Fusion

Welding

1. Energy source

Classification of Fusion welding based on energy source

Energy source	Types of welding
Chemical	Oxy fuel gas welding, Exothermic welding/ Thermite welding, Reaction brazing/Liquid phase bonding
Radiant energy	Laser beam welding, Electron beam, Infrared welding/ brazing, Imaging arc welding, Microwave welding,
Electric-Perm. electrode arc	Gas tungsten arc welding, plasma arc welding, Carbon arc welding, atomic hydrogen welding, Stud arc welding
Electric-Consumable electrode	Gas metal arc welding, Shielded metal arc welding, Submerged arc welding, Electrogas welding, Electroslag welding, Flux cored arc welding
Electric-Resistance	Resistance spot, resistance seam, projection welding, flash/ upset welding, Percussion, Induction welding

ELECTRONE BEAM WELDING

Class: Fusion Welding

Energy Source: Electrone Beam

ELECTRON BEAM WELDING (EBW)

A welding process producing coalescence with a concentrated beam, composed primarily of high-velocity electrons, impinging on the joint. The process is used without shielding gas and without the application of pressure. ***See also high vacuum electron beam welding, medium vacuum electron beam welding, and nonvacuum electron beam welding.*** AWS A3.0M/A3.0:2010

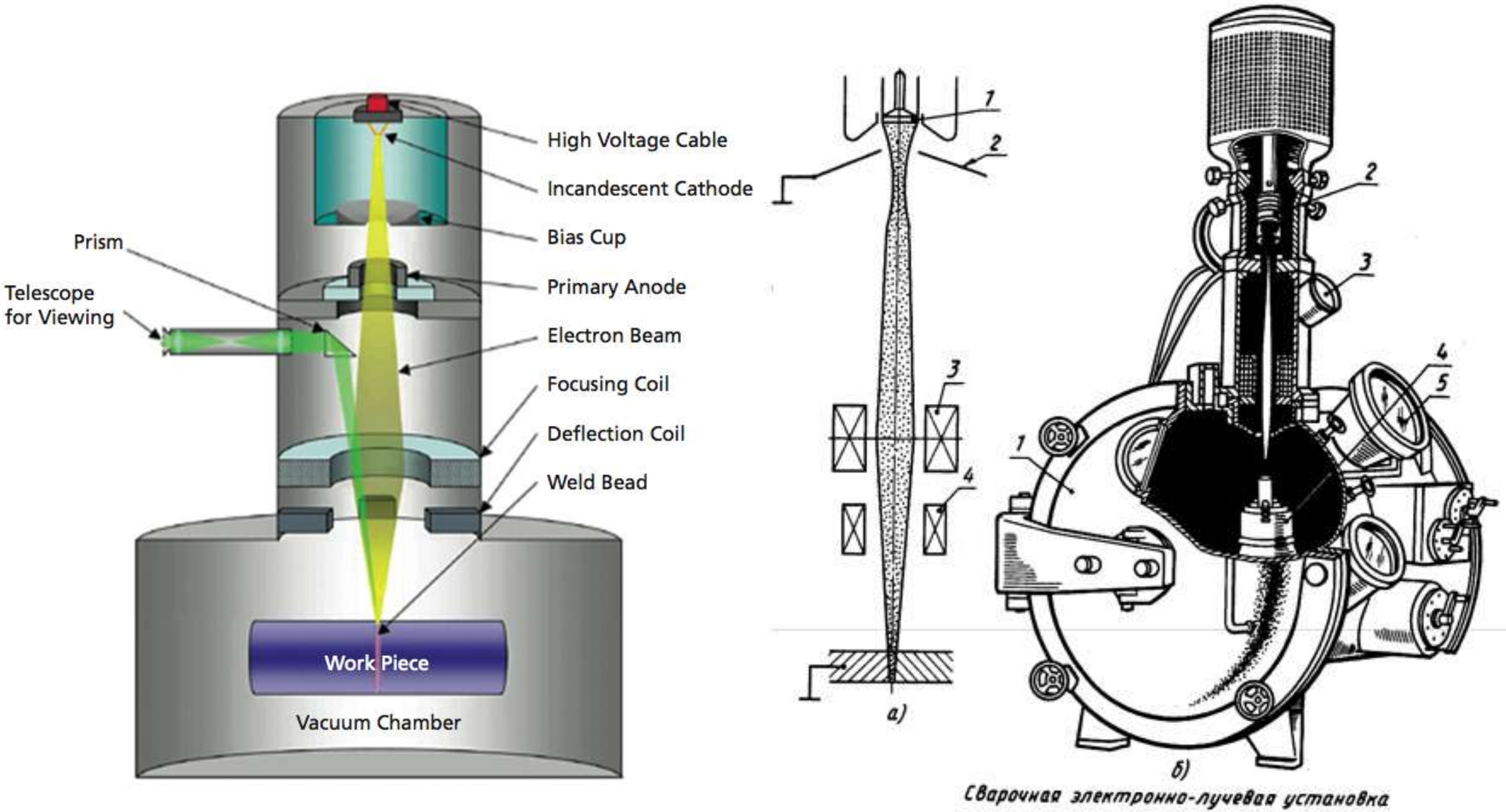
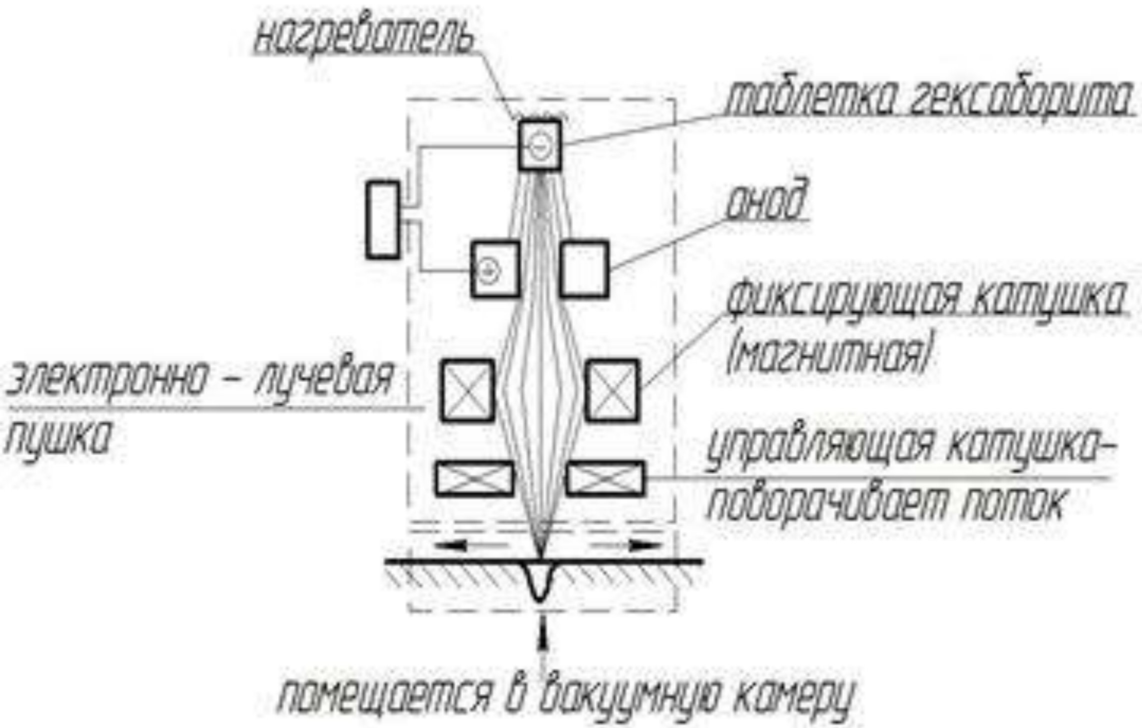
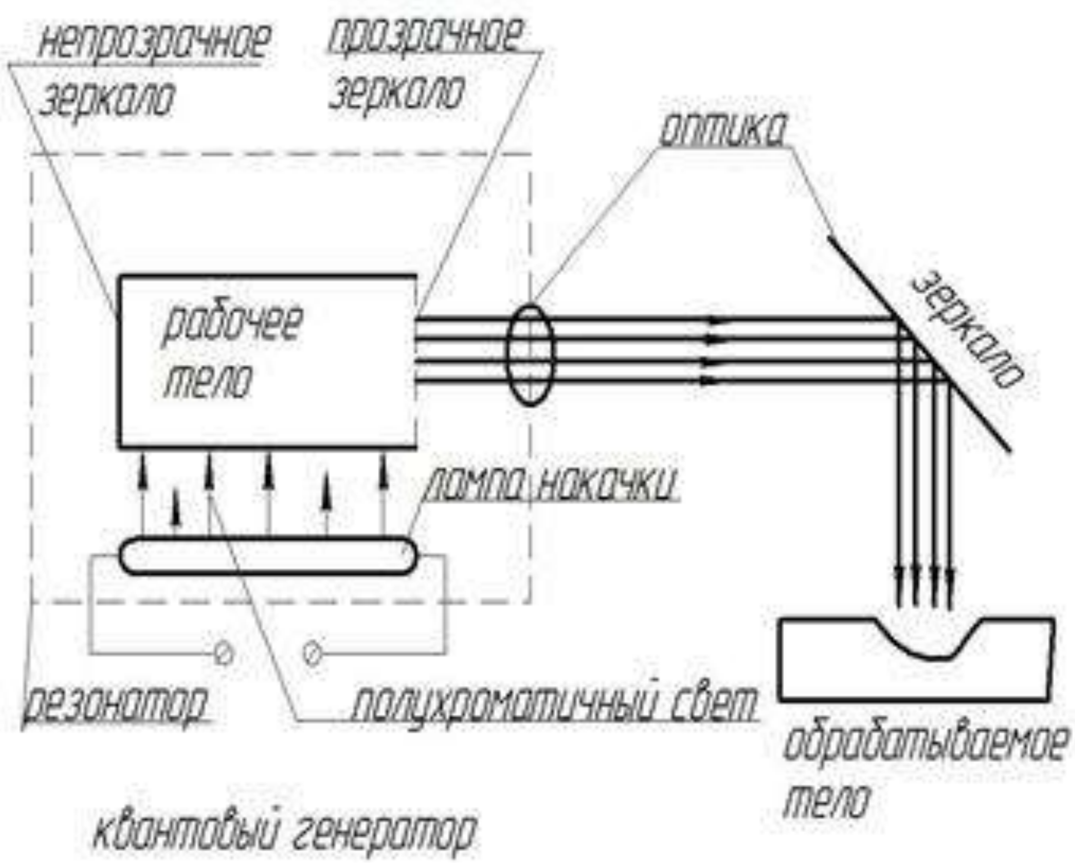


Figure 2. Electron Beam Welding

Электронно – лучевая сварка



лазерная сварка



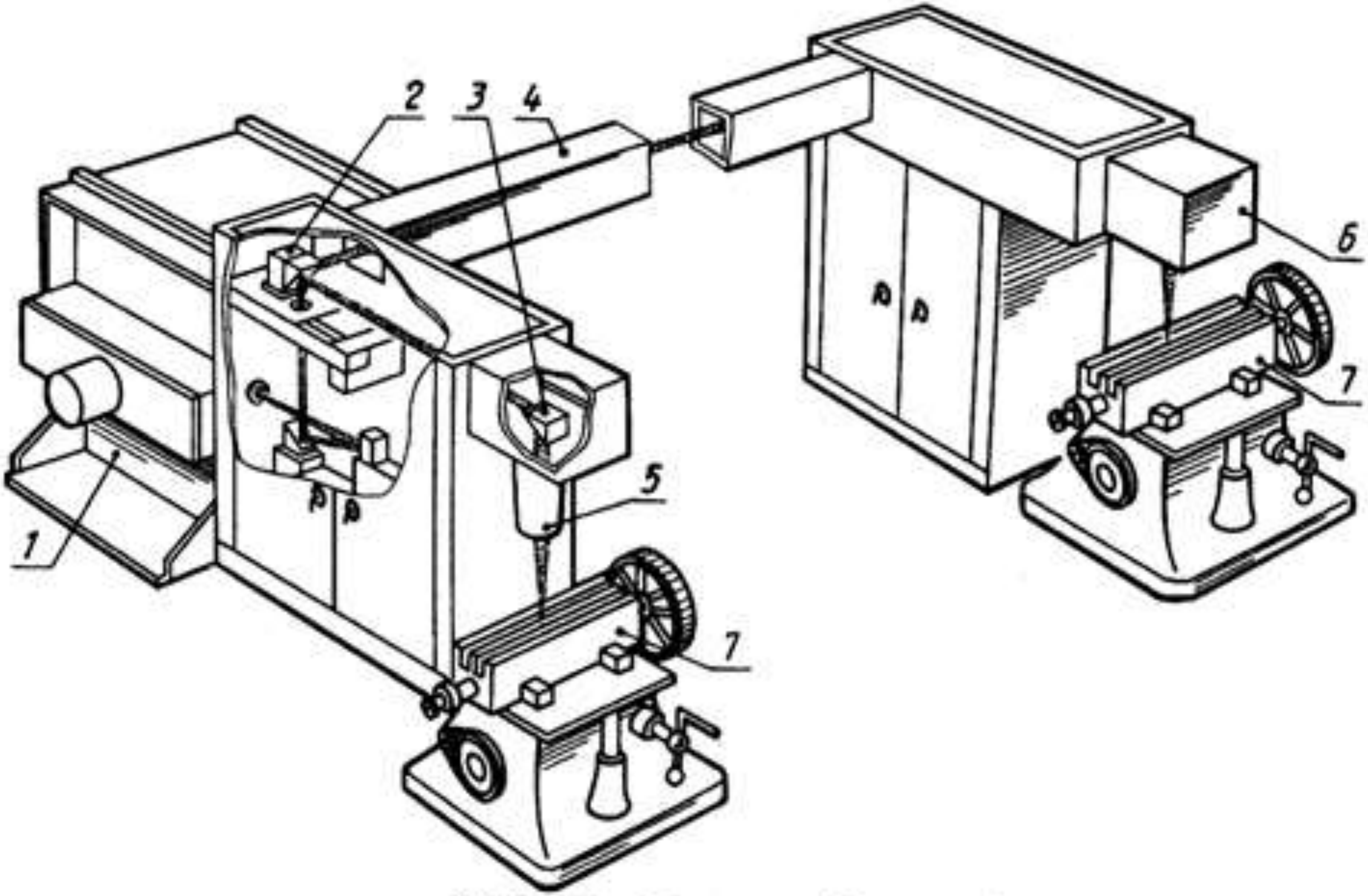
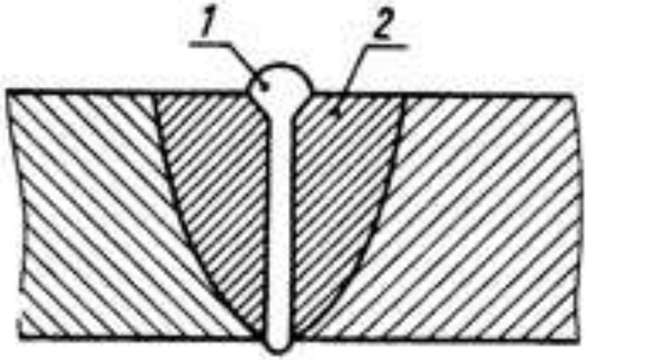
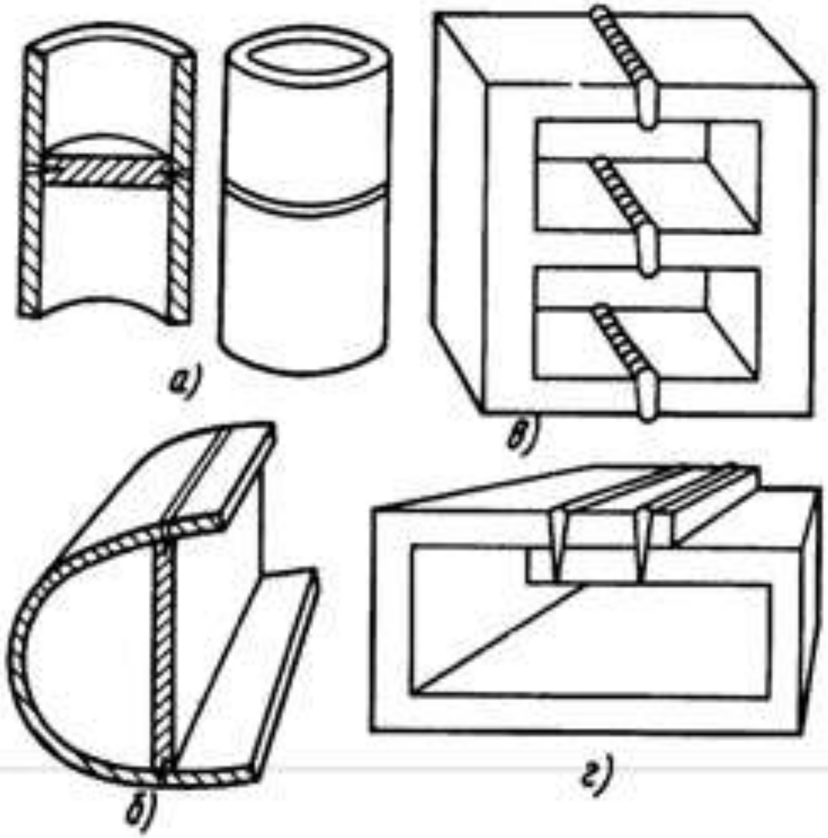


Схема мощной лазерной установки для сварки и термообработки

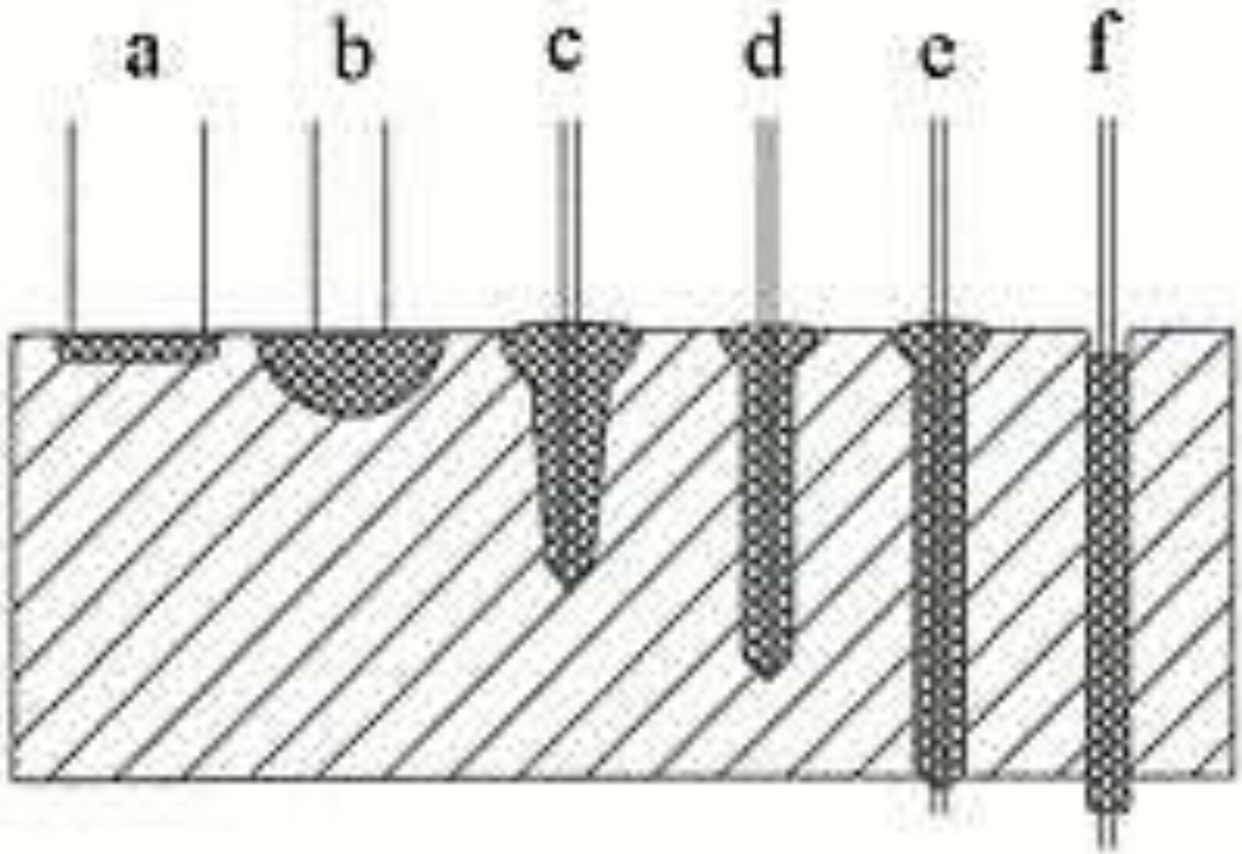


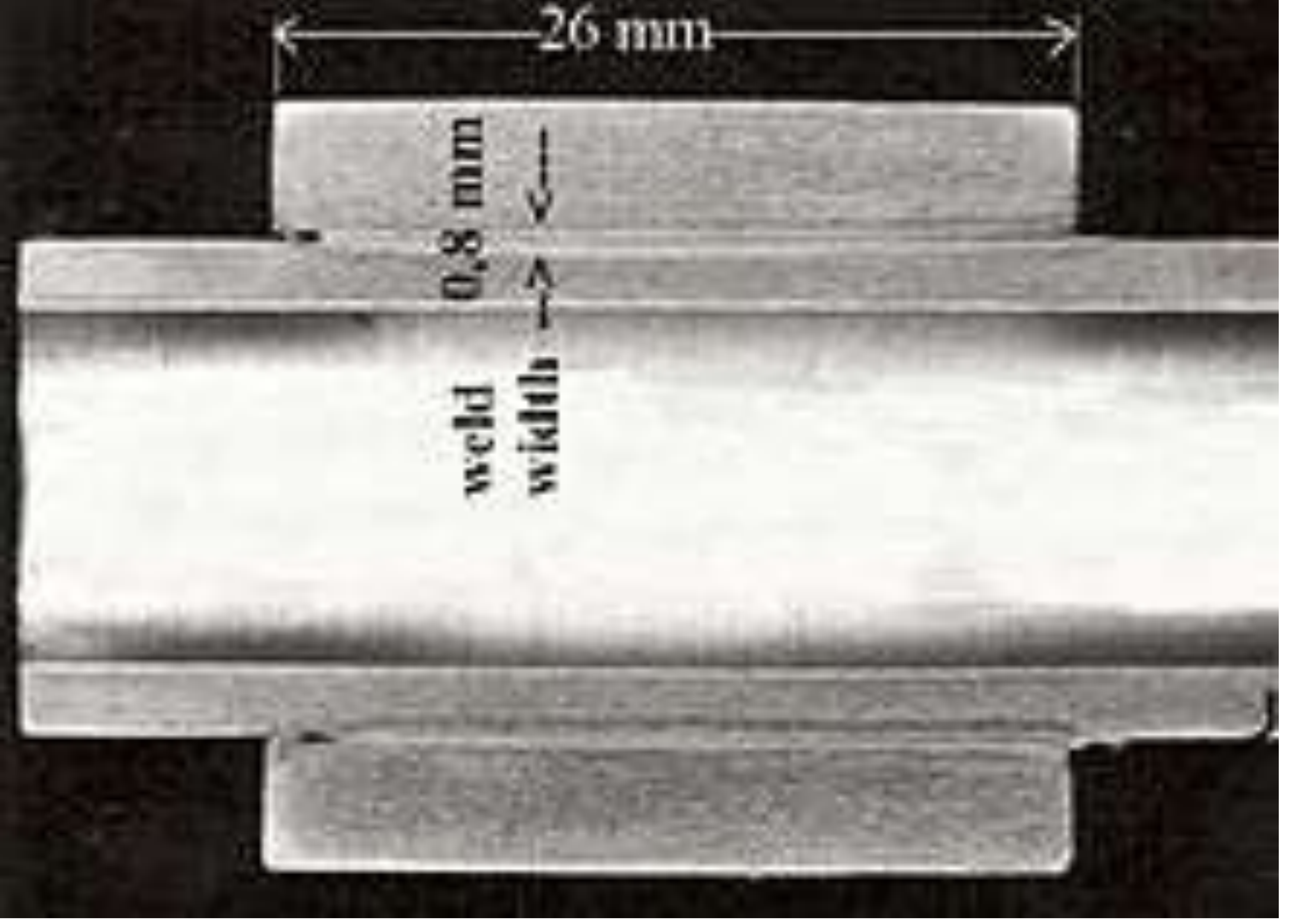
Форма шва при электронно-лучевой (1) и аргонодуговой (2) сварке

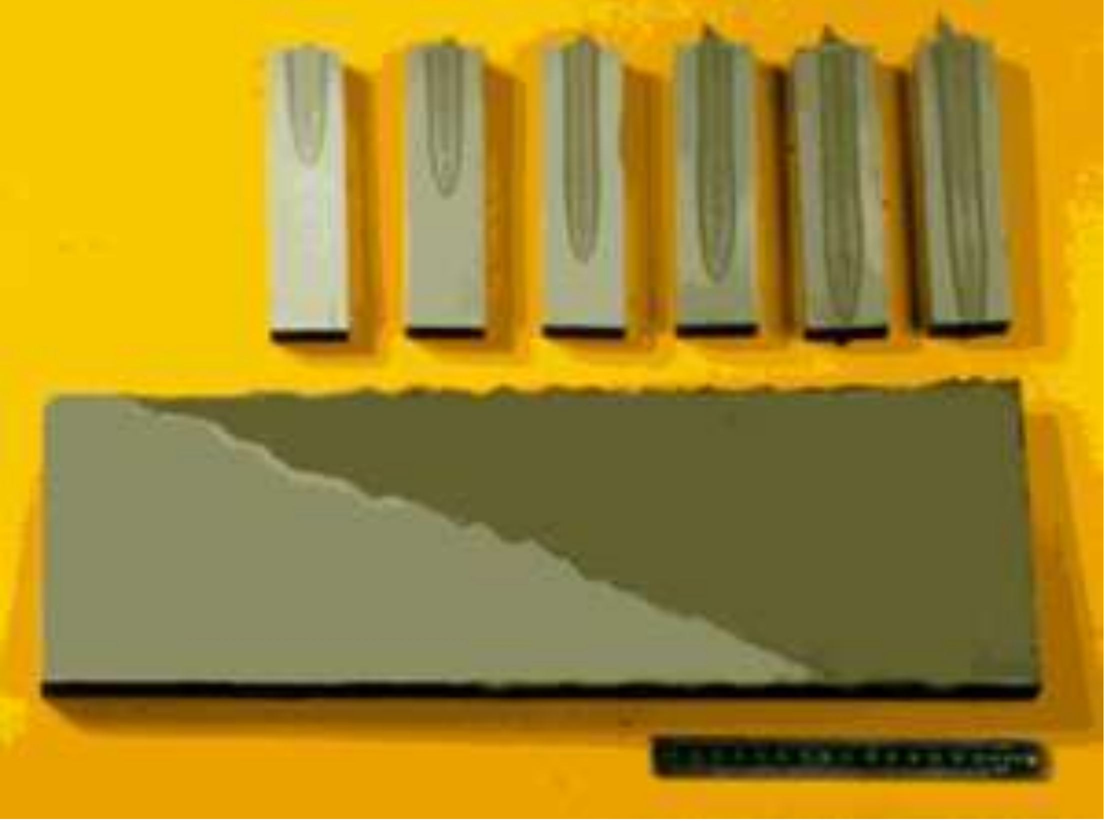
На рис. показана конструкция, сваренная путем одновременного проплавления трех листов.

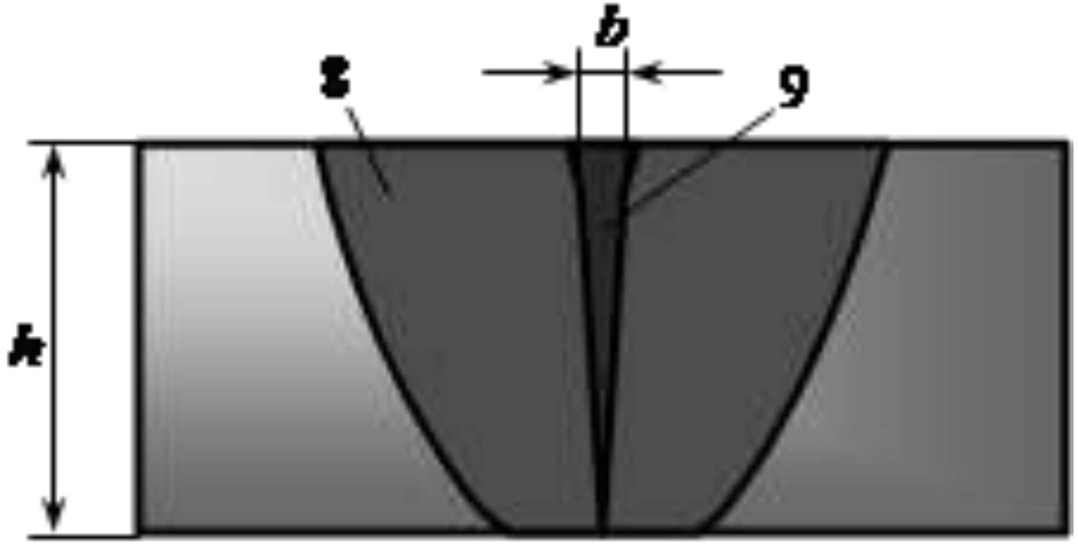


Конструкции, выполненные прорезными швами




26 mm
0,8 mm
weld
width





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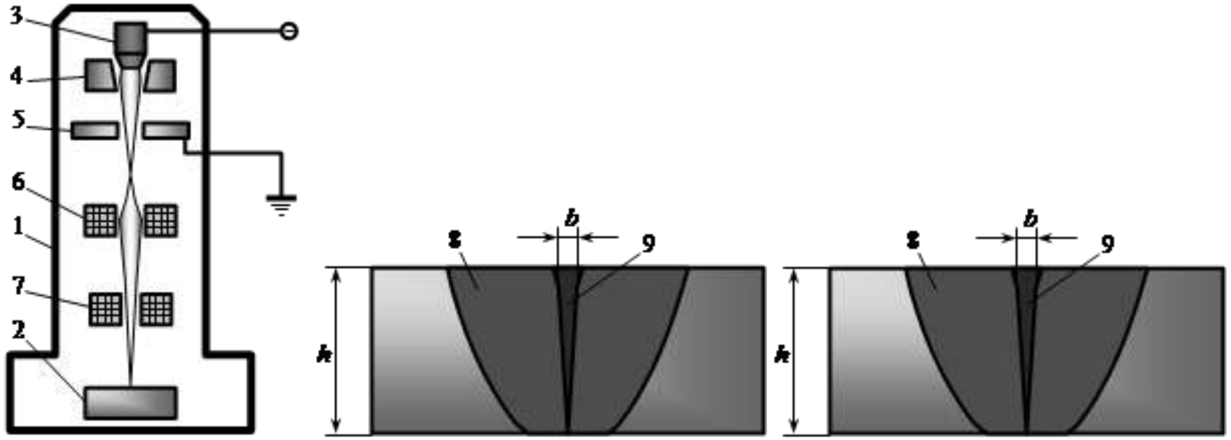


а) б) б)

electron beam gun. A device for producing and accelerating electrons. Typical components include the emitter (also called the *filament* or *cathode*) heated to produce electrons via thermionic emission, a cup (also called the grid or grid cup), and the anode.

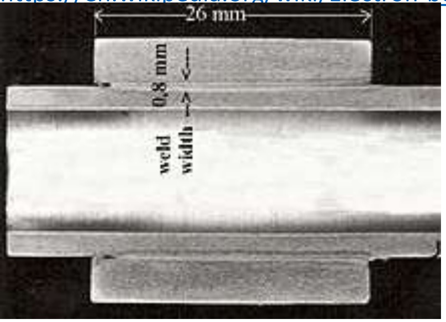
electron beam gun column. The electron beam gun plus auxiliary mechanical and electrical components that may include beam alignment, focus, and deflection coils.

electron beam cutting (EBC). A thermal cutting process severing metals by melting them with the heat from a concentrated beam, composed primarily of high-velocity electrons, impinging on the workpiece.

electron beam brazing (EBB). A brazing process using heat from a slightly defocused or oscillating electron beam. See Figures A.1 and A.6. See Tables A.1, A.2, and A.3.

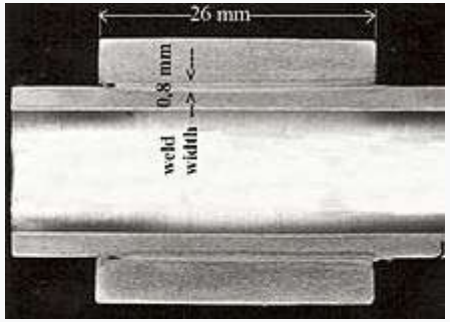
electron beam braze welding (EBBW). A braze welding process variation employing a defocused or oscillating electron beam as the heat source. See Figures A.1 and A.6. See Tables A.1, A.2, and A.3.

https://en.wikipedia.org/wiki/Electron-beam_welding



Electron-beam welding was developed by the German physicist Karl-Heinz Steigerwald in 1949,[1] who was at the time working on various electron-beam applications. Steigerwald conceived and developed the first practical electron-beam welding machine, which began operation in 1958.[2] American inventor James T. Russell has also been credited with designing and building the first electron-beam welder.[3][4][5]

Electron-beam welder



Deep narrow weld

Physics of electron-beam heating[edit]

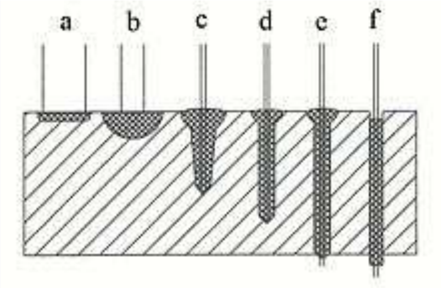
Electrons are elementary particles possessing a mass $m = 9.1 \cdot 10^{-31}$ kg and a negative electrical charge $e = 1.6 \cdot 10^{-19}$ C. They exist either bound to an atomic nucleus, as conduction electrons in the atomic lattice of metals, or as free electrons in vacuum.

Free electrons in vacuum can be accelerated, with their paths controlled by electric and magnetic fields. In this way narrow beams of electrons carrying high kinetic energy can be formed, which upon collision with atoms in solids transform their kinetic energy into heat. Electron-beam welding provides excellent welding conditions because it involves:

- Strong electric fields, which can accelerate electrons to a very high speed. Thus, the electron beam can carry high power, equal to the product of beam current and accelerating voltage. By increasing the beam current and the accelerating voltage, the beam power can be increased to practically any desired value.
- Using magnetic lenses, by which the beam can be shaped into a narrow cone and focused to a very small diameter. This allows for a very high surface power density on the surface to be welded. Values of power density in the crossover (focus) of the beam can be as high as 10^4 – 10^6 W/mm^2.
- Shallow penetration depths in the order of hundredths of a millimeter. This allows for a very high volumetric power density, which can reach values of the order 10^5 – 10^7 W/mm^3. Consequently, the temperature in this volume increases extremely rapidly, 10^8 – 10^{10} K/s.

The effectiveness of the electron beam depends on many factors. The most important are the physical properties of the materials to be welded, especially the ease with which they can be melted or vaporize under low-pressure conditions. Electron-beam welding can be so intense that loss of material due to evaporation or boiling during the process must be taken into account when welding. At lower values of surface power density (in the range of about 10^3 W/mm^2) the loss of material by evaporation is negligible for most metals, which is favorable for welding. At higher power density, the material affected by the beam can totally evaporate in a very short time; this is no longer electron-beam welding; it is electron-beam machining.

Results of the electron-beam application[edit]



Various forms of melted zone

The results of the beam application depend on several factors: Many experiments and innumerable practical applications of electron beam in welding technology prove that the effect of the beam, i.e. the size and shape of the zone influenced by the beam depends on:

(1) Beam power – The power of the beam [W] is the product of the accelerating voltage [kV] and beam current [mA], parameters easily measurable and precisely controllable. The power is controlled by the beam current at constant accelerating voltage, usually the highest accessible.

(2) Power density (focusing of the beam) – The power density at the spot of incidence of the beam with the workpiece depends on factors like the size of the electron source on the cathode, the optical quality of the accelerating electric lens and the focusing magnetic lens, alignment of the beam, the value of the accelerating voltage, and the focal length. All these factors (except the focal length) depend on the design of the machine.

(3) Welding speed – The construction of the welding equipment should enable adjustment of the relative speed of motion of the workpiece with respect to the beam in wide enough limits, e.g., between 2 and 50 mm/s.

(4) Material properties, and in some cases also on

(5) Geometry (shape and dimensions) of the joint.

The final effect of the beam depends on the particular combination of these parameters.

- Action of the beam at low power density or over a very short time results in melting only a thin surface layer.
- A defocused beam does not penetrate, and the material at low welding speeds is heated only by conduction of the heat from the surface, producing a hemispherical melted zone.
- At high power density and low speed, a deeper and slightly conical melted zone is produced.
- In the case of very high power density, the beam (well focused) penetrates deeper, in proportion to its total power.

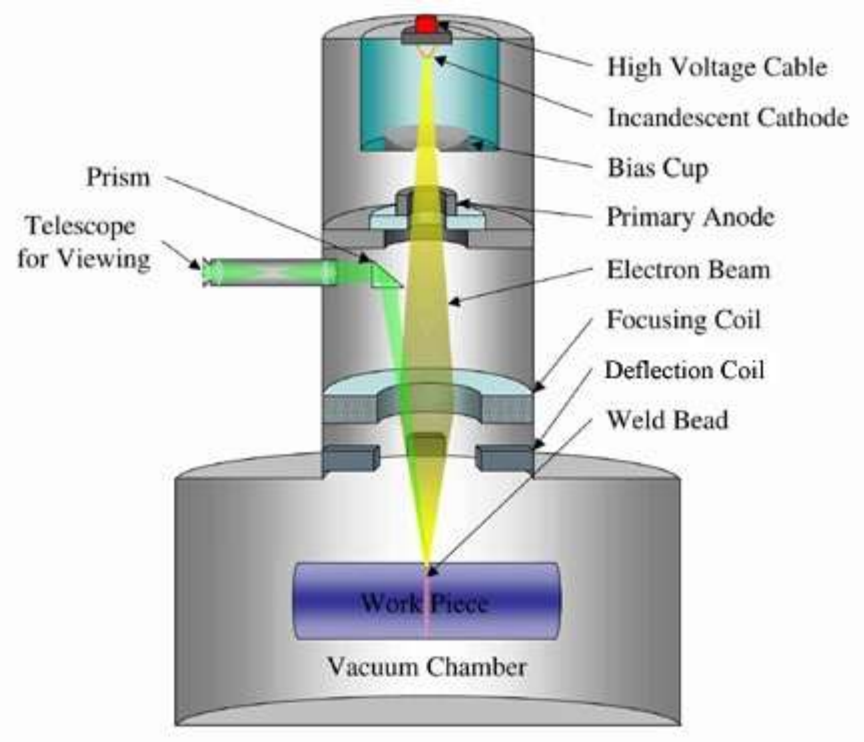
https://www.ebindustries.com/electron-beam-welding/

Electron Beam Welding is ideal when your application requires a very precise, clean weld with minimal heating of the material outside the primary area of the weld. Additionally, EB Welding is excellent for joining dissimilar and hard to weld metals.

What is Electron Beam Welding

Electron beam welding is the ultimate fusion welding process. Electrons are generated (via an electron gun) and then accelerated to very high speeds using electrical fields. This high speed stream of electrons is then focused using magnetic fields and precisely applied to the materials to be joined. As the electrons impact the materials their kinetic energy is converted to heat, which causes the metals to melt and flow together. Electron beam welding generally occurs in a vacuum as the presence of gas molecules can scatter the beam.

Because of the high voltages involved in EB welding, and the required vacuum, the entire process is computer controlled and heavily automated. The precise nature of the technology often calls for specialized fixtures to secure parts for joining, and CNC tables are commonly used to move the fixtures and workpieces within the welding chamber.



Electron beam welders are very expensive, must be tightly maintained, and the support required by the high voltage and high vacuum technologies can be demanding. However, electron beam welds are incredibly precise, strong and pure, the entire process accurately repeatable, and for many applications and materials, electron beam welding is the best joining technology there is.

A Typical Electron Beam Welding Procedure

While every Electron Beam welding job is different, there is a base procedure we follow at EB Industries that allows us to maintain both weld quality and production rate.

- The parts to be assembled are thoroughly inspected and cleaned.
- Fixtures to hold the parts securely in place during the welding process are devised. We try to maximize the number of parts that can be welded per vacuum cycle to maintain high production rates. If necessary, fixtures are custom made in our complete machine shop.
- Parts are loaded into their fixtures and the fixtures attached to the Electron Beam welder's CNC table. The CNC table is programmed to precisely move the parts into position under the electron beam during the welding process
- The vacuum chamber is secured and the air pumped out of it to achieve the necessary partial or full vacuum required by the customer specification
- If necessary, test welds are preformed to check for proper beam alignment and focus, beam power, weld penetration and overall quality of the weld. Parameters are adjusted as needed, and continually monitored during all welder operations.

- If it is a production weld cycle, the welding operator initiates the CNC table programming and Electron Beam firing cycle. The parts are then Electron Beam welded
- At the end of the welding cycle, the vacuum chamber is pumped down and the parts and fittings are removed from the welder.
- The parts are carefully removed from their fixtures and then subjected to a full quality control inspection.

Application Advantages of Electron Beam Welding

Precise Control, Excellent Weld Depth: Weld penetration can be closely controlled — from a minuscule 0.001 inches to a depth of up to 2 inches.
Small Heat Affected Zone: Electron beam welding has a very high depth-to-width ratio. This allows for a deep and very narrow heat affected zone, which minimizes material shrinkage and distortion and allows welds in close proximity to heat sensitive components.
Strength: EB welds retain up to 95% of the strength of the base materials.
High Purity: Because electron beam welding takes place in a vacuum environment impurities such as oxides and nitrides are eliminated, and impurities in the materials are simply vaporized. This results in extremely clean welds perfect for joining a wide range of metal alloys. Click here to download a Welding Compatibility Chart.
Versatile: Electron Beam welding is excellent for joining refractory and dissimilar metals which are not weldable with conventional welding process.
Production Capable: Our CNC controlled welders ensure precise control and repeatability at feed rates from 1 to 200 inches per minute.

http://www1.nas.gov.ua/pwj/beam/technol.html

National Academy of Sciences of Ukraine
E.O. Paton Electric Welding Institute

Electron Beam Welding

CLOSING OF CIRCUMFERENTIAL WELDS OF THICK STEELS

The accomplishment of the circumferential closed welds in thick-walled cylindrical shells encounters specific difficulties connected with a setting-up of the conditions at the weld closing, as there exists a danger of the defect initiation at this region. The E.O. Paton Welding Institute has developed the technique and technology of EBW of up 150 mm thick steels, which provides the high quality of the welded joints not only in the linear part of the welds, but, what is especially important, in the region of their overlapping and crater run - off. Figure 1 shows the longitudinal and transvers macrosections of the weld closing region in EBW of 150 mm thick steel. During development of the circumferential weld closing technique the new special procedures were used to prevent the defect formation due to decrease in the effect of perturbation factors on the weld formation and increase in the welding pool stability.

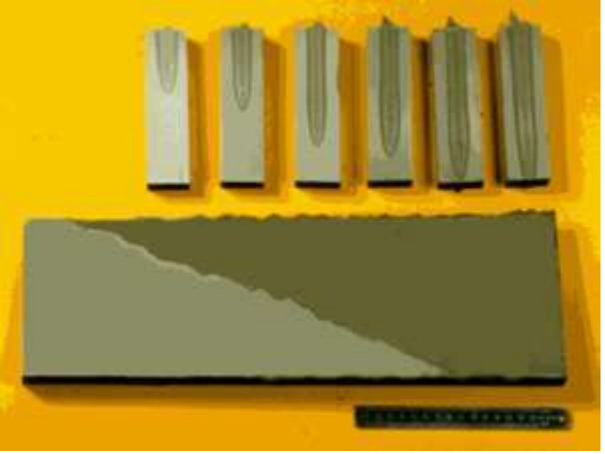


Fig.1. The longitudinal and transverse macrosections of the weld closen region in electron beam welding of 150 mm thick steel.

BIREFRINGENCE SCANNING

Application of the birefringence scanning of beam (1) became an additional means for the weld shape control (Figure 2).

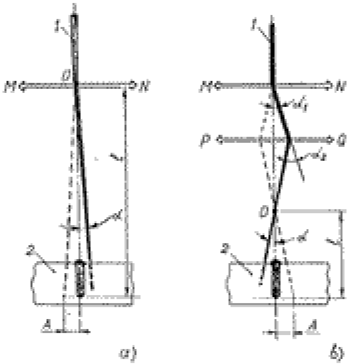


Fig. 2. Scheme of electron beam scanning
a) conventional scanning with one deflection system,
b) birefringence scanning (with use of two deflection systems), A-scanning amplitude.

Scanning is performed by two electromagnetic deflection systems MN and PQ located one after another along the gun axis . By changing the ratio between the currents in the deflection systems it is possible to control the position of the deflection centre, namely: to immerse into the welding pool depth, to scan in height with respect to the workpiece (2), to change the scanning amplitude and, due to this, to control the weld shape.

EBW PROCESS CONTROL

Taking into consideration the complexity in EBW process control at the region of the welding conditions setting- up, a software and hardware were developed by using a processor being compatible with IBM-PC/AT.

When programming the EBW conditions at the fade-out region, the operator divides all the length of the region into separate areas, sets the coordinates of points of the beginning and end of the regions into the program, indicates the currents of a beam, focusing lens, welding speed and other condition parameters. In the process of welding the parameters are displayed on the monitor in the form of graphs in a real time (Figure 3).

https://www.techbriefs.com/component/content/article/tb/features/articles/9998

Laser Beam vs. Electron Beam Welding Which process works best for what?

Proponents of laser beam welding (LBW) and electron beam (EBW) welding each pronounce the singular praises of their favored technology, but often the best solution for a customer is to use both technologies together. Both processes are well suited to joining components with complex geometries, and capable of meeting the most stringent demands for metallurgical characteristics of the final assembly.

Figure 1. Solid-state Laser Welding System (Photo courtesy of TRUMPF Inc.)

Using both laser and electron beam technologies in a single facility can streamline the manufacturing process when a component's design incorporates multiple weld joints separately tailored for one process or the other. Examples include sensors, medical devices, and products that require an inert gas or vacuum to be sealed within the finished part.

Laser processing is required either when the size of the final assembly is too large for an EB welding chamber, some component in an assembly is incompatible with vacuum processing (such as a liquid or gas), or when the weld is inaccessible to an electron beam source. Electron beam will be the primary choice when the completed assembly must be sealed with internal components under vacuum, when weld penetrations exceed ½", when the material is challenging to initiate laser coupling, or when the weld must not be exposed to atmospheric conditions until it has cooled to an acceptable temperature. Examples are aerospace welding of titanium and its alloys, and many refractory metals such as tungsten, niobium, rhenium, and tantalum.

LBW – Simpler Tooling and Shorter Cycle Times

Laser welding energy sources utilize either a continuous wave (CW) or pulsed output of photons. With CW systems, the laser beam is always on during the welding process. Pulsed systems are modulated to output a series of pulses with an off time between those pulses. With both methods, the laser beam is optically focused on the workpiece surface to be welded. These laser beams may be delivered directly to the part via classical hard-optics, or through a highly flexible fiber optic cable capable of delivering the laser energy to distant workstations.

It is the high energy density of the laser that allows the surface of the material to be brought to its liquidus temperature rapidly, allowing for a short beam interaction time compared to traditional welding methods such as GTAW (TIG welding) and similar processes. Energy is thus given less time to dissipate into the interior of the workpiece. This results in a narrow heat-affected zone and less fatigue debit to the component.

Beam energy output can be highly controlled and modulated to produce arbitrary pulse profiles. Weld seams may be produced by overlapping individual pulses, which reduces heat input by introducing a brief cooling cycle between pulses, an advantage for producing welds in heat sensitive materials.

Salay Stannard, a materials engineer for Joining Technologies, an East Granby, CT-based innovator in laser cladding, electron beam and laser welding applications, notes that CW lasers can achieve penetrations up to and exceeding 0.5 inches, while pulsed lasers typically achieve only 0.030-0.045 inches. She says, “These results may vary between laser systems and are largely dependent on processing parameter choice and joint design.” Figure 1 depicts the construction of a solid-state laser welding system.

Table 1 - Advantages of Laser Welding

Lower capital equipment costs – cost advantage over EBW • No physical constraints of an enclosure or vacuum chamber enables simplified setup, rapid cycling, and less complex single station tooling
Shorter cycle than EBW times translate to lower cost
Simpler tooling requirements than EBW
Small heat affected zone
Scalable (1 laser servicing several platforms)
Many OEMs support the technology
Lower training costs than EBW
No x-rays generated

Table 2 - Advantages of EB Welding
Welding in a vacuum ensures no gas contamination
Deeper penetration than LBW with high aspect ratios
Energy absorption independent of material or surface conditions
Similar heat affected zone to LBW
Permits welding of refractory and dissimilar metals not weldable with conventional welding processes
Proven track record, widely accepted
Included in many welding specifications

Salay Stannard, a materials engineer for Joining Technologies, an East Granby, CT-based innovator in laser cladding, electron beam and laser welding applications, notes that CW lasers can achieve penetrations up to and exceeding 0.5 inches, while pulsed lasers typically achieve only 0.030-0.045 inches. She says, "These results may vary between laser systems and are largely dependent on processing parameter choice and joint design." Figure 1 depicts the construction of a solid-state laser welding system.

Stannard adds, "Since the heat source in this type of welding process is the energy of light, the weld material's reflectivity should be considered. For example, gold, silver, copper and aluminum require more intense energy input. Once melted, the reflectivity is reduced and the thermal conductance of the process progresses to achieve penetration."

As noted, the laser's high power density results in small heat-affected zones and ensures that critical components are unharmed. This has particular advantage for surgical instruments, electronic components, sensor assemblies and many other precision devices. Unlike EBW, LBW does not generate any x-rays and is easily manipulated with automation and robotics. Generally, LBW has simpler tooling requirements as well, and there are no physical constraints of a vacuum chamber. Shorter cycle times translate to cost advantages without sacrificing quality. Table 1 lists the advantages of continuous wave and pulse LBW.

BW – DEEPER WELD PENETRATION AND CONTAMINATION FREE

Widely accepted across many industries, EBW permits the welding of refractory and dissimilar metals that are typically unsuited for other methods. As shown in Figure 2, the workpiece is bombarded with a focused stream of electrons travelling at extremely high speed. The kinetic energy of the electrons is converted to heat energy, which in turn is the driving force for fusion. Usually no added filler material is required or used, and post-weld distortion is minimal. Ultra-high energy density enables deep penetration and high aspect ratios, while a vacuum environment ensures an atmospheric gas contamination-free weld that is critical for metals such as

Figure 2. Electron Beam Welding titanium, niobium, refractory metals, and nickel-based super-alloys.

However, the main necessity for operating under vacuum is to control the electron beam precisely. Scattering occurs when electrons interact with air molecules; by lowering the ambient pressure electrons can be more tightly controlled.

Modern vacuum chambers are equipped with state-of-the-art seals, vacuum sensors, and high-performance pumping systems enabling rapid evacuation. These features make it possible to focus the electron beam to diameters of 0.3 to 0.8 millimeters.

By incorporating the latest in microprocessor Computer Numeric Control (CNC) and systems monitoring for superior part manipulation, parts of various size and mass can be joined without excessive melting of smaller components. The precise control of both the diameter of the electron beam and the travel speed allows materials from 0.001" to several inches thick to be fused together. These characteristics make EBW an extremely valuable technology.

The process puts a minimal amount of heat into the workpiece, which produces the smallest possible amount of distortion and allows finish machined components to be joined together without additional processing. Table 2 lists the main advantages of EB welding.

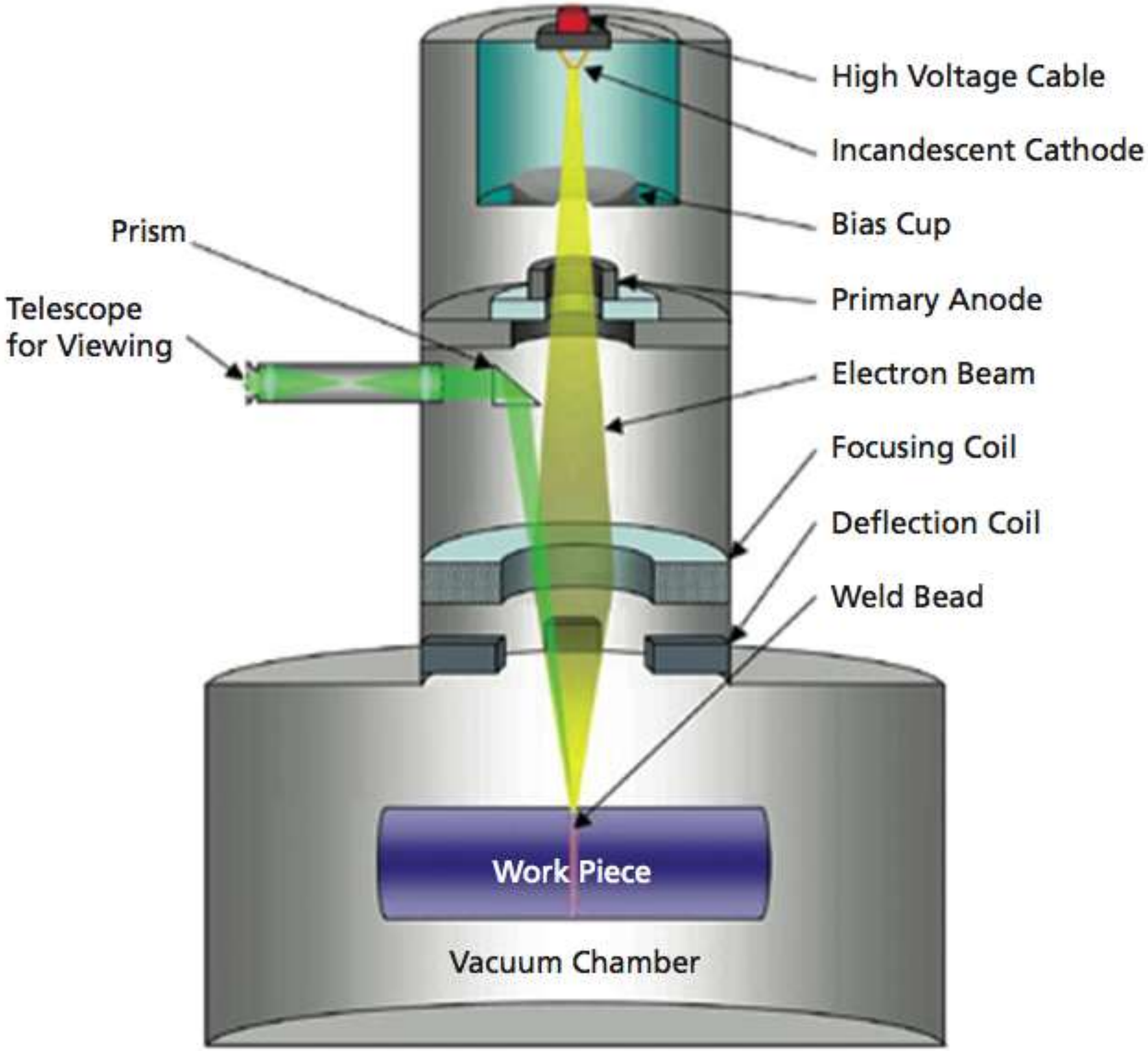


Figure 2. Electron Beam Welding

According to John Rugh, marketing and general sales manager for Enfield CT-based PTR-Precision Technologies, Inc., EBW is a process that will be in use for a long time. “Since most EB welding is performed inside a vacuum chamber, it is an excellent fit for joining advanced materials used in such industries as aerospace, power generation, medical and nuclear, which need to be produced in a vacuum environment to protect them from oxygen and nitrogen found in an open air environment.”

He adds, “The cleanliness of the welding environment is one variable that you just don’t have to worry about. In addition to providing the ideal welding environment, new EB welding controls allow for fast electromagnetic deflection of the beam, which allows the heat input of the weld and surrounding area to be customized for optimum material properties.”

For example, this rapid deflection allows preheating, welding and post heating simultaneously just by rapidly moving the beam location, focus and power levels. This provides the ability to weld difficult or “impossible to weld” alloys.

According to Geoffrey Young, general manager of Massachusetts-based Cambridge Vacuum Engineering, “EBW parts require a minimum of post weld machining and heat treatment and, unlike other fusion welding processes, EBW requires no shielding gases.” He adds, “The weld quality is exceptional, the process is extremely efficient (typically 95 percent), all the process parameters are carefully controlled and the process fully automated.”

THE BEST OF BOTH WORLDS

The Continuous Coaxial Powder Feed Nozzle allows for multidirectional laser cladding where high powder efficiency is required. It also offers excellent atmospheric shielding capabilities for materials that are highly susceptible to extreme oxidation, such as titanium.

According to John Rugh, LBW is commonly used for welding steel sheet metal components and machined components under 1/3 to ½ inches thick. Laser welding is also useful for joining parts that are not suitable for processing inside a vacuum chamber.

“Some parts and their associated welding fixtures may be too large to fit into the EB welding chambers available,” said Rugh. “Aside from size, if the components being welded contain liquids that would interfere with vacuum pumping, laser welding would be a good choice.” It takes minutes to evacuate an EB welding chamber and that time may not be worth it for a less sensitive weld.

If components are of high value, made of a material that would benefit from the vacuum environment such as titanium and nickel alloys, the welds are deeper than 1/3 to 1/2 inch or if the laser beam has difficulty coupling with the material being welded, such as aluminum alloys, EB welding is often the process of choice over laser welding.

While each technology has its benefits, in practical terms, many component designs incorporate both EB and laser welds. In these cases performing both types of welding at the same facility definitely streamlines the manufacturing process.

This article was written by John Lucas, Process Development Technician, Joining Technologies (East Granby, CT). For more information, contact John at jlucas@joiningtech.com, or visit http://info.hotims.com/34454-200.

laser. A device producing a concentrated coherent light beam by stimulated electronic or molecular transitions to lower energy levels. Laser is an acronym for "light amplification by simulated emission of radiation."

laser beam diameter. The diameter of a laser beam circular cross section at a specified location along the laser beam axis.

laser beam welding (LBW). A welding process producing coalescence with the heat from a laser beam impinging on the joint.

laser beam cutting (LBC). A thermal cutting process severing metal by locally melting or vaporizing it with the heat from a laser beam. The process is used with or without assist gas to aid the removal of molten and vaporized material. See also **laser beam air cutting**, **laser beam evaporative cutting**, **laser beam inert gas cutting**, and **laser beam oxygen cutting**.

laser beam air cutting (LBC-A). A laser beam cutting process variation melting the workpiece and using an air jet to remove molten and vaporized material.

laser beam oxygen cutting (LBC-O). A laser beam cutting process variation using heat from the chemical reaction between oxygen and the base metal at elevated temperatures. The necessary temperature is maintained with a laser beam.

laser beam inert gas cutting (LBC-IG). A laser beam cutting process variation melting the workpiece and using an inert assist gas to remove molten and vaporized material.

laser beam evaporative cutting (LBC-EV). A laser beam cutting process variation vaporizing the workpiece, with or without an assist gas, typically inert gas, to aid the removal of vaporized material.

laser beam brazing (LBB). A brazing process using a laser beam as the heat source.

laser beam braze welding (LBBW). A braze welding process variation using a laser beam as the heat source.