

Specification for Robotic Arc Welding Safety



American Welding Society



Key Words—Robot, robotic arc welding, robot welding systems, robotic welding operator, qualified robot technician, safety, risk assessment

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Specification for

Robotic Arc Welding Safety

Prepared by
AWS D16 Committee on Robotic and Automatic Welding

Under the Direction of
AWS Technical Activities Committee

Approved by
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 a part of AWS D16.1, 2004, *Specification for Robotic Arc Welding Safety*, 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 (see Annex B).

This first edition of AWS D16.1M/D16.1:2004, *Specification for Robotic Arc Welding Safety*, provides guidelines for the safe use of arc welding robots. Although safe practices for arc welding are covered in many standards, this standard focuses on safety aspects unique to robotic arc welding applications.

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, 550 N.W. LeJeune Road, Miami, FL 33126.

Official interpretations of any of the technical requirements of this standard may be obtained by sending a request, in writing, to the Managing Director, Technical Services Division, American Welding Society. A formal reply will be issued after it has been reviewed by the appropriate personnel following established procedures (see Annex A).

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Specification for Robotic Arc Welding Safety

1. Scope

1.1 Scope and Objectives. The requirements of this standard apply to industrial robots that are used to perform the gas metal arc welding (GMAW) 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.

A robotic arc welding system consists of a manipulator, power source, arc welding torch and accessories; electrode feed system, dereeling system, welding circuit, shielding and communication control, and grounding system. There may be other accessories that are outside the scope of this document. A typical system is illustrated in Figure 1.

This specification makes use of both U.S. Customary Units and the International System of Units (SI). These measurements may not be exact equivalents; therefore each system must be used independently of the other without combining in any way. The specification D16.1M uses SI units. The specification with the designation D16.1 uses U.S. Customary Units. The latter are shown in appropriate columns in tables or within parentheses () when used in the text.

1.2 Applications

1.2.1 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.

1.2.2 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 sections of this standard.

1.2.3 All Installations. The requirements of Sections 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 approval of this standard.

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

- (1) Robots with a payload capacity greater than 20 kg (45 lbs)
- (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.

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

1.4.1 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 Section 4 of this standard.

1.4.2 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 Section 4 of this standard applicable to components being rebuilt or modified.

1.4.3 System Integrator. The system integrator shall ensure that the system complies with Section 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 Section 4. The employer shall be the system integrator unless another party contractually accepts responsibility as the system integrator.

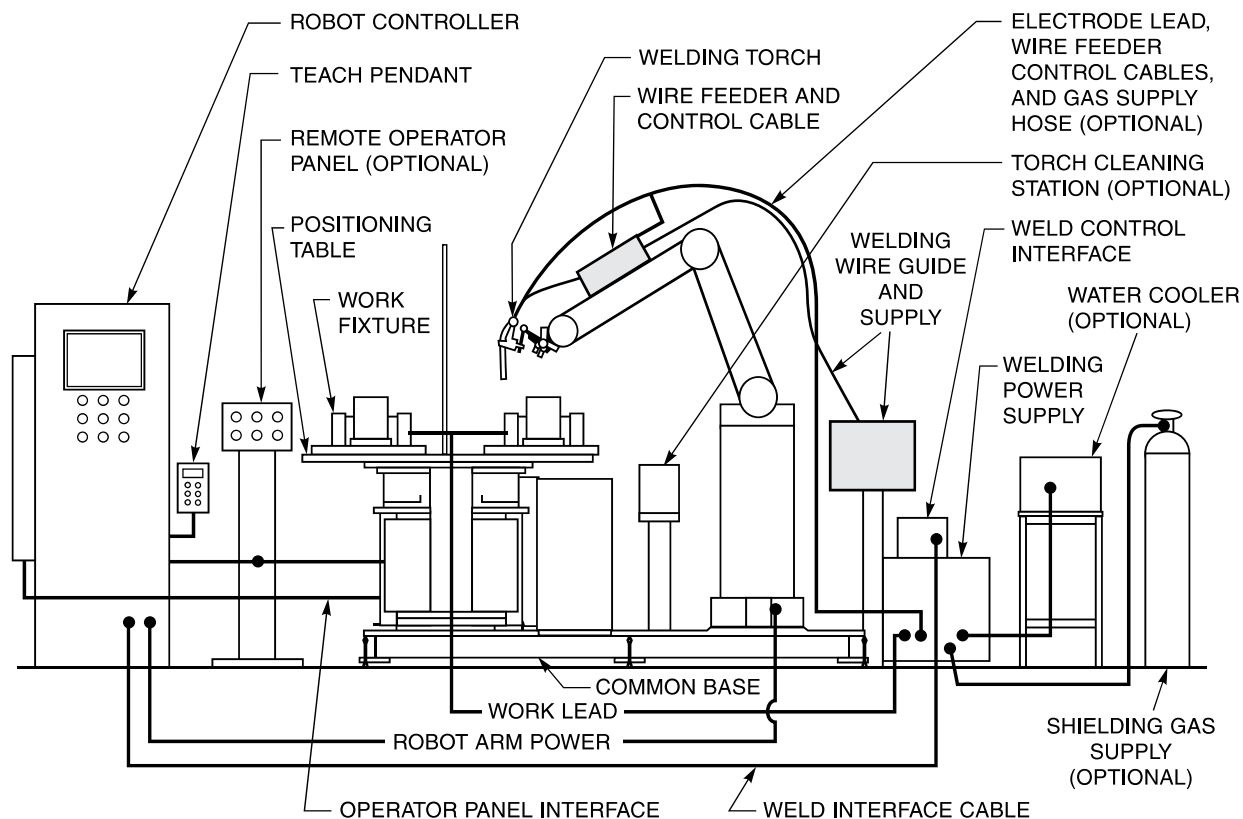


Figure 1—Example of a Typical Robotic Arc Welding Cell

1.4.4 Employers. Employers 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.

2. Normative References¹

The following standards contain provisions, which, through reference in this text, constitute provisions of this American National Standard. All standards are subject to revision, and parties are encouraged to use the most recent editions of the standards indicated below.

- (1) ANSI/NFPA² 79, *Electrical Standard for Industrial Machinery*
- (2) ANSI/NFPA 70, *National Electrical Code*

(3) ANSI/NFPA 51B, *Standard for Fire Prevention during Welding, Cutting, and Other Hot Work*

(4) ANSI/NFPA³ T2.13.8, *Hydraulic Fluid Power—Fire Resistant Fluids—Definitions, Classifications, and Testing*

(5) ANSI/RIA⁴ R15.06, *Industrial Robots & Robot Systems—Safety Requirements*

(6) ANSI⁵ Z535.1, *Safety Color Code*

(7) ANSI Z535.2, *Environmental and Facility Safety Signs*

(8) ANSI Z535.3, *Criteria for Safety Symbols*

(9) ANSI Z535.4, *Product Safety Signs and Labels*

(10) ANSI Z535.5, *Accident Prevention Tags*

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

1. All standards referenced may be obtained through Global Engineering Documents at 1-800-854-7179 or at www.global.ihs.com.

2. National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02269-9101.

3. National Fluid Power Association, 3333 N. Mayfair Road, Milwaukee, WI 53222-3219.

4. Robotic Industries Association, 900 Victors Way, P.O. Box 3724, Ann Arbor, MI 48106.

5. American National Standards Institute, 1819 L Street, NW, 6th floor, Washington, DC 20036.

(12) AWS⁶ A3.0, *Standard Welding Terms and Definitions*

(13) AWS D16.3, *Risk assessment Guide for Robotic Arc Welding*

(14) AWS D16.4, *Specification for the Qualification of Robotic Arc Welding Personnel*

(15) AWS AWR, *Arc Welding with Robots: Do's and Don'ts*

(16) AWS, *AWS Safety and Health Fact Sheets*

(17) UL⁷ 1740, *Safety Standard for Industrial Robots and Robotic Equipment*

(18) UL 551, *Transformer-Type Arc-Welding Machines*

(19) NEMA⁸ EW-1, *Electric Arc Welding Power Sources*

(20) NEMA EW-3, *Semiautomatic Wire Feed Systems for Arc Welding*

(21) IEC⁹ 60974-1, *Arc Welding Equipment—Part 1: Welding Power Sources*

(22) IEC 60974-7, *Arc Welding Equipment—Part 7: Torches*

(23) ISO 8373:1994, *Manipulating Industrial Robots—Vocabulary*

(24) OSHA¹⁰ 3120, *Control of Hazardous Energy (Lockout/Tagout)*

(25) OSHA 3075, *Controlling Electrical Hazards*.

3. Definitions

Terms used in this document should be interpreted in accordance with AWS A3.0, *Standard Welding Terms and Definitions*, and definitions used in the normative references cited in Section 2 of this standard except for the following terms:

alarm. An indication (visual or auditory) that a failure or misadjustment of a device has occurred.

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.

Note: There shall be no inference that the purpose of anti-repeat is to prevent an inadvertent cycle initiation of the robot system. An inadvertent cycle start is the result of a malfunction.

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

attended program verification. The act when a person within the safeguarded space verifies the robot's programmed tasks at programmed speed not to exceed a TCP speed of 250 mm/sec (10 in./sec).

automatic mode. Operating mode in which the control system operates in accordance with the task program.

awareness barrier. Physical and visual means that warn a person of an approaching or present hazard.

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

concurrent. Acting in conjunction, and is used to describe a situation, wherein two or more controls exist in an operated condition at the same time.

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.

door. A movable barrier that when closed prevents the entry of any portion of a person's body into the robot's or other moving equipment's operating space.

emergency stop. An operation of a circuit that overrides all machine control, removes drive power, and causes all moving machinery to stop.

employer. Any person who contracts, hires, or is responsible for the personnel associated with the operation, maintenance, and setup of arc welding robot systems.

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 wrist or tool mounting plate to enable the robot to perform the arc welding process.

energy source. Any electrical, mechanical, hydraulic, pneumatic, laser, chemical, thermal, potential, kinetic, or other sources of power/movement that can be a hazard.

fixed guard. A protective barrier that cannot be moved except with the use of tools.

6. American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

7. Underwriters Laboratory, 333 Pfingsten Road, Northbrook, IL 60062.

8. National Electrical Manufacturers Association, 1300 N. 17th Street, Suite 1847, Rosslyn, VA, 22209.

9. International Electrotechnical Commission, IEC Regional Centre for North America (IEC-ReCNA), 1740 Massachusetts Avenue, Suite D, Boxborough, MA 01719.

10. Occupational Safety & Health Administration, Department of Labor, Washington DC; On-line ordering of publications: <http://www.osha.gov/pls/publications/pubindex.list>.

former installation. A currently existing arc welding robot system installed prior to the compliance date of this standard.

gate. A movable barrier that when closed prevents the exposure of any portion of a person's body to a hazard.

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

hardwired. The components of an electrical circuit that are permanently, electrically wired together, resulting in an electrical circuit that is independent of electronic logic (hardware or software).

hazard. A potential source of harm.

industrial robot (robot). An automatically controlled, reprogrammable, multipurpose manipulator that is programmable in three or more axes.

industrial arc welding robot system (robot system).

- (1) An industrial robot combined with ancillary and peripheral equipment necessary to perform a production arc welding process. Typically, the robot is electrically interfaced to the ancillary and peripheral equipment.
- (2) Any 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 peripheral devices are supervised by the robot control system.

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

interlock control. An electrical or mechanical means by which activation will cause all hazardous motion to cease and all stored energy devices to return to a zero energy state.

joint. An axis of motion. For a six (6) axis, articulated servo controlled 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

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

manual. A text document for use as a guide or reference.

manual mode. A machine-operational control method that requires a deliberate and continuous act to initiate and sustain movement of any portion of the arc welding robot system.

manufacturer. Any person or organization who manufactures robotic arc welding systems and ancillary equipment or both. A manufacturer may also be a modifier or rebuilder.

modifier. Any person or organization who converts, changes or otherwise alters arc welding robot systems.

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

movable guard. A protective device which may be relocated or moved without the use of tools.

new installation. A new, rebuilt, or remanufactured arc welding robot that is installed in a production environment for the first time.

operator. An individual who has been trained and authorized by the employer to perform production work with the arc welding robot system.

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 linked to the control system of the robot which allows the robot to be programmed or moved. Also called a teach pendant.

perimeter guarding. Protective barrier or guarding placed around an arc welding robot system or machine cell.

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 area within the arc welding robot system where the welding process is performed.

presence sensing device. A device capable of detecting an intrusion into a specified area.

program.

- (1) The instruction set of commands and locations within the robot control that determines robot arm path, trajectory, speed and interface.
- (2) The act of teaching the robot commands and path information.

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

remanufacturer. Any person or organization who remanufactures an arc welding robot system for installation in the United States. The remanufacturer is not limited to the original equipment specification or capability.

restraint. A mechanism, which prevents the arc welding robot from inadvertent movement.

risk assessment. A comprehensive evaluation of the possible injury or damage to health in a hazardous situation in order to select appropriate safeguards.

safeguarding. A device or procedure used to protect personnel from hazard(s).

safety stop. A type of interruption of operation that allows an orderly cessation of motion for safeguarding purposes.

shall. A term used to designate a mandatory requirement.

shield. A barrier that protects against the hazards of weld spatter and flying sparks. The barrier may move with the fixture, positioner, or other safety barrier.

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 the initiation of robot motion from one source of control is only possible from that source and cannot be overridden from another source.

singularity. A condition caused by the collinear alignment of two or more robot axes resulting in unpredictable robot motion and velocities.

slow speed control. A mode of robot motion control where the speed is limited to 250 mm/sec (10 in./sec) to allow a person sufficient time to either withdraw from the hazardous motion or stop the robot.

space. The three dimensional volume encompassing the movements of all robot parts through their axes.

- (1) **maximum space.** The volume of space encompassing the maximum designed movements of all robot parts including the end-effector, workpiece and attachments.

- (2) **restricted space.** That portion of the maximum space to which the robot movement is restricted by limiting devices.

- (3) **operating space.** That portion of the restricted space that is actually used by the robot while performing its task program.

- (4) **safeguarded space.** The hazardous space defined by the perimeter safeguarding devices.

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.

teach. Programming the robot through the use of a hand held pendant specifically designed for the task.

tool center point (TCP). The point defined for a given end effector with regard to the mechanical interface coordinate system. The TCP is typically the location of the end of the filler metal or tungsten electrode at its stick-out distance.

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.

The initiation of motion by a two-hand control may be permissible when additional safety devices are in place such as guards, electronic light curtains, or other devices which would stop the motion of the machine when the safety guarding and operation has been compromised.

user. The owner or operator of a facility that utilizes arc welding robots for welding applications.

work level. The surface where the point of operation is located.

4. Arc Welding Robot System Manufacturing Requirements

4.1 Hazards to Personnel. 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 Section 5 for alternate methods of safeguarding fixtures, and see Section 6 for additional safeguards for burn hazards). The employer shall perform a risk assessment on the arc welding robot system and ancillary equipment to determine and select the safeguarding necessary to achieve

and maintain a safe work environment. The risk assessment shall comply with the requirements of AWS D16.3.

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. Robots 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 components shall be designed, constructed, secured or contained so that hazards caused by breaking, loosening, or releasing stored energy are minimized.

4.1.5 Sources of Energy. A means of isolating any hazardous energy source to the robot shall be provided. This means shall have the capability to be locked out and tagged out in accordance with federal OSHA regulations such as OSHA 3120, *Control of Hazardous Energy (Lockout/Tagout)*, and OSHA 3075, *Controlling Electrical Hazards*.

4.1.6 Stored Energy. Means shall be provided for the controlled release of stored energy. Labels shall be affixed to the stored energy source to identify the source.

4.1.7 Electromagnetic Interference. The design and construction of the robot shall incorporate proven engineering practices of shielding (where appropriate), filtering, suppression, and grounding to prevent hazardous motion from occurring.

4.2 Actuating Controls

4.2.1 Protection from Unintended Operation. Actuating controls that initiate power or motion shall be constructed or located so as to prevent inadvertent operation.

4.2.2 Status Indication. Actuating controls shall be equipped with control features that indicate the status of the actuating control.

4.3 Pendant and Other Teaching Controls. Where a pendant control or other control device is provided to control the robot from within the safeguarded space, the requirements in 4.3.1 through 4.3.5 shall apply.

4.3.1 Automatic. It shall not be possible to place the robot into automatic mode using the pendant or teaching device exclusively.

4.3.2 Motion Control. Motion of the robot initiated from the pendant shall be at slow speed.

4.3.3 Enabling Device. The pendant shall have an enabling device that uses a three position switch for control. Only the mid position of the switch will allow for robot arm movement and program advance. Release of or full compression of the enabling device shall cause the robot to immediately cease motion.

4.3.4 Pendant Emergency Stop. The pendant shall be equipped with an emergency stop push button that will immediately cause all hazardous operations to cease. The emergency stop control shall use a hardwired connection to the motor start controls of the robot.

When activated, the emergency stop control shall produce a category 0 or category 1 stop as defined in NFPA 79.

The emergency stop pushbutton shall be the red mushroom type with a safety alert yellow background. The emergency stop control shall require a manual resetting after activation.

A deliberate act shall be required to resume the robot automatic cycle after the activation of an emergency stop.

4.3.5 Single Point of Control. When local pendant control is selected, the initiation of motion shall be prevented from any source except that source selected.

4.4 Attended Weld Program Verification. Robot welding programs can be verified visually by trained operators and technicians. The procedures for verifying the robot welding shall include the following requirements:

(1) Personnel shall be trained on the safe use of the robot, the welding process, and the system requirements prior to performing program verification.

(2) The program shall be executed without the welding arc being on to verify the actual weld path and control function of the robot.

(3) One trained individual shall observe the actual welding process in the restricted space. The individual shall be equipped with an enabling device and the overall speed of the robot shall be restricted to a maximum TCP speed of 250 mm/sec (10 in./sec).

(4) Active safeguards shall be in place prior to the initiation of automatic cycle start to prevent any personnel, other than the individual programming the robot, from occupying the restricted space of the robot during verification.

4.5 Slow Speed Control. Slow speed control shall limit the maximum velocity of the robot measured at the tool center point of the robot to 250 mm/sec (10 in./sec).

4.6 Singularity Protection. The robot control shall have the ability to stop robot motion and alert the **teacher** prior to the robot passing through or correcting for singularity during interpolated motion initiated from the teach pendant.

4.7 Axis Limiting Devices. The robot shall be equipped with mechanical axis limiting device(s) that restrict the primary motion, Joint 1, of the robot. The robot shall be designed to allow for the addition of mechanical axis limiting devices that restrict the motion of Joints 2 and 3.

4.8 Provisions for Lifting. Provisions for the safe lifting of the robot by mechanical means shall be provided.

4.9 Electrical Connectors. Electrical connectors shall be designed to avoid unintended separation that could cause a shock hazard. Electrical connectors shall be keyed to prevent the inadvertent application of incorrect motor or signal power to the robot.

4.10 Pinch Points. Hazards associated with pinch point locations that are not otherwise identified shall be safeguarded. If a movable guard is used, it shall be interlocked. When a guard is removed or modified to accommodate manual material handling, alternate interlocked perimeter guarding shall be incorporated.

4.11 Electrical Controls

4.11.1 Two-Hand Control Device. A two-hand control device shall be utilized to initiate a manually controlled cycle of the arc welding robot system.

4.11.1.1 Unintentional Operation. Each hand control shall be protected against unintentional operation.

4.11.1.2 Concurrent Control. Each hand control shall be arranged by design, construction, and/or separation to require the use of both hands to actuate the controls concurrently.

4.11.1.3 Control Location. The hand controls shall be located to prevent exposure to the hazard.

4.11.1.4 Concurrent Pressure. Each hand control shall require continuous and concurrent pressure while the hazard exists.

4.11.1.5 Control Release. The hazardous machine motion shall stop or reverse, if reverse motion does not create a hazard, when either control is released.

4.11.1.6 Next Cycle Initiation. The control system shall require an anti-repeat/anti-tie down feature so that each button must be released and reactivated to initiate the next cycle.

4.11.2 Control Interlock Circuit

4.11.2.1 Fail-Safe Control. Control interlock circuits shall be designed to operate in a fail-safe manner.

4.11.2.2 Operator Intervention. Control interlock circuits shall inhibit automatic or operator-initiated actions when all safe conditions are not met.

4.11.2.3 Machine Suspension. When safe conditions are not met, control interlock circuits shall suspend further or additional actions and shall notify the operator of the suspended state of the machine.

4.11.2.4 Additional Actions. Control interlock circuits shall require the operator to acknowledge the suspended state of the machine before additional actions can take place.

4.11.3 Emergency Stops. Every arc welding robot system shall have an emergency stop circuit using hardware-based components. The emergency stop circuit, when activated, shall override all other controls and cause all motion and other hazardous operations to stop. The stop action shall produce a Category 0 or Category 1 condition as defined in NFPA 79.

4.11.3.1 Unobstructed Emergency Stop Device. Each arc welding robot system operator control station shall be provided with a readily accessible, unobstructed emergency stop device.

4.11.3.2 Emergency Stop Button Design. Push-buttons that activate an emergency stop circuit shall be red and unguarded, and shall have a yellow background. Emergency stop pushbuttons shall be palm or mushroom head type. All emergency stop pushbuttons shall be of the type requiring manual resetting.

4.11.3.3 Emergency Stop Button Restrictions. Red palm type or red mushroom head type pushbuttons shall not be used for any function except emergency stop.

4.11.3.4 Start-Up Procedure. Following an emergency stop, restarting operation shall require a deliberate action to follow a prescribed start-up procedure outside the safeguarded space.

4.11.4 Power Source. The power source of the arc welding robot system shall be clearly identified and shall be provided with electrical disconnect and lockout for the purpose of maintenance or repair of the arc welding robot system or its ancillary equipment.

4.11.5 Power Loss. Safeguards shall be implemented to ensure that a loss of power shall not result in an operator hazard. Safeguards shall be designed to ensure that a loss of power shall produce an emergency stop condition that shall immediately de-energize all equipment that is potentially hazardous in the robot operating area.

4.11.6 Electrical Requirements. New and remanufactured arc welding robot systems shall be built in accordance with NFPA 79.

4.12 Hydraulic Fluids and Compressed Gases

4.12.1 Nitrogen. Machines and systems that require compressed nitrogen shall be designed in accordance with applicable industry standards.

4.12.2 Air. Machines and systems that require compressed air shall be designed in accordance with applicable industry standards.

4.12.3 Hose and Tubing. All hoses and tubing that transport gases and fluids that can produce potential hazards shall be restrained in accordance with applicable industry standards. An example of a restraint for a hose is a mechanical clamp located to prevent “whipping” of a loose hose.

4.12.4 Accumulators. Hydraulic accumulators shall be properly restrained and charged in accordance with manufacturer specifications. Charged accumulators shall be identified with appropriate signage for high pressure potential hazard.

Barrier type piston accumulator systems shall have a device that automatically removes all stored hydraulic energy in a controlled manner when electrical or control power is removed.

All other accumulator systems shall have a lockable manual energy isolating device that blocks all stored hydraulic energy.

4.12.5 Hydraulic Fluids. All hydraulic fluids used by the arc welding robot system, fixturing, and its ancillary equipment shall comply with NFPA T2.13.8 requirements for Group I or Group II.

Flame retarding hydraulic fluids should conform to local, state, federal and industry requirements, such as, but not limited to, OSHA, ANSI standard (National Fluid Power Association) and Factory Mutual Research Corporation (FMRC).

4.12.6 Loss of Pressure. Safeguards shall be implemented to ensure that a loss of pressure shall not result in an operator hazard. Safeguards shall be designed to hold parts in fixtures when there is a loss of hydraulic, air, or gas pressure.

4.13 Manual Mode. All motions in manual mode shall be limited to a maximum speed that is less than full machine speed. Any motion that creates a hazard within the operator’s reach in manual mode shall be controlled with a two-hand control device.

Maximum speed is to be based on application; recommended maximum safe speed for manual mode is 250 mm/sec (10 in./sec).

4.14 Safety Signs. All new signs shall conform to the color, format, size, and content requirements of the ANSI Z535 series, where feasible.

5. Weld Fixture Requirements

5.1 Design, Construction, and Use. Weld fixtures shall be designed to avoid the following hazards:

(1) Burn hazards associated with weld spatter and hot surfaces

(2) Impact and pinch points associated with fixture motion, clamp actuator motion, and broken parts.

(3) Flying projectiles, such as unrestrained parts that can come out of their fixtures during system or part loading operations.

5.1.1 Size. Fixtures shall fit within the guarding provided on the weld table, positioner or within the safeguarded space.

5.1.2 Broken Parts. Fixtures shall be guarded to prevent injury from broken parts and/or springs. Fixtures equipped with springs containing potential energy shall be equipped with signs indicating their presence. To protect against spring failure, resulting in part of the mechanism becoming a flying projectile, guards should be provided over all such mechanisms.

5.1.3 Weight. Fixture weight shall be permanently indicated on the fixture to safeguard against overloading fixture handling equipment.

5.1.4 Mounting. Fixture fastening provisions shall be made to securely mount the fixtures to the weld table or positioner.

5.1.5 Handling. Fixtures and accessories shall have provisions to facilitate handling. For heavy fixtures, lifting eyes, straps and other assist devices should be added to the fixture to facilitate safe fixture handling.

5.1.6 Part Restraints. Based on the risk assessment, the end user shall determine if fixtures and accessories require safety interlocks to prevent system operation if clamping devices fail to properly secure the part or parts to be loaded and welded.

5.2 Fixture Setting. Impact and pinch point hazards associated with fixture setting and handling shall be safeguarded. The employer shall establish procedures for the installation and removal of fixtures from the welding system. The safeguarding procedure shall include a lock-out/tagout program, selection and use of fixture handling equipment, and selection and use of personal safety equipment.

5.3 Fixture Changing System. A fixture changing system can be used in conjunction with an arc welding robot system. It shall be permissible for motion to occur in the operating area with the machine doors and/or guards open or removed only if and when the following conditions are met:

(1) A key-operated selector switch is provided to enable the fixture changing process.

(2) If the fixture changer is mobile, it shall act as a barrier to the restricted area, replacing the opened or removed gate and/or guard when in position. The mobile unit shall include an electrical interlock plugged into the machine when the unit is in position.

(3) If the fixture changer is fixed, it shall act as a barrier to the restricted area, essentially replacing the opened or removed gate and/or guard.

(4) If the fixture changer, mobile or fixed, does not act as a barrier to the restricted area, then interlocked perimeter guarding shall be used to guard the restricted and operating area of the robot system.

6. System Requirements

6.1 Ancillary Equipment

6.1.1 General Requirements. The installation and use of any ancillary equipment shall not reduce the level of safety embodied in this standard.

This standard describes the use of ancillary equipment in conjunction with an arc welding robot. It is not intended to define the design and construction of ancillary equipment.

All ancillary equipment shall be interlocked to achieve safe, controlled operation and to prevent hazardous motion when the arc welding robot system is not in a predetermined ready state. Electrically powered ancillary equipment shall be installed in accordance with NFPA 70, *National Electrical Code*, and all local codes.

Any arc welding robot system safety device that is removed or altered for the use of ancillary equipment shall be replaced by one or more of the following: modified guarding, additional guarding, presence sensing devices, or perimeter guarding. These additional safety devices shall comply with the safeguard requirements described in Section 4.

6.1.2 Arc Welding Power Sources. Arc welding power sources used for robotic and automatic welding installations shall be constructed and tested in accordance with NEMA EW-1, *Electric Arc Welding Power Sources*, UL 551, *Transformer-Type Arc-Welding Machines*, and International Electrotechnical Commission IEC 60974-1, Part 1: *Arc Welding Equipment* and Part 7: *Torches*. Additional power source safety information is provided in ANSI Z49.1 *Safety in Welding, Cutting, and Allied Processes*, and the AWS publication *Safety and Health Fact Sheets*, all of which are made part of the requirements of this standard.

6.1.3 Arc Welding Torches. Arc welding torches shall be specifically designed and appropriately rated for

robotic welding applications. Torch and torch mounting equipment weight shall not exceed the rated load capacity recommended by the robot manufacturer. The torch insulation shall be sufficient to prevent exposure to hazardous voltage levels and to prevent leakage of hazardous current from the welding circuit. Torch utility cables shall be designed with appropriate strain relief to prevent hazards that may arise due to a cable or hose failure.

The rating of the torch shall be continuous duty in accordance with NEMA EW-3, *Semiautomatic Wire Feed Systems for Arc Welding*. The torch may be used with different gas mixtures and modes of metal transfer in accordance with the torch manufacturers specifications. The torch shall meet the requirements of IEC 60974-7, *Arc Welding Equipment—Part 7: Torches*.

6.1.4 Torch Holder. The torch mounting equipment shall provide electrical isolation between the torch and the manipulator tool mounting plate. The torch holder shall be mechanically rigid to withstand collision. This feature does not preclude the use of interlocks.

6.1.5 Torch Accessories

6.1.5.1 An arc welding robot system can be equipped with different accessories that can enhance the performance of the system. These accessories include, but are not limited to, the following devices:

- (1) Torch Cleaning Station
- (2) Water Cooler
- (3) Alignment Tool (Station)
- (4) Welding Wire Cutters

6.1.5.2 All accessories shall be equipped with the following safeguards and operating features:

(1) The devices shall be electrically grounded and isolated in accordance with NEMA EW-1 and NEMA EW-3.

(2) The devices shall not create any unguarded pinch or collision point hazards.

(3) The devices shall be electrically integrated to allow for single point of control during robot teaching, maintenance, and program verification.

6.1.6 Dereeling System. The dereeler system shall be designed and installed to provide for safe loading of the wire package.

(1) A failure of the dereeler to properly deliver welding wire to the welding torch shall not create an electrical shock or pinch point hazard.

(2) All dereeler components in direct contact with the welding wire shall be isolated from the welding work lead and earth ground with a minimum resistance of one megaohm at 500 Vdc.

6.1.7 Welding Positioner. All welding positioners, regardless of the type of drive or stopping mechanism

employed, shall exhibit the following safeguards and operating features:

(1) The devices shall be electrically grounded and isolated in accordance with NEMA EW-1 and NEMA EW-3.

(2) The devices shall not have or create any unguarded pinch or collision point hazards.

(3) The devices shall be integrated to allow for single point of control during robot teaching, maintenance, and program verification.

(4) The operation of the positioner shall not create any unguarded pinch points.

6.2 Emergency Stop Circuitry. The emergency stop circuitry shall be hardwired and act independently from the electronic control systems. All ancillary equipment shall have a hardwired emergency stop circuit connected in series with the robot emergency stop circuit.

6.3 Control Interlocks

6.3.1 Timers. Timers shall not be used in conjunction with interlocks to control the arc welding robot or ancillary equipment during automatic or semi-automatic operation. Timers should not be used to delay or initiate motion of an interlocked guard.

6.3.2 Interlock Resets. Resetting the arc welding robot system shall not automatically reset ancillary equipment.

7. User Requirements

7.1 Training. The employer shall train and instruct personnel in the safe operation and maintenance of the arc welding robot system and ancillary equipment. The employer shall document training and assessment of personnel.

7.2 Lockout/Tagout. The employer shall establish a program and procedure for affixing lockout or tagout devices. The isolating devices shall disable machines components and other equipment to prevent unexpected start-up or release of stored energy.

7.3 Risk Assessment. The employer shall perform a risk assessment on arc welding robot system and ancillary equipment to determine and select the safeguarding necessary to achieve and maintain a safe work environment. The risk assessment shall comply with the requirements of AWS D16.3.

7.4 Work Area. The employer shall provide adequate work areas for safe operation of machines, maintenance, and material handling. All walkways and working surfaces shall be kept in good condition and free from debris and fluids.

7.5 Personal Protective Equipment. The employer shall establish a personal protective equipment program for personal safety. Safety equipment selected as a result of risk assessment shall be appropriate for the task to be performed and in compliance with applicable state, federal, and ANSI standards.

The Personal Protective Equipment program should include, but not be limited to, these types of equipment:

- (1) Eye protection.
- (2) Hand protection
- (3) Body protection
- (4) Foot protection
- (5) Hearing protection

7.6 Ventilation. A means of ventilation shall be provided to vent hazardous vapors and fumes away from personnel work areas.

8. Maintenance Requirements

8.1 Training. The employer shall train and instruct personnel in the safe operation and maintenance of the arc welding robot system and its ancillary equipment.

Maintenance personnel shall be trained on the electrical, hydraulic, and pneumatic systems. Training shall include mechanical operation of the arc welding robot system and ancillary equipment through on-the-job training or specialized training.

8.2 Lockout/Tagout. The employer shall establish a program and procedure for affixing lockout/tagout devices (see 7.2).

8.3 Risk Assessment. The employer shall perform a risk assessment on all arc welding robot systems and ancillary equipment under their control to determine the safeguarding necessary to achieve and maintain a safe work environment for maintenance personnel. The risk assessment shall comply with the requirements of AWS D16.3.

8.4 Maintenance Operations While Under Power. When motion of the arc welding robot system is required for maintenance, it shall occur in manual mode at a speed that is less than full machine speed. Any motion that creates a hazard within the operator's reach in manual mode shall be controlled with a two-hand control device.

Maximum speed is to be based on application; maximum safe recommended speed for Manual Mode is 250 mm/sec (10 in./sec).

9. General Information

9.1 Equipment Identification. The following indications shall be clearly and durably attached to the arc welding robot system:

- (1) Name and address of the manufacturer.
- (2) Type of machine.
- (3) Serial number/machine number.
- (4) Year of manufacture.
- (5) Electrical characteristics.
- (6) Weight.
- (7) Safety Signage.

9.2 Machine Manual. The manufacturer or remanufacturer shall supply a machine manual. The machine manual shall include the following information:

- (1) Equipment identification.
- (2) Type of machine.
- (3) Installation and transport weight.
- (4) Intended use of the machine.
- (5) Machine hazard identification.
- (6) Safety instructions.
- (7) Machine operating specifications.
- (8) Operating procedures.
- (9) The prohibition of unauthorized reconstruction and modification of the machine.
- (10) Instruction by the manufacturer that only personnel properly trained in the operation, setup, maintenance, should be authorized to operate the machine.
- (11) Alarm descriptions.
- (12) Troubleshooting information.
- (13) Recommended lockout procedures.

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Nonmandatory Annex

Annex A

Guidelines for Preparation of Technical Inquiries for AWS Technical Committees

(This Annex is not a part of AWS D16.1M/D16.1:2004, *Specification for Robotic Arc Welding Safety*, but is included for informational purposes only.)

A1. Introduction

The AWS Board of Directors has adopted a policy whereby all official interpretations of AWS standards will be handled in a formal manner. Under that policy, all interpretations are made by the committee that is responsible for the standard. Official communication concerning an interpretation is through the AWS staff member who works with that committee. The policy requires that all requests for an interpretation be submitted in writing. Such requests will be handled as expeditiously as possible but due to the complexity of the work and the procedures that must be followed, some interpretations may require considerable time.

A2. Procedure

All inquiries must be directed to:

Managing Director, Technical Services
American Welding Society
550 N.W. LeJeune Road
Miami, FL 33126

All inquiries must contain the name, address, and affiliation of the inquirer, and they must provide enough information for the committee to fully understand the point of concern in the inquiry. Where that point is not clearly defined, the inquiry will be returned for clarification. For efficient handling, all inquiries should be typewritten and should also be in the format used here.

A2.1 Scope. Each inquiry must address one single provision of the standard, unless the point of the inquiry involves two or more interrelated provisions. That provision must be identified in the scope of the inquiry,

along with the edition of the standard that contains the provisions or that the Inquirer is addressing.

A2.2 Purpose of the Inquiry. The purpose of the inquiry must be stated in this portion of the inquiry. The purpose can be either to obtain an interpretation of a standard requirement, or to request the revision of a particular provision in the standard.

A2.3 Content of the Inquiry. The inquiry should be concise, yet complete, to enable the committee to quickly and fully understand the point of the inquiry. Sketches should be used when appropriate and all paragraphs, figures, and tables (or the Annex), which bear on the inquiry must be cited. If the point of the inquiry is to obtain a revision of the standard, the inquiry must provide technical justification for that revision.

A2.4 Proposed Reply. The inquirer should, as a proposed reply, state an interpretation of the provision that is the point of the inquiry, or the wording for a proposed revision, if that is what inquirer seeks.

A3. Interpretation of Provisions of the Standard

Interpretations of provisions of the standard are made by the relevant AWS Technical Committee. The secretary of the committee refers all inquiries to the chairman of the particular subcommittee that has jurisdiction over the portion of the standard addressed by the inquiry. The subcommittee reviews the inquiry and the proposed reply to determine what the response to the inquiry should be. Following the subcommittee's development of the response, the inquiry and the response are presented to the entire committee for review and approval. Upon

approval by the committee, the interpretation will be an official interpretation of the Society, and the secretary will transmit the response to the inquirer and to the *Welding Journal* for publication.

A4. Publication of Interpretations

All official interpretations will appear in the *Welding Journal*.

A5. Telephone Inquiries

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The Board of Directors' policy requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be

obtained only through a written request. The Headquarters staff cannot provide consulting services. The staff can, however, refer a caller to any of those consultants whose names are on file at AWS headquarters.

A6. The AWS Technical Committee

The activities of AWS Technical Committees in regard to interpretations, are limited strictly to the interpretation of provisions of standards prepared by the committee or to consideration of revisions to existing provisions on the basis of new data or technology. Neither the committee nor the staff is in a position to offer interpretive or consulting services on: (1) specific engineering problems; or (2) requirements of standards applied to fabrications outside the scope of the document or points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

List of AWS Documents on Robotic and Automatic Welding

Designation	Title
D16.2/D16.2M	<i>Guide for Components of Robotic and Automatic Welding Installations</i>
D16.3M/D16.3	<i>Risk Assessment Guide for Robotic Arc Welding</i>
D16.4	<i>Specification for the Qualification of Robotic Arc Welding Personnel</i>
AWR	<i>Arc Welding With Robots: Do's and Don'ts</i>

For ordering information, contact Global Engineering Documents, an Information Handling Services (IHS) Group company, 15 Inverness Way East, Englewood, Colorado 80112-5776; telephones: (800) 854-7179, (303) 397-7956; fax (303) 397-2740; Internet: www.global.ihs.com.

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