AWS C7.1M/C7.1:2026
An American National Standard

Recommended Practices for Electron Beam Welding and Allied Processes

American Welding Society®

Approved American National Standard
ANSI

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An American National Standard

Approved by the
American National Standards Institute
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Recommended Practices for Electron Beam Welding and Allied Processes

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Prepared by the
American Welding Society (AWS) C7 Committee on High Energy Beam Welding and Cutting

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

This document presents recommended practices for electron beam welding and allied processes. It is intended to cover common applications of the process. Processes definitions, safe practices, general process requirements, and inspection criteria are provided.

American Welding Society®

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Foreword

This foreword is not part of this standard but is included for informational purposes only.

Background: Electron beam processing was initiated in the early 1900s, when an electron beam was used to produce tantalum metal by melting tantalum sponge. Since then, electron beam technology for materials processing has steadily advanced and is now commonly used. While electron beam processing encompasses a wide range of metal processing activities, this document focuses on welding and joining. The commercial application of electron beam welding (EBW) was first introduced in the late 1950s and subsequently gained rapid and widespread acceptance by the industrial community because of its ability to produce high aspect ratio (depth-to-width) welds and join dissimilar and difficult-to-weld materials. Welding speeds on the order of 760 mm/s [1800 in/min] and single-pass autogenous welds in metals of greater than 150 mm [6 in] thickness have been achieved.

There are significant numbers of electron beam welders presently in operation throughout the world utilized in automotive, aircraft and aerospace, nuclear, job shop, and other industrial applications. Units having over 35 years of operational time are still being used on a regular basis—if not by the original purchaser, then by the 2nd or 3rd owner of the unit. This shows that the equipment being supplied by the EBW manufacturers has a demonstrated history of performing durably and reliably.

The information contained in the Recommended Practices was compiled by the American Welding Society's C7B Subcommittee on Electron Beam Welding and Cutting and has been carefully reviewed by a number of experts in the field, and should provide a helpful guide for use in applying the electron beam welding process. It must be noted that the operating parameters specified in these recommended practices will not be the only possible parameter combinations that can be employed for successfully processing the materials and thicknesses shown. Changes in material composition, dimensional tolerances, and machine calibration will cause changes in the resulting welds. Therefore, the procedures contained herein are offered simply as a guide and are intended only for use in aiding the application of electron beam technology and increasing process consistency.

The first edition of C7.1M/C7.1 was published in 1992 as *Recommended Practices for Electron Beam Welding*. This code was revised in 1999, 2004, and again in 2013. This is the fifth edition AWS C7.1M/C7.1, *Recommended Practices for Electron Beam Welding and Allied Processes*.

This revision has undergone significant editorial and technical revisions from the previous edition; for readability and formatting purposes changes from the previous edition have not been underlined. This edition has undergone significant revisions including, but not limited to, the list below:

Summary of Changes

Clause/Annex	Modification
Clause 4	Equipment description has been moved to Clause 4 previously listed in Clause 6. Defined EBW System Upgrades and Options. Added process modes to Vacuum Chamber Configurations of Electron Beam Welding.
Clause 7	A new section has been added to describe Electron Beam Directed Energy Deposition (EB-DED) and Electron Beam Powder Bed Fusion (EB-PBF) processes.
Clause 9	The allied processes are defined in their own section under Electron Beam Transformation Hardening and Allied Processes
Annex C	Practical examples are no longer a part of the body of the specification, they have been moved to Annex C.

Normative Annexes. These annexes address specific subjects in the code and their requirements are mandatory requirements that supplement the code provisions.

Informative Annexes. These annexes are not code requirements but are provided to clarify code provisions by showing examples, providing information, or suggesting alternative good practices.

Errata. All errata to a standard shall be published in the *Welding Journal* and posted on the AWS website <www.aws.org/standards/page/errata>.

Suggestions. Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary, AWS C7 Committee on High Energy Beam Welding and Cutting, American Welding Society, 8669 NW 36 St, # 130, Miami, FL 33166.

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Recommended Practices for Electron Beam Welding and Allied Processes

1. General Requirements

1.1 Scope. These recommended practices present descriptions of electron beam welding equipment and procedures for welding a wide range of metals and thicknesses; allied processes, to include electron beam braze welding (EBBW), cutting, drilling, surfacing, additive manufacturing, surface texturing, and heat treating, are also discussed. The appropriate terms, definitions, and safety considerations are presented. Information is included on designing for electron beam welding (EBW), welding dissimilar metals and thicknesses, fixturing, specifications, and operator training and qualification.

Highly technical and detailed descriptions of metallurgy and the physics of the EBW process, though important to the engineer and scientist, were considered beyond the scope of this publication.

Although this recommended practice is not written with mandatory requirements, mandatory language, such as the use of "shall", will be found in those portions of the document where failure to follow the instructions or procedures could produce inferior, misleading, or unsafe results.

1.2 Units of Measurement. This standard makes use of both the International System of Units (SI) and U.S. Customary Units. The latter are shown within brackets ([ ]) or in appropriate columns in tables and figures. The measurements may not be exact equivalents; therefore, each system must be used independently.

1.3 Safety. Safety issues and concerns are addressed in this standard, although health issues and concerns are beyond the scope of this standard.

Safety and health information is available from the following sources:

American Welding Society:

(1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*

(2) AWS Safety and Health Fact Sheets

(3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

(1) Safety Data Sheets supplied by materials manufacturers

(2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous, and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments or revisions of the publications may not apply since the relevant requirements may have changed.

American Welding Society (AWS) standards:

AWS A2.4, *Standard Symbols for Welding, Brazing, and Nondestructive Examination*

AWS A3.0M/A3.0**,** *Standard Welding Terms and Definitions*

American National Standards Institute (ANSI) standards:

ANSI/ASSE Z87.1, *Occupational and Educational Personal Eye and Face Protection Devices*

ANSI/HPS N43.3, *For General Radiation Safety—Installations Using Nonmedical X-Ray and Sealed Gamma-Ray Sources, Energies up to 10 MeV*

ANSI Z535.1, *Safety Color Code*

ANSI Z535.2, *Environmental and Facility Safety Signs*

ANSI Z535.5, *Accident Prevention Tags*

American Vacuum Society (AVS) document:

AVS M-1, *Vacuum Hazards Manual*

3. Terms and Definitions

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions*, provides the basis for terms and definitions used herein. However, the following terms and definitions are included below to accommodate usage specific to this document. In addition, Annex B, Extended Glossary for Electron Beam Processing, is included to supplement the following terms and definitions.

alignment. Any mechanical or electromagnetic adjustment of the electron beam equipment that is made for the purpose of correcting the path or position of the beam.

alignment coils. Electromagnetic deflection coils immediately below the anode used to deflect the beam so its axis coincides with the magnetic axis of the focus coil.

anode. The more electrically positive element of the electron beam gun (usually at the ground potential of the machine) through which the electron beam passes.

back-up bar. Material placed on the opposite side of a joint for the purpose of containing beam energy exiting a complete joint penetration weld.

beam current. Measure of the quantity of electrons flowing per unit time in an electron beam, usually expressed in units of milliamperes (mA).

beam deflection. Translation of the electron beam is controlled via an electromagnetic field rather than the physical motion of the electron gun or workpiece. It can be static or dynamic movement superimposed on the steady movement along the weld path. The manipulation of the electromagnetic fields that is used to direct the beam can be in a variety of patterns: circular, elliptical, linear, sinusoidal, or user defined. See also **beam rastering** for application of beam deflection and beam oscillation. An act of beam deflection using repeated movements.

beam deflection coils. Electromagnetic coils used to change the path of the electron beam.

beam forming electrode. See **bias cup**.

beam modulation. Any change in beam current (may be periodic).

beam oscillation. An act of beam deflection using repeated movements. See **beam deflection**.

beam power. A measure of the kinetic energy of the beam per unit time and equal to the product of the accelerating current times the beam current. In equation form, the beam power, P, in watts (W), is as follows:

$$P = V \times I \quad (1)$$

where

V = Accelerating current, kilovolts (kV)
I = Beam current, milliamperes (mA)

beam rastering. A method of high speed beam deflection (kilohertz range or higher) used for simulated multi-beam processing (joint detection, pattern generation, multi-welds, and in situ postweld heat treatment).

beam spot. Apparent size of the beam impingement area on the surface of the workpiece (working spot size as opposed to focal spot size). See also **focal spot** in AWS A3.0M/A3.0, *Standard Welding Terms and Definitions*.

bias cup. Component of a triode gun, more electrically negative than the cathode, used as a grid to control the beam current and shape the beam. Also referred to as grid cup, Wehnelt, or cathode. See also **triode gun**.

cathode. A filament or for triode gun an assembly consisting of bias cup and filament. Usually the removable components that facilitate replacement of the filament. See also **electron beam gun**.

CNC. An acronym for *Computerized Numerical Control*.

cold shut. A form of weld discontinuity caused by material solidifying at an interface before the liquid metal on either side of the interface flows together to form a continuous structure.

column valve. A vacuum valve between the electron gun and the work chamber, used to preserve vacuum and prevent contamination of the gun when the chamber is vented. Also referred to as gun valve.

conduction mode. Welding at a power density below that required to form a keyhole, where the primary method of obtaining joint penetration is heat conduction in the material being welded. See also **keyhole mode**.

convergence angle. The angle formed between the axis of the beam and the outermost electron trajectories as they approach sharp focus.

corona clear. A technique for removing contamination from the electron beam gun by using a higher than normal accelerating potential. Sometimes referred to as glow discharge cleaning or gun clearing.

defocus. The act of positioning the focal spot above or below the workpiece level when welding. See also **focus**.

degauss. The act of demagnetizing a part or fixture in order to reduce unwanted magnetic fields.

diode gun. An electron beam gun where the cathode and bias cup operate at the same electrical potential.

electron beam. Electrons accelerated and shaped into a directed stream by an applied electrical potential.

electron beam directed energy deposition (EB-DED) *additive manufacturing*. A process using commercially available wire or powder as feedstock material, melted by the electron beam with parts built layer by layer on a substrate until a targeted near net shape is achieved. This process, also known as electron beam free form fabrication (EBFFF), electron beam direct manufacturing (EBDM) or electron beam additive manufacturing (EBAM).

electron beam direct manufacturing (EBDM). See electron beam directed energy deposition (EB-DED).

electron beam free form fabrication (EBFFF). See electron beam directed energy deposition (EB-DED).

electron beam gun. A device for producing and accelerating electrons. The components include a filament, a bias cup, and an anode.

emitter. See **filament**.

external gun. An electron beam gun mounted outside the welding chamber. This beam is passed through the chamber wall and the workpiece is moved to accomplish welding.

filament. The source of electrons, commonly a segment of tungsten or tantalum, heated to a temperature where thermionic emission occurs. The term is often used to describe the electron emitting component of an **electron beam gun**.

filament current. Direct or alternating current used to heat the cathode to produce electron emission.

filament kneeing. A technique used to establish space charge limited emission of the cathode and to prevent cathode overheating. Also referred to as filament peaking. See also **space charge limited emission**.

fluence. The number of electrons, or other charged particles, deposited on a surface area. It is proportional to current density x time, therefore proportional to the deposited electric charge and measured in Coulombs. It is not proportional to energy. It is not used in connection with beam power tools.

focus. Converging an electron beam to form a focal spot using electromagnetic or electrostatic forces. See also **focusing coil**.

focus block. See **target**.

focusing coil. Electromagnetic coil, coaxial to the electron beam, acting as a lens to converge the beam's electrons radially to form a focal spot. Sometimes referred to as focusing lens.

gun cartridge. An interchangeable gun component allowing for filament insertion and alignment away from the welding machine.

gun-to-work distance. A linear measurement made between a reference surface, related to the electron beam gun, and the workpiece.

high energy beam welding (HEBW). A group of welding processes using beams of energy with sufficient density to produce the coalescence of workpieces. The processes are applied with and without the application of pressure and with or without the application of filler metal.

high-energy electron beam (HEEB). An electron beam having an energy level in the 1 MeV to 10 MeV range. See also **fluence**.

high voltage electron beam. A relative term normally used to identify electron beam equipment employing an accelerating potential in excess of 60 kV, but under 1 MeV. See also **low voltage electron beam**.

high voltage tank. A container, usually filled with insulating oil, which encloses and isolates the high voltage generating components of an electron beam system.

joint scanning. Preweld joint sensing using a low-power electron beam employed for alignment purposes.

keyhole mode. A technique in which a concentrated heat source penetrates partially or completely through a workpiece, forming a hole (keyhole) at the leading edge of the weld pool. As the heat source progresses, the molten metal fills in behind the hole to form the weld bead.

kneeing. See **filament kneeing**.

lens. See **focus coiling**.

low-voltage electron beam. A relative term normally used to identify electron beam equipment employing a accelerating potential of 60 kV or less. See **high-voltage electron beam**.

multi-beam. Employing high speed deflection as a means for utilizing a single beam to perform multiple tasks in a seemingly simultaneous manner.

mobile gun. Electron beam gun that may be moved about within the welding chamber and typically operates at 60 kV or less. Higher voltages are possible and are being explored.

oscillation frequency. The frequency at which the electron beam is deflected.

outgassing. A condition where a material, object, or one or more of their constituents has a vapor pressure greater than the surrounding environment and evaporates. See also **virtual leak**.

overpowering. Using more beam power than is required for full penetration in order to avoid sensitivity to material and equipment variations.

pulse. A brief, controlled excursion of beam-input energy generally performed in a repetitious fashion.

pump-down time. The time required to evacuate the weld chamber down to the desired welding vacuum level in high or medium vacuum variations.

pumped gun. An electron beam gun with its own directly connected evacuation system.

radiation shielding. Material to protect personnel from exposure to harmful radiation. Lead shielding or heavy-section steel is used.

radiographic window. A groove cut into a weld joint used to help verify partial penetration welds tested by radiographic methods. The groove is typically consumed and filled by the weld. When the groove is not consumed, an incomplete joint penetration or a missed joint condition is indicated.

space charge limited emission. Equilibrium condition in which any additional electron emission from additional cathode heating is prevented by electrons accumulating in front of the cathode. The cathode temperature at which emission becomes space-charge limited increases with increasing accelerating voltage. See also **filament kneeing**.

specific power. Power density in the electron beam, usually expressed in units of watts per square centimeter.

spiking. A condition in partial penetration welding where the depth of fusion is nonuniform and changes abruptly.

spot size. See **focal spot** in AWS A3.0M/A3.0, *Standard Welding Terms and Definitions*.

target. A piece of material, usually copper or tungsten, used for electron beam impingement while setting welding parameters and during radiation leakage checks.

temperature-limited emission. Condition in which beam current increases with cathode temperature and is not considered a stable emission condition for welding applications.

thermionic emission. Emission of electrons or ions by substances that are highly heated, the charged particles being called thermions. The number of thermions emitted increases rapidly as the temperature of the substance rises.

triode gun. An electron gun configuration utilizing a bias electrode, commonly called a bias or bias cup, to regulate beam current independently of accelerating potential. See also **bias cup**.

vacuum level. Internal chamber pressures less than ambient atmospheric pressure. Higher vacuum level correlates to lower internal pressure

vapor plating. Condensation of metal vapors evolved during welding.

vapor shields. Optically transparent elements used to protect the optical surfaces of viewing systems or windows from the metal vapors produced during welding.

virtual leak. An apparent vacuum leak that has no communication with atmosphere.

witness lines. Scribed lines on either side of a joint used to verify weld centering on the joint. These lines may or may not be consumed during welding, allowing for postweld inspection.

Supplemental terms and definitions are included in Annex B, Extended Glossary for Electron Beam Processing.

4. Equipment Description

4.1 Introduction. Electron beam processing can be performed in a variety of ways utilizing various machine designs and power ratings. This section describes the four most common types of EBW systems, differences between high and low-voltage machines, and typical components that make up an EBW machine.

4.2 Vacuum Chamber Configurations of Electron Beam Welding. The level of vacuum needed to perform a sufficient weld will determine the system type required.

4.2.1 High-Vacuum Electron Beam Welding (EBW-HV) (1.3×10^{-3} mBar [1.0×10^{-3} torr] or higher). High-vacuum electron beam welding (EBW-HV) is the most common form of electron beam welding which produces high-quality weldments. This is when the welding chamber is held at 1.3×10^{-3} mbar [1.0×10^{-3} torr] or higher.

4.2.1.1 Gun Styles: Stationary or Mobile. Generally stationary guns have gun columns that are hard mounted externally to the workpiece chamber or to a single axis slide for minimal/limited motion. Truly mobile guns are mounted on a gantry system internal to the workpiece chamber and have a much broader range of motion, sometimes up to 5 axes. Mobile gun systems like that shown in Figure 1, tend to rely on the workpiece chamber vacuum to provide adequate vacuum