

Training Guide for Robotic Arc Welding Personnel



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Training Guide for Robotic Arc Welding Personnel

1st Edition

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 training guide provides technical information necessary to train personnel in the safe and effective use of industrial welding robots and welding robot systems. This guide includes a summary of the requisite education resources required for training and the emphasis will be placed on training individuals need in accordance with the principles of the AWS D16.4M/D16.4 Certified Robot Arc Welder (CRAW) program. The training guide is designed for use by all robot arc welding personnel and it is not intended to be used exclusively in support of the CRAW program.



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Foreword

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

The AWS Committee on Robotic and Automatic Welding was organized in 1985 to provide a centralized source for the exchange of technical information between manufacturers, installers, and operators of robotic and automated equipment. In 1988, the Committee was expanded to include representation of the Arc Welding Section of the National Electrical Manufacturers Association (NEMA). The relationship was formalized in September 1989 when the NEMA Codes and Standards Committee approved formation of a joint AWS/NEMA Committee to prepare a series of documents on various phases of the installation, maintenance, and operations of robots for welding. NEMA formally withdrew its partnership with the AWS D16 Committee in 1996.

AWS D16.5M/D16.5:2021, *Training Guide for Robotic Arc Welding Personnel*, provides technical information necessary to train personnel in the safe and effective use of industrial welding robots and welding robot systems. The training guide includes a summary of the requisite education resources required for training and the emphasis will be placed on the training of individuals in accordance with the principles of the AWS D16.4M/D16.4 Certified Robotic Arc Welder (CRAW) program. The training guide is designed for use by all robot arc welding personnel and it is not intended to be used exclusively in support of the CRAW program.

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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Training Guide for Robotic Arc Welding Personnel

1. General Requirements

1.1 Scope. This document applies to the requirements and procedures necessary to train personnel to allow them to safely and effectively apply industrial robots to the task of arc welding. The recommended training applies to all personnel, regardless of their specific job duties. The training is recommended for individuals who design, integrate, install, and use industrial welding robotic and automatic systems. The intent of this document is to identify the recommended knowledge for these individuals. The processes included for consideration in this document are gas metal arc welding (GMAW), gas tungsten arc welding (GTAW), and flux cored arc welding (FCAW). Pertinent parts may address additional welding processes.

Robotic arc welding systems consist of a robot arm, positioner, power source, arc welding torch and accessories, electrode feeding system, dereeling system, shielding gas delivery system, welding circuit, shielding and communication control, and grounding system. There may be other accessories that are outside the scope of this document, such as safety devices and monitoring, weld joint-tracking, and vision systems. A typical system is illustrated in Figure 1.

1.2 Units of Measure. This standard makes use of both the International System of Units (SI) and U.S. Customary Units. The measurements may not be exact equivalents; therefore, each system must be used independently of the other without combining in any way. The latter are shown within brackets [] or in appropriate columns in tables and figures.

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 to, or revisions of, any of these publications do not apply.

American Welding Society (AWS) documents:

- AWS AWR, Arc Welding with Robots, Do's and Don'ts*
- AWS QC1, Standard for AWS Certification of Welding Inspectors*
- AWS QC19, Specification for AWS Certification of Robotic Arc Welding Personnel*
- AWS WIH, Welding Inspection Handbook*
- AWS WHB-1, Welding Handbook—Volume 1, Welding Science and Technology*
- AWS 058, Cary, Howard, Arc Welding Automation*
- AWS A2.4, Standard Symbols for Welding, Brazing, and Nondestructive Testing*
- AWS A3.0M/A3.0, Standard Welding Terms and Definitions, Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying*
- AWS A5.23/A5.23M, Specification for Low-Alloy Steel Electrodes and Fluxes for Submerged Arc Welding*
- AWS B1.10, Guide for Nondestructive Examination of Welds*
- AWS B1.11, Guide for Visual Examination of Welds*
- AWS B2.1, Specification for Welding Procedure and Performance Qualification*
- AWS B4.0, Standard Methods for Mechanical Testing of Welds*
- AWS B5.1, Qualification Standard for AWS Welding Inspectors*
- AWS D16.1M/D16.1, Specification for Robotic Arc Welding Safety*
- 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*
- AWS WIT-T, Welding Inspection Technology*

American National Standards Institute (ANSI) standards:

- ANSI B11.0, Safety of Machinery, General Requirements and Risk Assessment*
- ANSI B11.19, Performance Requirements for Risk Reduction Measures: Safeguarding and Other Means of Reducing Risk*
- ANSI B11.20, Safety Requirements for Integrated Manufacturing Systems (IMS)*
- ANSI/UL 1740, Safety Standard for Robots and Robotic Equipment*

National Fire Protection Association (NFPA) documents:

- ANSI/NFPA 70, Standard for Electrical Safety Requirements for Employee Workplaces*
- ANSI/NFPA 79, Electrical Standard for Industrial Equipment*
- ANSI/NFPA T2.13.8-97, Hydraulic Fluid Power—Fire Resistant Fluids—Definitions, Classifications, and Testing*

Robotic Industries Association (RIA) document:

- ANSI/RIA 15.06, American National Standard of Industrial Robots and Robot Systems—Safety Systems*

Occupational Safety and Health Administration (OSHA) documents:

- OSHA 1910.147, Control of Hazardous Energy (Lockout/Tagout)*
- OSHA 1910.212, General Requirements for all Machines (Machine Guarding)*

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.

acceptance criteria. Specified limits placed on characteristics of an item or process defined in codes, specifications, or other documents.

actuator. A mechanism used to affect motion.

- (1) A power mechanism which converts electrical, hydraulic, or pneumatic energy to affect motion.
- (2) A mechanical mechanism within a control device (e.g., a rod which opens contacts).
- (3) 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, torch cleaners, wire cutters, anti-spatter spray, wire straighteners).

arc established. A discrete signal indicating that a welding arc is present.

arc on/arc off. A discrete signal that initiates or terminates the welding process.

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

automatic operation. The state in which the robot is executing its programmed task as intended.

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).

awareness signal. A device that warns a person of an approaching or present hazard by an audible or visible means.

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

certified robotic arc welding engineer (CRAW-E). An individual meeting the criteria of Engineer in accordance with requirements of AWS D16.4M/D16.4 and QC19.

certified robotic arc welding operator (CRAW-O). An individual meeting the criteria of Operator in accordance with requirements of AWS D16.4M/D16.4 and QC19.

certified robotic arc welding technician (CRAW-T). An individual meeting the criteria of Technician in accordance with requirements of AWS D16.4M/D16.4 and QC19.

code. A standard suitable for adoption by a governmental or other authority.

continuous duty. The capability of a power source to operate 100% of the time without interruption and without exceeding the maximum temperature criteria of the insulation and components within the power source. In all cases, the required load should not exceed the weld power source duty cycle rating for continuous duty.

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 user.

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).

coordinated motion. Control wherein the axes of the robot and auxiliary axes arrive at their respective end points simultaneously, giving a smooth appearance to the motion. Control wherein the motions of the axes are such that the tool center point (TCP) moves along a prescribed path (line, circle, or other).

CWI. AWS Certified Welding Inspector.

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.

electrode stick check. A signal generated by the welding power source to indicate if the electrode has fused to the workpiece.

emergency stop. The circuit (safety function) that, when engaged, overrides all other robot controls, removes drive power, causes all moving parts to stop, and removes power from other hazardous functions present in the safeguarded space.

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 robot wrist or tool mounting plate to enable the robot to perform its intended task. (Examples may include gripper, spot weld gun, arc weld torch, 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).

gas on. Discrete output signal used to turn on the gas solenoid, activate auxiliary equipment, or both.

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.

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 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 equipment. Physical apparatus used to perform industrial tasks, such as welding equipment, conveyors, machine tools, fork trucks, turntables, positioning tables, or robots.

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 cell. One or more robot systems including associated machinery and equipment and the associated safeguarded space and protective measures.

industrial robot line. More than one robot cell performing the same or different functions and associated equipment in single or coupled safeguarded spaces.

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

infrared sensor. An electric device which monitors the light spectrum for infrared emissions. The sensor will send a signal to the controller when the infrared light is detected at or above a preset level.

ingress and egress barrier. A cage that does not allow entry into nor exit from the welding/robotic area during operation.

inspector. A person who performs an inspection, test, or examination to verify conformance to specific requirements.

integration. Act of combining a robot with other equipment or another machine (including additional robots) to form a machine system capable of performing useful work such as production of parts. This act of machine building can include the requirements for the installation of the system.

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.

interlock control. An electrical or mechanical means by which activation will cause all hazardous motion to cease and prevent operation from resuming.

interlock switch. An electrical or mechanical means by which operation of a component is prevented or maintained unless required conditions are met.

interlocked barrier. A physical barrier that serves two purposes: (1) to physically separate personnel from a potential hazard, and (2) used to disable and thereby prevent the operation of the equipment if the barrier is removed or if the operator crosses into the space that the barrier protects.

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

light curtain. An optical safeguard that detects an object within its detection field and sends a signal to the system controller.

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.

load current. The amperage flowing in the welding circuit when a load is applied to the welding terminals.

load voltage. The voltage between the welding terminals of the arc welding power source when a load current is flowing in the welding circuit.

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

man/machine coordination. Hazard associated with the real time interaction of operators with moving automation systems such as industrial robots.

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.

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

manual mode. Control state that allows for the direct control by an operator.

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.

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.

noise. Hazards producing sound vibrations exceeding the prevailing code regulations for noise exposure.

operating space. That portion of the restricted space that is actually used by the robot while performing its task program.

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 linked 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.

perimeter guarding. Protective barrier or guarding placed around an arc welding robot system or matching 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 location(s) within the safeguarded space where work is performed on the material or workpiece.

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

presence-sensing safeguarding device. A device designed, constructed, and installed to create a sensing field or area to detect intrusion or presence within such field or area by personnel, robots, or other objects.

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.

program path. The path traced by the TCP during the execution of a task program.

program verification. The execution of path instructions for the purpose of confirming the robot path and process performance. Verification may include the total program path or a segment of the path. The instructions may be executed in a single instruction or continuous instruction sequence. It is used in new applications and in fine tuning/editing of existing ones.

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.

rated output. Consists of a designated limit of output or capacity expressed as a rated load voltage, rated load current, and rated load duty cycle when the power source is operated at rated input voltage(s) and rated frequency(ies) or at rated speed.

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.

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

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

robot. See **industrial robot**.

robot actuator. Powered mechanism that converts electrical, hydraulic, or pneumatic energy to effect motion.

robot system. See **industrial robot system**.

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.

safe state. Condition of a machine or piece of equipment where it does not present an impending hazard.

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

safeguarded space. The space defined by the perimeter safeguarding.

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

safety mat. A flat pressure-sensitive mat and safety controller that detects presence on the sensing surface and sends a signal to the robotic controller if activated.

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 stop. A type of interruption of operation that allows an orderly cessation of motion for safeguarding purposes. This stop retains the program logic for troubleshooting purposes and to facilitate a restart.

safety rated monitored space. Safety rated function that causes a protective stop when either the Cartesian speed of a point relative to the robot flange (e.g., the TCP), or the speed of one of more axes exceeds a specified limit value.

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

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

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.

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

safety rated zone output. Output indicating the state of the robot position relative to a safety rated soft limit.

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

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.

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

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

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 control program. The inherent set of control instructions which defines the capabilities, actions, and responses of the robot system.

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.

teach mode. The control state that allows the generation, storage, and playback of positional data points while under slow speed control; this is not verification.

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 welding torch 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.

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

validation. Confirmation by examination and provision of objective evidence that the particular requirements for a specific intended use are fulfilled.

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 (i.e., lights, moving equipment, etc.) informing the operator of a situation requiring his attention. Steady lights, flashing light, and flags are all examples of visual alarms.

weld voltage reference. A low-voltage output signal that controls the output voltage of the weld power source.

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

welding equipment status. Discrete input signal to monitor readiness of the welding equipment.

welding positioner. A device used to convey parts in and out of the robot envelop and/or may include axes to orient the part. The part positioner axes may be axes controlled by the robot or may have independent drives sequenced by the robot.

welding terminals. The output terminals of the welding power source.

welding torch. An apparatus 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.

wire feed speed reference. A low voltage output signal that controls the electrode wire feed rate.

4. Arc Welding Robot System Integration Requirements

The safeguarding of robots is covered by industry standards for safety and the welding process by AWS standards. Personnel should become familiar with the terms and requirements for robotic and welding safety in order to properly design, integrate, and use an arc welding robot system. This clause covers some of the functions and requirements used in robotic safeguarding.

4.1 Hazards to Personnel. Potential hazards to personnel shall be eliminated by design, or protection shall be provided against the hazards. If a hazard cannot be eliminated by either design or protection, a warning and instructions to protect against the specific hazard shall be provided.

4.1.1 Power Transmission Components. Robots shall be designed and constructed to prevent exposure 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 or voltage surges or changes in oil or air pressure do not create a hazard or hazards.

4.1.4 Component Malfunction. Robot components shall be designed, constructed, secured, or contained so hazards caused by breaking or 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.

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 good engineering practices of shielding, 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. When the enabling device is continuously held in the detented position, it permits motion. Release of or compression past the midpoint detent of the device shall stop robot motion immediately.

4.3.4 Pendant Emergency Stop. The pendant will be equipped with an emergency stop push button that will immediately interrupt the power to the robot arm and controller.

- 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 requires 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. Robot motion shall be initiated only by the pendant control when the robot is in teaching mode.

4.4 Attended Weld Program Verification. Robot welding programs can be verified visually by trained personnel. 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 dry run to simulate the actual weld path and control function of the robot prior to verification.

(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 by the maximum linear welding speed achieved by the robot while performing the weld process.

(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.

Program verification requires that an individual be certified as a Level One or Level Two technician in accordance with AWS D16.4M/D16.4, *Specification for the Qualification of Robotic Arc Welding Personnel*.

4.5 Slow Speed Control. The robot shall be equipped with a slow speed control that limits the maximum velocity of the robot measured at the tool center point of the robot to 250 mm/s [10 in/s].

4.6 Singularity Protection. The robot control shall prevent the robot arm from moving in an unpredictable manner in teach mode due to the presence of a singularity condition.

4.7 Axis Limiting Devices. The robot shall be equipped with mechanical axis limiting devices to restrict the primary motion, Joint 1, of the robot.

The robot shall be designed to allow for the addition of mechanical axis limiting devices to restrict the motion of Joint 2 and Joint 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 Other Pinch Points. Hazards associated with other pinch point locations that are not otherwise identified shall be safeguarded. If a movable guard is used, it shall be interlocked.

4.11 Electrical Controls

4.11.1 Control Interlock Circuit

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

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

4.11.1.3 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.

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

4.11.2 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 to stop. The stop action shall produce a Category 0 or Category 1 condition, as defined within NFPA 79, *Electrical Standard for Industrial Equipment*.

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

4.11.2.2 Emergency Stop Button Design. Pushbuttons 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.

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

4.11.2.4 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.

4.11.3 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.

4.11.4 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.

4.11.5 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 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.

(E4.12.1 Hose and Tubing—An example of a restraint for a hose is a mechanical clamp located to prevent “whipping” of a loose hose.)

4.12.2 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.

4.12.3 Hydraulic Fluids. All hydraulic fluids used by the arc welding robot system, fixturing and its ancillary equipment shall comply with NFPA T2.13.8-97 requirements for Group I or Group II.

(E4.12.3 Hydraulic Fluids—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].)

4.13 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 teach pendant.

(E4.13 Manual Mode—Maximum speed is to be based on application; maximum safe recommended speed for Manual Mode is 250 mm/s [10 in/s].)

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. Training Subjects

5.1 Welding Equipment Setup

5.1.1 Installation of Hardware. The equipment installed will vary for most installations, but the major pieces of hardware are illustrated in Figure 1.

- (1) Welding Power Source: The installed welding power source requires power (typically 3 phase).
- (2) Interface: There are many options to interface the communication between cell equipment. The communication between robot controller and the welding power source is usually discrete communication, a bus communication protocol, or an Ethernet based protocol. An outlet in form of a plug is usually mounted on the welding power source.
- (3) Interface Communication Cable is a shielded cable for discrete interface or a bus communication between the robot controller and the welding power source.
- (4) (Optional) Water Cooler: Requires coolant, power, and coolant lines to be connected to the power source. Internal as well as external watercoolers are available.
- (5) Wire Feeder: The feeder's communication cable must be connected to the welding power source, a shielding gas hose must be connected, and proper drive rolls matching the welding wire must be installed.

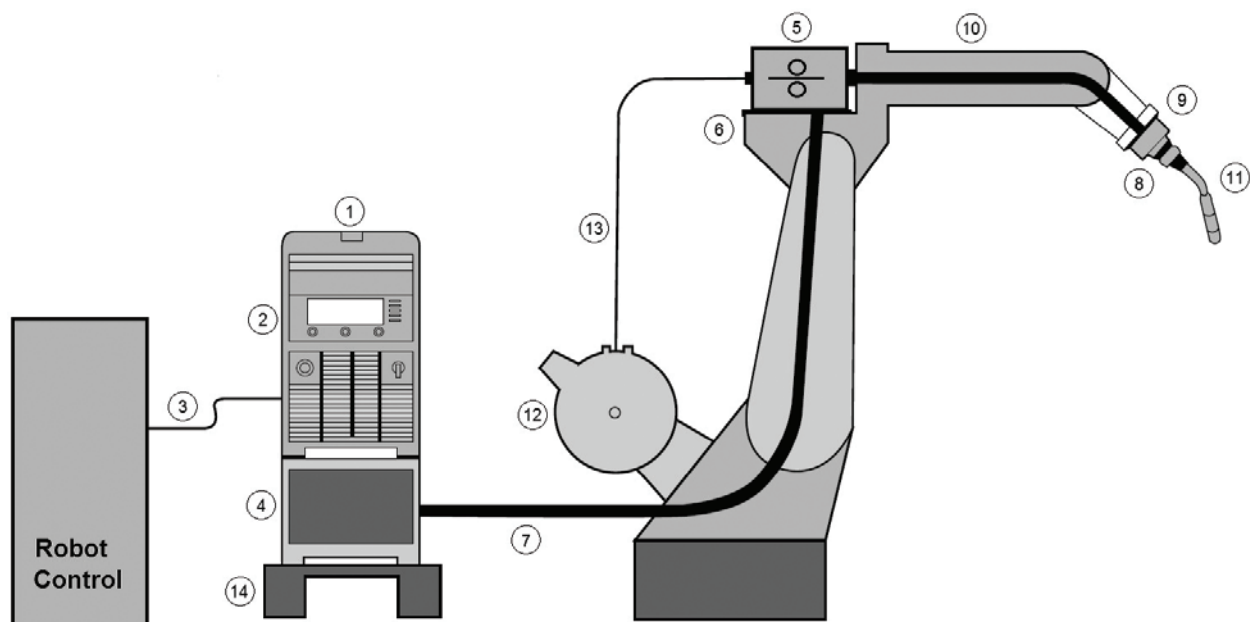


Figure 1—Schematic of a Typical GMAW Robotic Welding System's Major Equipment

- (6) Wire Feeder Bracket should include provisions to electrically isolate between the wire feeder and robot.
- (7) Hose Package (contains the wire feeder communication cable, positive lead or negative lead for self-shielded wire, shielding gas hose, and coolant lines if needed)
- (8) Collision Sensor or Solid Mount if robot collision software is used.
- (9) Insulation Disc (mounted between the Collision sensor and tool mount joint of the robot)
- (10) Torch Cable (also referred to as the whip)
- (11) Torch Neck (also referred to as gooseneck)
- (12) Weld Wire Holder (can be a spool holder or a barrel)
- (13) Weld Wire Conduit (installed between the wire feeder and the welding wire storage)
- (14) (Optional) Power Source Stand

5.2 Welding Processes. Robotic arc welding personnel are concerned with applying arc welding processes using robotics. A general knowledge of the available welding processes and equipment required for using each process can be useful. Numerous joining processes are commercially available for use in the fabrication of metal products. Figure 2 shows the American Welding Society's Master Chart of Welding and Joining Processes. The welding processes are further divided into eight groups:

- (1) arc welding
- (2) solid-state welding
- (3) resistance welding
- (4) oxyfuel gas welding
- (5) soldering
- (6) brazing
- (7) high energy beam welding
- (8) other welding and joining

The allied processes include thermal spraying, adhesive bonding, and thermal cutting (oxygen, arc, and other cutting).

Although there are many processes available, not all of them are suitable for use with a robot. Therefore, the processes discussed here will only include those which are applicable for the AWS Certified Robotic Arc Welding examination. With that in mind, the following processes will be discussed:

- (1) gas metal arc welding
 - (a) tandem gas metal arc welding
 - (b) reciprocating wire feed gas metal arc welding
- (2) flux cored arc welding
- (3) gas tungsten arc welding
- (4) plasma arc welding
- (5) submerged arc welding

Before our discussion of the various welding processes, it is appropriate to define what is meant by the term welding. According to AWS A3.0M/A3.0:2020, a weld is "a localized coalescence of metals or nonmetals produced either by heating the materials to the welding temperature, with or without the application of pressure, or by the application of pressure alone and with or without the use of filler material." Coalescence means "joining together." Therefore, welding refers to the operations used to accomplish this joining operation. This clause will discuss the features of some of the processes more commonly applied with robotics, all of which employ the use of heat without pressure.

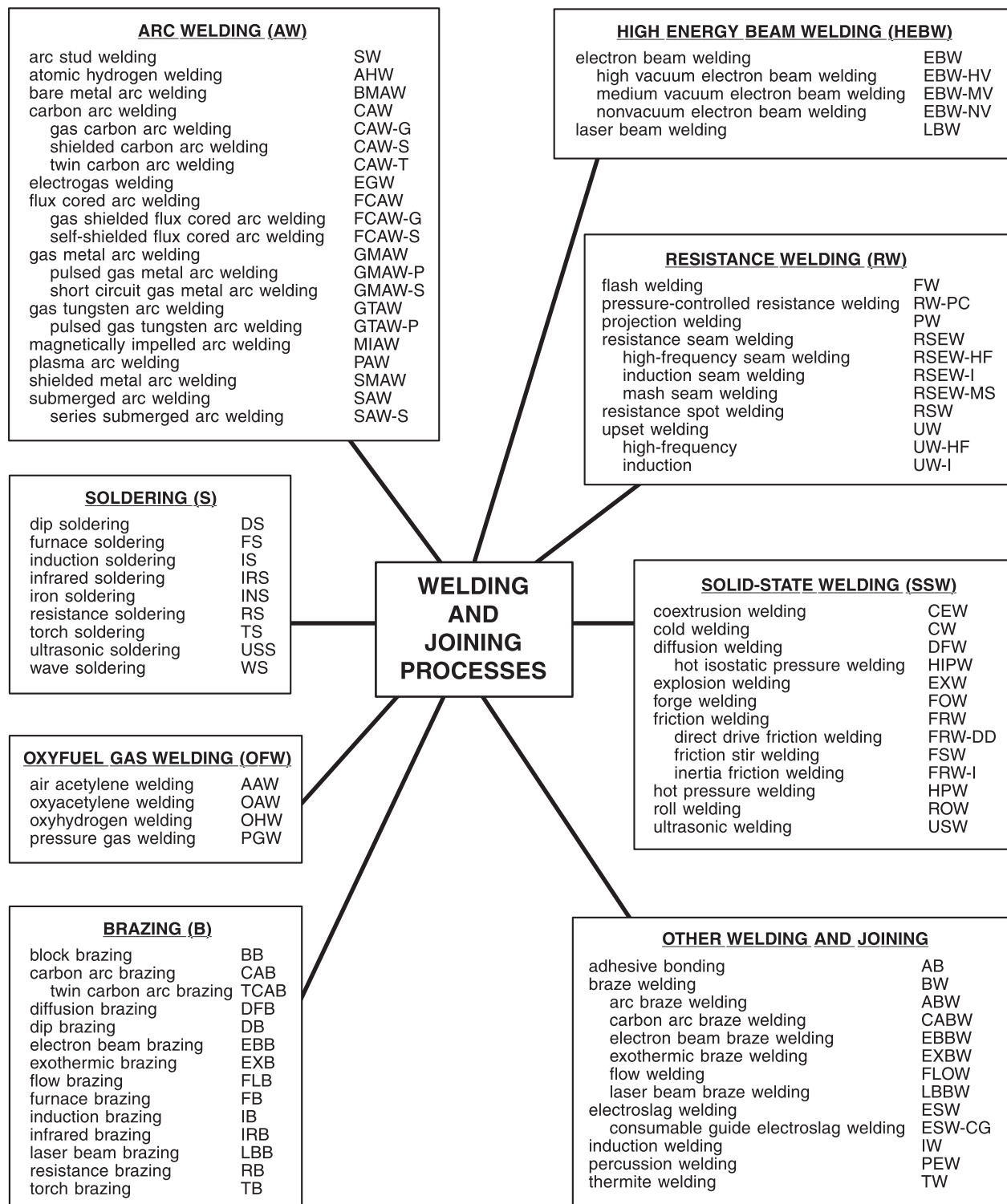


Figure 2—Master Chart of Welding and Joining Processes

5.2.1 Gas Metal Arc Welding (GMAW). GMAW is the AWS designation for the process also referred to as “MIG” or “MAG” welding. It is most commonly employed as a semi-automatic process; however, it is also used in mechanized and automatic applications. It is very well suited for robotic applications and as such it is the most widely used arc welding process when robotically arc welding. An example of robotic GMAW is shown in Figure 3.

GMAW is accomplished with either a solid wire electrode or a metal cored electrode which is fed continuously through a welding torch. An arc is created between this wire and the workpiece to heat and melt the base and filler materials. Once molten, the wire becomes deposited in the weld joint. Figure 4 depicts the essential elements of the process.

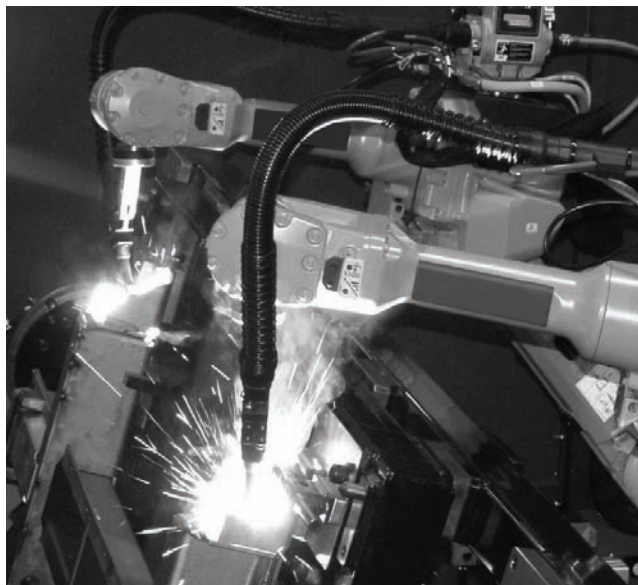


Figure 3—Robotic GMAW

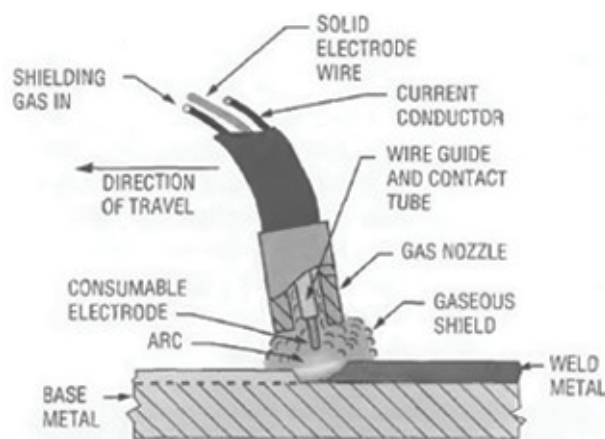


Figure 4—GMAW, Including Schematic of Details

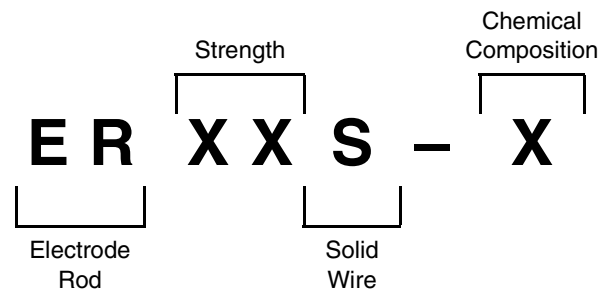


Figure 5—GMAW Solid Carbon Steel Wire Electrode Identification System

An important feature for GMAW is that all of the shielding for welding is provided by a protective gas atmosphere which is also emitted from the welding torch from some external source. Gases used include both inert and reactive types. Inert gases such as argon and helium are used for some applications. They can be applied singly, or in combination with each other, or mixed with reactive gases such as nitrogen, oxygen, or carbon dioxide. Some GMAW applications use carbon dioxide shielding alone, because of its relatively low cost compared to inert gases.

The electrodes used for this process are solid or metal cored wires which are supplied on spools/coils or bulk packages of various sizes. There are approved AWS identification systems for GMAW electrodes. For example, solid carbon steel electrodes are denoted by the letters “ER” followed by two or three numbers, the letter “S,” a hyphen, and then another number and shown in Figure 5.

“ER” designates the wire as being an electrode and a rod, meaning that it may conduct electricity (electrode), or simply be applied as a filler metal (rod) when used with other welding processes. The next two or three numbers state the minimum tensile strength of the deposited weld metal in thousands of pounds per square inch. For example, a “70” denotes a filler metal whose tensile strength is at least 70 000 psi. The letter “S” stands for a solid wire. Finally, the number after the hyphen refers to the particular chemical composition of the electrode. This will dictate both its operating characteristics as well as what properties are to be expected from the deposited weld. These wires typically have increased amounts of deoxidizers such as manganese, silicon, and aluminum to help avoid the formation of porosity.

Even though the wire doesn’t have a flux coating, it is still important to store the material properly when not in use. The most critical factor here is that the wire must be kept clean. If allowed to remain out in the open, it may become contaminated with rust, oil, moisture, grinding dust, or other materials present in a weld shop environment. So, when idle, the wire should be kept in its original plastic wrapping and/or shipping container. Even when a spool of wire is in place on the wire feeder, it should be covered with a protective covering when not used for prolonged periods of time.

The power source used for GMAW is a constant voltage, or constant potential, power source. That is, welding is accomplished using a preset value of voltage over the range of welding currents.

GMAW is normally accomplished using direct current, electrode positive (DCEP). When this type of power source is combined with a wire feeder, the result is a welding process which can be semiautomatic, mechanized, or fully automatic. Figures 1 and 6 show a typical GMAW setup.

A complete setup includes a power source, wire feeder, gas source, and welding torch which includes a flexible cable that the electrode and shielding gas pass through. To set up for welding, the operator will adjust the voltage and wire feed speed or current through the programming of the robot. Some equipment operates on wire feed speed and some operate on current. As the wire feed speed is increased, the welding current is also increased. The melt-off rate of the electrode is proportional to the welding current, so the wire feed speed actually controls this feature as well.

Although a GMAW power source is described as constant potential, a look at a typical V-A curve (Figure 7) will show that the line is not flat, but actually has a slight slope. This system could also be described as “self-regulating constant potential” because changes in the contact tip to work distance (CTWD), commonly called stickout, will result in changes in the arc current. Reducing the CTWD decreases the amount of electrical resistance and therefore increases the amount



Figure 6—GMAW Equipment

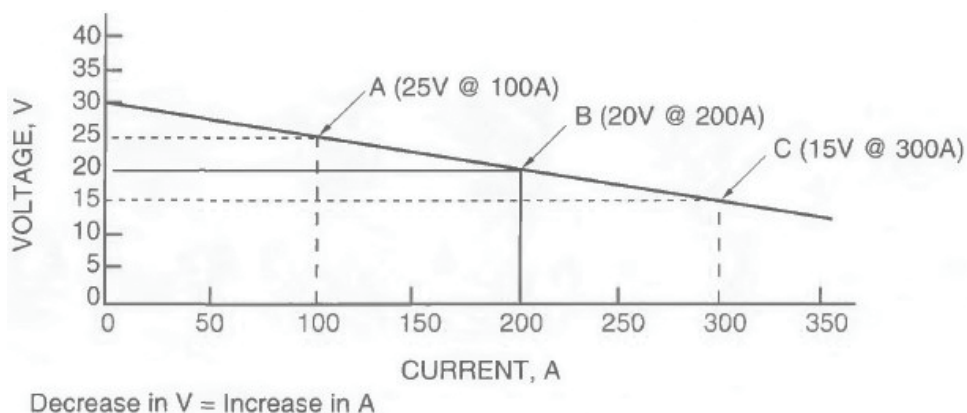


Figure 7—Typical Constant Potential V-A Curve

of welding current. This increases the melt-off rate and restores the arc length to the previous condition. Common GMAW torch nomenclature can be seen in Figure 8.

Machine settings have a large impact on the operating characteristics of the process. Of primary concern is the manner in which the molten metal is transferred from the end of the electrode, across the arc region, to the base metal. With GMAW, there are three basic modes of metal transfer. They are short circuiting, globular, and spray. In addition, the spray mode has three variations: standard, pulsed, and rotational.

Figure 9 shows the three transfer modes. Each specific transfer mode has definite advantages and limitations which make it better for some applications than others. The type of metal transfer depends on several factors, including shielding gas, current levels relative to wire diameter, voltage levels, and power source characteristics.

One of the basic ways in which these three transfer modes differs is that they provide varying amounts of heat to the workpiece. Standard spray transfer is considered to be the hottest, followed by pulsed spray, globular and short circuiting.