Local Vacuum Electron Beam Welding Technique

By N DEVARAJAN*

Introduction

Electron beam welding is a recent technique which involves several fields of physics, vacuum technology, particle optics, electronics, mechanics etc. Initially this was used by highly trained technicians in advanced scientific applications (in nuclear and space laboratories). This process is now commonly used for commercial application in many industries, for example in automotive and appliance industries.

Electron beam is a high power density, small diameter heat source having a specific power in the order of 10 to 100 Kw/mm^2. When the power density is a few Kw/mm^2, the beam is used for fusion of metals, when it is in the order of 10 Kw/mm^2 to 100 Kw/mm^2 the beam is utilized for welding. When the power density is in excess of 100 Kw/mm^2, the beam is used for machining.

This high power density offers several advantages over conventional welding methods such as

1. Welding of high melting point and dissimilar metals,
2. Narrow heat affected zones.
3. Lower shrinkage and distortion,
4. High welding speeds,
5. Deep narrow welds making it possible to weld heavy thickness in single pass.

The disadvantages of this process are ;

1. Necessity to operate under vacuum.
2. The joints to be welded have to be machined precisely.

   (The gaps are in the order of 50 to 100 microns).
3. A careful degreasing of parts prior to welding as well as grinding and demagnetising are required.
4. The capital cost of the equipment is comparatively high.

Till recently, most of the electron beam welding has been done inside a vacuum chamber. Large chambers were built to accommodate bigger components. Because of this, its application in heavy industry was limited.

However, to overcome these difficulties, portable local vacuum machines have been developed recently and as per our knowledge, this technology has not been used in a commercial way for fabricating large sized components. Recently, using such a local vacuum machine some assemblies of nuclear vessels were fabricated in BARC, which is the first of its kind in the world.

A facility for Butt welding of tubes was also developed employing the local vacuum technique.

Operating Principle

The principle of electron beam welding is relatively simple. Electrons are extracted from an appropriate

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surface (cathode). They are imparted with a kinetic energy by being accelerated by a difference of electrical potential and concentrated on a target. The electron's kinetic energy is then transformed into thermal energy which is used for the given application.

The Equipment

Local vacuum E.B Welding System consists of

1. Electron Gun
2. The vacuum system
3. Viewing system
4. Manipulators for moving the gun or the part
5. High voltage power supply
6. Control cabinet

Electron Gun

The electron gun Fig. (1) consists of an emitting surface (cathode), an accelerating electrode (anode). an electrode for the formation of the beam (wehnelt) magnetic coils for focussing the beam. and deflection or oscillating the beam.

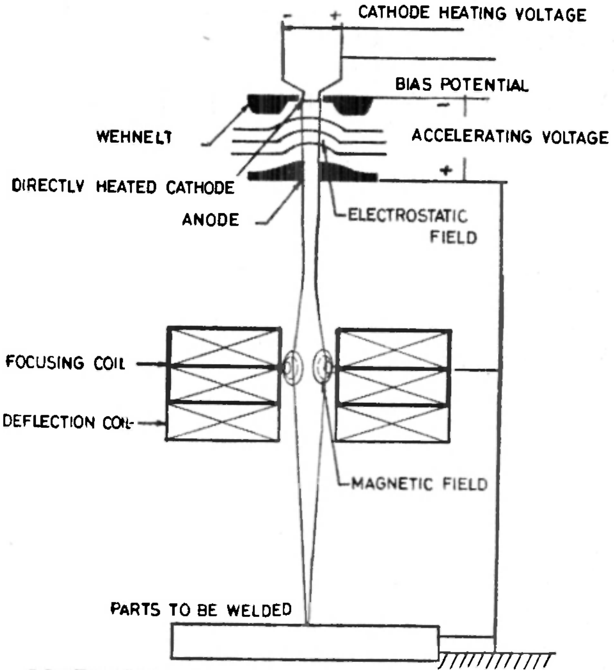
The high voltage is applied between the cathode and anode. This potential difference accelerates the electrons emitted from the heated cathode towards the anode. The electrons pass through a small hole in the anode and travel further to strike the target. By biasing the wehnelt, the number of electrons passing through the anode and thus the beam current can be varied as required.

Under the effect of mutual repulsion of the electrons (space charge) the beam will diverge and it is necessary to concentrate the electrons on the work piece situated at a certain distance from the anode, in order to get the required power density. This is achieved by the use of magnetic focussing coils.

Oscillation of the beam is used where it is necessary to agitate the weld pool. This agitation of the weld pool enhances the escapement of the gases from the molten metal. This is done by employing deflection coils.

Vacuum System

If the electron beam meets gas molecules (air for example) in its path its electrons will be subjected to a series of collisions with the gas molecules and will get diffused thereby decreasing the power density. Therefore the use of the beam in air is limited. It is also necessary to have a low pressure in the gun in order to protect the cathode against oxidation and to avoid insulation difficulties under high voltage operating conditions.



SCHEMATIC DIAGRAM OF ELECTRON GUN

FIG.NO.1

For these reasons, the gun and the welding chamber must be evacuated and the vacuum should be maintained during the welding phase which also produces outgassing.

The pressure in the gun must not exceed 10^{-5} to 10^{-4} torr. The pressure at the part to be welded can be 10^{2} torr. At such pressures there is no geat risk of an oxidised molten bath and the degree of protection is the same as in helium or argon arc welding. But high vacuum at the weld zone eliminates gas inclusions in molten metal. This characteristic is of particular interest in the case of welding refractory metals like titanium and zirconium and also maraging steels and other steels produced under vacuum.

The volume of the chamber is determined by the largest part to be welded in the base of chamber type machines. In the case of local vacuum machines small enclosures around the joint are used to maintain the part under vacuum. By this technique, it is possible to use the basic equipment to weld a variety of jobs irrespective of the size by using small enclosures and parts for sealing the component to keep the weld joint under vacuum.

Viewing System

The problem of placing the heat source on the joint to be welded is common to all welding processes. In the case of E.B. welding, the problem is more complex. This is so because :

1. The width of the weld is extremely narrow 0.3mm
2. The weld is done remotely on a narrow joint.
3. The pump down of the chamber can cause mechanical deflections which could affect beam alignment.

The viewing system is very essential to preset the beam accurately on the joint. The most common methods employed are :

1. Viewing lens.
2. Television system.
3. Aligning with reflectron system.

However some commercial machines are being manufactured without such viewing facilities.

Mechanisms for moving the beam along the joints

In the case of chamber type machines this is mostly achieved by having work holding tables with X—Y and rotary motions. In the case of local vacuum machines the gun can be made to do the required movements. The methods employed to achieve this are dependent on the specific application and a wide variety of arrangements can be found in commercial machines.

High Voltage Supply : (Accelerating Voltage)

The accelerating voltage ranges from 30 KV to 150 KV. Guns operating between 30 KV to 60 KV are called low voltage guns. Guns operating between 100 to 150 KV are called high voltage guns. In the low voltage gun, the lower limit results from the fact that in conformity with opto-electronic laws, the power concentration in the spot cannot be made sufficiently high for use in material processing, below 30 KV. The upper limit is given by the X-ray emission by the process, which above 60 KV will reach such an intensity that lead screening will have to be provided.

High voltage guns normally work between 100 KV to 150 KV. Here the upper limit is because of the fact that under the unfavourable vacuum conditions, accelerating voltage above 150 KV cannot be safely managed. The medium range (60 to 100 KV) is rarely used because the disadvantages of reduced beam quality are added to the necessity of increased X-ray protection without any particular advantages.

The use of accelerating voltage of 150 KV in the local vacuum machines has certain disadvantages like :

1. Higher accelerating voltages produce higher energy X-ray radiation. Additional protection has to be provided to shield the energy.
2. Increases the complexity of the electrical insulation.
3. The narrower beam requires precision alignment of the beam on the joint.

For local vacuum machines, accelerating voltages upto 60 KV present no special problem.

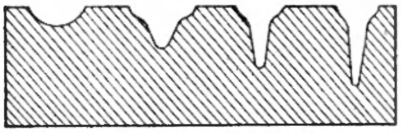
Regulation and control

In E.B. welding, the various parameters like :

1. Beam current
2. High voltage
3. Welding speed
4. Focus current
5. Vacuum level
6. Gun to work distance
7. Gap in the joint etc.

have to be controlled and maintained precisely to get a good quality weld.

At constant voltage if the beam current is varied, the specific power varies and this affects the weld configuration. Fig. 2 gives the weld appearance for various power densities, the other parameters remaining contant. At low power densities, the results obtained are practically the same as those for the conventional processes. Fusion is obtained through heat conduction through the metal, the source being situated on the surface



VARIATION OF THE PROFILE OF THE MELTED ZONE AS A FUNCTION OF THE POWER DENSITY. (VALUE INCREASING FROM LEFT TO RIGHT)
FIG.NO.2

of the metal. The shape of the weld bead is the same as in arc welding. With higher power densities, the profile of the melted zone varies as shown in Fig. 2.

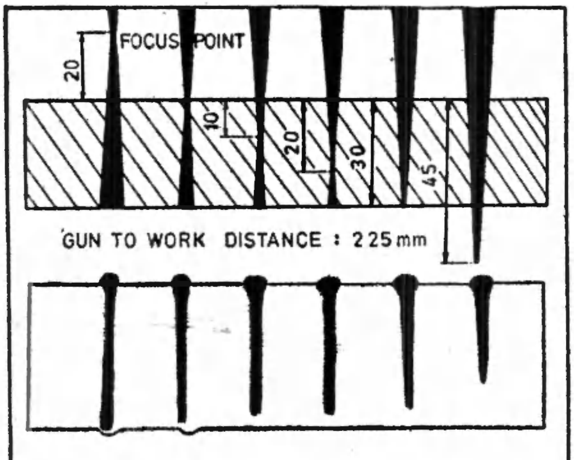
Accelerating voltage affects weld quality in two ways—by acting on the power carried by the beam (since power=V×I) and by modifying the focal point of the beam. It is therefore essential to stabilise and regulate this high voltage within precise limits.

Welding speed has an effect on the width and penetration of the weld.

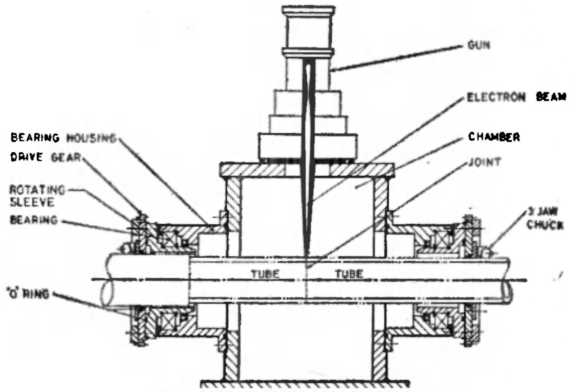
The position of the focal point in relation to the work piece plays a major role in the weld quality. First the variation of the focal point causes a variation of the beam diameter at the level of the work piece and consequently a variation in power density. Fig. (3) shows the depth of the molten zone for various positions of the beam focal point. Certain flaws like porosities can be eliminated by varying the focal point.

It is therefore essential that these parameters are maintained within a precise limit by regulating with servo controls.

With these fundamental ideas about the effect of various parameters on the weld geometry and quality, the optimum parameters for a given application can be arrived at only after extensive trials.



EFFECT OF THE FOCAL LENGTH ON THE GEOMETRY OF THE MELTED ZONE
FIG.NO.3



LOCAL VACUUM SETUP FOR BUTT WELDING TUBES
FIG.NO.4

Field Work

Recently at the Central Workshops, BARC, two large components involving tube to tubesheet welding were fabricated using the local vacuum E.B. technique.

Further, using the existing gun of the already available machine, a set up was designed and fabricated for butt welding of tubes. This arrangement is shown in Fig. (4).

The tubes that are required to be manufactured are as shown in Fig. (5). The tubes are 5.4m long and most of the precision machining is concentrated at one end. Finish machining these long tubes to the required tolerances on conventional lathes is difficult and the rejection rate will be very high and expensive.

It was decided to finish machine this in two pieces; one small in length having the precisions and another length of tube having a wider tolerance.

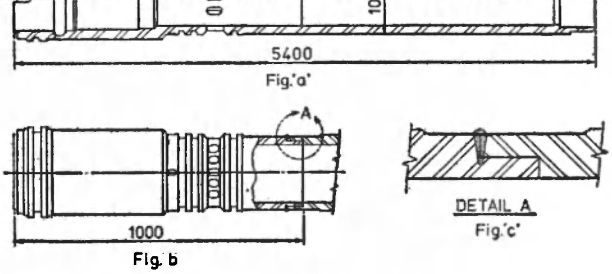


Fig.'a'

Fig. b

Fig.'c'

TUBE FABRICATED BY E.B. WELDING
FIG.NO.5

Since electron beam welding introduces minimum shrinkage and distorton it was expected that welding these by E.B. process after finish machining will not affect the dimensions appreciably.

As it can be seen in Fig. (4) the machined tubes are inserted into the local vacuum chamber. There is an 'O' ring seal between the tube and the rotating sleeve, The rotating sleeve is mounted on bearings and a vacuum seal is provided between the housing and the sleeve. The tube is held in the rotating sleeve with a three jaw chuck. Indentical arrangement is on the other side of the chamber.

The rotation of the tube is done by rotating the sleeve which is coupled by gearing to a DC motor.

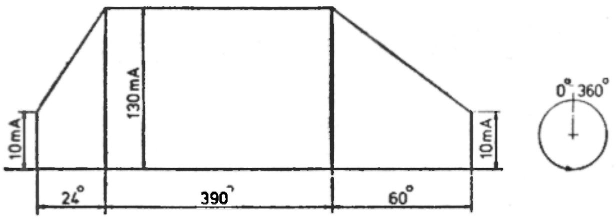
The electron gun of an available machine was used along with this set up.

The tubes were welded using the following parameters. Depth of penetration required is 5 mm.

Beam Current	130 ma
Voltage	39 KV
Focus current	
Setting	527,527,540
Gun to work distance	610 mm
Welding speed	62 cm/min
Vacuum level in the weld zone	1×10^{-2} Torr
Joint gap maintained	0.080 to 0.10 mm

The tubes were cleaned near the joining areas, free of dust, grease oil, etc. This is important as even minute traces of the above can give rise to defects like local depressions, blow holes, porosities etc. The joints were aligned with the beam using the gun TV system.

The welding current intensity was gradually increased and decreased during up slope phases and down slope phases of the welding sequence as given in Fig. (6). No cosmetic pass was given.



WELDING CYCLE – BEAM CURRENT
FIG.NO.6

The tubes were dimensionally inspected after welding. No appreciable differences in the dimensions were noticed beyond 100mm distance from the weld joint. The shrinkage was around 0.14-mm. Straightness was within 0.13 mm/meter.

Thus with a simple arrangement the application of the existing machine has been made more versatile. Presently we are working on an attachment for linear welds.

In a separate development work, BARC has also developed a complete electron beam welding of tube to tube sheets.

The electron beam melting furnaces developed in BARC are already in use in DAE units.

Conclusion

With a simple arrangement, the application of an existing machine has been made more versatile. By the application of the local vaccum E.B. technique, a difficult manufacturing task has also been made simple.

The electron beam welding technology even though complex in nature is easy to handle and the know how for this is available within the country. This know how if appropriately exploited can enable the commercial use of E.B. welding machines indigenously.