	60 Kw
Focal Length Range	2 - 72 inch
Gun Tilt Range	± 35 degrees
Tilt Accuracy	± .01 degree

Positioning Axes

X Table Dimension	76 x 66½ inch
X Table Range	105.5 inch
Y Table Dimension	66½ x 66½ inch
Y Table Travel	35 inch
Speed Range X & Y Axes	0 - 72 ipm
Position Accuracy X & Y Axes	± .001 in./ft.
Position Repeatability X & Y Axes	± .0005 inch
X Table Load Capacity	65,000 lbs.
Y Table Load Capacity	45,000 lbs.
Parallelism Straightness and Squareness X & Y Axes	.001 in./ft.
Rotary Table Diameter	72 inch
Rotary Table Speed Range	.16 to 60 rev/hr.
Rotary Table Accuracy	± .008 degree
Rotary Table Load Capacity	50,000 lbs.
Concentricity of Table Top	.002 in. TIR
Speed Accuracy all Axes	± .1% of set pt.
"T" Slot Size	1 inch "T" bolt
Fixture Plate Diameters	76, 96, 120 inch
Fixture Plate Part Load	20,000 lbs.
Max part size (standard configuration)	31 in. Hgt. x 9 ft. dia.
Load Capacity Air Beam	42,000 lbs.

Vacuum System

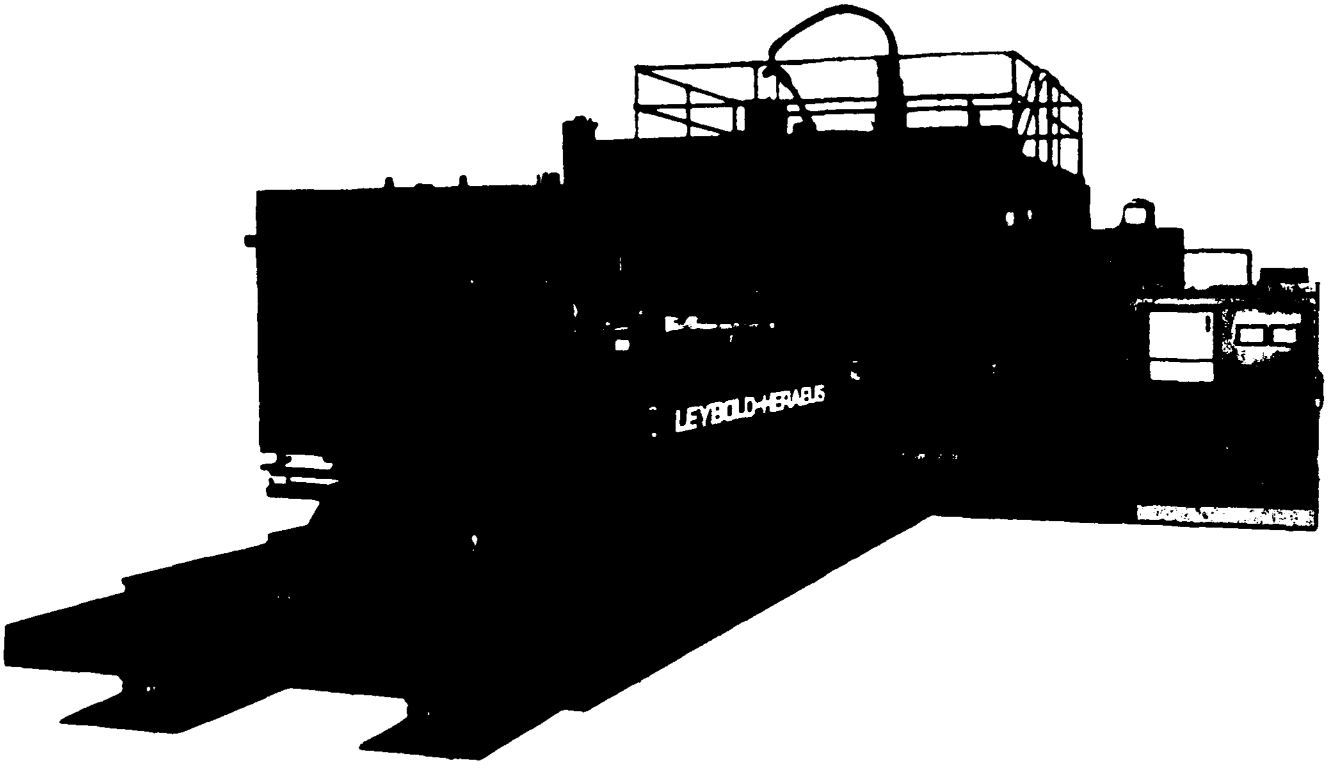
Roughing Pump Set	(2) L-H WAU 2000 (1383 cfm) (4) L-H DK200 (132 cfm)
High Vac Pumps	(2) L-H RPK 10,000 Cryogenic Pumps
Evacuation Time to 4×10^{-4} Torr	20 min.
Base Pressure	1×10^{-5} Torr
CNC Control	Allen Bradley 7300 (std.) (optional; Allen Bradley 8200R, GE 2000X CNC)
Weld Depth Penetration	0 - 12 inch (material dependent)

Electron Beam Equipment | Laser Equipment | System Engineering | LEYBOLD-HERAEUS

LEYBOLD-HERAEUS
VACUUM SYSTEMS INC.

62-210.2

Electron-Beam Welding

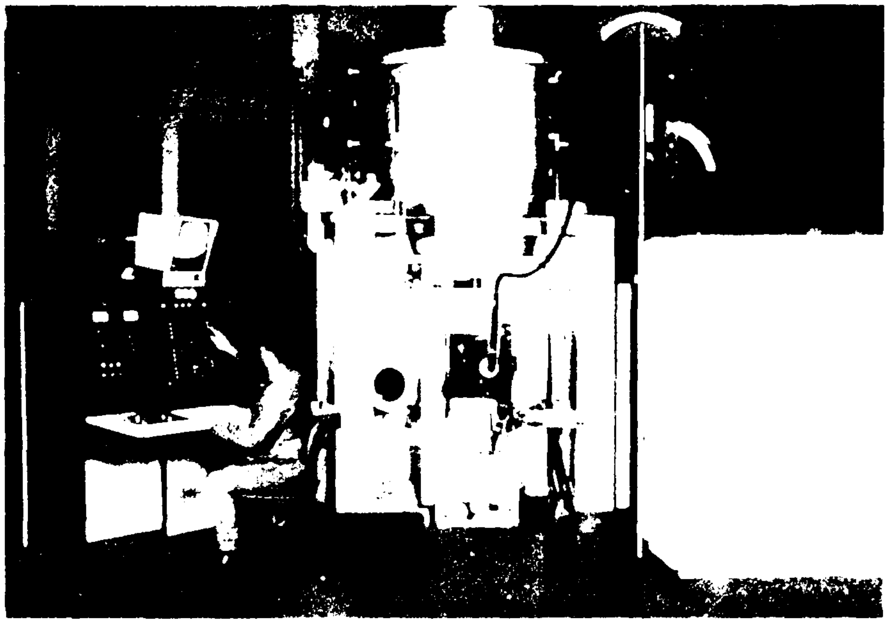


Large-Chamber Machines

Contents

For Large Workpieces- EB Large-Chamber Machines

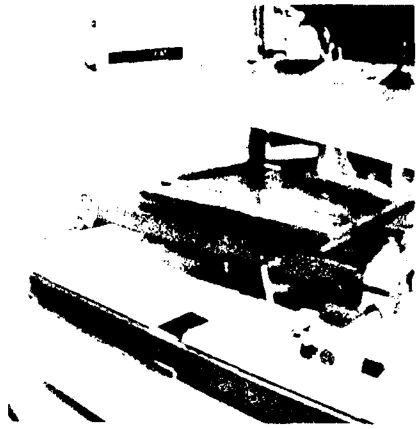
[illegible] the Machine with a Component



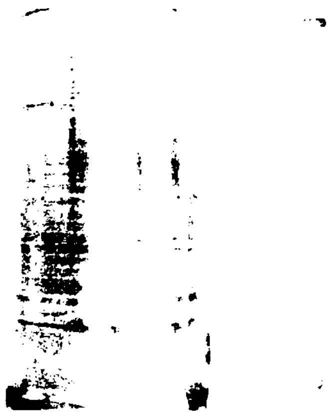
EBW [illegible] with Vertical Gun Movement CNC-Control and TV Monitoring

[illegible]

3 Examples of Various Uses



Structured Component of Europe-Rocket ARIANE

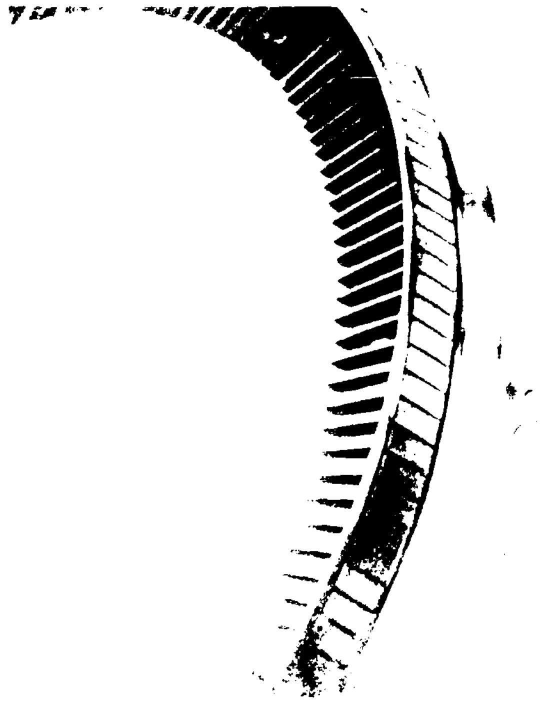


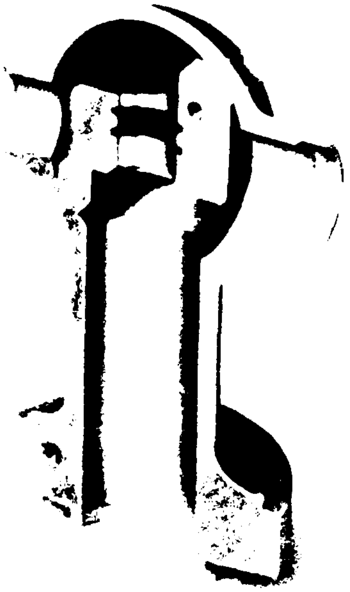
[illegible] Type Housing with P.EB Welds for SPACELAB

Aerospace

[illegible]

- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]



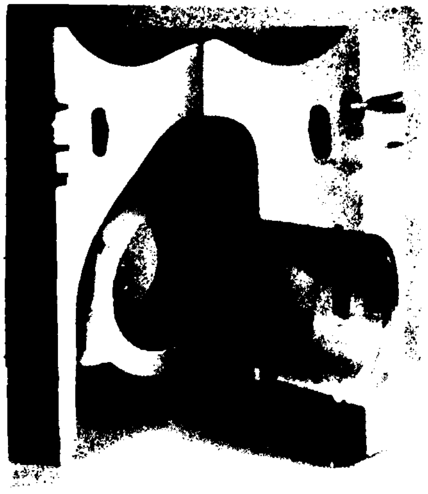


alve Body

Power Engineering

[illegible]

[illegible]



Aluminum Piston with 2 EB Welds

of electricity. These components have been operating trouble-free for many years.

EB Welding offers many advantages in conventional steam turbines also, especially the high welding speed together with the capability of deep penetration welding. In addition, preheating of the workpiece and the use of filler material can be eliminated in most instances, which greatly reduces the cost of the operation compared with conventional processes. LEYBOLD-HERAEUS EB Welding Machines offer a production-wise and most cost-effective alternative to this sector of the industry.

General Manufacturing

[illegible]

- Automation
- [illegible]
- [illegible]

EB technology is increasingly being employed in many fields, both because of the growing use of higher grade materials and the resulting minimal distortion, which usually eliminates the need for post-weld machining. There are already materials that cannot be welded satisfactorily or at all by conventional techniques. With our EB System, however, you will have no difficulty welding most of these materials.

We could continue endlessly [illegible] of EB-welded products, especially if we were to include automotive parts. Even though the high production rates required can be attained only by automatic production machines tailored to the specific workpiece and [illegible] the general [illegible] Computer Machines [illegible]

[illegible] [redacted]

System Design & Operating Sequence

[illegible]

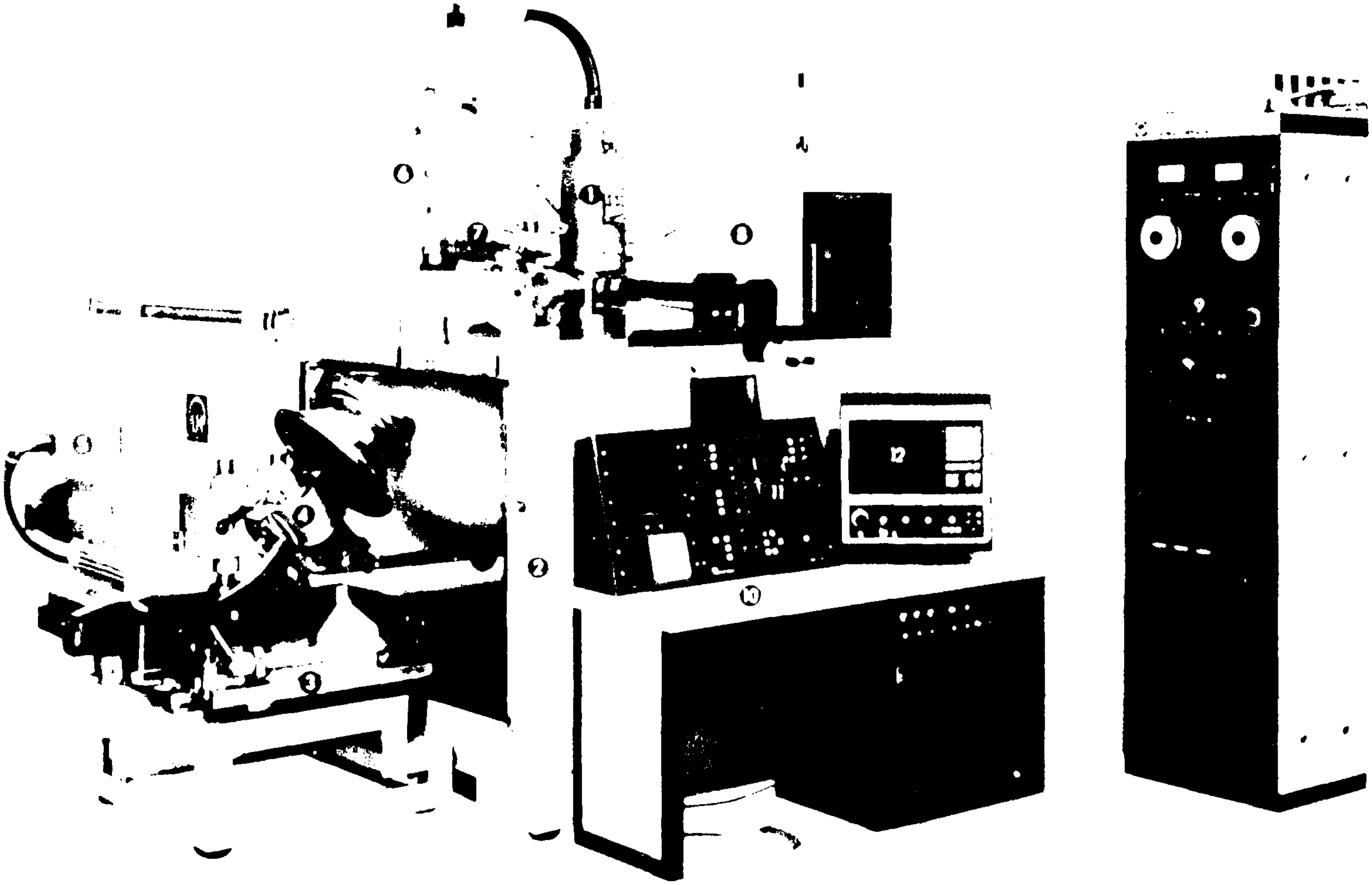
A. Extensive Standardization [illegible]

[illegible]

B. Maximum Versatility [illegible]

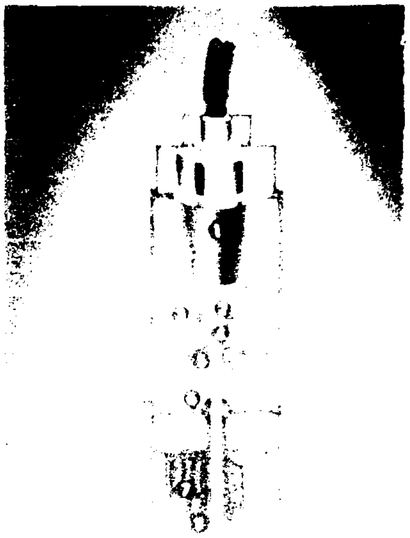
[illegible] EBW [illegible]
EBW

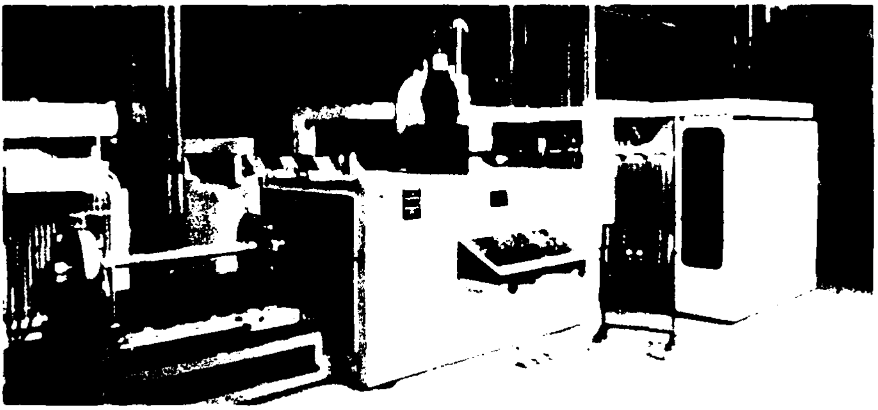
[illegible]



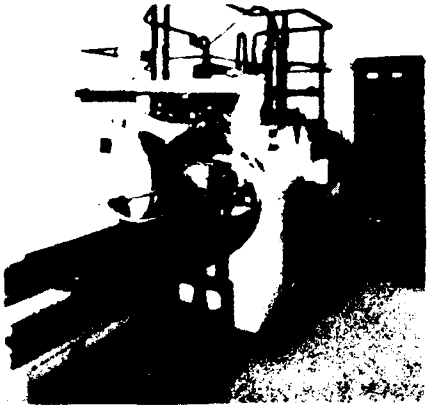
① EB Gun (15 kW 60 kV)
② Work Chamber (1000 liters)
③ Runout Platform
④ Workpiece Manipulator
⑤ Vacuum Pumping System for the Work Chamber
⑥ High-Vacuum Valve
⑦ Vacuum Pumping System for the EB Gun
⑧ High-Voltage and Auxiliary Power Supplies for the EB Gun
⑨ Control Cabinet
⑩ Operating Desk
⑪ Operating Panel
⑫ CNC

Standard Assemblies





EBW 4001/7.5-150 with 8-fold Revolving Rotary System



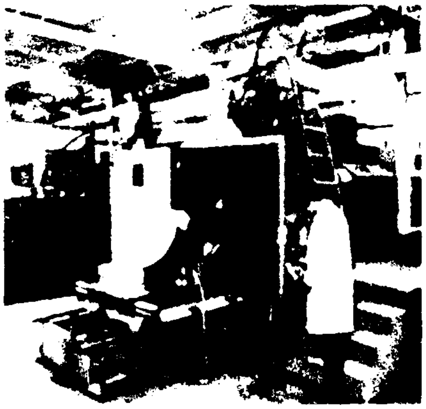
EBW 1500 S/7.5-60 with Cylindrical Work Chamber

The Work Chamber

Workpiece size, clamping devices and workpiece manipulator [illegible] determine the size of the work chamber. Best suited for general purpose use are chambers with rectangular cross section and differing lengths. The incremental graduation of standard chamber sizes generally satisfy most customer requirements. However, the product line also [illegible] special sizes tailored to specific problems.

[illegible] the work chamber is a cuboid [illegible] one end by a [illegible] which the EB gun is mounted [illegible] middle of the chamber [illegible]

The [illegible] quality of the [illegible] used in the high-vacuum chambers are compatible with LEYBOLD-HERAEUS reputation as [illegible] leader in vacuum technology and vacuum process engineering.

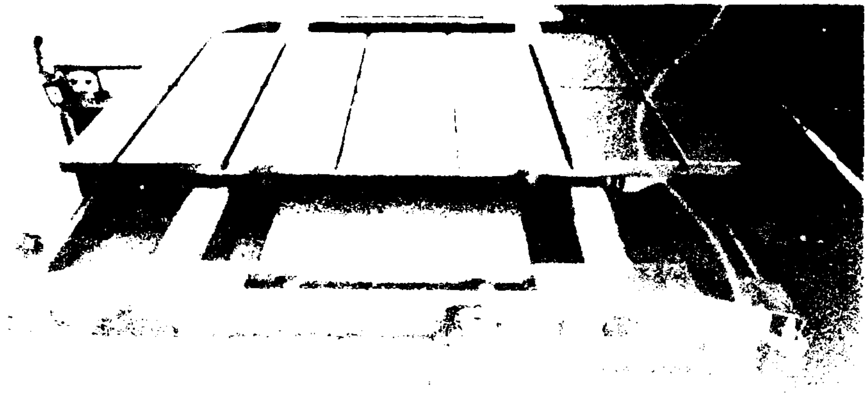


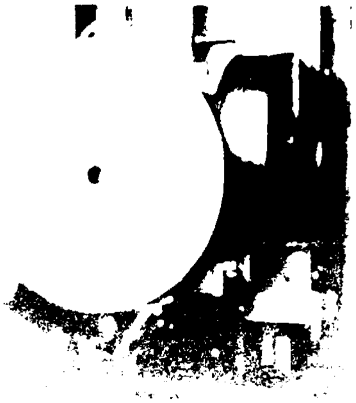
EBW 10 000 / 15-150 with 4-Axis-Manipulator

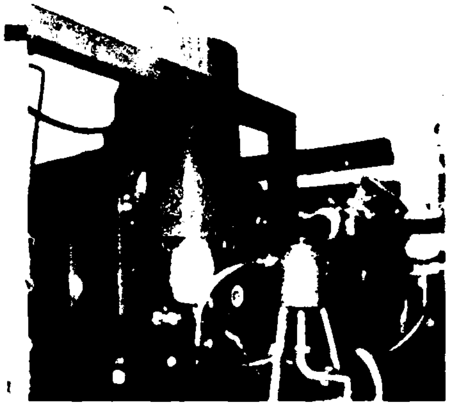
Runout Platform

For loading and unloading, the workpiece manipulator is conveyed out of the work chamber onto the runout platform. This is especially necessary when welding large heavy workpieces with commensurately large clamping devices.

Standard Assemblies







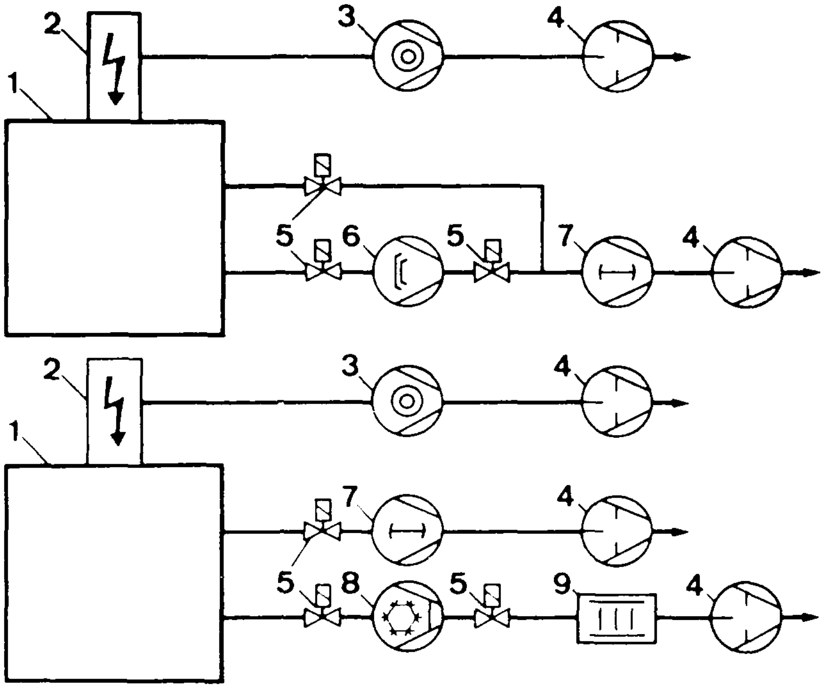
Cryo Pumping System

Vacuum Pumping Systems

LEYBOLD-HERAEUS Welding Machines generally have two separate pumping units – one for the work chamber and one for the gun column. This plus a flow limiting aperture makes it possible to keep the beam generation zone continuously under high vacuum (10^{-4} mbar) regardless of the pressure in the work chamber, an essential condition for producing and maintaining the electron beam.

Chamber Pumping System

The desired operating vacuum and the maximum pumpdown time determine the design and size of the work chamber's pumping system. We distinguish here between medium vacuum (10 [illegible] mbar) and high-vacuum (10 [illegible] mbar) pumping systems. The former consist of a combination of Roots pumps with rotary-vane and/or rotary piston pumps. But if high vacuum is to be attained, then an oil diffusion pump is also required.



1 Chamber
2 EB Gun
3 Turbomolecular Pumps
4 Roughing Pumps
5 Valves
6 Oil Diffusion Pump
7 Roots Pumps
8 Cryo Pump
9 Absorption Trap

Several Versions of a High-Vacuum Pumping System

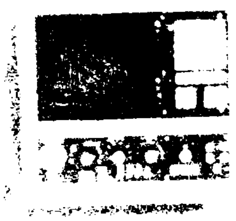
As an alternative to the diffusion pump, a cryo pumping system can be supplied. This system is recommended where an absolutely oil-free vacuum is needed, where extremely short pumping times are required for large chambers, or for many repeatable pumping times in high humidity environments.

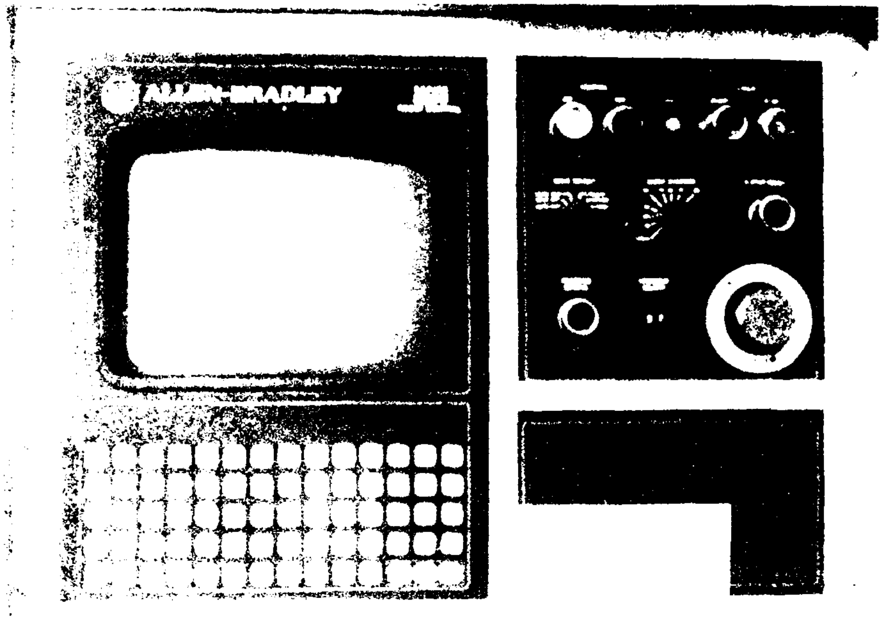
Gun Pumping System

In LEYBOLD-HERAEUS guns, the pumping system used to evacuate the beam-generator zone down to high vacuum normally consists of a diffusion pump followed by a rotary-vane pump. Alternatively a turbomolecular pump can be supplied instead of the diffusion pump. This provides for an oil-free vacuum and greater gun operating safety.

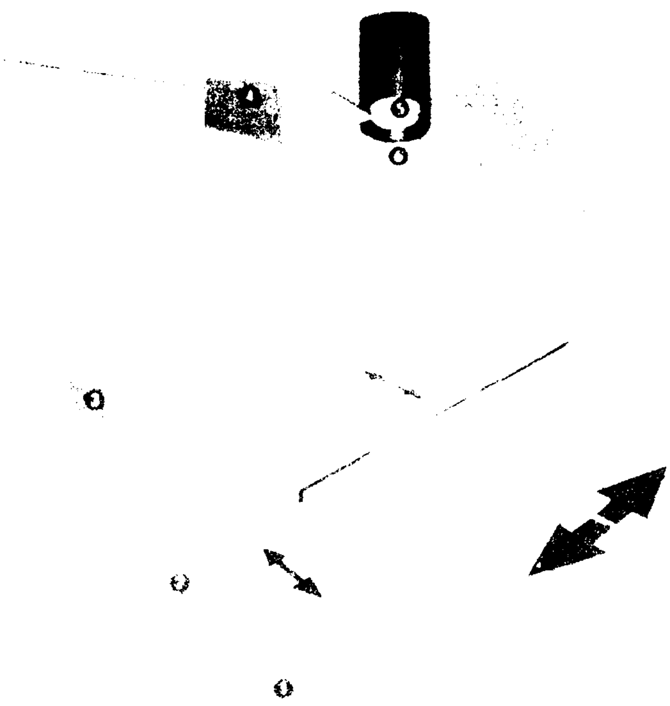
Standard Assemblies

Additional Features



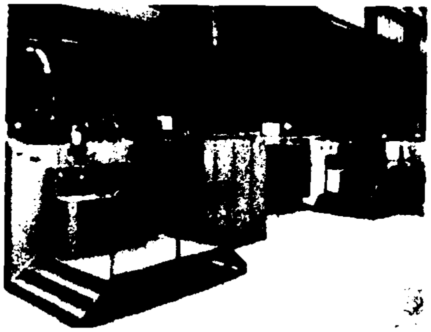


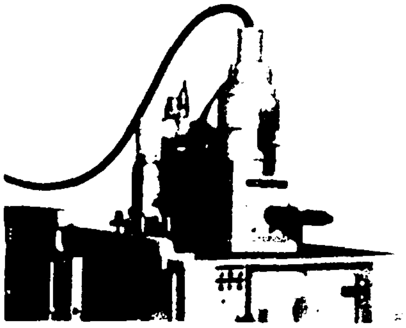
Additional Features



[illegible] Measuring [illegible]

Service





Technical Data: Standard Large-Chamber Machines [1])

Characteristics	Unit	Type of Machine EBW 700	EBW 1500	EBW 4000	EBW 6000	EBW 10000	EBW 20000
Chamber volume, approx.		700	1500	4000	[illegible]	10000	20000
Chamber							
Length	[illegible]	[illegible]	1400	2000	2200	2600	[illegible]
Width)	[illegible]	750	900	1270	1500	1700	2200
Height	[illegible]	900	1200 (900)	1700 (1300)	1900 (1600)	2400 (2000)	2800 (2400)
Height above table)	[illegible]	690	900 (600)	1300 (1000)	1500 (1200)	1700 (1300)	2200 (1800)
Coordinate table							
Length	[illegible]	550	700	1000	1100	1250	1600
Width	[illegible]	350	450	600	750	820	1050
Admissible load	[illegible]	[illegible]	500	1000	1500	2000	[illegible]
Travelling distance of table							
in x-direction	[illegible]	[illegible]	[illegible]	900	1000	[illegible]	[illegible]
in y-direction	[illegible]	[illegible]	[illegible]	400	500	820	[illegible]
Second gun position							
possible	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Workpiece							
Diameter, max)	[illegible]	[illegible]	[illegible]	[illegible]	1400 [illegible]	1600 (1200)	2100 (1700)
Length		[illegible]					

LEYBOLD-HERAEUS
VACUUM SYSTEMS INC
120 Post Road
Enfield, CT 0608[illegible]
(203) 741-22[illegible]
Telex 955 344
Fax (203) 745-[illegible]

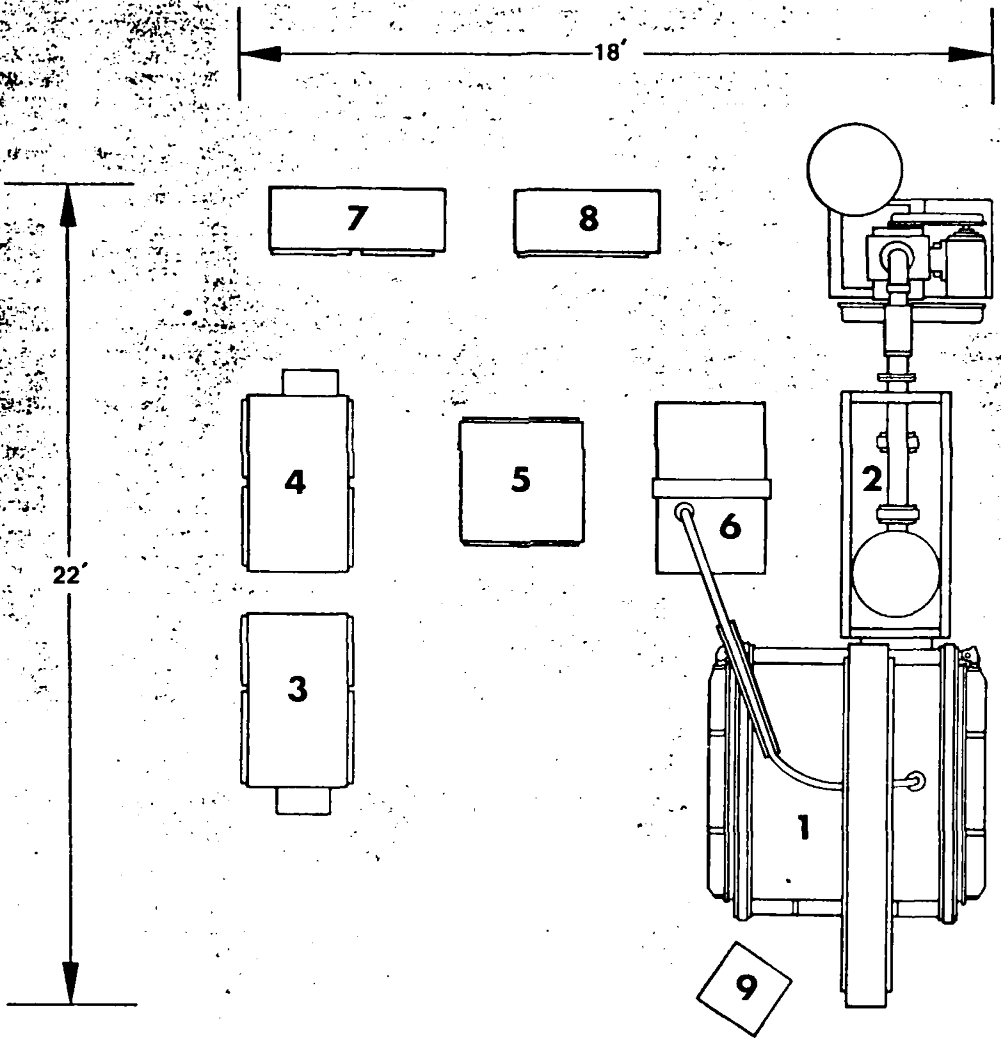
APPENDIX B

MANUFACTURER'S LITERATURE
FURNISHED BY

SCIAKY BROS., INC.

The basic Mark VII EB welding system.

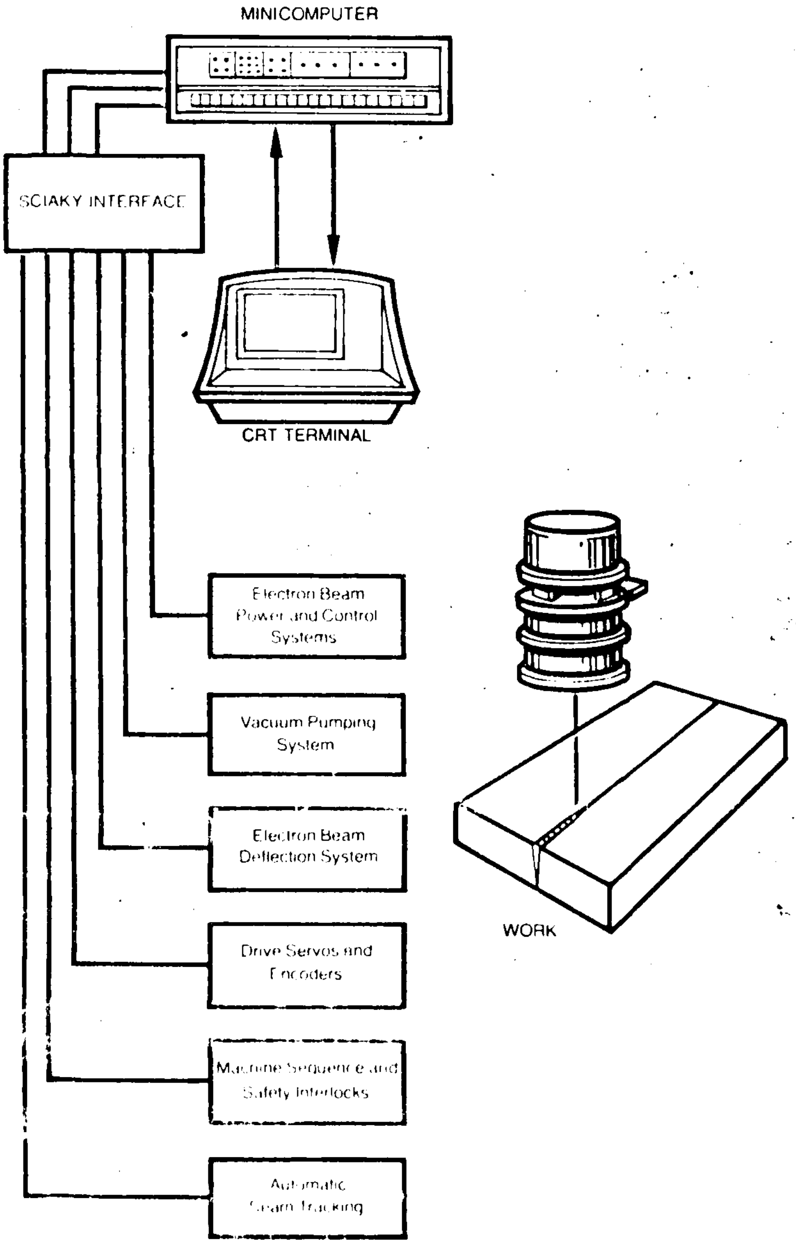
Diagram shows typical floor plan layout of hard vacuum welding facility with VX-68x68x78 welding chamber (other chamber sizes available as standard or sized to application).



The Sciaky Mark VII system consists of the following equipment:

- 1. Vacuum Chamber and Manipulating Mechanisms
- 2. Vacuum Pumping System
- 3. Mark VII Computer Control Cabinet
- 4. Servo Cabinet
- 5. AVR (Automatic Voltage Regulation) Cabinet
- 6. High Voltage Power Supply
- 7. Power Distribution Cabinet
- 8. Pumping Control Cabinet
- 9. Operator Console

The heart of the Sciaky EB system...Mark VII computer control.



The introduction of the Mark VII computer control into the Sciaky welding system takes the guesswork out of process control by the use of an operating system for complete machine and process control, programming and extensive monitoring of process variables.

Mark VII is a totally integrated system that includes solid state automatic voltage regulator (AVR), solid state filament control, modern servo drives and vacuum pumping monitoring all under the control of a powerful minicomputer through its interface.

Mark VII system precisely controls all aspects of beam power, focus, travel, and positioning [illegible] operation including [illegible] of all [illegible] functions

B. ELEMENTS OF MACHINE

(a) Introduction

This Title briefly describes the main elements, or systems of your electon beam welder. These elements are as follows: vacuum chamber and pumping system, motion, and beam power. The pumping system is an independent control system; motion and beam power are controlled through a computer.

This computer control system allows you to control the machine completely from the program and also allows manual control by the operator. For an illustration showing the control arrangement of this welder, see the block diagram of Fig. 2.1, *Typical Mark VII Computer Controlled VX Welder.*

(b) Vacuum Chamber & Pumping System

The chamber is an enclosure for the gun and workpiece so that they can be pumped down to the weld level of vacuum. This chamber is made rigid with enough strength so that when it is pumped down, deflection caused by pressure at the exterior is at a minimum. Additionally, the walls are thick enough and design features have been provided so that X-rays generated during the weld are kept to a safe level. Doors and windows are provided for easy access and viewing.

The chamber for your VX, or hard vacuum welder is pumped down by a vacuum system. This system contains three pumps; holding, roughing-backing, and diffusion. The first two pumps are mechanical units. Gasses in these units are compressed and pumped away by pistons or vanes. The diffusion pump uses molecules from a heated pool of specially refined oil to pump away gasses.

The pumping system requires air to operate the valves associated with it and water to cool the pumps. Before operating this system, make sure that the power, air, and cooling water are on.

When the system is first turned on, the oil in the diffusion pump is heated to the required operating temperature and the roughing-backing pump is used to evacuate the diffusion pump. The oil heating time is controlled through a delay timer. Once this delay times out, the roughing-backing pump is valved off from the diffusion pump and this system is said to be in a standby, or ready-to-operate condition.

When the chamber is closed and the system is in standby, the chamber can be evacuated. When the pumpdown starts, the chamber is evacuated by the roughing-backing pump.

Pumpdown of the chamber is monitored by a thermocouple gauge, which has a switchover setting. When this switchover setting is reached, the roughing-backing pump is switched to back the diffusion pump and the diffusion pump is used to evacuate the chamber. The roughing backing pump backs the diffusion pump throughout the weld operation.

The switching in this system is controlled through limits shown at your Vacuum Monitor display. These limits are identified as DL, delay limit; LL, low limit; and HL, high limit. When you are pumping down from atmospheric pressure, you will be at Vacuum Ready when high limit is reached. After reaching high limit, outgassing may cause vacuum level to drop. If vacuum goes below low limit, Vacuum Ready will drop. When Operation Program is being run, vacuum level is allowed to go down to Delay Level before Vacuum Ready drops.

The holding pump is used to hold vacuum on the diffusion pump while the chamber is roughing down and while the system is in Standby.

(c) Motion, Mechanical

The chamber is equipped with motorized carriages for the gun and workpiece. This arrangement allows the gun and/or work to be moved to any location in the chamber providing for a mobile system even though the gun and work are enclosed.

Three axes of motion are typically provided for a VX chamber as follows: X, Y and Z. X and Y are used to drive either the gun or the work carriage, depending on the arrangement of your welder. If X drives the work, Y drives the gun etc. Axes and drive directions are specified facing the pumping port in the chamber. X-axes drives a carriage laterally, left and right; Y-axes drives the associated carriage in and out. Z-axis drives the gun carriage up and down.

In addition to the X, Y and Z-axes, optional drives may also be supplied. Usually these optional drives are mounted on top of the work carriage.

— Reference Positions

Your reference to determine direction of movement is looking into the chamber facing the inlet ports of the pumping system. The system also has two reference positions from which all moves are programmed; home and zero set. See Fig. 2.2 for an illustration showing axes of motion, direction of movement, and home positions provided for your welder.

Home is a 0.000 absolute reference position. This position is established through the location of a limit switch and an encoder. Zero Set is a position electrically marked from which all moves will be made and can be set at any position desired. If Zero Set is not activated, this position is taken to be at home.

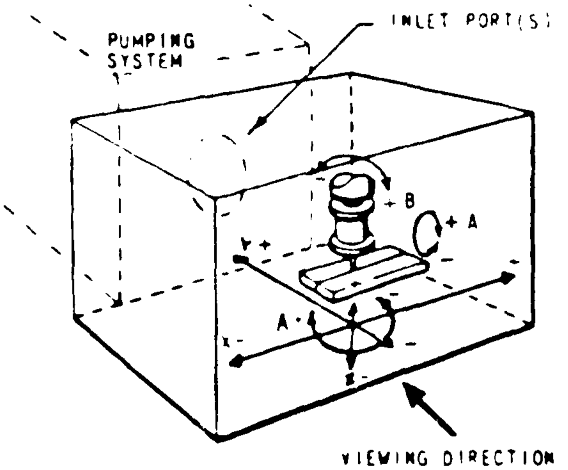


Fig. 2.2 Illustration, Axes Motions

AXES HOME POSITIONS

X = Full Left
Y = Full In, Toward Pumps
Z = Full Up

AXES DIRECTIONS

X+ = Away From Home
X- = Toward Home
Y+ = Toward Home
Y- = Away From Home
Z+ = Up, Toward Home
Z- = Down, Away From Home
A+ = CW
A- = CCW

— Programmed Modes & Control

Axes moves are programmed in two modes; absolute and incremental. These modes are identified with G codes, 90 for absolute, and G91 for incremental.

Absolute allows you to go to a position specified using Home or Zero Set as reference. Incremental allows you to make a step move of a specified distance using your present position as reference.

The axes can be controlled by the operator through remote controls and through a program. Direct operator control is usually used for jogging. In this operation the operator selects the axes to be run, travel direction, and jog velocity. When the system is under full program control, the operator only enables the axes to be run. In this latter operation, axes selection, direction of travel, and velocity are controlled through the program.

(d) Beam Power

This paragraph describes the factors that affect the beam power applied to the workpiece. Beam power is controlled through two parameters, accelerating voltage and beam current. Under certain conditions, a third parameter, filament voltage will also affect current.

— Gun, General Description

The following is a brief description of how the gun operates. This information will give you a better understanding of what happens when you change the beam power operating parameters. For a more detailed description of the gun, see SECTION 6.

When the temperature of the filament is increased, electrons are liberated and form into a cloud in front of this device. A high voltage between the filament and the anode accelerates these electrons and pulls them into a beam.

As the electrons leave the filament, they pass through a hole in the cathode. The cathode helps form them into a beam. This element can also be used to restrict the flow of electrons to control beam current. When used in this way, the cathode acts simular to a control grid in a conventional vacuum tube.

Electrons are not collected at the anode, but pass through a hole in this device. As they pass through this hole, they converge, reach a narrow crossover point, and then again diverge.

After diverging, the electron beam passes through the focus coil where it is again focused. Focus is set so that the beam forms a spot of some desired size at the work.

— Filament

Within certain limits, filament voltage determines the supply of free electrons, or current that is available for the beam. However, this is not an arbitrary setting. Filament voltage is a critical setting and must be correctly set for the system to operate properly. The following is a brief description of how the system operates and of setting the filament voltage.

With the accelerating voltage held constant and filament voltage at a low level, as filament voltage is increased, the beam current also increases. This proportional increase continues up to a given level. The gun is referred to as operating in a temperature limited region when a proportional filament current/voltage increase is noted. This region is usually not used for welding, but at the low end of the range, about 3 mA, may be used for scanning a part.

As the filament voltage level continues to be increased, a saturation point is reached where the beam current no longer follows the increase in filament voltage. The beam current increase slows down and then almost stops following filament voltage. This saturation point changes with the accelerating voltage level.

The correct filament operating level for most welds is slightly above the point where the apparent increase in beam current stops. The procedure of making this adjustment is referred to as "kneeing the filament." At this time, the filament is said to be operating in a space charge region. Since the saturation point changes with the kV operating level, knee the filament each time the kV accelerating level is changed. We recommend that you knee the filament with the Bias OFF.

— Beam Current

Beam current can be controlled by applying a bias voltage to the cathode which allows it to act as a control electrode. This bias is used to limit the number of electrons that are allowed to enter into the beam which, in turn, limits the beam current. The desired level of current is set with the Beam Current parameter. This current can range from the maximum rating of your system to some minimum value as indicated in the following description:

Maximum beam current is determined by the kV operating level, how well filament was set at knee, and range of components used in the gun. To make maximum as high as possible for your kV operating level, switch Bias OFF when kneeing the filament. If you knee the filament at 60 kV (Bias OFF), using 250 mA components, maximum beam current will be slightly above 250 mA.

Minimum beam current is determined by all the factors indicated in maximum beam current, plus bias set with the Beam Current parameter.

If the current is not cut-off at minimum, this level can be lowered by lowering the kV kneeing level of the filament. If the knee was set at 60 kV using 250 mA components, you should be able to control the current from 250 mA to cut-off. If the knee was set at 60 kV using 500 mA components, you can expect 75 mA, or more at minimum. However, you should be able to obtain cut-off by kneeing the filament at 30 kV in this range. When kneeing at 60 kV and 700 mA (500 mA components and spacer), you can expect 100 mA or more at minimum.

— Accelerating Voltage

Accelerating Voltage and Beam Current are the two power control parameters for the weld. Accelerating Voltage is usually kept at a constant level and Beam Current is varied to control weld power. The kV level is set so that the beam current range is wide enough for good power control. To assure that this range is wide enough, the kV level used when kneeing out the filament, should produce a slightly higher level of beam current than required for the weld. Note that the kV level used when kneeing the filament should be the kV Accelerating Voltage for the weld.

— Focus

While Focus is not a direct beam power control, it must be considered in this category as it changes the effects of beam power. Focus changes the spot size, or diameter of the beam, and the distance from the gun where it is most concentrated.

If the associated beam power parameters are held constant, as the spot size is made smaller, the power density, or heat concentration of the beam is increased which increases penetration. If the spot size is made larger under these conditions, penetration decreases.

Focus may be adjusted so that the point of concentration is above, below, or at the surface of the work. For each gun-to-work distance, a single focal point exists where the beam is at its smallest diameter.

(e) Beam Deflection

Beam Deflection provides a convenient means of moving the beam over short distances. This function deflects the beam magnetically off it's normal path through two coils positioned at right angles to each other. These coils are enclosed in a housing attached to the bottom of the focus coil, gun pointing down. See Fig. 2.3 for an illustration of these coils and the deflection action.

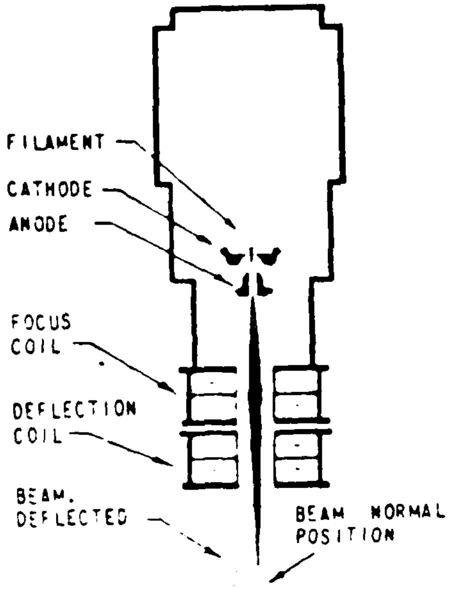
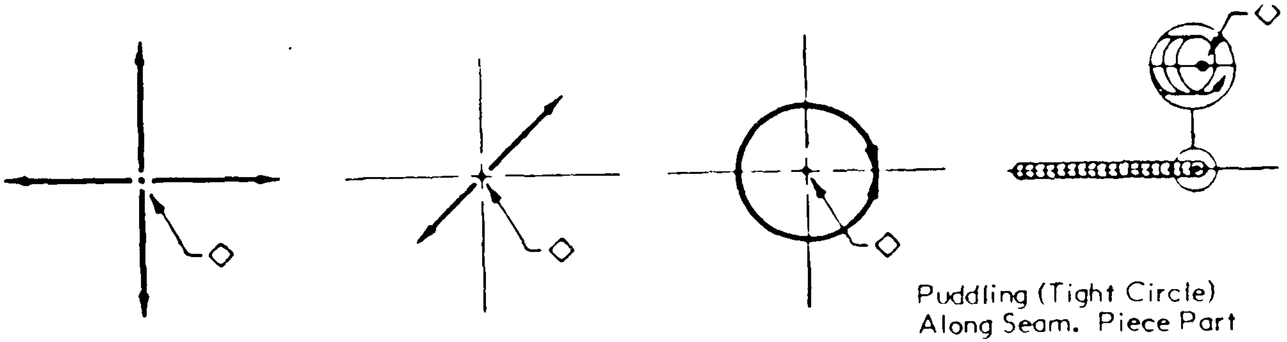


Fig. 2.3, Illustration,
Beam Deflection

The two coils provide two axes of motion defined as X and Y. Each coil can deflect the beam in the + and - direction. This arrangement can be used to move the beam in all four quadrants of X and Y.

The moves obtained from Beam deflection can be used for various purposes. Some of these purposes are as follows: offsetting beam, seam tracking, scanning, welding with gun stationary, and welding with a combination of gun, work, and deflection moves.

Beam Deflection is not restricted to simple moves. Complex moves are made by applying signals simultaneously to both coils. These signals can be used to produce the following: linear vector moves in any quadrant, circles, squares, sine, or almost any type of motion. The type of motion obtained depends on how the deflection axes are programmed. The following illustration shows some of these moves and uses.



Basic Moves

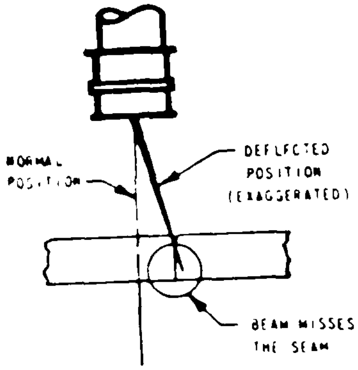
Linear Vector

Circle

Puddling (Tight Circle) Along Seam. Piece Part Moved By Axes Drive

◇ Denotes normal position of Beam (Not Deflected)

Note that as you deflect the beam, it is moved off it's normal position at some angle. The distance that the beam moves varies directly with the gun-to-work distance. For example: a move that deflects the beam 1/2" at 3" gunto-work provides 1" deflection at 6" gun-to-work. Also, note that as you increase deflection, you increase the angle of the beam. In some cases, this angle could cause problems. For example, if you aim the beam at a seam when welding, you could be cutting the seam at an angle. This angle could provide only limited penetration of the seam as shown in the following illustration.



Beam deflection is usually measured in degrees. A standard coil provides 7° deflection at maximum. At 6" gun-to-work, 7° should deflect the beam 0.737". Since the characteristics of coils may vary slightly, check under actual operating conditions. Note that special purpose coils may be ordered within the limit of your system.

TABLE OF CONTENTS

SECTION 3, OPERATOR CONTROLS

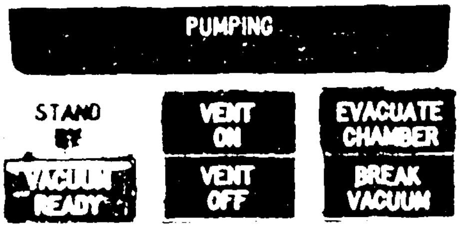
SECTION 3

OPERATOR CONTROLS

A. PUMPING SYSTEM CONTROLS

(a) Pumping Controls, Console

These controls are used to control the pumpdown, venting, and show status of the pumping system.



(1) STANDBY/VACUUM READY
Indicators lit to show following states of pumping system:
— STANDBY; system warmed up and ready for pumpdown to weld level.
— VACUUM READY; chamber pumped down, ready to weld.

(2) VENT ON/VENT OFF
Push button to control vent valve. Press VENT OFF to keep valve closed. VENT ON allows vent to be switched through control system.

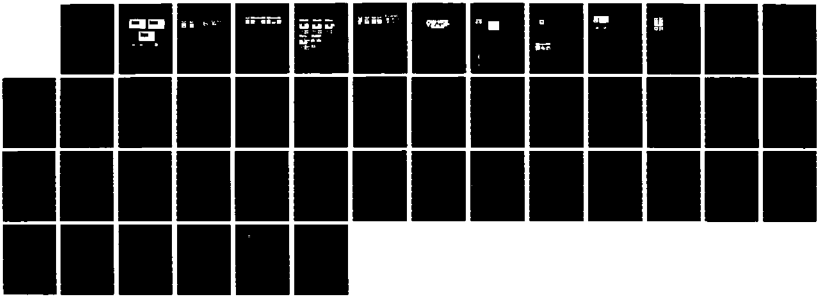
(3) EVACUATE CHAMBER/BREAK VACUUM
Pumping control push buttons. Press EVACUATE CHAMBER when system is in STANDBY condition to begin pumpdown to weld level. Press BREAK VACUUM to valve off pumping system from chambers. At this point, press VENT ON to admit air into chamber when it is pumped down

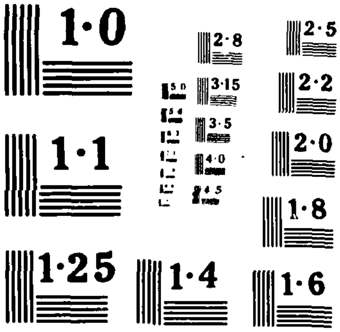
CAUTION

To turn off pumping system in case of an emergency, turn OFF power using disconnect at pumping control cabinet.

AD-A170 149 ASSESSMENT OF ELECTRON BEAM WELDING IN SHIPYARD CONSTRUCTION(U) AMERICAN WELDING INST LOUISVILLE TN J C DANKO DEC 85 AWI-CR-86-002 N884RAC45137 3/3

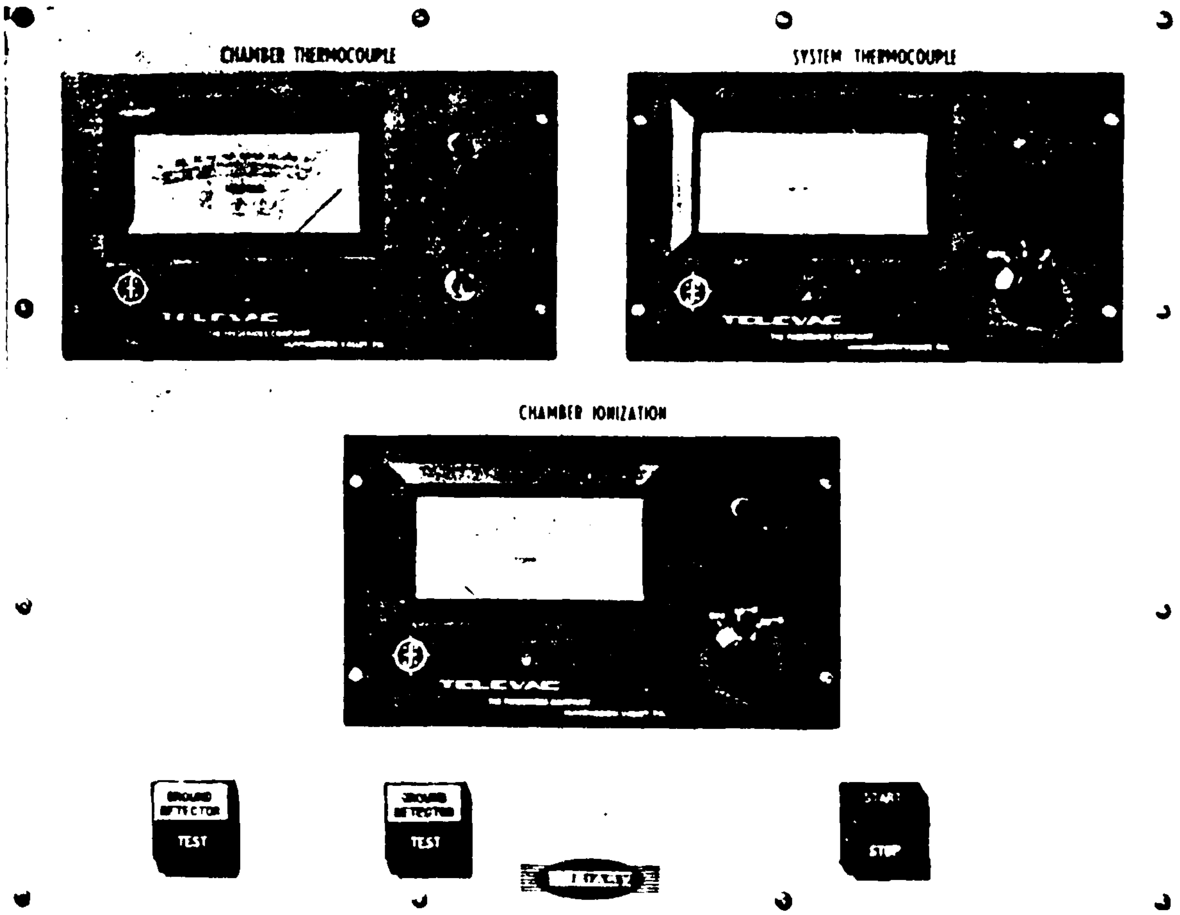
UNCLASSIFIED F/G 13/8 NL




1·0
2·8
2·5
3·15
2·2
5·0
3·5
1·1
4·0
2·0
4·5
1·8
1·25
1·4
1·6

(b) Pumping Controls, Cabinet

The controls of this panel are used to turn the pumping system on and off, show the vacuum level at various points in the system, and to control the switching point from low to high vacuum.



(1) START/SYSTEM ON/STOP
Pumping system control pushbuttons and indicator provide following use:
- START; press to begin warm up cycle after air, water, and power are on.
- SYSTEM ON; indicator lit when pumping system is on.
- STOP; press to begin auto cycle to shut down pumping system. Full shut-down occurs after diffusion pump cools down.

NOTE

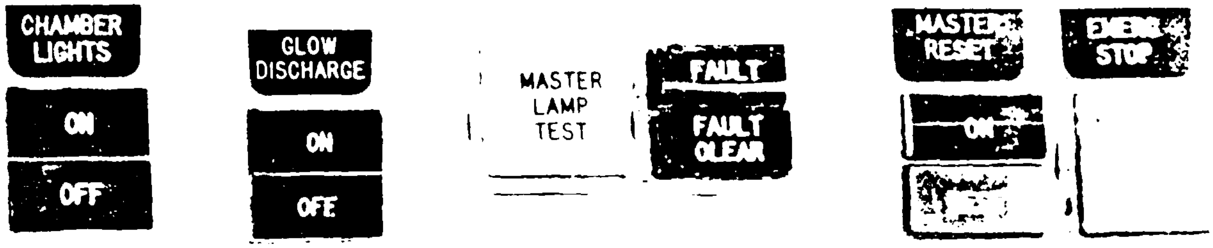
Pumping system will be automatically switched to stop if water flow and/or air pressure is low.

(2) CHAMBER THERMOCOUPLE
Gauge shows chamber vacuum in lower range (higher pressure) and controls switchover from rough-to-high vacuum pumping. Switchover is factory set from 80 to 100 microns. Turn gauge ON/OFF with switch at front panel. Red indicator is lit when gauge is on.

B. WELD SYSTEM CONTROLS, MAIN CONSOLE

(a) Initial Set-Up Controls

This group of main console controls is used during set-up and for Emergency and fault conditions.



(1) MASTER RESET, ON/RESET
Reset push button and indicator for control system.
— ON; indicator lit when system is enabled.
— RESET; press to enable motion and beam power control systems.

(2) EMERGENCY STOP
Press to immediately interrupt and disable motion and beam power control systems.

(3) GLOW DISCHARGE, ON/OFF
Push button controls for Glow Discharge system. Press On to select Glow Discharge program activated. Press OFF for regular operation of machine and to disable Glow Discharge operation. See SECTION 5., Title D., for Glow Discharge procedures.

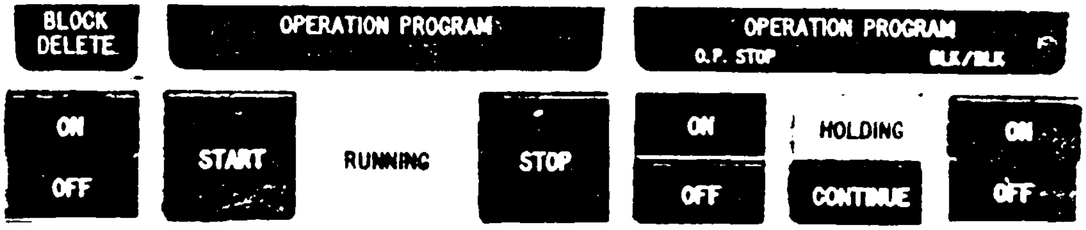
(4) FAULT/FAULT CLEAR
Indicator for errors detected in part program at monitors and push button to clear.
— FAULT; error band status indicator. Lamp Off, conditions normal: lamp flashing, narrow band exceeded; lamp stays on, wide band exceeded.
— FAULT CLEAR; press to clear fault.

(5) MASTER LAMP TEST
Push button to check condition of lamps. Press to light all lamps.

(6) CHAMBER LIGHTS, ON/OFF
Power control push buttons for lights in chamber, press to turn on or off.

(b) Operation Program

This group of controls is used to control the running of the Operation Program and to select the run mode of this program.



(1) OPERATION PROGRAM, START/STOP
Push button switches to control active program, press to start or stop.

(2) OPERATION PROGRAM, RUNNING
Indicator lit when program is being run.

(3) BLK/BLK, ON/OFF
Program mode selector push buttons. Press ON to run block-by-block; program will hold after each block. May be selected at any time, including after program starts. Press OFF to cancel block-by-block operation.

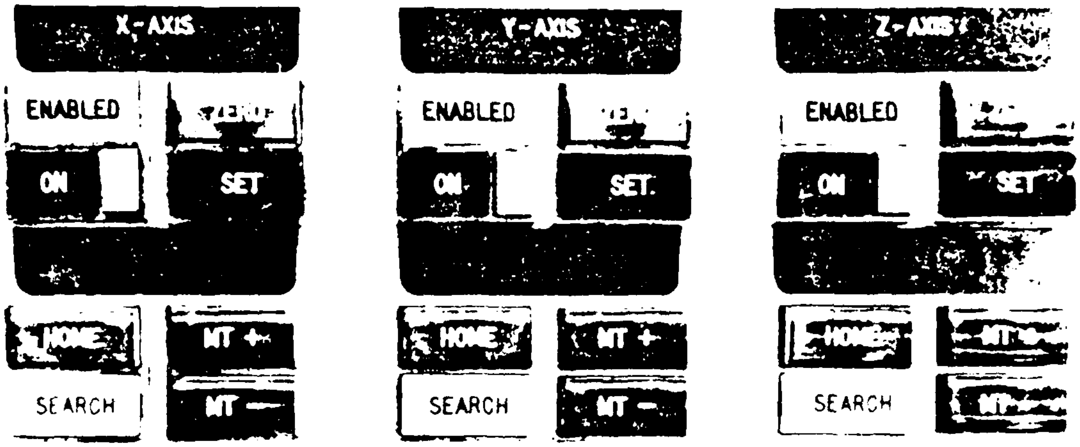
(4) OP STOP, ON/OFF
M1 code recognition selector push buttons. Press ON to stop program after each M1 code is read. Press OFF to bypass optional stop. May be selected at any time, including after program starts.

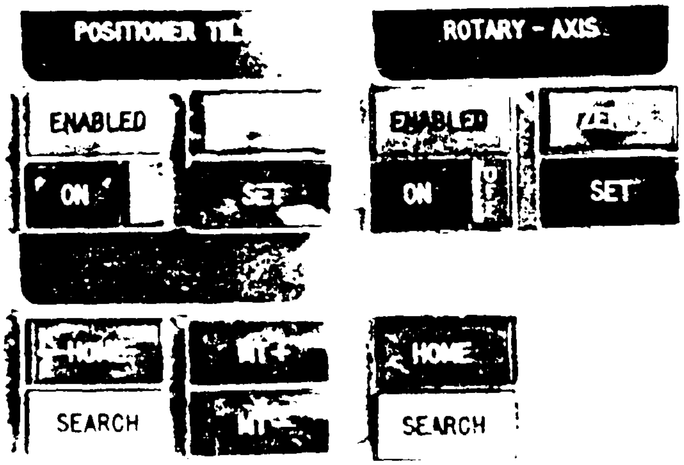
(5) CONTINUE/HOLDING
CONTINUE push button and HOLDING indicator.
Press CONTINUE to resume operation after any hold. HOLDING indicator is lit during a program HOLD.

(6) BLOCK DELETE, ON/OFF
Push button selectors to allow programmed information to be bypassed. Press OFF to run regular program. Press ON to delete all information to right of a "/" reference, program continues running. Select before starting to run Operation Program. If selected when program is being run, will be ignored until program is completed.

(c) Motion Controls

These controls are used to enable, indicate the status, and to operate the axes drives. A similar group of controls is used at each drive. A single description has been provided for each control since the use of like titled controls in each group is similar. See Title D., Par (c), for associated controls used mainly for jogging, and Fig. 2.2 for an illustration showing travel driection of each axes.





(1) ON/OFF
Drive control push buttons. Press ON to enable and OFF to turn drive off.

(2) ENABLED
Indicator lit (steady on) when drive is enabled and conditions are normal. Indicator flashing means problem in drive system, attempt to clear as indicated in SECTION 5, Title A., Par (b).

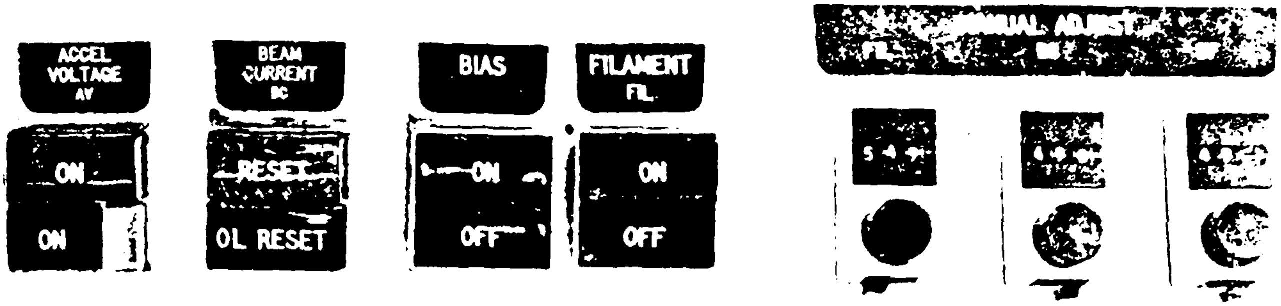
(3) SEARCH & HOME
SEARCH push button and Home indicator. Press SEARCH to run drive to home positon. Indicator flashes during home search and stays lit in home position.

(4) SET & ZERO
Zero set position push button and indicator. Press SET to mark reference point from which all moves will be made, rather than from home. ZERO indicator is lit in zero set position. Axes must have been homed before Zero Set is allowed.

(5) MT+ & MT-
Normally off. Indicator flashing shows maximum travel limits exceeded and direction Travel was exceeded.

(d) Weld Parameter Controls

This group of controls is used to control the beam power and focus.



(1) ACCEL VOLTAGE, ON/OFF & ON
Accelerating voltage (AV) control push buttons and ON indicator. Press ON to enable and OFF to disable accelerating voltage. On indicator is lit when accelerating voltage is enabled.

(2) BEAM CURRENT, OL RESET & RESET
Push button to reset beam current and a status indicator. RESET indicator is normaly lit. Flashing indicates not RESET or overload. Press OL RESET to restore normal operation.

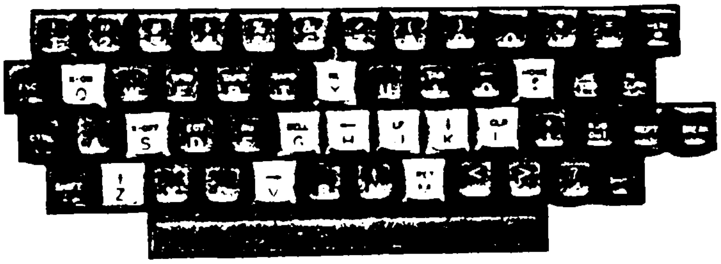
(3) BIAS, ON/OFF
Bias control push buttons. Press ON to enable and OFF to turn off and disable bias control system.

(4) FILAMENT, ON/OFF
Filament control push buttons. Press ON to enable and OFF to turn off and disable current to filament of gun.

(5) MANUAL ADJUST, FIL, BC, & BF
Manual controls to adjust programmed override levels for each of these functions, FIL (Filament), BC (Beam Current), and BF (Beam Focus). Activate RUN display, CTRL R, to note override value.

(e) Keyboard

This keyboard is used by the operator to communicate with the system. The operation of this device is similar to that of a standard typewriter keyboard. Since the keyboard is standard, this paragraph only describes the special frequently used features of this device.

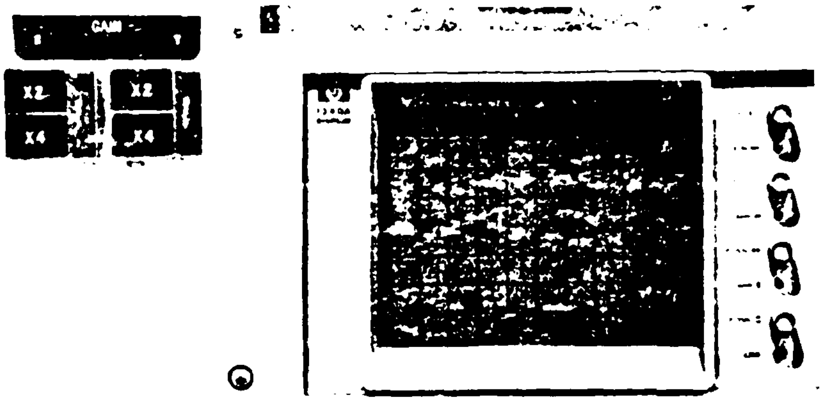


(1) CTRL E
Erase screen command. To obtain, press both the CTRL and E keys and hold closed momentarily. Use the same basic procedure to activate most displays; press CTRL and key identified by letter following CTRL.
(2) RETURN
Press this key to end line of text. This key is identified as in these instructions.
(3) ESC or ALT mode.
Use when paging. Pressing ESC displays next page of a multi-page display when it overflows capacity of screen.
(4) RUB OUT
Use to erase character(s) to left of cursor when correcting errors.
(5) RPT (repeat)
Press RPT with another key to repeat the character, letter, or action indicated by other key.
(6) SHIFT
Press SHIFT with another key to obtain action, number, or character shown at upper part of other key.
(7) Lower Bar
Press to obtain blank space in input character string.

C. CRT SCREENS, MAIN CONSOLE

(a) Monitor, Beam Deflection-Reflectron

This CRT monitor is used to display the beam deflection patterns. For a description of this monitor, see the supply manufacturer's manual furnished under separate cover, Hewlett Packard 1340A Display.



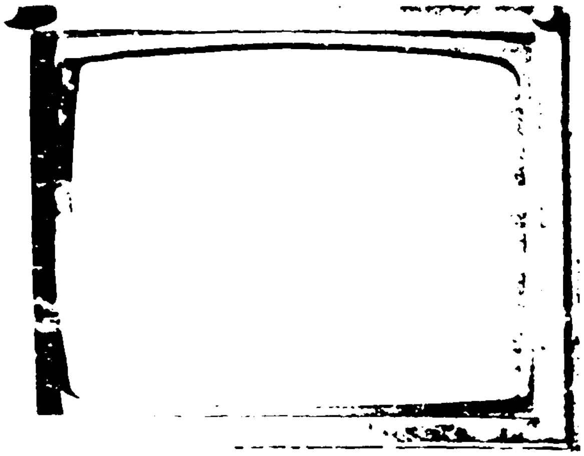
(1) INTENSITY
Turn to control brightness.
(2) FOCUS
Turn to control sharpness of image.
(3) POSITION
Two image-positioning controls. Turn to move image as shown by arrow next to control.

(4) GAIN, X & Y, OFF/X2/X4 (Console Controls)
Push button selectors to control gain of X and Y axes. Operation of both groups is similar. Press OFF for a gain of X1, X2 to increase twice and X4 to increase four times.

(b) System Monitor

CRT at main console for system displays. This Monitor is activated as soon as power is turned on to the machine. An Emergency Stop will clear, but not disable the display.

(1) Upper Left Knob.
ON/OFF and brightness control.
(2) Upper Right Knob.
Contrast control.



D. PENDANT

(a) Initial Set-Up Controls

This control serves the same use as a like titled control at the main console.

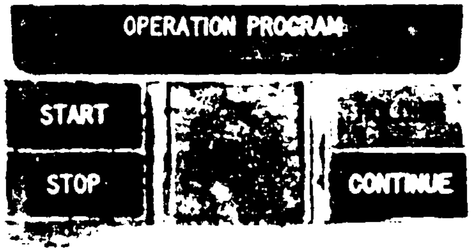
(1) EMERGENCY
Press this push button to immediately stop operation of motion and beam power functions.

CAUTION

This EMERGENCY does not affect pumping system. To turn pumping system off in an emergency, use disconnect at pumping cabinet.

(b) Operation Program Controls

These controls also serve the same use as like titled controls at the main console.



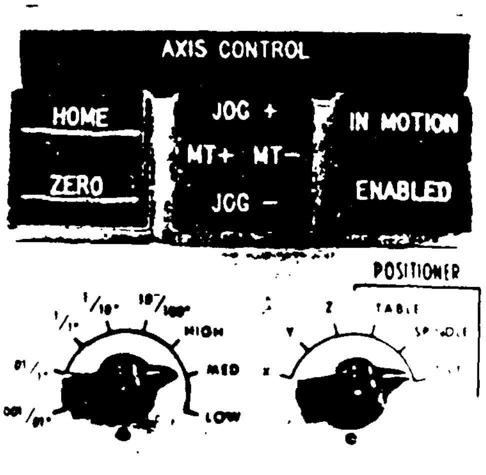
(1) START/STOP
Program control push buttons, press to START or STOP.

(2) RUNNING
Indicator lit when program is being run.

(3) CONTINUE & HOLDING
Restart pushbutton and indicator. Press CONTINUE to resume program after hold. HOLDING indicator is lit during a program hold.

(c) Motion Controls

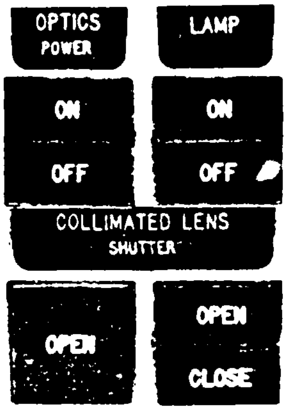
This group of controls at the hand-held pendant is used primarily for jogging. The pendant allows you to keep close watch of the drive when jogging.



(1) X/Y/Z or C
Selector to enable one of the indicated axes for jogging.
(2) .001"/.01° to 10"/100° and HIGH/MED/LOW
Selector to choose type of jog operation desired; step or momentary; length of step, and momentary speed range. Use five positions from .001"/.01° to 10"/100° to select step moves and length of step. Use HIGH/MED/LOW to select momentary operation and speed.
(3) ENABLE
Indicator lit when drive selected is enabled at main console.
(4) IN MOTION
Indicator lit when drive selected is in motion.
(5) HOME
Indicator lit when axis selected is in home position.
(6) ZERO
Indicator lit when axis selected is in Zero Set position.
(7) MT+/MT-
Indicators lit to show overtravel and direction of overtravel. Normally off.
(8) JOG+/JOG-
Push buttons to select travel direction and to jog enabled drive.

E. OPTIONS

(a) Optical Viewing, Console



The following controls are used with the Optical Viewing System to observe the weld and/or align the gun travel with the work-piece seam.

(1) OPTICS POWER, ON/OFF
Power control push buttons. Press ON to enable, or OFF to turn system off.

(2) LAMP, ON/OFF
Power control push buttons for illuminating lamp of system.

(3) COLLIMATED LENS SHUTTER, OPEN/CLOSE
Shutter-control push buttons. Only press OPEN when beam power is off. Press CLOSE before weld power is turned on.

(4) OPEN
Indicator lamp lit when shutter is open.

TABLE OF CONTENTS
SECTION 4 DISPLAYS

SECTION 4

DISPLAYS

A. DESCRIPTION

(a) Introduction

This Title shows the displays that are available with a typical EB welder, the commands to activate them, and a brief description of each display. A detailed description of these displays and the associated programming information is described in the companion Programmer's Manual.

The displays of this welder allow you to see information contained in stored programs, operating limits and ranges of various parameters, and the status of various inputs, outputs, and logicals for the machine. In addition, the bottom four lines of the screen are reserved to show information as it is being keyed in. This information is rolled, that is, when you exceed the line capacity, the top line moves out of the display range. The bottom line always shows latest information keyed in.

(b) Displays Listing

This paragraph lists all the displays that are described in Title B., and provides a brief description of these displays. Each display is activated by pressing two keys at the same time; press CTRL first, hold pressed and then press key identifying display. For example; if you want to look at the RUN display, press keys CTRL and R.

The displays are listed in alphabetical order of the CTRL command. All of the displays listed may not be supplied for your machine. If a display is not supplied, it will be noted in the associated paragraph.

Display	Press Keys Command	Description
ANALOG METER	CTRL A	Reference of actual operating level for beam power, motion, beam deflection, etc.
TIME	CTRL C	Run time of system, 24 hour clock.
SEAM TRACK MONITOR	CTRL D	Seam Track data and end point range.
	CTRL E	Erases active display.
SYSTEM FILE DIRECTORY	CTRL F	Lists stored programs and remaining capacity of storage. May be longer than one page.
DIGITAL METER	CTRL G	Current operating levels of AV, BC and BF.
HEAT TREAT DIRECTORY	CTRL H	Shows heat treat pattern and program.
DIGITAL INPUTS	CTRL I	Status of inputs to machine, low or high
CORRECTION MONITOR	CTRL K	Moves axis to keep beam on the weld seam.

LOGICAL OUTPUTS	CTRL L	Dynamic display of status of logical outputs.
ADAPTIVE SCAN MONITOR	CTRL N	Bias reference and filament volts in scan mode.
DIGITAL OUTPUTS	CTRL O	Status of outputs from machine that operates devices, high or low.
PROGRAM MONITOR	CTRL P	Weld program now in use.
ERROR QUEUE	CTRL Q	Lists error messages. Top line is last error message.
RUN PARAMETER	CTRL R	Shows programmed parameters of beam deflection and beam power.
SERVO MONITOR	CTRL S	Programmed motion parameters.
TIMER MONITOR	CTRL T	Status and operating limits of timers in system. May be longer than one page.
EVENT COUNTER	CTRL U	Current status and operating limits of counters.
VACUUM MONITOR	CTRL V	Chamber vacuum set points and operating level.
PROCESS MONITOR	CTRL W	Operating limits of deflection and beam power parameters
AXIS POSITION TABLE	CTRL X	Stored axes coordinates.
ANALOG SETPOINT	CTRL Y	Shows operating limits of analog outputs.
COLLECTION MONITOR	CTRL Z	Current state of data collection operation
RACK MONITOR	CTRL ↗M	Status of input-output control modules.
BAR GRAPH DISPLAY	CTRL ↗N	Graphic display of filament, beam current, and bias levels.

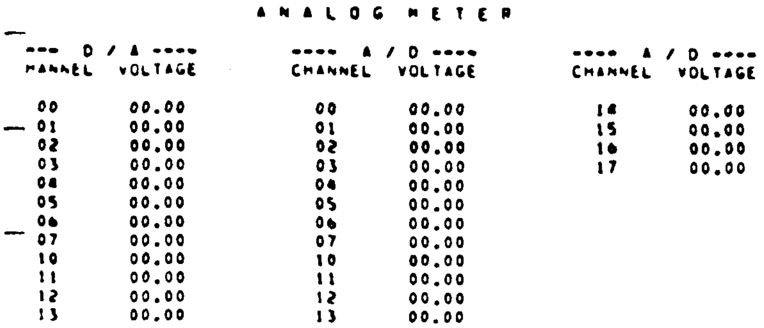
(↗ = press shift key)

NOTE

To erase any display being shown, press CTRL and E.

B. DISPLAYS & HOW TO GET THEM

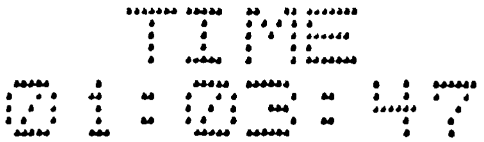
(a) ANALOG METER



```
                         A N A L O G   M E T E R

 ---  D / A ----        ---- A / D ----          ---- A / D ----
HANNEL  VOLTAGE         CHANNEL  VOLTAGE         CHANNEL  VOLTAGE

  00      00.00           00      00.00            14      00.00
  01      00.00           01      00.00            15      00.00
  02      00.00           02      00.00            16      00.00
  03      00.00           03      00.00            17      00.00
  04      00.00           04      00.00
  05      00.00           05      00.00
  06      00.00           06      00.00
  07      00.00           07      00.00
  10      00.00           10      00.00
  11      00.00           11      00.00
  12      00.00           12      00.00
  13      00.00           13      00.00
```

Activated by ---CTRL A
Display type ---Dynamic
Purpose ---Shows reference signals that determine operating levels of functions, and feedback signals representing actual operating levels. Used when calibrating and troubleshooting.

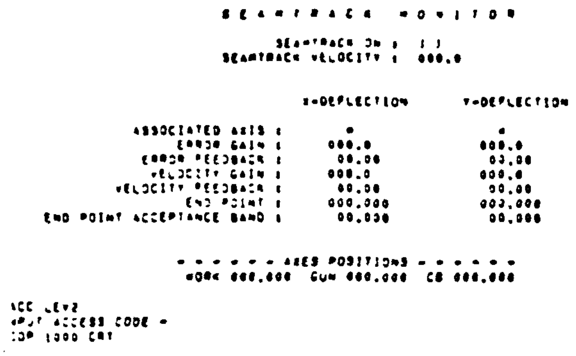
(b) TIME



```
   TIME
01:03:47
```

Activated by ---CTRL C
Display type ---Dynamic
Purpose ---24 hour real time clock, shows time of day..

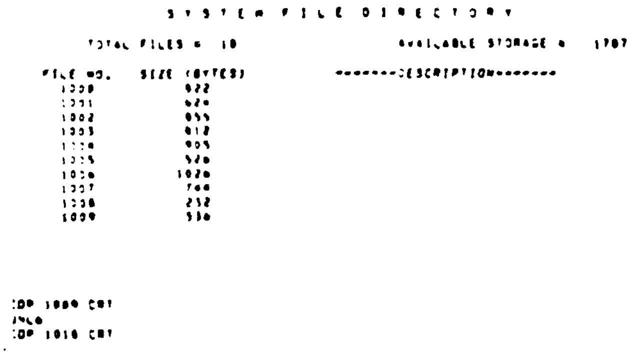
(c) SEAM TRACK MONITOR



```
                    S E A M T R A C K   M O N I T O R

                          SEAMTRACK ON :  [ ]
                    SEAMTRACK VELOCITY :  000.0

                               X-DEFLECTION       Y-DEFLECTION

              ASSOCIATED AXIS :     [illegible]        [illegible]
                   ERROR GAIN :     000.0              000.0
               ERROR FEEDBACK :      00.00              00.00
                VELOCITY GAIN :     000.0              000.0
            VELOCITY FEEDBACK :      00.00              00.00
                    END POINT :     000.000            000.000
    END POINT ACCEPTANCE BAND :      00.000             00.000

                - - - - - - AXES POSITIONS - - - - - -
                 WORK 000.000  GUN 000.000  CB 000.000

ACC LEV2
INPUT ACCESS CODE -
:OP 1000 CRT
```

Activated by ---CTRL D
Display type ---Dynamic
Purpose ---Operator's and programmers aid when developing program. Shows deflection gains, velocity gains, and acceptable limits of end point in data collection.

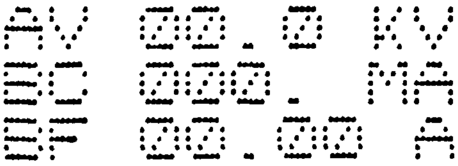
(d) SYSTEM FILE DIRECTORY



```
                S Y S T E M   F I L E   D I R E C T O R Y

      TOTAL FILES =  10                        AVAILABLE STORAGE =   1707

   FILE NO.   SIZE (BYTES)              --------DESCRIPTION--------
     1000          922
     1001          626
     1002          855
     1003          812
     1004          905
     1005          576
     1006         1076
     1007          766
     1008          232
     1009          536



:OP 1009 CRT
INCO
:OP 1010 CRT
```

Activated by ---CTRL F
Display type ---Static
Purpose ---Lists all programs in storage, available storage capacity, and file number of these programs. Used as a reference file for Operator, Programmer, and Maintenance.

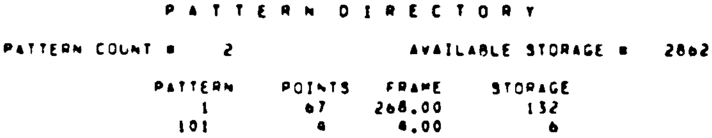
(e) DIGITAL METER



```
AV 00.0 KV
BC 000. MA
BF 00.00 A
```

Activated by ---CTRL G
Display type ---Dynamic
Purpose ---Provides expanded view of actual operating level of selected functions, typically; beam current, accelerating voltage and beam focus. Use as easy to read, wide angle meter, showing frequently-needed operating levels.

(f) HEAT TREAT DIRECTORY (only with Heat Treat option)

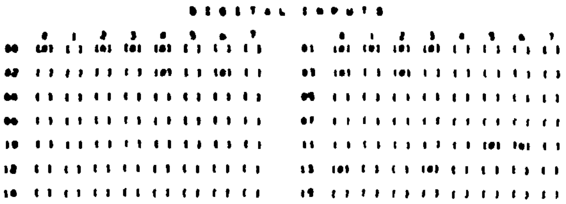


```
                 PATTERN DIRECTORY

PATTERN COUNT =    2                 AVAILABLE STORAGE =   2862

                PATTERN    POINTS   FRAME     STORAGE
                    1         67   268.00        132
                  101          4     4.00          6
```

Activated by ---CTRL H
Display type ---Static
Purpose ---Supplied with Heat Treat option to show heat treat pattern and program information. Used as a file directory for Heat Treat programs.

NOT SUPPLIED

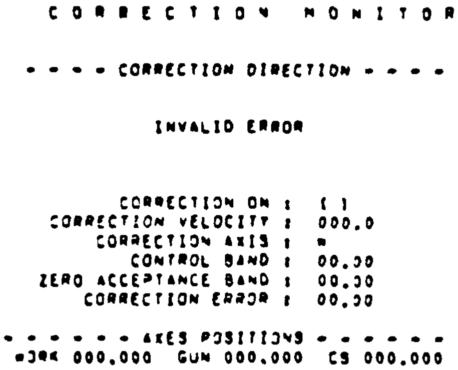
(g) DIGITAL INPUTS



```
                        D I G I T A L   I N P U T S
     0   1   2   3   4   5   6   7          0   1   2   3   4   5   6   7
00  [#] [ ] [#] [#] [#] [ ] [ ] [ ]    01  [#] [#] [#] [#] [ ] [ ] [ ] [ ]
02  [ ] [ ] [ ] [ ] [#] [ ] [#] [ ]    03  [#] [ ] [#] [ ] [ ] [ ] [ ] [ ]
04  [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]    05  [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]
06  [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]    07  [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]
10  [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]    11  [ ] [ ] [ ] [ ] [ ] [#] [#] [ ]
12  [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]    13  [#] [ ] [ ] [#] [ ] [ ] [ ] [ ]
14  [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]    15  [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]
```

Activated by ---CTRL I
Display type ---Dynamic
Purpose ---Shows states of inputs to machine. Usually used when troubleshooting to see if a switch is open or closed. The # sign in a bracket indicates a high, closed or on state.

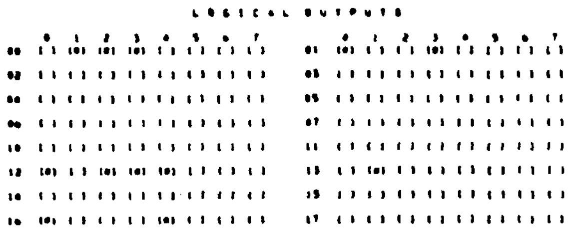
(h) CORRECTION MONITOR



```
      C O R R E C T I O N   M O N I T O R

   - - - - CORRECTION DIRECTION - - - -

              INVALID ERROR


          CORRECTION ON :  [ ]
    CORRECTION VELOCITY :  000.0
        CORRECTION AXIS :  W
           CONTROL BAND :  00.00
    ZERO ACCEPTANCE BAND :  00.00
       CORRECTION ERROR :  00.00

 - - - - - - AXES POSITIONS - - - - - -
  WORK 000.000  GUN 000.000  CS 000.000
```

Activated by ---CTRL K
Display type ---Dynamic
Purpose ---Corrects for the error of the beam being off the weld seam by a defined axis and a given velocity. The defined axis is the axis that is moved to keep beam on the weld seam. Velocity is in in./min.

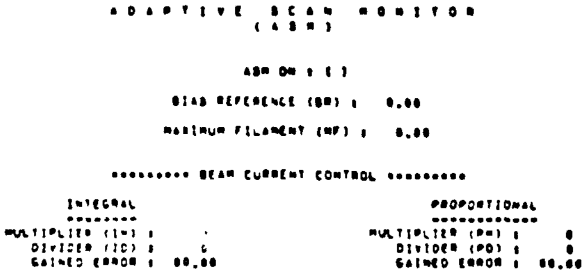
(i) LOGICAL OUTPUTS



```
                          LOGICAL OUTPUTS

      0   1   2   3   4   5   6   7             0   1   2   3   4   5   6   7
00   [ ] [*] [*] [*] [ ] [ ] [ ] [ ]      01   [*] [ ] [ ] [*] [ ] [ ] [ ] [ ]
02   [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]      03   [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]
04   [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]      05   [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]
06   [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]      07   [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]
10   [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]      11   [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]
12   [*] [ ] [*] [*] [*] [ ] [ ] [ ]      13   [ ] [*] [ ] [ ] [ ] [ ] [ ] [ ]
14   [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]      15   [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]
16   [*] [ ] [ ] [ ] [*] [ ] [ ] [ ]      17   [ ] [ ] [ ] [ ] [ ] [ ] [ ] [ ]
```

Activated by —CTRL L
Display type —Dynamic
Purpose —Shows status of Logical Outputs in sequence control for machine. Usually used when troubleshooting to determine where machine is in operating cycle.

(j) ADAPTIVE SCAN MONITOR

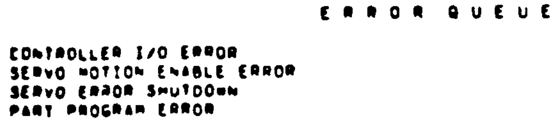


```
             A D A P T I V E   S C A N   M O N I T O R
                              ( A S M )

                            ASM ON : [ ]

                    BIAS REFERENCE (BR) :   0.00

                   MAXIMUM FILAMENT (MF) :   0.00

           ********** BEAM CURRENT CONTROL **********

     INTEGRAL                                       PROPORTIONAL
     ********                                       ************
MULTIPLIER (IM) :                              MULTIPLIER (PM) :     0
   DIVIDER (ID) :     6                           DIVIDER (PD) :     0
   GAINED ERROR :  00.00                          GAINED ERROR :  00.00
```

Activated by — CTRL N
Display type — Dynamic
Purpose — Used to improve scan signal during scanning operation.

e 2249   5/82

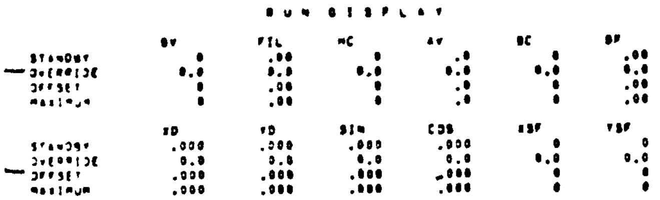
(m) ERROR QUEUE



```
                           E R R O R   Q U E U E

CONTROLLER I/O ERROR
SERVO MOTION ENABLE ERROR
SERVO ERROR SHUTDOWN
PART PROGRAM ERROR
```

Activated by —-CTRL Q or automatically by fault.
Display type —Dynamic
Purpose -—Shows why and where error occurred and keeps a listing of errors. Top line shows latest message.

(n) RUN PARAMETER

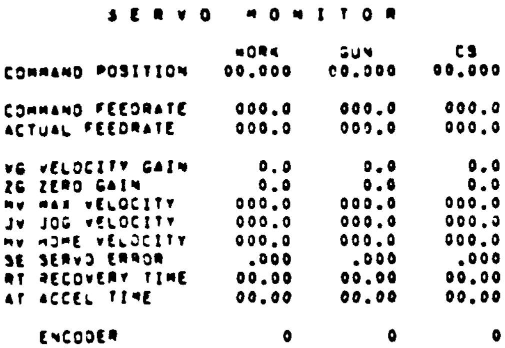


```
                         R U N   D I S P L A Y

              BV        FIL       HC        AV        BC        BF
STANDBY        0        .00        0        .0         0        .00
OVERRIDE     0.0        0.0      0.0       0.0       0.0        0.0
OFFSET         0        .00        0        .0         0        .00
MAXIMUM        0        .00        0        .0         0        .00

              XD        YD        SIN       COS       XSF       YSF
STANDBY     .000       .000      .000      .000        0          0
OVERRIDE     0.0        0.0       0.0       0.0      0.0        0.0
OFFSET      .000       .000      .000      .000        0          0
MAXIMUM     .000       .000      .000      .000        0          0
```

Activated by — CTRL R
Display type — Dynamic
Purpose — Shows following information for beam deflection and beam power functions.

1. Standby operating levels.
2. Maximum operating parameter value.
3. Constant offset value, + or -is added to operating level.
4. *Override range in percent* for both programmed and manually adjusted level.
   Use to determine standby conditions and to see how basic operating level is affected by override.

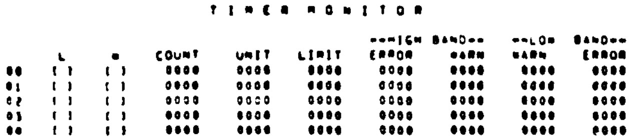
(o) SERVO MONITOR



```
            S E R V O   M O N I T O R

                       WORK      GUN       CS
COMMAND POSITION     00.000    00.000    00.000

COMMAND FEEDRATE      000.0     000.0     000.0
ACTUAL FEEDRATE       000.0     000.0     000.0

VG VELOCITY GAIN        0.0       0.0       0.0
ZG ZERO GAIN            0.0       0.0       0.0
MV MAX VELOCITY       000.0     000.0     000.0
JV JOG VELOCITY       000.0     000.0     000.0
HV HOME VELOCITY      000.0     000.0     000.0
SE SERVO ERROR         .000      .000      .000
RT RECOVERY TIME      00.00     00.00     00.00
AT ACCEL TIME         00.00     00.00     00.00

   ENCODER                0         0         0
```

Activated by —CTRL S
Display type —Dynamic
Purpose —Control parameters for motion functions to control response. Use when calibrating and troubleshooting.

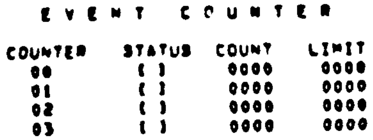
(p) TIMER MONITOR



```
                          T I M E R   M O N I T O R

                                               --HIGH BAND--   --LOW  BAND--
      L     M    COUNT    UNIT    LIMIT    ERROR    WARN    WARN    ERROR
00   ( )   ( )    0000    0000    0000     0000     0000    0000    0000
01   ( )   ( )    0000    0000    0000     0000     0000    0000    0000
02   ( )   ( )    0000    0000    0000     0000     0000    0000    0000
03   ( )   ( )    0000    0000    0000     0000     0000    0000    0000
04   ( )   ( )    0000    0000    0000     0000     0000    0000    0000
```

Activated by —CTRL T
Display type —Dynamic
Purpose —Shows status and operating limits of timers in system. Usually used when checking out a fault in system being caused by some device operating too slow, or not operating.

(q) EVENT COUNTER

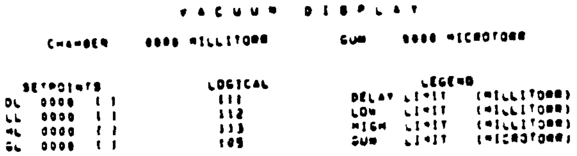


```
              EVENT   COUNTER

COUNTER    STATUS   COUNT    LIMIT
  00        ( )      0000     0000
  01        ( )      0000     0000
  02        ( )      0000     0000
  03        ( )      0000     0000
```

Activated by --- CTRL U
Display type --- Dynamic
Purpose — Shows status and operating limits of counters. Used to count number of times a function or device is operated before initiating another function or device.

NOT SUPPLIED

(r) VACUUM MONITOR



```
                         VACUUM   DISPLAY

       CHAMBER    0000 MILLITORR         GUN    0000 MICROTORR

   SETPOINTS              LOGICAL                  LEGEND
DL   0000   ( )             111          DELAY LIMIT   (MILLITORR)
LL   0000   ( )             112          LOW   LIMIT   (MILLITORR)
HL   0000   ( )             113          HIGH  LIMIT   (MILLITORR)
GL   0000   ( )             105          GUN   LIMIT   (MICROTORR)
```

Activated by ---CTRL V
Display type ---Dynamic
Purpose ---Shows actual levels of vacuum in chamber and set point defining low level (LL), high level (HL) of vacuum and the delay level (DL). Usually used as a quick check of vacuum when pumping down. For description of limits, see SECTION 2., Title B., Par (b), Vacuum Chamber and Pumping System.

(u) ANALOG SETPOINT

```
                     ANALOG SETPOINTS

POINT   CHANNEL   LOGICAL     VOLTS     HIGH      LOW
 00     N/A 00      0 ( )     00.00     00.00     00.00
```

Activated by — CTRL Y
Display type --- Dynamic
Purpose — Set operating band for defined analog outputs.

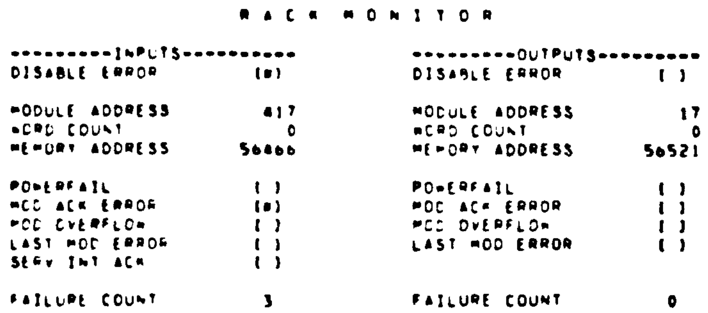
NOT SUPPLIED

(v) COLLECTION MONITOR

```
  COLLECTION  MONITOR


    - - - SEGMENT COLLECTION - - -

      COLLECTING SEGMENT :      0
         COLLECTION AXES :  WGC
            CONTROL AXES :  WG
     COLLECTION INTERVAL :  00.000
           TRUNCATION ON :  ( )



- - - - - - AXES POSITIONS - - - - - -
 WORK 000.000  GUN 000.000  CS 000.000
```

Activated by ---CTRL Z
Display type ---Dynamic
Purpose —Shows current state of parameters in data collection process. Use to note location of axes with respect to collection points in each segment and APT points in Seam Track operation. Used by Operator and programmer when developing program.

(w) RACK MONITOR



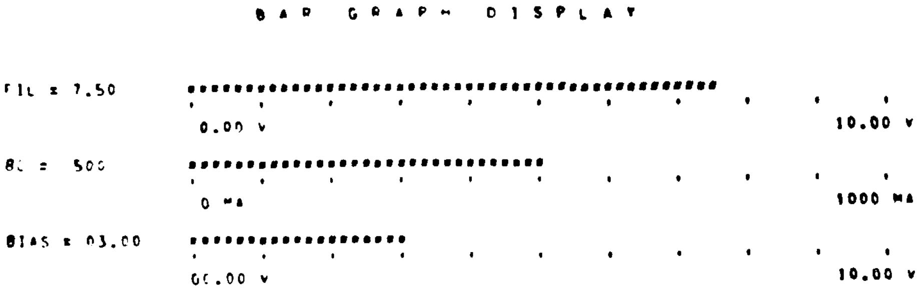
```
                    R A C K   M O N I T O R

----------INPUTS-----------              ----------OUTPUTS----------
DISABLE ERROR             (*)            DISABLE ERROR             ( )

MODULE ADDRESS            417            MODULE ADDRESS             17
WORD COUNT                  0            WORD COUNT                  0
MEMORY ADDRESS          56466            MEMORY ADDRESS          56521

POWERFAIL                 ( )            POWERFAIL                 ( )
MOD ACK ERROR             (*)            MOD ACK ERROR             ( )
MOD OVERFLOW              ( )            MOD OVERFLOW              ( )
LAST MOD ERROR            ( )            LAST MOD ERROR            ( )
SERV INT ACK              ( )

FAILURE COUNT               3            FAILURE COUNT               0
```

Activated by —CTRL / M.
Display type —Static
Purpose —Troubleshooting aid, shows status of input and output modules.

NOTE

The arrow means press SHIFT key. Be sure to press and hold momentarily all three keys; CTRL, SHIFT, and the associated character.

(x) BAR GRAPH DISPLAY



```
                     B A R   G R A P H   D I S P L A Y

FIL = 7.50      ********************************************************
                .     .     .     .     .     .     .     .     .     .     .
                 0.00 V                                                 10.00 V

BC =  500       **************************************
                .     .     .     .     .     .     .     .     .     .     .
                 0 MA                                                   1000 MA

BIAS = 03.00    ***********************
                .     .     .     .     .     .     .     .     .     .     .
                00.00 V                                                 10.00 V
```

Activated by —CTRL / N.
Display type —Dynamic
Purpose —Graphically displays filament, beam current, and bias levels. Primarily used when kneeing filament in bar graph format.

APPENDIX C

MANUFACTURER'S LITERATURE

FURNISHED BY

MG INDUSTRIES

MACHINE CONTROL AND SUPPLY

5.1 MACHINE CONTROL

The control of the installation is a microprocessor based program (Pc). It is separately and clearly arranged in the central switching cabinet, and it comprises the pump station controls of the chamber and of the gun as well as all interlocks and logic operations.

The control is composed of a central processor unit and of a number of discrete input/output modules clearly arranged on tracks. The individual modules have LED status indicators allowing quick fault detection. The processor is equipped with an internal operating system which not only continuously monitors the clock frequency of the inquiry logic, the program flow, the busline function and the internal logic voltage, but also checks whether there is any fault in the track, in a module or in the connection from the track to the processor.

Such fault signals are separately transmitted for each track. These signals are processed through the program in view of self-protection of the installation, e.g. in case of mains failure. The program, which is included in the scope of delivery, is stored in CMOS-RAM and is protected against voltage loss by buffer batteries.

5.2 ELECTRIC SUPPLY OF THE MACHINE

The electric supply of the machine is arranged in slide-in units and mounting plates and is accommodated in the central switching cabinet. The mains supply includes the current distribution for the high voltage, the motion device and the vacuum pump station.

The master switch is located in the front door of the switching cabinet.

5.3 TECHNICAL DATA PC CONTROL

PROCESSOR	Director 4001 Processor L
Input and output	CPU designed for connection of 256 discrete I/O's
Program memory	RAM, up to 4K depending on the design
Buffer batteries	Lithium battery 3 years lifetime
CPU connections	Up to 8 tracks to receive a maximum of 256 I/O's
Monitoring	CPU with fault monitor and display, self-checking facility, discrete I/O's, and display
Power consumption	36 VA
Voltage	120 V/220 V AC
Dimensions LxWxH	457 x 216 x 76 mm
TRACKS	
Capacity	8 discrete or 8 data modules
Self-checking facility	Test modules plus track Test track (switch-selected)
Power consumption	30 VA
DISCRETE INPUT MODULES	
Number	8 inlets per module
Display	LED display for each input
Input voltage	24 V AC/DC
Maximum voltage	2 x nominal voltage for 10s
Input current	20 mA
Insulation	Separation by optocoupler max. 1500 V for 16 ms

5.4 CNC PROCESS CONTROL EBCON 4

5.4.1 GENERAL CONCEPT

The advantages of electron beam welding - high welding speed, low heat penetration due to high energy concentration, accurate repeatability of welding parameters - are used by the CNC process control EBCON 4 in the most expedient way. This control has been designed by Messer Griesheim especially for electron beam and laser applications. The computer not only controls the mechanical axes of motion and the switching functions but also the beam parameters. The control has been designed for manual input by keyboard and CRT display as well as for output and input of component programs by mini-cassette (magnetic tape). Paper tape reader/punches are available as an option. The control program is stored in EPROMS while data specific of the machine as well as component programs are filed in the CMOS-RAM. This memory can be extended up to 400kByte.

5.4.2 FIELD OF APPLICATION

MG Industries has electron beam machines for welding, drilling (perforating) and surface treatment. Laser installations for welding, cutting, surface treatment, drilling.

5.4.3 MECHANICAL LAYOUT

Mobile 19" cabinet with a CRT display on top of it and with a retractable keyboard. Permanently incorporated cassette drive. External dimensions of the cabinet:

W x H x D	approximately 600 x 1000 x 600mm
Weight	approximately 70 kg

Back panel and side panels are removable for servicing operations

5.4.4 HARDWARE

The following essential units are included in the scope of delivery:

Computer board with 16 bit microprocessor MG 6800 and control program EPROM

Memory card 32 kByte RAM with battery backup (lithium battery), lifetime approximately 8 years

Power supply

Closed loop position controls depending on the machine design

Digital-to-analog converter for set values of beam parameters and beam deflection

Path measuring systems on all mechanical axes, resolution 0.01 mm or 0.005 degrees respectively for axes of rotation

Control panel, built into the central control console for the machine

CRT display, 24 lines, 80 characters each

Alpha-numerical keyboard for editing component programs, for data input of machine parameters and for interactive communication with the computer

Magnetic tape cassette drive with interface, 40 kByte per face of the cassette (mini-cassette for digital data) writing/reading speed 600 characters/sec

Printer (optional, line width 80 characters, printing speed 80 characters/sec)

Paper tape reader/punch combination (optional), photo-electric reader with a reading speed of 250 characters per second and supply box for folded tape. Punching speed 30 characters/sec.

5.4.5 SOFTWARE

The scope of delivery includes the editor program ECOPAC as well as the process control program COPAC. The teach-in program AUPRO can be supplied as an option.

Besides standard functions such as deleting, inserting, changing of characters, lines, or sections, the editor program ECOPAC offers further possibilities to facilitate the user's operations. This includes e.g. guidance by questions and answer (dialog), listing the available M-functions, menu technique for program selection, the possibility of carrying comments, automatic block number correction in case of changes, also in branch instructions.

The process control program COPAC includes full sequence control with many programming possibilities for the user. With linear and circular interpolation in the X/Y plane, the mechanical axes of motion as well as beam deflection in the X/Y plane can be controlled. The programmer will preselect whether the welding contour in the X/Y plane is to be performed by moving the positioning table or by beam deflection or by combination of both possibilities.

By "addition" of the inertia-free beam deflection (relative motion of the beam with reference to the workpiece) to the mechanical motion, it is possible to ensure speed tolerance of +/- 1% even on sharp corners or small radii with high rates of feed. This is most important for troublefree welding. In areas where the speed of the positioning table must be reduced, the relative speed with reference to the workpiece is maintained by beam deflection. After this, the table motion is accelerated and the beam deflection is controlled in the opposite direction so that the beam will reach its normal position again.

This compensation of speed variations or deviations from the position set value by beam deflection is protected for Messer Griesheim by patents.

If the machine is equipped wtih additional axes, these can either be interpolated simultaneously with X or Y, or can be positioned independently.

The following parameters are controlled additionally:

Beam current from 0 to maximum value depending on gun type, resolution 0.1 mA.

Lens current (focal distance), range 1 to 3A, resolution 1 mA.

Rate of feed 0 to 10 000 mm/min (depending on axis drive system), resolution 0.1 mm/min.

All three parameters can either be given a constant value or can be linearly interpolated. For interpolation, initial values of parameters, end values and the distances can be programmed, upon which the linear change is to be effected. Thereby all relevant data for slope-in and slope-out can be programmed.

The component programs are stored in the RAM memory and are marked by an alpha-numerical name with up to six characters. About 30 kByte are available for this purpose. If required, the memory can be extended up to 400 kByte (30 kByte correspond to approximately 75 m punched tape in the ASCII code).

5.4.6 PROGRAM INPUT ACCORDING TO

Input format DIN 66025 or EIA RS 274 respectively, special functions of EBCOBN 4 are not standardized

Input code for paper tape: ASCII, alternatively ISO

Manual input and editing by alpha-numerical keyboard, to be checked on the CRT-display

Filed programs are read-in directly or by cassette or punched tape respectively

Teach-in with the program AUPRO: Automatic programming in set-up operation by manual positioning on the reference points (one point for straight lines, three points for arcs). Input dialog for feed motion, beam parameters and machine instructions.

Absolute and incremental programming, selectable (G90-G91)

Resolution 0.01 mm or 0.005 dgerees respectively for axes of rotation

Direct feed rate programming in mm/min

Continuous feed correction by potentiometer between 0 and 100%

Dwell time programming up to 9 999 msec (G04)

5.4.7 PROGRAM OUTPUT

For filing and date protection, the contents of the memory can be dumped on the micro-cassette and on papertape respectively.

5.4.8 SUBROUTINE TECHNIQUE

Arbitrary number of data blocks to be defined as subroutine, repeatable up to 999 times

Nesting of subroutines up to five levels

Programmable branches (conditional and unconditional)

5.4.9 SAFETY AND CONTROL FUNCTIONS

Permanent control loop monitoring

Voltage supply monitoring

Processor monitoring

Parity control with external and internal data transfer

Fault display in case of programming or operating error

5.4.10 MACHINE PARAMETERS

After measuring the tolerances of the machine, correction values for compensation of pitch errors of the driving spindles and for correction of possible backlash are entered. These values can be adapted by the user if required.

5.4.11 CONTROLS AND DISPLAYS

Control is effected by a multi-function keyboard on the central control console of the machine:

Incremental and continuous manual feed motions, jogging operation, incremental feed motion +/- 0.01; 0.1; 1; 10mm)

Feed correction by potentiometer 0 to 100%

Start/Stop

Warning lamp and sound signal

On the display screen, the following is indicated during welding operation:

The data record being processed

The following data record

Set values for table position and additional axes

Fault reports

Additional functions

If specified in the order, the CNC process control EBCON 4 will take over evaluations of signals from the seam tracking system FUPI ENC as well. This unit can be retrofitted.

Refer to OPTIONAL EQUIPMENT.

5.4.12 COPAC

Continuous path control program for EB welding machines. COPAC includes the following functions:

1. Positioning 5 axes
2. Continuous path control, interpolating linearly in 2 out of 5 axes, 10 kc
3. Continuous path control, interpolating circular in 2 out of 5 axes, 10 kc
4. Beam current control, also linearly interpolated along a given distance
5. Lens current control, also linearly interpolated along a given distance
6. Welding speed control, also linearly interpolated along a given distance
7. Beam deflection control in X and Y
8. Switching of deflection factor from 1- to 2- and 4- times
9. Switching on and off of an external deflection function generator
10. Programming and call up of subroutines (program loops)
11. Programmable jumps, unconditionally and conditionally
12. Programmable halts, unconditionally and conditionally
13. Data ipnut by teletype or tape reader
14. Data output on punched tape
15. Comprehensive editor functions

Additional functions if equipped with seam tracking equipment FUPI:

16. Switchiing to seam tracking mode

17. Programmable tracking area and direction

18. Internal verification of linearity of seam

19. Welding, including the corrections found by tracking

6. CONTROL CONSOLE

The complete installation can be operated from the central control console. It is provided in front of the working chamber and designed in such a way as to allow the operator to control the machine in sitting or upright position. The functional arrangemnt of setting potentiometers, switching elements and monitors, combined with the viewing telescope, allow quick adjustment of beam parameters and welding positions. A keylock pushbutton protects the installation against unauthorized operation. An emergency stop pushbutton allows immediate deactivation of all control loops.

The control elements and monitors are clearly arranged in the top plate of the control console, subdivided into three main groups:

6.1 Electron Beam Control

All beam parameters can be preselected, adjusted, activated or displayed by means of highly accurate switching and setting elements. This applies to high voltage, beam current, lens current, cathode heating and beam deflection. A switch selected digital instrument is used for display of the most important parameters - high voltage, beam current and lens current. The cathode heating current is indicated by an analog instrument.

6.2 Work Motion

The control elements for all axes of work motion are combined on a control panel. The speed of each welding motion is continuously adjustable and is indicated in mm/s or rpm on a digital instrument.

6.3 Vacuum Installation

The pump stations for chamber and gun are switched by means of luminous pushbuttons indicating the specific status by lighting of the corresponding symbol.

5.5 SEAM TRACKING CONTROL SYSTEM (FUPI ENC)

This system serves for correcting automatically possible differences between the position of the electron beam and the position of the gap.

To eliminate the effect of residual magnetic fields, low-powered electron beam is used as a measuring probe during one sensing cycle.

The differences measured between the desired and the actual position of the gap with respect to the electron beam are received either by the numerical control system described under Optional Equipment or by a special microprocessor and in the following welding program they are considered and compensated by beam deflection.

By this procedure a possible thermal distortion of the workpiece, resulting from preceding welding cycles, is automatically compensated.

Certain conditions with respect to the geometry of the gap edges will have to be considered.

TECHNICAL DATA

Maximum deviation	± 2.0 mm	(± 0.08")
Tracking accuracy	± 0.15 mm	(± 0.006")

MG

Installation for automatic welding groove detection and positioning on EB welding machine with NC control.

FUPI E-NC

Problem definition

a. Welding groove detection

The installation for automatic welding groove detection determines the actual contour of the groove prior to welding, and stores it in memory. The influence of magnetic fields is compensated.

b. Positioning control causes the position of the groove and of the beam to be superimposed according to the stored groove contour during the welding process.

Layout

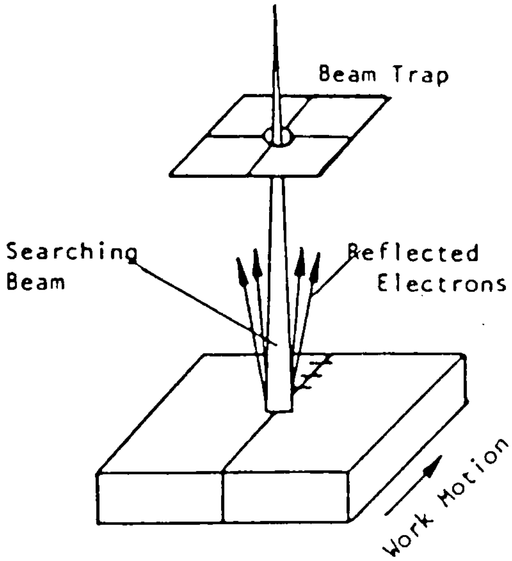
a. Mechanical layout

A beam trap has been provided in the working chamber in the gun opening area. It consists of insulated metal plates with an electrically conductive surface and with appropriate heat resistance. Electric leads and electric vacuum-tight feedthroughs transmit the intercepted signals outside the chamber.

b. Electrical layout

An amplifier for the signals produced in the beam trap is provided on the chamber.

A control panel in the control console contains the few sets of control equipment required for operation of the automatic groove detection and positioning control.



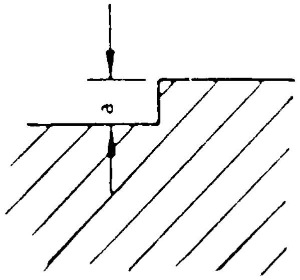
A soft accurately focused electron beam ("searching beam") is scanning over the welding groove in programmed points, thereby collecting the test points. A portion of the electron hitting the workpiece are thereby reflected (secondary electrons), are captured by the sensors, and transmitted to an amplifier. The amplified signals are processed in the computer and converted into the "actual position" of the groove. This "actual value" is then compared with the programmed "set value" and the determined correction values are stored into the program.

For a workpiece containing several welding contours, the correction values for all the contours can be determined in a single pass. But it is also possible to determine the correction values individually for each contour and to weld these contours immediately afterwards. This process has the advantage that the thermal deformation due to the preceding welds will be taken into consideration for the following contours, and that in addition it requires less space in the memory.

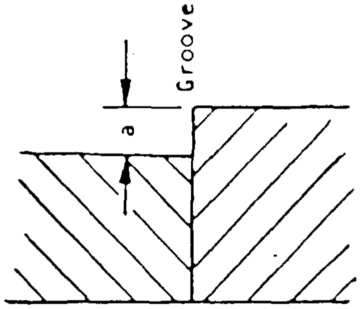
Admissible shape of the welding groove cross section

To ensure safe operation, the cross section of the welding groove must meet certain conditions:

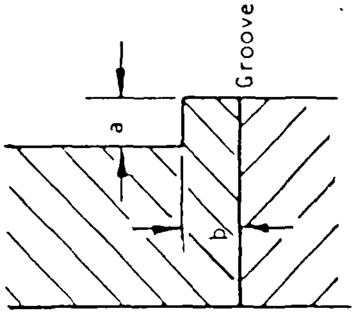
a. Protruding edges



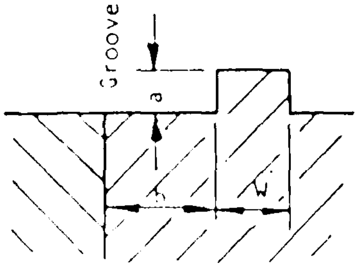
A step of a 0.5 on the workpiece surface will be sufficient for well defined position detection.



The most favorable conditions are obtained with the step being arranged immediately on the welding groove.



A step running near the welding groove and maintaining a constant distance "b" from the welding groove is also suitable for position detection.



The maximum value of the distance "b" depends on the workpiece and on the fixtures, and must be determined for each individual application.

Width of the step web "W" 1 mm.

b. Other welding groove cross sections can be used if appropriate tests are carried out.

Shape of the Groove - This means the contour of the joining line on the workpiece surface of the part to be welded.

a The welding groove is a straight line.

This also includes circumferential welds ("w" welds) on rotating workpieces.

If the actual welding groove is within a searching zone 4 mm wide, its position and direction are detected and stored. Any points which are not on a straight line are not stored.

b. The welding groove is circular

If the actual welding groove forms a circle the radius of which corresponds to the programmed radius, but the center of which is offset with respect to the programmed center, groove detection is possible with a special program.

This program determines and stores the positional offset of all points of the circle.

c. The welding groove is an unknown curve

If required, it is also possible to use the automatic groove detection in this case. The program required for this purpose, however, must be adapted to the marginal conditions of the application. This requires consultation.

Positioning accuracy to be achieved.

The position of the electron beam across the groove required for welding is determined with an accuracy of ± 0.15 mm.

OPERATING PROCESS

a. Preparing adjustments

i Welding task without NC welding program.

The width of the searching zone (e.g. 4mm), the welding beam current, the welding speed, the slope times and the focal distance for the searching beam are to be adjusted. The starting point of the groove must be positioned under the beam.

ii Welding task with NC welding program:

No pre-adjustments are required.

b. Starting the searching process

Readiness for this operation is indicated by a lamp. By depressing the pushbutton "TRACKING" the workpiece is automatically positioned from one searching point to the other, and the actual groove position is stored.

c. If the actual groove cannot be found, a warning tone will sound, and the searching process is stopped. Reclosing is achieved by depressing the pushbutton "TRACKING."

Termination of the searching process is indicated by the extinction of the lamp "TRACKING."

d. Starting the welding process

Adjust the focus value for welding (only for welding without welding program)

Initiate the welding process by depressing the pushbutton "WELDING."

MG

7.0 OPTIONAL EQUIPMENT

7.1 TELEVISION VIEWER

This option provides for simultaneous viewing through the precision binocular unit or viewing on a TV screen.

The system is equipped with a high response RCA camera for black and white TV viewing.

7.1.2 This option provides a color TV camera in place of the standard unit to provide enhanced viewing.

7.2 WIRE FEED UNIT

The proposed unit is a production proven system built by "Astro-Arc Co." and includes:

- Model WFS-4 Wire Feeder-Positioner
- WFC-C Control Unit
- Remote Operator's X-Y-Z Axis Control

The wire feed unit is compact. precision built and designed for operation in a vacuum system. It is housed in a shielded enclosure for EMI control.

The unit is specifically designed to precision feed wire for exacting requirements such as turbine seal knife edge build up.

7.3 SEAM TRACKING CONTROL SYSTEM (FUPI ENC)

This system serves for correcting automatically possible differences between the position of the electron beam and the position of the gap.

To eliminate the effect of residual magnetic fields. low-powered electron beam is used as a measuring probe during one sensing cycle.

The differences measured between the desired and the actual position of the gap with respect to the electorn beam are received either by the numerical control system or a special microprocessor and are considered and compensated for by beam deflection.

Possible thermal distortion of the wrokpiece is automaticaly compensated for from preceding welding cycles.

Certain conditions with respect to the geometry of the gap edges will have to be considered.

Technical Data:

Maximum deviation	+/- 2.0 mm	(+/- 0.08")
Tracking accuracy	+/- 0.15 mm	(+/- 0.006")

7.4 GUN SYSTEMS

The welder system can be equipment with guns and power supplies to provide additional weld power. The proposed system includes a highly regulated 8.5 kW gun system.

Optional units are 15 kW, 30 kW and 60 kW. Either of these are fully compatible with quoted welder system and CNC control.

7.5 SPECIAL DUAL TOOLING CONCEPT

The standard welder will be modified to provide for utilization of dual tooling and transfer platforms. This concept allows for welding of one assembly while another is being unloaded and reloaded with new parts outside of the chamber.

A special runout platform is provided with storage areas on either side for the transfer platforms. The tooling transfer platforms are powered onto and from the special X/Y table assembly.

The special tooling transfer platforms will mount the rotary/tilt units for part rotation requirements.

MG

STANDARD PROGRAM FOR CHAMBER MACHINES

	K 6	K 10	K 12	K 30	K 60	K 100	K 175
Dimensions of Chamber (mm/feet)	1050 3,4'	1600 5,2'	1320 4,3'	1600 5,2'	3200 10,5'	2700 8,8'	2600 8,5'
(mm/feet)	710 2,3'	710 2,3'	880 2,9'	1250 4,1'	1250 4,1'	2000 6,6'	2600 8,5
(mm/feet)	850 2,8'	850 2,8'	1100 3,6'	1500 4,9'	1500 4,9'	2100 6,9'	2600 8,5'
Volume (m^3/ft^3)	0,6 22	1,0 33	1,2 45	3,0 104	6,0 208	11,3 400	17,5 614
X/Y Table (feet x feet)	1,5' x 1,2'	1,5' x 1,2'	2,1' x 1,4'	2,5' x 2,0'	5,2' x 2,1	5,6' x 3,9'	4,2' x 4,2'
Mounting Plate (mm x mm)	475 x 355	475 x 355	640 x 420	780 x 600	1580 x 650	1700 x 1200	1275 x 1275
Travel in chamber/ In X total (mm x mm)	500/1150	500/1650	640/1400	780/1675	1400/3300	950/2975	1275/3245
Travel in Y (mm)	300	300	420	600	500	700	1275
Free Height Above Table to Cooling Plate (mm)	570	570	750	1050	1050	1600	2100
Admissible Load (kg/lbs)	400 880	400 880	400 880	1200 2640	1500 3300	3000 6600	2000 4400
Alpha-rotating device Face Plate (mm/inch)	220 8.6	220 8.6	220 8.6	600 23.6	600 23.6	600 23.6	600 23.6
ee Height Above xing Plate (mm/inch)	420 16.5	420 16.5	600 23.6	850 33.5	850 33.5	1400 55	1900 75
Admissible Load (kg/lbs)	300 660	300 660	300 660	1000 2200	1000 2200	1000 2200	1000 2200

	K 6	K 10	K 12	K 30	K 60	K 100	K 175
Omega Rotating Device Face plate (mm/inch)	220 8.6	220 8.6	220 8.6	600 23.6	600 23.6	600 23.6	600 23.
Height of Centers (mm/in)	291	291	291	405 520	405 520	405 520	405 520 700
Admissible Load (kg/lbs)	250 550	250 550	250 550	500 1100	500 1100	500 1100	500 1100
Vacuum Pumping Set Pumping time, partial vacuum 2×10^{-2} mbar (min)	2	3	3	4	6	8	8
Pumping time, high vacuum 7×10^{-4} mbar (min)	3	7	5	7	9	12	17

END

DTIC

8-86