AWS D16.1M/D16.1:2026
An American National Standard

Specification for Robotic Arc Welding Safety



American Welding Society®



AWS D16.1M/D16.1:2026
An American National Standard

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Specification for

Robotic Arc Welding Safety

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Prepared by the
American Welding Society (AWS) D16 Committee on Robotic and Automatic Welding

Under the Direction of the
AWS Technical Activities Committee

Approved by the
AWS Board of Directors

Abstract

This standard establishes safety requirements with respect to the design, manufacture, maintenance, and operation of arc welding robot systems and ancillary equipment. It also helps to identify and minimize hazards involved in maintaining, operating, integrating, and setting up of arc welding robot systems.

American Welding Society®

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Foreword

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

The AWS D16 Committee on Robotic and Automatic Welding was organized in 1985 to provide a centralized source for the exchange of technical information between manufacturers, installers, integrators, and operators of robotic and automated equipment. It has developed a number of standards related to robotic arc welding systems and their applications, as shown in the List of AWS Documents on Robotic and Automatic Welding.

The first edition of AWS D16.1M/D16.1:2004, *Specification for Robotic Arc Welding Safety*, was initially published in 2004. The third edition provides updated guidelines for the safe use of arc welding robots. It includes requirements for collaborative applications and safety features. Although safe practices for arc welding are covered in many standards, this standard focuses on safety aspects unique to robotic arc welding applications.

A vertical line in the margin or underlined text in clauses or figures indicates an editorial or technical change from the previous edition.

Comments and suggestions for the improvement of this standard are welcome. They should be sent to the Secretary, AWS D16 Committee on Robotic and Automatic Welding, American Welding Society, 8669 NW 36 St, # 130, Miami, FL 33166.

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1 Example of a Typical Robotic Arc Welding Cell 1

Specification for Robotic Arc Welding Safety

1. General Requirements

1.1 Scope. The requirements of this standard apply to industrial robot systems that are used to perform the gas metal arc welding (GMAW) with solid or metal cored wires, and flux cored arc welding (FCAW) processes. The purpose of this standard is to establish minimum safety requirements with respect to the design, manufacture, maintenance, and operation of arc welding robot systems and ancillary equipment. It is also designed to help identify and minimize hazards involved in maintaining, operating, and setting up of arc welding robot systems. This standard includes principles that may be applied to robotic systems with other arc welding processes.

A typical industrial arc welding robot system is illustrated in Figure 1. There may be other accessories that are outside the scope of this document.

1.1.1 Applications

1.1.1.1 New or Remanufactured Installations. The requirements of this standard pertaining to design and manufacture shall apply to all new or remanufactured arc welding robot systems, fixtures, and ancillary equipment manufactured for installation or installed after the compliance date subsequent to the ANSI approval date of this standard. Compliance to the standard shall be 12 months after the ANSI approval date.

1.1.1.2 Existing or Rebuilt Installations. Existing installations or the repair or rebuilding thereof shall be compliant with the standards in effect at the time of their original installation. Modifications to fixtures, end-of-arm devices, or ancillary equipment shall be reviewed for the creation of new hazards. Such new hazards shall be safeguarded in accordance with the applicable clauses of this standard.

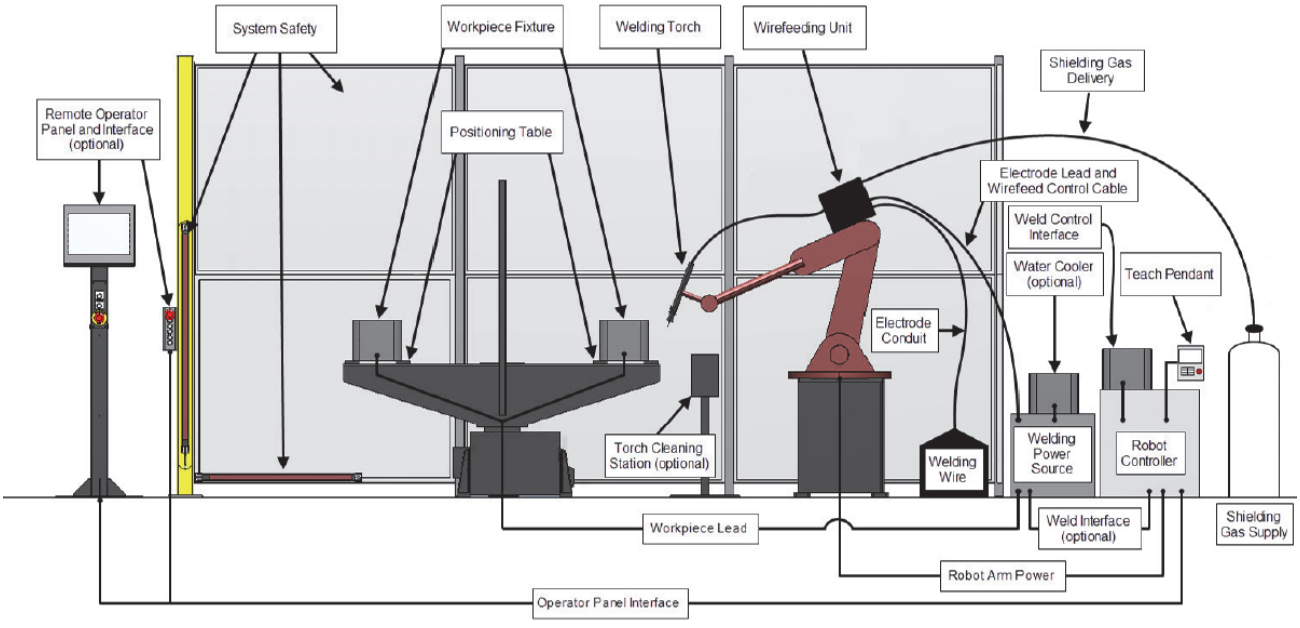


Figure 1—Example of a Typical Robotic Arc Welding Cell

1.1.1.3 All Installations. The requirements of Clauses 7 and 8 of this standard pertaining to the use and maintenance of arc welding robot systems shall apply to all users subsequent to the specification of this standard.

1.1.2 Exclusions. This standard applies to arc welding robot systems and is not intended to apply to the following machines:

(1) Non arc welding robots

(2) Automated guided vehicle systems

(3) Undersea and space robotics

(4) Automatic conveyor and shuttle systems

(5) Teleoperators

(6) Mobile robots

(7) Resistance welding robots

This list is not intended to be all-inclusive.

1.1.3 Responsibilities. The responsibility for the application of this standard is defined by this standard.

1.1.3.1 Manufacturer or Remanufacturer. It shall be the responsibility of the arc welding robot machine manufacturer or remanufacturer to design and construct the arc welding robot system in accordance with Clause 4 of this standard.

1.1.3.2 Rebuilder or Modifier. It shall be the responsibility of any person rebuilding or modifying arc welding robot systems to do so in accordance with portions of Clause 4 of this standard applicable to components being rebuilt or modified.

1.1.3.3 System Integrator. The system integrator shall ensure that the system complies with Clause 6 of this standard. The System Integrator has the responsibility to ensure that any modifications made to the arc welding robot systems shall conform to Clause 4. The user shall be the system integrator unless another party contractually accepts responsibility as the system integrator.

1.1.3.4 User. Users should make training available for operators, programmers, and maintenance technicians to help them attain and maintain certifications, such as the Certified Robotic Arc Welding Technician/Operator Program.

1.2 Units of Measurement. This standard makes use of both 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 A3.0M/A3.0, *Standard Welding Terms and Definitions, Including Terms for Additive Manufacturing, Adhesive Bonding, Brazing, Soldering, Thermal Cutting, Thermal Spraying, and Nondestructive Examination.*

AWS D16.2M/D16.2, *Guide for Components of Robotic and Automatic Arc Welding Installations*

AWS D16.3M/D16.3, *Risk Assessment Guide for Robotic Arc Welding*

AWS D16.4M/D16.4, *Specification for the Qualification of Robotic Arc Welding Personnel*

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

International Organization for Standardization (ISO) standards:

ISO 8373, *Manipulating Industrial Robots— Vocabulary*

ISO 10218-1, *Safety Requirements Part 1, Industrial Robots*

ISO 10218-2, *Safety Requirements Part 2, Industrial Robot Applications and Robot Cells*

Occupational Safety and Health Administration (OSHA) documents:

OSHA 1910.147, *Control of Hazardous Energy (Lockout/Tagout)*

OSHA 1910.212, *General Requirements for all Machines*

OSHA 1910.219, *Mechanical Power Transmission Apparatus*

OSHA 1910 Subpart Q, Welding, Cutting, and Brazing

OSHA 3120, *Control of Hazardous Energy (Lockout/Tagout)*

OSHA 3075, *Controlling Electrical Hazards*

Robotic Industries Association (RIA) document:

ANSI/RIA R15.06, *Industrial Robots & Robot Systems—Safety Requirements*

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.

actuating control. Mechanical mechanism within a control device. (e.g., a rod which opens contacts).

actuator. A mechanism used to affect motion.

(a) A power mechanism which converts electrical, hydraulic, or pneumatic energy to effect motion.

(b) A mechanical mechanism within a control device (e.g., a rod which opens contacts).

(c) A device (e.g., specialized key) which initiates a (un)locking sequence.

ancillary equipment. A component added to an industrial robotic welding system to provide an extra function to support the welding process or its application. (e.g., laser scanners, video cameras, nozzle cleaners, wire cutters, anti-spatter spray, wire straighteners).

anti-repeat. The part of the machine control system designed to limit the arc welding robot system to a single cycle if the cycle actuating means are held or tied down. Anti-repeat requires release of all cycle actuating mechanisms before another cycle can be initiated.

anti-tie down. A circuit designed to prevent machine operation in case a control is continuously actuated.

application. A description compiled by the user of the components that are to be welded, the weld process to be used, the sequence of operation of the welding robot(s), and any other information needed to understand the operation of the system and assess potential risks.

automatic mode. Operating mode in which the robot executes the task program independent of continuous operator control or teaching, with robot operation limited by the safeguarding and safety functions defined in the risk assessment to protect personnel.

auxiliary equipment. A component integrated into an industrial robot system to provide a function additive to that of the primary robot. (e.g., integrated servo positioner under teach pendant control).

barrier. A physical means of separating persons from the hazard.

certification. The act of determining, verifying, and attesting in writing to the qualification of personnel in conformance to specified requirements.

certified operator. Any individual who has earned an AWS Certification in Robotic Arc Welding (CRAW).

cobot. A nonstandard term used to describe a robot that is intended to work in close proximity to humans, however, the application and corresponding risk assessment shall determine the appropriate proximity to humans.

collaborative application. Intended use and purpose of the robot that contain one or more collaborative task(s).

collaborative task. Portion of the robotic sequence where both the robot application and operator(s) are within the same safeguarded space.

control device. Any piece of control hardware providing a means for human intervention in the control of a robot or robot system, such as an emergency-stop button, a start button, or a selector switch.

control program. The inherent set of control instructions which defines the capabilities, actions, and responses of the robot system. This program is usually not intended to be modified by the operator.

control station. Part of the robot system which contains one or more control devices intended to activate or deactivate functions of the system or parts of the system. The control station can be fixed in place (e.g., control panel), or movable (e.g., control pendant).

cycle. The single execution of a task program.

dereeler. A system for conveying welding wire from the wire package (i.e., spools, payoff packs) of any size to the entrance of the wire feeder mechanism.

drive power. The energy source or sources for the robot actuators.

emergency stop. The circuit that, when engaged, overrides all other robot controls, removes drive power, causes all moving parts to stop, and removes energy sources, including stored energy, from other hazardous functions present in the safeguarded space but does not cause additional hazards.

enabling device. A manually operated device which when continuously activated, permits motion.

end-effector. An accessory device or tool specifically designed for attachment to the robot wrist or tool mounting plate to enable the robot to perform its intended task. Examples may include gripper, spot weld gun, arc welding gun, spray paint gun, or any other application tools.

energy source. Any electrical, mechanical, hydraulic, pneumatic, chemical, thermal, potential, kinetic or other sources of power/movement.

envelope. The three-dimensional space encompassing the movements of all robot parts (see space).

guard. A physical barrier which protects personnel from exposure to a hazardous area.

hand guiding. State in which an operator uses a hand-operated device to transmit motion commands to the robot system. The task is carried out by manually actuating the guiding device, which is typically located at or near the robot end-effector.

hazard. A potential source of harm.

hazardous motion. Any motion that is likely to cause physical harm to personnel.

industrial arc welding robot system (robot system).

(1) An industrial robot combined with ancillary and auxiliary equipment necessary to perform a production arc welding process. Typically, the robot is electrically interfaced to the ancillary and auxiliary equipment.

(2) Any work holding equipment, devices, or sensors required for the robot to perform its task.

(3) Any communication interface that is operating and monitoring the robot, equipment, or sensors, as far as these ancillary devices are supervised by the robot control system.

industrial robot. An automatically controlled, reprogrammable multipurpose manipulator programmable in three or more axes which may be either fixed in place or mobile for use in industrial automation applications.

industrial robot system. Equipment that includes the robot(s) (hardware and software) consisting of the manipulator power supply and control system; the end-effector(s); and any other associated machinery and equipment within the safeguarded space.

inspection. Examination or measurement to verify whether an item or activity conforms to specified requirements.

integrator. Entity that designs, provides, manufactures, or assembles robot systems or integrated manufacturing systems and is in charge of the safety strategy, including the protective measures, control interfaces and interconnections of the control system. The integrator can be a manufacturer, assembler, engineering company, or the user.

interlock. An arrangement whereby the operation of one control or mechanism allows or prevents the operation of another.

joint. An axis of motion. For a six (6) axis, articulated servo controlled industrial welding robot, the joints are typically defined as follows:

Joint 1—Rotary or waist rotation
Joint 2—Shoulder rotation
Joint 3—Elbow rotation
Joint 4—Outer link or upper arm rotation
Joint 5—Wrist bend or yaw
Joint 6—Wrist roll or swivel

light curtain. A non-contact perimeter barrier device which will send a signal to the system controller if an object penetrates or interrupts the plane of the perimeter.

limiting device. A device that restricts the maximum space by stopping or causing to stop all robot motion and is independent of the control program and the task programs.

lockout/tagout. A means to render equipment incapable of inadvertent release of energy from sources such as electrical, mechanical, pneumatic, and hydraulic, including stored energy, during periods of maintenance or servicing. Lockout/tagout procedures are identified within OSHA 1910.147, *The Control of Hazardous Energy (Lockout/Tagout)*.

maintenance. The act of keeping the robots and robot systems in their proper operating condition.

maintenance personnel. Person employed to inspect, repair, and maintain arc welding robot systems.

manipulator. The mechanism of a machine that usually consists of a series of segments jointed or sliding relative to one another used for grasping and/or moving objects usually in several degrees of freedom.

manufacturer. Any person or organization who manufactures, converts, modifies, or otherwise alters robotic arc welding systems.

maximum space. Space which can be swept by the moving parts of the robot as defined by the manufacturer plus the space which can be swept by the end-effector and the workpiece.

mobile robot. A self-propelled and self-contained autonomous device that is capable of moving over a mechanically unconstrained course.

monitoring device. A device, which may be used to verify the function of another device.

operator. The person designated to start, monitor, and stop the intended operation of a robot or robot system. An operator may also interface with a robot for production purposes.

operator control. Point of operation performed solely by a single individual who is responsible for the safe use of the robot.

pendant. A hand-held device electrically interconnected to the control system with which a robot can be programmed or moved. Also called teach pendant.

perimeter barrier. A rigid, fence-like structure that surrounds the restricted envelope (space) of a system of one or more robots and may have entry openings for process equipment, material, and/or personnel authorized to operate or maintain the robot system.

physical barrier. A rigid boundary to safeguard personnel access. Cages, gates, walls, shields, and fences are all examples of physical barriers.

pinch point. Any location where it is possible to be caught between moving parts or between a moving and stationary part.

point of operation. The location(s) within the safeguarded space where work is performed on the material or work piece.

power source interface. A physical box or connection between the robot controller and weld equipment to facilitate sequencing of the welding process and control of variables.

program.

(1) The instruction set of commands and locations within the robot control that determines robot arm path, speed, and could include logic and control of ancillary and/or auxiliary devices.

(2) The act of teaching the robot commands and path information.

programmers. Programmers include the system development engineers and technicians doing the initial work and the weld technicians who maintain the programs that are in production.

protective stop. Type of interruption of operation that allows a cessation of motion for safeguarding purposes, and which retains the program logic to facilitate a restart

qualification. Verification by testing of the knowledge or abilities gained through training, experience, or both that enables individuals to perform certain functions.

qualified. Having complied with specific requirements defined within a standard.

rebuilder. Any person or organization who rebuilds all or a portion of an arc welding robot system. The rebuilding may consist of any restoration of the machine to its original specification and capability.

repair. To restore robots and robot systems to operating condition after damage, malfunction, or wear.

restricted space. The portion of the maximum space restricted by limiting devices that establish limits which will not be exceeded.

risk. A combination of the probability and the degree of the possible injury or damage to health in a hazardous situation.

risk assessment. A comprehensive, documented evaluation of the possible injury or damage severity to health in a hazardous situation in order to select appropriate prevention or remediation safeguards. Risk assessments should be

conducted and documented in phases and in advance of equipment purchase, design and build, after integration, and upon final integration, installation, and commissioning at the end-user site.

robot. See industrial robot.

robot actuator. Powered mechanism that converts electrical, hydraulic, or pneumatic energy to effect motion and controlled by the robot controller.

robot system. See industrial robot system.

robotic arc welding gun. An apparatus fixed to the end of the robot that directs the placement of an electrode, plasma column or filler metal supplied as a continuous electrode and provides the means for supplying welding current and shielding gas as necessary.

robotic arc welding personnel qualification. The verification of robotic arc welding personnel's ability to meet prescribed standards for performance qualification.

robotic arc welding personnel. Individuals who may be operators, technicians, or maintenance support personnel for robotic arc welding applications.

safeguarding device. A means that detects or prevents access to a hazard.

safeguard. A barrier guard, device or safety procedure designed for the protection of personnel.

safeguarded space. The space where safeguards are active or where the perimeter safeguard provides protection.

safeguarding. The act of providing personnel with protection from a hazard.

safety procedure. A set of instructions designed for the protection of personnel.

safety rated. Tested, evaluated, and proven to operate in a reliable and acceptable manner when applied in a function critical to health and welfare of personnel.

safety rated reduced speed. A safety function that limits the robot speed to 250 mm/s [10 in/s] or less.

safety rated output. Output signal having a specified sufficient safety-related performance.

safety rated monitored standstill. Condition where the robot motion is stopped with drive power active, while a monitoring system with sufficient safety-rated performance is active.

safety rated soft axis and space limiting. Limit placed on the range of motion of the robot by a software or firmware based system having a specified sufficient safety related performance. The safety rated soft limit may be the point where the stop is initiated, or it might ensure the robot does not move beyond the limit.

sensor. A device that responds to physical stimuli (such as temperature, light, sound, pressure, magnetism, motion) and transmits the resulting signal or data for providing a measurement, operating a control, or both.

shall. A term used to designate a mandatory requirement.

shield. A barrier that protects against the hazards of arc flash, weld spatter, and/or flying sparks. The barrier may move with the fixture, positioner, or be integrated into other safety barriers.

should. A term used to designate recommended (non- mandatory) safe practices.

signage. Graphic communication whose functions include direction, identification, information, regulation, warning, or restriction.

single point of control. The ability to operate the robot such that initiation of robot motion from one source of control is only possible from that source and cannot be overridden from another source.

slow speed control. A mode of robot motion control where the speed is limited to 250 mm/s [10 in/s] to allow persons sufficient time to either withdraw from hazardous motion or stop the robot.

space. The three-dimensional volume encompassing the movements of all robot parts through their axes (previously called envelope, see Annex B for illustrations).

specification. A group of attributes, conditions, or tolerances that are desired or required.

standard. A generic term incorporating codes, specifications, recommended practices, classifications, methods, and guides that have been prepared by a sponsoring body and approved and adopted in accordance with established procedures.

suspended state. An operation that is stopped.

system integrator. The party that is responsible for assuring the system design and control interlocking of the arc welding robot system and other ancillary equipment into a system that conforms to the requirements of this standard.

task program. Set of instructions for motion and auxiliary and ancillary functions that define the specific intended task of the robot system.

task programming. The act of providing the task program (see teach).

teach. Programming the robot through the use of a handheld pendant specifically designed for the task or use of hand guiding with robots designed with that feature.

teach mode. The control state that allows the generation, storage, and playback of positional data points and peripheral equipment functions while under slow speed control. This is not functional or performance verification.

teacher. A person who provides the robot with a specific set of instructions to perform a task.

tool center point (TCP) The point defined for a given application with regard to the mechanical interface coordinate system. For robot arc welding systems, typically the termination of the arc welding gun electrode extension.

two-hand control. A two-hand actuator that requires simultaneous or concurrent pressure from both hands of the operator to sustain or initiate the motion.

user. Entity that uses robots and is responsible for the personnel associated with the robot operation.

verification. Confirmation by examination and provision of objective evidence that the requirements have been fulfilled.

visual alarm. A mechanical or electronic signal, clearly discernible above environmental distractions (e.g., lights, moving equipment) informing the operator of a situation requiring his attention. Steady lights, flashing light and flags are all examples of visual alarms.

welding circuit. All attachments connected to the welding terminals of the arc welding power source.

welding terminals. The connectors of an arc welding power source which furnish welding power and, when provided, high-frequency energy for the welding arc.

4. Arc Welding Robot System Requirements

4.1 Hazards to Personnel. The integrator and user shall perform a risk assessment on the arc welding robot system and ancillary equipment to determine the safeguarding achieves and maintains a safe work environment. The risk assessment shall comply with the requirements of AWS D16.3M/D16.3. Potential hazards to personnel shall be eliminated by design, or otherwise protection shall be provided against the hazards. If a hazard cannot be eliminated by either design or protection, a warning against the specific hazard shall be provided (see Clause 5 for alternate methods of safeguarding fixtures and Clause 6 for additional safeguards for electrical hazards).

4.1.1 Power Transmission Components. Robots shall be designed and constructed to prevent exposure by personnel to components, gears, drive belts, or linkages.

4.1.2 Failure to Reach Intended Location. If failure of the robot to reach an intended location presents a hazard, a stop shall be initiated and an awareness signal generated.

4.1.3 Power Loss or Change. Robot systems shall be designed and constructed so that loss of electrical power, voltage surges, or changes in oil or air pressure do not impair the safe operation of the system.

4.1.4 Component Malfunction. Robot system components shall be designed, constructed, secured, or contained so that hazards caused by breaking, loosening, or releasing stored energy are minimized.