

Recommended Practices for Gas Tungsten Arc Welding



AWS C5.5-80

Recommended Practices for Gas Tungsten Arc Welding

Prepared by
AWS Committee on Arc Welding
and Arc Cutting

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors, September 11, 1979

AMERICAN WELDING SOCIETY
2501 N.W. 7th Street, Miami, FL 33125

Library of Congress Number: 80-65185
International Standard Book Number: 0-87171-193-1

American Welding Society, 2501 N.W. 7th Street, Miami, FL 33125

© 1980 by American Welding Society.
All rights reserved.

Note: By publication of this standard, the American Welding Society does not insure anyone utilizing the standard against liability arising from the use of such standard. A publication of a standard by the American Welding Society does not carry with it any right to make, use, or sell any patented items. Each prospective user should make an independent investigation.

This standard is subject to revision at any time by the responsible technical committee. It must be reviewed every five years and if not revised, it must be either reapproved or withdrawn. Comments (recommendations, additions, or deletions) and any pertinent data which may be of use in improving this standard are requested and should be addressed to AWS headquarters. Such comments will receive careful consideration by the responsible technical committee and you will be informed of the committee's response. Guests are invited to attend all meetings of AWS committees to express their comments verbally. Procedures for appeal of an adverse decision concerning your comments are provided in the Rules of Operation for AWS Technical Committees. A copy of these Rules can be obtained from the American Welding Society, 2501 N.W. 7th Street, Miami, FL 33125.

Printed in the United States of America

Contents

<i>Personnel</i>	v
<i>Foreword</i>	vii
1. Scope and Definitions	1
1.1 Scope	1
1.2 Definitions and History	1
1.3 Development of Process Variations	1
1.4 Growth in Adaptability	2
1.5 Process Limitations	2
2. Recommended Practices for Gas Tungsten Arc Welding	2
2.1 Materials and Joint Design	2
2.2 Shielding Gas	6
2.3 Arc Initiation Methods	6
2.4 Welding Current: Types and Application	8
2.5 Arc Voltage	10
2.6 Welding Speed	11
2.7 Tungsten Electrode	14
2.8 Filler Metal	16
2.9 Fixturing	17
2.10 Welding Schedule and Procedure	18
2.11 Welding Equipment Setup	18
3. Welder and Welding Engineer	22
3.1 Welder Training and Qualification	22
3.2 Areas of Responsibility	22
4. Quality Control	23
4.1 Inspection and Test Methods	23
4.2 Specifications	23
5. Typical Equipment for Process Applications	23
5.1 Manual Gas Tungsten Arc Welding	23
5.2 Semiautomatic Gas Tungsten Arc Welding	25
5.3 Automatic Gas Tungsten Arc Welding	26
6. Safe Practices	37
6.1 Introduction	37
6.2 Safe Handling of Shielding Gas Cylinders and Regulators	37
6.3 Cylinder Use	37
6.4 Gases	37
6.5 Metal Fumes	37
6.6 Radiant Energy	37
6.7 Noise and Hearing Protection	38
6.8 Safe Handling of Welding Equipment	38

Personnel

AWS Committee on Arc Welding and Arc Cutting

<i>R. T. Hemzacek, Chairman</i>	International Harvester Company
<i>L. C. Northard, 1st Vice Chairman</i>	Tennessee Valley Authority
<i>J. R. Hannahs, 2nd Vice Chairman</i>	Midwest Testing Laboratories
<i>H. W. Raths, Secretary</i>	American Welding Society
<i>W. L. Ballis</i>	Columbia Gas Distribution Company
<i>L. R. Colarossi</i>	Pittsburgh-Des Moines Steel Company
<i>S. M. El-Soudani</i>	Aircraft Engine Group, General Electric Company
<i>N. A. Freytag</i>	The Budd Company
<i>R. E. Garner</i>	Boeing Company
<i>J. E. Hinkel</i>	Lincoln Electric Company
<i>J. A. Hogan</i>	Hypertherm, Inc.
<i>D. J. Kotecki</i>	Teledyne McKay Company
<i>T. E. Junk</i>	Westinghouse Electric Corporation
<i>R. K. Lee</i>	Consultant
<i>R. A. Manley</i>	Naval Ship Engineering Center
<i>R. D. Mann</i>	Airco Welding Products
<i>E. R. Pierre</i>	Edward R. Pierre Enterprises
<i>L. J. Privoznik</i>	Westinghouse Electric Corporation
<i>P. W. Ramsey</i>	A. O. Smith Corporation
<i>G. R. Rothschild</i>	Airco, Inc.
<i>H. S. Sayre</i>	Consultant
<i>W. K. Scattergood</i>	Suntech, Inc.
<i>B. L. Shultz</i>	General American Transportation Corporation
<i>M. D. Stepath</i>	Arcair Company
<i>E. P. Vilkas</i>	Astro-Arc Company
<i>N. S. Wamack</i>	Combustion Engineering, Inc.
<i>G. K. Willecke*</i>	Miller Electric Manufacturing Company
<i>F. J. Winsor</i>	Foster Wheeler Corporation
<i>*Advisory Member</i>	

PERSONNEL

Subcommittee on Gas Tungsten Arc Welding

<i>E. P. Vilkas, Chairman</i>	Astro-Arc Company
<i>H. W. Raths, Secretary</i>	American Welding Society
<i>N. Chappel</i>	Consultant
<i>H. R. Conway</i>	Huntington Alloys, Inc.
<i>J. C. Downey</i>	E G&G Idaho, Inc.
<i>I. S. Goodman</i>	Westinghouse Electric Corporation
<i>G. K. Hicken</i>	Sandia Labs
<i>R. G. Hirsch</i>	Norfolk Naval Shipyard
<i>J. Lanza fame</i>	Daniel International
<i>D. C. Leach</i>	Harrison Radiator Division, General Motors Corporation
<i>R. A. Manley</i>	Naval Ship Engineering Center
<i>J. O. Nelson</i>	Grumman Aerospace Corporation
<i>L. C. Northard</i>	Tennessee Valley Authority
<i>G. R. Rothschild</i>	Airco, Inc.
<i>F. A. Shaikh</i>	Carolina Power and Light Company
<i>T. W. Shearer, Jr.</i>	Fisher Body Division, General Motors Corporation
<i>G. R. Stoeckinger</i>	Roy E. Hanson, Jr., Manufacturing Company
<i>J. C. Wormeli</i>	Quality Systems, Inc.

Foreword

Gas tungsten arc welding was introduced as a practical fabricating process approximately thirty-five years ago. In the past several years, rapid advances have been made in the development of techniques for automatic applications, and gas tungsten arc welding is now accepted as the only practical method in some metal joining applications.

Sufficient data have been recently gathered and organized to yield an authoritative source of sound technical practices for gas tungsten arc welding. Accordingly, the AWS Committee on Arc Welding and Arc Cutting and the Subcommittee on Gas Tungsten Arc Welding have prepared these recommended practices. These recommended practices are based on a survey of gas tungsten arc welding as used in the metal fabricating industry.

The description of gas tungsten arc welding and its features is presented here as clearly and concisely as possible. The Committee has developed these guidelines in the hope that they would lead to further development of the gas tungsten arc welding process and, thus, to higher quality and performance standards. Comments on this publication will be most welcome. They should be addressed to:

Secretary, AWS Arc Welding and Arc Cutting Committee
American Welding Society
2501 N.W. 7th Street
Miami, FL 33125

Recommended Practices for Gas Tungsten Arc Welding

1. Scope and Definitions

1.1 Scope. GTAW has become indispensable as a tool for industry in the relatively few years since its inception. This has occurred through improvement of equipment and by development of new GTAW process controls and techniques. The information prepared in this document describes the established standards and enumerates the recommended practices.

1.2 Definitions and History. Welding in an inert gas atmosphere was first considered in the late 1920's. In 1930, a patent was issued to Hobart and Devers covering the use of an electric arc within an inert gas atmosphere. Various others experimented with argon and helium as shielding gases, but cost considerations were against adoption of the process.

The first commercial development of gas tungsten arc process equipment occurred in the aircraft industry. Leading the development were Russell Meredith and V. H. Pavlecka. In 1941, these men and their associates developed the first practical electrode holders (torches) provided with metal nozzles; helium gas was fed through the electrode holder to protect the electrode, weld pool, and adjacent heated areas of the workpiece from atmospheric contamination. They found that the gas shield must provide full protection, since even a small amount of entrained air can contaminate the weld. The process was called "Heli-Arc" welding, and a patent was issued to Meredith in February 1942.

The first gas tungsten arc (GTA) welding was done on magnesium alloys with dc generators of the rotating type, utilizing dc reverse polarity (electrode positive). Today, dc reverse polarity is almost never used, since its limitations are well established. For example, an electrode about 3/16 in. (4.8 mm) in diameter must be used when welding with 100A DCRP, to avoid overheating. If the circuit polarities are switched to electrode negative (DCSP), then a 1/16 in.

(1.6 mm) diameter tungsten electrode can be used.

The slow response of the dc generator to changing conditions was first improved by attaching a unit that superimposed high frequency ionization on the welding current. This unit permitted the welding of aluminum.

Then a high frequency stabilized ac welding machine was used, and results on the aluminum alloys being welded were far superior to those of the existing dc power sources. Although there are other differences between DCRP and DCSP, the phenomenon of cathodic cleaning associated with electrode positive welding (DCRP) is most important in welding aluminum alloys. The mechanism responsible for removing surface oxides from aluminum is generally agreed to be best explained by the theory of atomic sputtering. Alternating current, with current flow in one direction and then in the other, allows the advantages of cathodic cleaning without the disadvantages associated with DCRP welding. Power sources were then developed specifically for GTAW (often called TIG welding).

Welding studies have revealed that the type of power supply used for GTAW has a profound effect on the arc characteristics and properties of the welds. However, until recently, little was done to study the effect of power supply waveform on the characteristics of GTA welds, because suitable equipment was not available.

1.3 Development of Process Variations. GTAW is adaptable to both manual and automatic operation and can be used to produce continuous welds, intermittent welds, and spot welds. Because the electrode is essentially non-consumable, a weld can be made by fusion of the base metal without the addition of filler metal. A filler metal may also be used, depending upon the requirements that have been established for the particular joint. The hot wire method of filler metal addition was introduced in 1966 as a tool for increasing deposition rates of GTAW. Filler metal addition is desirable in many applications. Automatic

2 / RECOMMENDED PRACTICES FOR GAS TUNGSTEN ARC WELDING

tungsten electrode-to-work positioning devices have been developed to allow welding of contoured parts with a uniform heat input and more efficient filler metal additions. The completely automatic GTAW process has the following basic variables controlled from the start to the finish:

- (1) Welding current with up- and downslopes
- (2) Arc voltage with up- and downslopes, which is equivalent to arc length control
- (3) Welding speed
- (4) Inert gas flow
- (5) Filler wire feed rate and position

Since the GTAW process was most practical for welding materials such as titanium, many weldments were produced within enclosures or so-called dry boxes. This process variation requires vacuum pumping equipment to evacuate the ambient atmosphere from the dry box so it can be filled with inert gas.

Another GTAW process operation was arc spot welding with or without filler metal addition. As arc initiation methods were improved, new GTAW process operations were developed, employing several tungsten electrodes positioned around the part to be welded and initiated either sequentially or simultaneously.

1.4 Growth in Adaptability. GTAW involves a number of basic functions. The arc is usually considered the heart of GTAW. However, processing and positioning of the parts to be welded and measurement of the welded product are, in many applications, as important as the handling of the welding arc as a tool.

The growth of GTAW process adaptability must be attributed to innovations in electrode holder designs, developments in dc and ac power sources, the evolution of automatic arc starting systems, automatic positioning and process sequence controls, and a concentrated effort to establish gas tungsten arc welding as the process for fabrication.

1.5 Process Limitations. GTAW requires continuous and efficient weld metal shielding. Backup shielding is also required in many applications. This basic requirement tends to limit the process to indoor types of applications; however, with proper shielding techniques, field welding is also readily accomplished.

The duty cycle of the GTAW equipment generally exceeds the intended service requirements. However, many problems have been experienced through neglect in checking the welding duty cycle and matching it with the duty cycle of the rectifier, water cooling efficiency, tungsten electrode holder efficiency, and the efficiency of tooling with respect to heat dissipation.

The fact that the gas tungsten arc has the shape of a cone rather than a cylinder required development of various techniques in manual application and arc positioning controls in automatic applications. It should be noted that the widely used arc voltage control method requires a considerable amount of practical understanding, since arc voltage is not a linear function of arc length.

Weld penetration has been controlled for many years by various designs of backup tooling. Other methods of controlling weld penetration have been developed recently, when backup tooling became either impossible or impractical to apply to the butt joint. One basic approach was to improve the fundamental GTAW process controls, thereby assuring constant weld penetration. The first adaptive controls were developed in order to compensate for such variables as weld joint gapping, thickness, and mismatch and to control weld penetration or weld geometry.

In the GTAW spot welding process, tungsten electrode tip life is the greatest limiting factor. Nevertheless, multiple electrode GTAW spot welding equipment is presently used successfully by several automotive manufacturers.

Many new dissimilar metal joining application problems have been solved by development of proper filler metals.

2. Recommended Practices for Gas Tungsten Arc Welding

2.1 Materials and Joint Design. The GTAW process is perhaps the most flexible of all fusion welding processes in the variety of metals welded. Variations in weld joint design are limited only by the characteristics of the particular metal and joint efficiency requirements. In addition to the wide choice of joint designs and metals that may be welded with this process, the filler metal (if used) may be added to the weld pool by manual or automatic means, or as a preformed shape.

Most of the commercially available welding power sources offer precision control over the welding variables; and along with the excellent visibility of the exposed gas shielded arc, the addition of filler metal may be precisely controlled to suit the metallurgical requirements of the particular weldment.

This section includes guidelines and accepted practices concerning materials and joint designs. Specific information concerning base metals and their respective joint designs is discussed in depth in the AWS handbooks.

2.1.1 Composition and Quality. Most of the metals weldable by other fusion processes may be welded by the GTAW process. Successful welding requires the base metal to be of a chemical composition suitable for welding. The chemical composition of the base metal should be known prior to welding so that variables such as filler metals, metallurgical properties, preheating or postheating, and other important considerations may be included in the application of the welding process. In some cases, the chemical composition of the base metal may be unknown and various weldability tests are conducted. These may be destructive or nondestructive tests and are generally conducted on small samples. These tests easily determine whether the material is compatible with GTAW.

Base metals that can be traced to a particular chemical

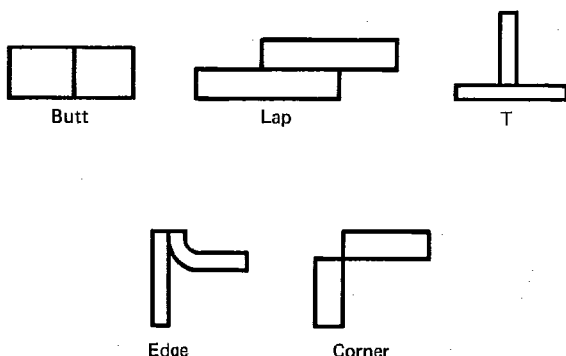
composition are usually referenced in the AWS handbooks, which deal with specific welding details. Nevertheless, certain chemical compositions that appear to be within the limitations for the major elements may display undesirable characteristics during and after welding. These characteristics are generally found to be related to unreported trace elements within the metal. Lack of weld penetration when using fixed welding conditions, excessive porosity, and microcracking are a few of the undesirable characteristics that have been identified and traced to various trace element effects.

Although the possibility of trace element problems exists, the chemical certifications generally provide sufficient information for determining the relative weldability of a particular metal. The final test of quality metal is the actual welding; and, in certain instances, the addition of a filler metal having a slightly different but compatible chemistry may help to eliminate or minimize a metal problem.

2.1.2 Joint Design. Due to the variety of base metals and their individual characteristics (such as surface tension, flowability, melting temperature, etc.), joint geometries or designs that provide for optimum welding conditions should be used. Factors affecting joint designs include metal thickness, weld penetration requirements, and joint efficiency requirements, along with the metals characteristics previously mentioned.

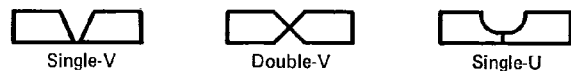
The first consideration in joint design is provision for proper accessibility. The joint opening must be adequate to permit the arc, proper gas shielding, and filler metal to reach the bottom of the joint. If manipulation is required, the opening must be sufficient to allow for proper manipulation. In determining correct joint design, the characteristics of the weld metal must be considered. For example, the high nickel alloys are very sluggish when molten and, therefore, the weld metal does not spread. The weld metal must be placed at the proper location in the joint. Therefore, high nickel alloy joints must be more open than those for carbon and alloy steel in order to provide space for manipulation.

The five basic joints (butt, lap, T, edge, and corner) shown in the figures below may be used for virtually all metals.



Many variations are derived from these five basic joints. Most are derived from the butt joint. These basic joints represent the minimum amount of preparation prior to welding. They also provide the most economical welding, since minimum filler metal, minimum preparation, and minimum setup time are required.

Weld requirements for complete joint penetration, high joint strengths, or other special requirements usually require some modifications to the square butt joint as the thickness increases over sheet gages. A few of these variations are shown below.

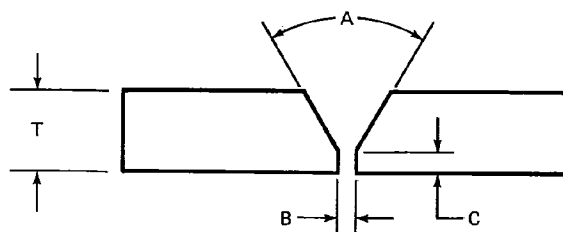


While there are no fixed rules governing the use of a particular joint design for any one metal, certain designs were developed for various reasons. Areas for which each joint type (single-V, double-V, single-U) is best suited are presented in the following paragraphs.

2.1.2.1 Single-V Butt Joint. This joint configuration is the most widely used of all joint designs when complete joint penetration is required from one side only.

There are three variables of this joint design: root opening, thickness of root face, and angle of bevel. All variables must be considered prior to joint preparation.

The amount of root opening and thickness of the root face depend upon whether the GTAW process is to be manual or automatic, whether filler metal is to be added during the root pass, and whether a backing is to be employed. The amount of angle depends upon the thickness of the metal and the clearance needed for arc movement to assure adequate fusion on both sides of the joint. These variables are generally determined by welding test samples which have been prepared using a variety of combinations. While specific information on joint designs may be found in the AWS handbooks or in the metals suppliers' literature, the following design is presented as a guide.



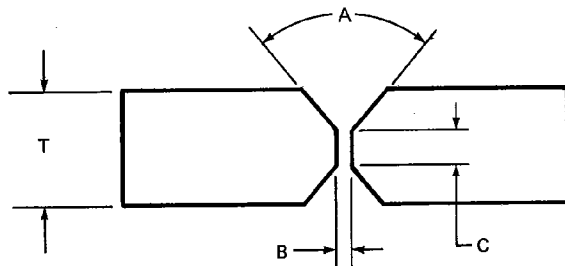
Most Metals

- T — 1/8 to 1/2 in. (3.2 to 12.7 mm)
- A — 60° to 90°
- B — 3/32 in. (2.4 mm) or less
- C — 1/16 in. (1.6 mm) or less

4 / RECOMMENDED PRACTICES FOR GAS TUNGSTEN ARC WELDING

2.1.2.2 Double-V Butt Joint. This joint is primarily used when thicker sections that require complete joint penetration are welded. It provides the economic advantage of a reduced amount of welding. Its use is usually confined to sections over 1/2 in. (12.7 mm) where weld distortion may be a problem. With careful weld pass sequencing, the double-V joint permits welding on both sides to hold weld distortion to a minimum.

The following design is presented as a guide.

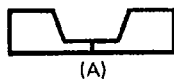


Most Metals

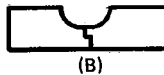
- T — 1/2 in. (12.7 mm) and over
- A — 60° to 90°
- B — 3/32 in. (2.4 mm) or less
- C — 1/16 in. (1.6 mm) or less

2.1.2.3 Single-U Butt Joint. This information concerning the single-U groove generally applies to all configurations obtained by preparation methods involving operations or tools for other than straight line metal removal. These types of joints are used on a variety of metals and thickness ranges. The type of metal to be welded often dictates a specially prepared joint, even though joint preparation costs are higher. Certain metals in the refractory group, such as the titanium alloys, tend to possess unusual fluidity during welding, and a specially prepared joint is the best answer for obtaining a satisfactory root pass. Butt welds in aluminum piping are often made with a joint as shown in illustration (A) for control of root pass penetration when welding in all positions without internal backing.

This joint design is usually applied after other less expensive avenues have been explored. Since the specific design for this type of joint varies considerably, two examples are shown.



Used where metal fluidity creates problems in obtaining root pass



Used where locating surfaces are required for accurate alignment

2.1.3 Joint Preparation and Tolerances. After the particular joint design has been established, the most important item for consideration is the method of joint preparation. There are many ways to remove metal to prepare a given joint angle, land thickness, or geometrical configuration. However, many GTAW problems or supposed problems are a direct result of using improper methods for joint preparation. Chief among these is the improper use of grinding wheels to prepare joints. Soft materials such as aluminum become impregnated with micro-sized abrasive particles which, unless subsequently removed, will result in excessive porosity. Grinding wheels should be cleaned and reserved exclusively for the material being welded. The ideal joint preparation is obtained through the use of a cutting tool such as a lathe for round or cylindrical joints or a milling cutter for longitudinal preparations. Care must be exercised in the choice of cutting fluid (if any) to be used, and cleaning after cutting or turning should be with safety-approved solvents that are free of residues.

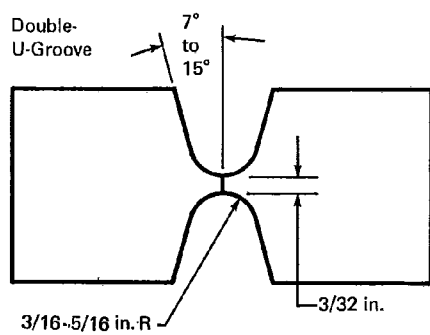
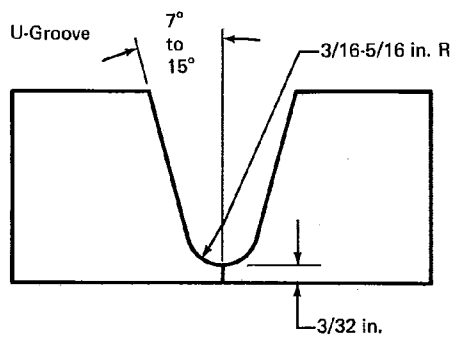
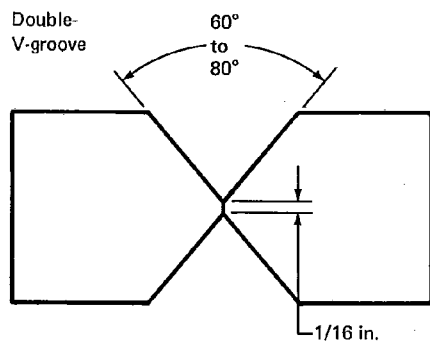
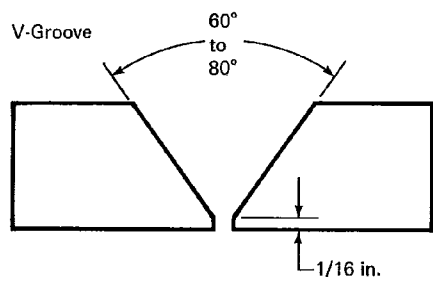
The required exactness of joint preparation also depends upon whether the GTAW is to be done manually or by automatic means. Manual welding conditions can tolerate greater irregularities in joint fit-up than automatic welding. The particular tolerance for a given application can be determined only by actual testing, and this tolerance should be specified for future work.

Beveling is usually not required for butt joints 1/8 in. (3.2 mm) or less in thickness in carbon, low alloy and stainless steels, and aluminum. For high nickel alloys, beveling is usually not required for material 3/32 in. (2.4 mm) or less in thickness. For greater thickness materials, the joint should be beveled to form a V-, U-, or J-groove. Otherwise, erratic penetration will result, causing crevices and voids that are potential areas of accelerated corrosion. Notches resulting from erratic penetration can also act as mechanical stress raisers and cause early mechanical failure in the weld joint.

Normally, a double-U or double-V joint design is preferred for material over 1/2 in. (12.7 mm) thick. The added cost of preparation is justified by the decreased amount of welding metal and lower welding time needed to complete the joint. Also, less residual stress will be developed than with the single groove design.

As shown in Fig. 1, V-groove joints are normally beveled to provide approximately a 60 degree groove for carbon, low alloy, and stainless steels, and an 80 degree groove for high nickel alloys. A 90 degree groove is commonly used when welding aluminum with ac GTAW. The U-groove joints are generally beveled to 7 to 9 degree side walls for carbon, low alloy, and stainless steels. A 15 degree side wall is recommended for high nickel alloys, and a 20 to 30 degree side wall bevel may be required for U-groove joints in aluminum. Single bevels for T-joints between dissimilar thicknesses of ferrous metals should have an angle of approximately 45 degrees. An angle of as much as 60 degrees may be necessary for aluminum alloys.

2.1.4 Production Conditions. Cleanliness is one of



Metric Equivalents

in.	mm
1/16	1.6
3/32	2.4
1/8	3.2
3/16	4.8
5/16	8.0
1/2	12.7

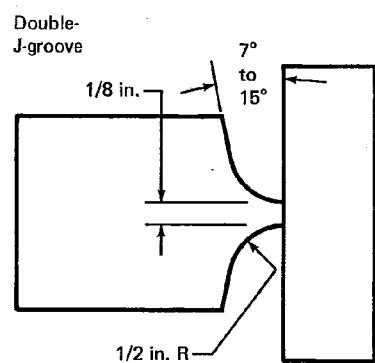
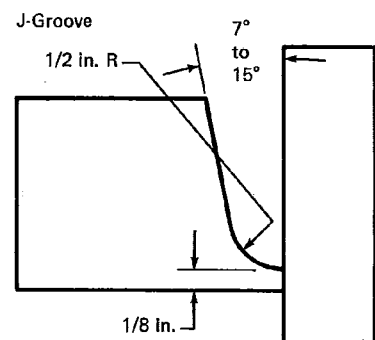
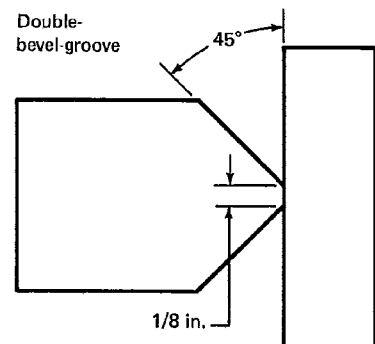
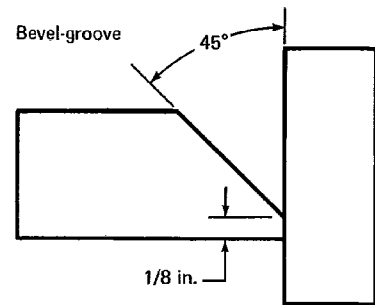


Fig. 1 – Typical joint designs for ferrous metals

6 / RECOMMENDED PRACTICES FOR GAS TUNGSTEN ARC WELDING

the most important and also one of the most often overlooked requirements for successful joining of metals. Many substances often used during normal manufacturing processes can cause welding difficulty if not thoroughly removed. Examples include grease, oil, paint, cutting fluids, marking crayons and inks, processing chemicals, and machine lubricants. Because it is frequently impractical to avoid the use of these materials during processing and fabrication of the alloys, it is mandatory that the metal be thoroughly cleaned prior to any welding operation. A minimum area of cleaning should extend 1/2 in. (12.7 mm) from the joint on each side. The cleaned area should include the edges of the workpiece and the interiors of hollow or tubular shapes.

The cleaning method depends upon the composition of the substance to be removed and should not cause any problems with the metals being joined. Shop dirt and materials having an oil or grease base can be removed by vapor degreasing or swabbing with non-toxic solvents. Paint and other materials not soluble in degreasing solvents may require the use of methylene chloride, alkaline cleaners, or special proprietary compounds.

Oxides should also be removed. For some metals, wire brushing is sufficient. However, wire brushing may not be sufficient for metals that have refractory oxides, such as aluminum, stainless steel, and high nickel alloys. Acceptable methods for removing the oxides include grinding, abrasive blasting, machining, or pickling (except for Al). Aluminum welds are often made by decreasing the weld joint opening when ac GTA welding is employed. The list of good practices shown below should be followed for all production conditions.

Metal Production Conditions Prior to Welding

- (1) Metal shall be free of foreign substances, oxides, moisture, marking crayons, etc.
- (2) Special cleaning of metal shall be accomplished when required by specifications.
- (3) Weld joint edges shall be clean and uniform. Edges shall be checked for laminations or other discontinuities in accordance with the applicable specification.
- (4) Weld joint fit-up shall be in accordance with the approved procedure.
- (5) Metal identification shall be maintained for accurate documentation of welded components.

Adhering to the above steps will, in most instances, assure that the metal is ready for welding and that adequate quality control measures have been observed.

2.2 Shielding Gas

2.2.1 Quality, Types, and Mixtures. The inert monatomic gases argon and helium are used as shielding for GTAW. Mixtures of argon and helium are useful when some balance between the characteristics of both is desired. Additions of hydrogen and nitrogen have been utilized in special applications. Welding grade argon and helium are supplied with purity of 99.995 percent or greater. Dew point is -70°F (-57°C) or lower.

Argon is the most commonly used gas as it provides

lower arc voltage at any given current value and arc length, a smoother and quieter arc, and easier arc initiation. Since it is a heavy gas (atomic weight 40), lower flow rates are required to provide good shielding.

Helium is used in welding heavy sections where the higher arc voltage characteristic is advantageous or greater penetration is desired, or both.

An excellent reference for the selection of shielding gases is Table 23.2 of Section 2 of the AWS Welding Handbook, 6th Edition. A similar table (Table 1) has been included here.

2.2.2 Shielding Efficiency. The purpose of shielding gas is to protect the weld area and the tungsten electrode from contamination by the atmosphere. Nozzle size, flow rates, and the type of gas utilized are critical factors in the process. See paragraph 2.7.2.3 (Atmospheric Contamination) and Tables 6 and 7.

2.2.3 Methods of Shielding. The shielding gas is generally delivered around the tungsten electrode through a concentric nozzle. Nozzle size must be adequate to provide coverage of the weld area. Automatic welding setups may include supplemental shielding by the use of leading or trailing shields that increase coverage area.

2.2.4 Economics. Argon is obtained from the liquefaction of air and is one of the three primary products of air separation plants. The other two primary products are oxygen and nitrogen. Although argon is less than one percent of the yield, it is readily available.

Helium is obtained from wells controlled by the Bureau of Mines, with a small amount produced by private industry through recovery from natural gas. Limited availability places a premium on this gas.

Shielding gas systems using a total of less than 10 000 cubic feet (283 000 liters) per month normally employ individual cylinders. Distribution manifolds fed by cylinder banks or trailers are used for higher consumption rates.

High consumption rate users of argon should consider a bulk liquid system. Since normal losses due to boiling of the liquid average one percent of the volume in 24 hours, withdrawal rates, hours per day on line, and vessel capacity must be carefully evaluated.

2.3 Arc Initiation Methods

2.3.1 Touch Start. The tungsten electrode tip is momentarily placed in contact with the workpiece and quickly withdrawn. Inert gas flow during this procedure is assumed. This starting method is not acceptable for critical applications, since small tungsten particles may become embedded in the workpiece.

2.3.2 Carbon Start. The tungsten tip is positioned close to the work and the resulting gap is momentarily bridged with a carbon rod or block. After the arc is formed, the carbon is withdrawn or the arc is moved over the joint to be welded. This method is undesirable when critical weld applications are involved, since carbon particles may be entrapped in the work. Also, the required application of the carbon rod is frequently impractical.

2.3.3 High Frequency Start. This method takes ad-

Table 1
Advantages of shielding gases

Metal	Welding type	Shielding gas	Advantages
Aluminum and Magnesium	Manual welding	Argon	Better arc starting, cleaning action, and weld quality; lower gas consumption.
		Argon-helium	High welding speeds possible.
	Machine Welding	Argon-helium	Better weld quality, lower gas flow than required with straight helium.
		Helium (DCSP)	Deeper penetration and higher weld speeds than can be obtained with argon-helium.
Carbon steel	Spot Welding	Argon	Generally preferred for longer electrode life. Better weld nugget contour. Ease of starting, lower gas flows than helium.
	Manual Welding	Argon	Better pool control, especially for position welding.
	Machine Welding	Helium	Higher speeds obtained than with argon.
Stainless steel	Manual Welding	Argon	Permits controlled penetration on thin gage material (up to 14 gage).
		Argon	Excellent control of penetration on light gage materials.
		Argon-helium	Higher heat input, higher welding speeds possible on heavier gages.
		Argon-hydrogen (up to 35% H ₂)	Prevents undercutting, produces desirable weld contour at low current levels, requires lower gas flows.
		Argon-hydrogen-helium	An excellent selection for high speed tube mill operation.
Copper, nickel, and Cu-Ni alloys	Machine Welding	Helium	Provides highest heat input and deepest penetration.
		Argon	Ease of obtaining pool control, penetration, and bead contour on thin gage metal.
		Argon-helium	Higher heat input to offset high heat conductivity of heavier gages.
Titanium	Machine Welding	Helium	Highest heat input for welding speed on heavy metal sections.
		Argon	Low gas flow rate minimizes turbulence and air contamination of weld; improved heat affected zone.
Silicon-bronze	Machine Welding	Helium	Better penetration for manual welding of thick sections (inert gas backing required to shield back of weld against contamination).
		Argon	Reduces cracking of this "hot short" metal.
Aluminum-Bronze	Machine Welding	Argon	Less penetration of base metal.

vantage of the ionization characteristic of gases. The application of an alternating voltage in the kilohertz frequency range causes the gas between the tungsten tip and the work to ionize. This establishes a conductive path, permitting the weld current to start flowing.

Since high frequency tends to erode the tungsten electrode tip, automatic circuit arrangements are usually provided which shut off the high frequency as soon as the arc has been established. Special design precautions are required to prevent the high frequency from radiating too much energy and causing interference with communica-

tion systems. FCC regulation Part 18 establishes the maximum high frequency radiation permissible.

2.3.4 Pilot Arc. A small current is maintained between electrode and torch nozzle to provide a conductive path for the main weld current. This method is most often used in GTA spot welding equipment.

2.3.5 Hot Tungsten Arc. The tungsten is resistively heated to a cherry red. At this temperature, the gas in the immediate vicinity of the tungsten electrode tip is easily ionized by the application of a reasonable open circuit voltage from the welding power supply. This starting

8 / RECOMMENDED PRACTICES FOR GAS TUNGSTEN ARC WELDING

method is also used in GTA spot welding equipment.

The temperature control of the tungsten and the preheating effect of the hot electrode are disadvantages of this arc starting method.

2.3.6 Impulse Start. The momentary application of a high voltage (usually from a bank of capacitors) between the tungsten electrode and the work creates an ionized path through which the weld current starts flowing.

2.4 Welding Current: Types and Applications. Three basic categories of available welding current are alternating current, direct current, and programmed or manipulated current. Programmed current is a category combining some of the features of ac and dc.

2.4.1 Alternating Current. Alternating current flows first in one direction and then in the other. When changing from positive to negative flow, the current must pass through zero, which extinguishes the arc. The arc must then be reignited or it will remain extinguished. In the GTAW process with some metals, the electrons flow from the tungsten to the work more readily than in the reverse direction. This difference in resistance to electron flow with direction of current is greater with some metals than with others. Aluminum, magnesium, and copper with oxide films are particular examples. When aluminum is welded using alternating current, the electron flow is from the plate to the tungsten during the reverse polarity (electrode positive) half wave, and from the tungsten to the plate during the straight polarity (electrode negative) half wave. Hot tungsten is a better emitter of electrons than the aluminum workpiece; thus, the straight polarity half wave has a higher magnitude of current, which results in an unbalance in current. This unbalance, spoken of as partial rectification of the arc, is shown in Fig. 2.

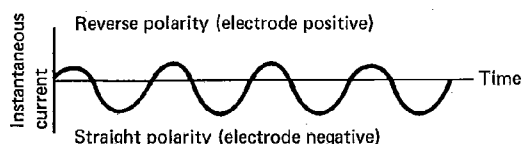


Fig. 2—Unbalanced current wave

At times, the electrode positive half cycle fails to ignite and complete rectification takes place. This is sometimes referred to as "clipping." This clipping effect is shown in Fig. 3.

Several methods of wave balance have been used to equalize the negative and positive portions of the current wave. Some of these are:

- (1) Series capacitors
- (2) Resistor-rectifier combinations
- (3) Batteries
- (4) Wave balance ratio

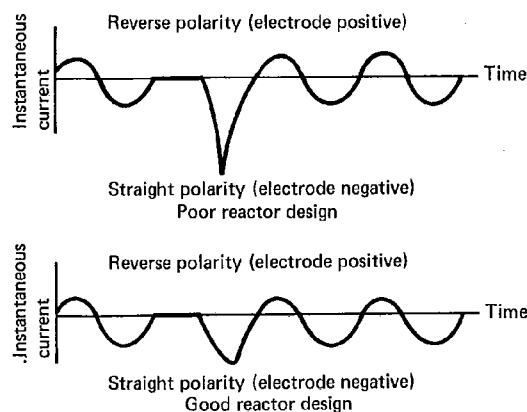


Fig. 3—Clipped wave form

Another method to stabilize the arc without balancing the current wave output is to utilize a superimposed high frequency.

The advantages of balanced current flow are:

- (1) Better work surface cleaning action
- (2) Smoother, more stable arc
- (3) Less electrical upset in welding power source resulting from unbalance and occasional fully rectified load current

The disadvantages of balanced current wave are:

- (1) A larger diameter electrode is required.
- (2) A higher open circuit voltage is required for balanced wave welding machines.
- (3) Cost is usually considerably higher than conventional power sources.

Balanced wave current is most desirable for mechanized welding and high speed welding applications.

2.4.2 Direct Current. Power supplies commercially available for dc welding are motor generators, transformer rectifiers in combination with saturable reactors or magnetic amplifiers, and, more recently, transformers with precisely controlled silicon controlled rectifiers (SCRs). The more sophisticated power supplies are most frequently used in conjunction with semiautomatic and automatic tungsten arc welding processes.

All power supplies incorporate some form of current-to-voltage characteristic commonly referred to as "constant current characteristic" whereby the welding current is essentially unaffected by variations in the arc length (voltage). Two types of direct current GTAW to be considered are: direct current straight polarity (DCSP), and direct current reverse polarity (DCRP). Each type has its own characteristics and areas of application.

Straight polarity (electrode negative) generates greater heat at the positive (work) end of the arc and less at the negative (electrode) end. Without the severe heating of the electrode, smaller diameter electrodes can be used; i.e., a 1/16 in. (1.6 mm) diameter electrode is capable of carrying 125 A.

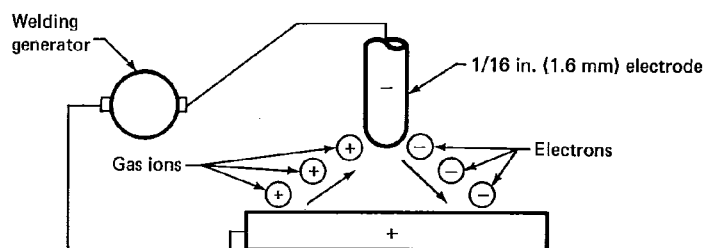


Fig. 4—Direct current—straight polarity (DCSP)

DCSP is normally used for welding practically all metals. The molten weld pool is narrower and the penetration deeper than with DCRP and ac welds. Results are narrower heat-affected zones, less distortion, and faster welding rates.

DCRP is rarely used but does have a particular advantage of surface cleaning on metals whose oxides cause problems to the welding operation. This cleaning action is beneficial for the welding of aluminum and magnesium. This same action occurs in the reverse polarity half cycle of ac welding.

With reverse polarity, the electrode is positive, and negative electrons strike the tungsten, causing electrode overheating. Since the electron flow heats the electrode and not the plate, the weld pool is shallow and wide. This excessive electrode heating limits the application of DCRP; i.e., a 1/4 in. (6.4 mm) diameter electrode has an allowable current-carrying capacity of approximately 125 A.

2.4.3 Programmed Current. Welding power supplies have also been developed capable of providing various types of "modulated" current with or without actual polarity reversal. These "current pulsation techniques" have been developed for the purpose of controlling or improving such items as weld root and bead contour, penetration,

grain size, and out-of-position welding capabilities.

Two such programmed current techniques are square wave ac pulsation and pulsating dc.

Square wave ac pulsation varies from ac balanced wave welding in that the generated wave form is from a precision dc current source which is switched in alternate pulses of reverse and straight polarity direct current. The time the current is flowing in one direction is adjustable from 1/120 to 1/6 second. This allows a programmed current of time and magnitude that will provide some surface cleaning action while on DCRP, as well as provide penetration patterns and depths approaching DCSP and good arc stability and controllability. Studies have also shown that weld pool agitation can be introduced with programmed alternating pulses that aid in producing consistently high quality welds (see Fig. 6).

The pulsating dc envelope pattern is composed of two different current levels selected to best suit the intended application. Time for each current level is selected to yield a program that produces consistent weld metal quality. The frequency of the ripple is 60 hertz. The ripple ratio is related to the ac reactance of the power supply and the external dc inductor usually used in a single-phase full wave rectifier system and is a factor of system design (see Fig. 7).

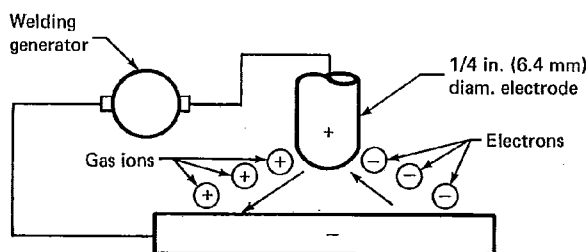


Fig. 5—Direct current—reverse polarity (DCRP)

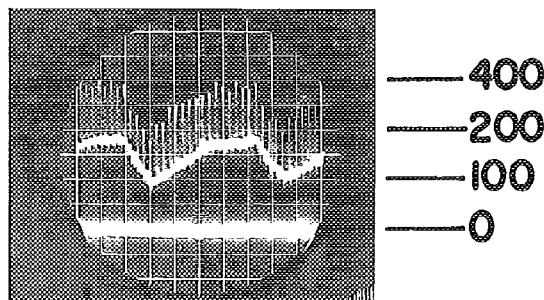


Fig. 6—New current wave pattern composed of slow and 60 Hz pulsation

2.5 Arc Voltage

2.5.1 Factors Affecting Arc Voltage. The voltage drop between the tip of the tungsten electrode and the work is influenced primarily by the type of welding current and the shielding gas used. The arc voltage is proportional to the arc gap length and gas composition. Shielding gases, such as helium and argon-helium, produce greater voltage drops than argon for the same arc gap. The difference between an argon and a helium voltage drop is approximately 4 volts. Therefore, helium gas is used for deeper penetration, particularly when DCSP welding aluminum alloys. During manual ac welding, the operator is not concerned with the arc voltage. However, he controls the arc length very carefully in order to make acceptable

welds. Although helium gas helps, it is difficult to manually weld aluminum with DCSP, as very short (approx. 0.060 in. [1.5 mm]) arc lengths are required. Therefore, automatic methods of controlling arc length or arc voltage were developed.

The voltmeter on the power supply indicates the total of all voltage drops in the cables, connections, tools, tungsten holder, electrode, and arc. The voltage most nearly representing the conditions of the arc is that measured between the tungsten electrode holder and the work. Electrode tip geometry is also an important factor affecting dc arc voltage, as indicated by Fig. 8.

Figure 8 illustrates that at the same tip-to-work distance the arc voltage is higher with a sharper cone tip on the electrode.

2.5.2 Methods of Controlling Arc Voltage. Two methods of arc voltage control are employed in automatic GTAW.

The first method is to move the tungsten electrode at a preset distance to the work independent of the arc voltage and current. These systems vary from simple visual adjustment to the use of elaborate magnetic and eddy current devices. During welding with the constant position method, a strip chart recording of arc voltage will indicate changes in arc length (penetration). The conformity of electrode tip used from weld to weld, as well as electrode tip deterioration, can be observed on a voltage recording meter. This observation may indicate the difference between defective and trouble-free welds.

The second method is to automatically control move-

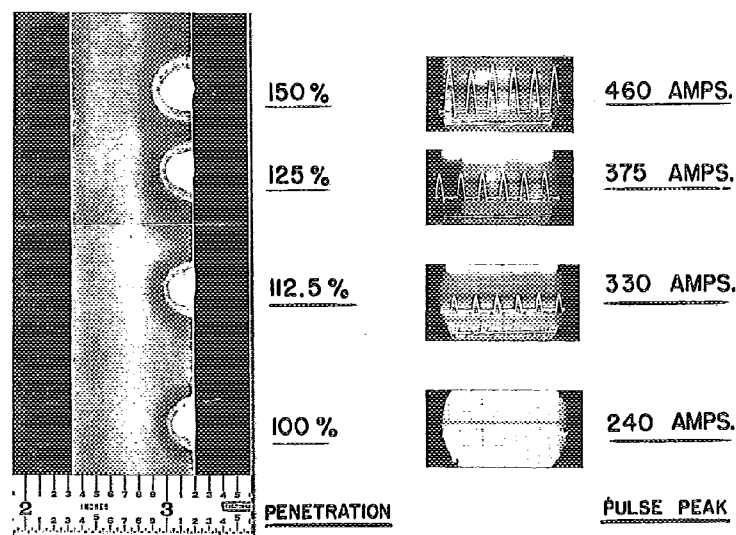


Fig. 7—Relationship between arc penetration and pulse peak (ripple ratio of power source) at an average current of 240 A.

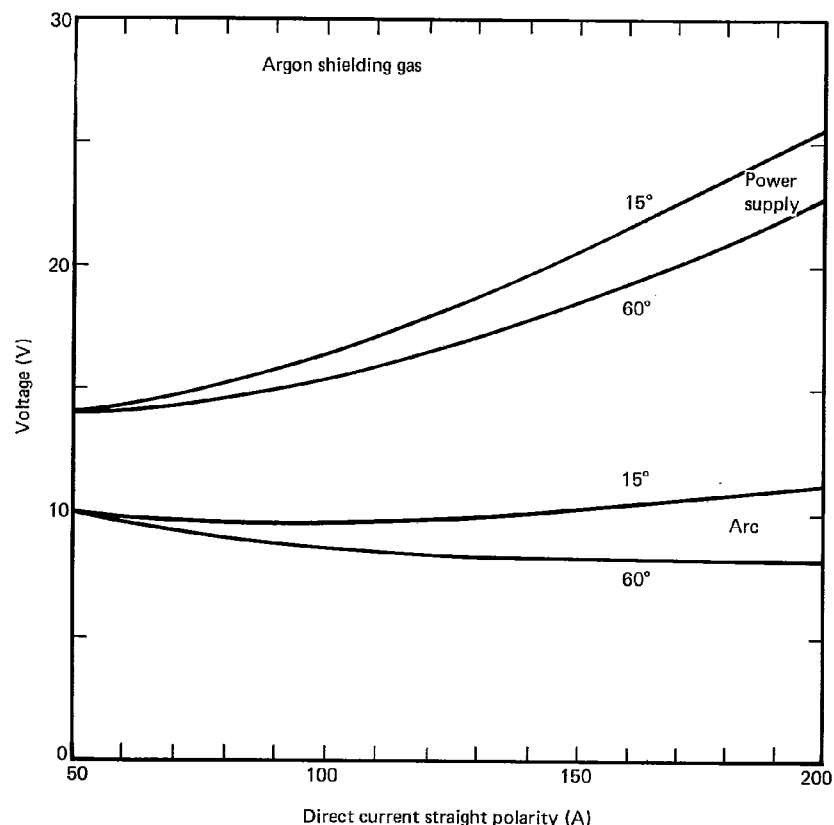


Fig. 8— Voltage and current for two different electrode tapers, as measured at power supply and directly across arc

ment of the tungsten electrode at a preset arc voltage. The voltage is held constant by a reversible gear motor, which raises or lowers the electrode to change the arc length to a preset voltage level. The basic schematic of an automatic GTAW voltage control system is given in Fig. 9. In such a system, the measured arc voltage consists of two distinct voltage drops: the $I \cdot R$ drop due to the arc itself, and the drop in the tungsten electrode. The voltage drop in the tungsten electrode begins to rise immediately after arc initiation, due to heat caused by the welding current. As the voltage drop increases, the AVC (arc voltage control) will shorten the arc length to maintain the sum at a constant value. The characteristic "diving" of the tungsten electrode often encountered in GTAW with AVC heads is partially due to resistance changes that occur during the warm-up period of a weld. The record of the tungsten tip geometry is also important for transferability of GTAW parameters from machine to machine in a plant or between plants for a given job.

2.6 Welding Speed

2.6.1 Principles Governing Speed Selection. Arc penetration is usually inversely proportional to welding speed. In automatic in-place butt welding of tube and pipe, for example, proper welding speed programming provides constant complete penetration welds in butt joints. Programming of welding current rather than welding speed can also produce acceptable tube welds. However, the constant heat density required to produce constant arc penetration is easier to develop and to reproduce with a variable welding speed system.

The welding speed pattern is affected by several factors. As illustrated in Table 2, the thermal conductivity of the tube metal is a major factor controlling speed.

2.6.2 Consistency of Heat Input. Experimentally optimizing the welding speed pattern minimizes distortions caused by thermal expansions and contractions during the welding. In the welding of highly conductive metals such as aluminum, fast welding speeds are preferred to keep

12 / RECOMMENDED PRACTICES FOR GAS TUNGSTEN ARC WELDING

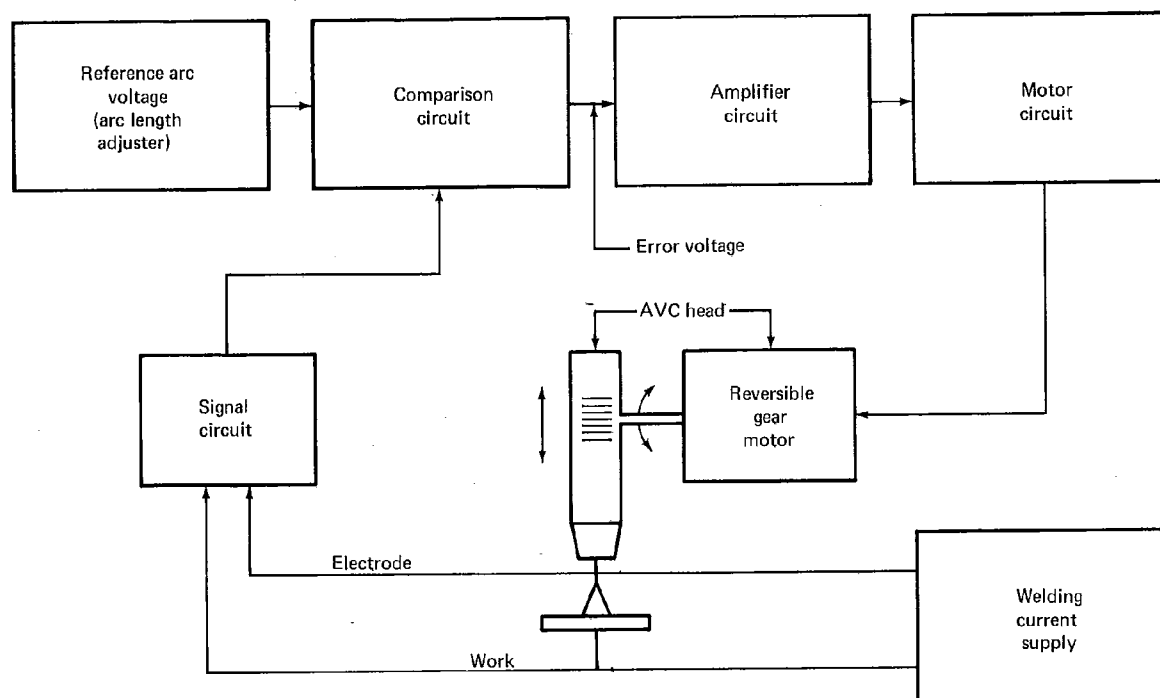


Fig. 9—Automatic GTAW voltage control system

Table 2
Typical welding speed program settings
with automatic in-place tube welding system

Tube alloy	Tube diameter of butt joint		Wall thickness		Start delay, s	Constant speed		Final speed		Total weld time, s
	in.	mm	in.	mm		in./min.	mm/s	in./min.	mm/s	
Stainless steel (AM-350)			0.028	0.71	0.4	7.85	3.2	8.7	3.7	12.4
Titanium (6Al 4V)	1/2	12.7	0.037	0.94	1.2	3.7	1.5	4.2	1.8	20.2
Copper-nickel (90-10)			0.050	1.27	0.7	2.1	0.87	7.1	3.0	33.7
Aluminum (3003)			0.049	1.24	1.0	4.7	1.9	20.7	8.7	15.4

ahead of the conducted heat.

Alloys prone to thermal cracking cannot be welded at high speeds, since the associated steep thermal gradients would contribute to crack formation. Fairly low weld speeds are applied to circumvent this cracking problem. Low weld speeds are often used in combination with preheating the base metal to further reduce the possibility of thermal shock.

The size of the molten weld pool is directly influenced by the weld speed. Only a small weld pool can be carried when welding in positions other than the flat position (downhand). Careful selection of the weld speed is therefore required. The problem of in-place welding and controlling the weld pool in heavy-wall tube butt joints has been solved for the ferrous and low conductivity metals, such as titanium, with the development of welding current pulsation controls. A programmed weld speed effectively produces a series of overlapping melt-thru spot welds, each of which solidifies before the next spot is made.

This pulsed current technique was further improved by the development of the step pulse or incremental welding arc travel control (see Fig. 10). Figure 10 illustrates a cross section of a typical step pulse melt-thru weld joining 1-1/2 in. (38 mm) diameter, 1/8 in. (3.2 mm) thick wall titanium tubing.

Figure 11 illustrates the step pulse welding control program which is indispensable in fully controlled penetration (root) passes. Metal as thick as 1/4 in. (6.4 mm), which is greater than the practical GTAW melt-thru welding thickness range, has been successfully welded.

The thermal expansions and contractions from

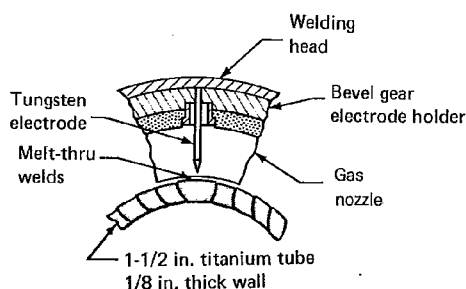


Fig. 10—Cross section of a typical overlapping melt-thru butt joint weld

multiple-pass welding heavy walls cause distortions which can be reduced by selecting a suitable combination of welding and torch cross-seam oscillation speed. Adjusting the dwell time at the end of each stroke provides the proper "wetting" action of filler metal to wall joint and eliminates the occurrence of "cold shuts." Also, proper selection of dwell time in the 2G (vertical) position provides control of weld bead sag during multiple-pass welding of pipes.

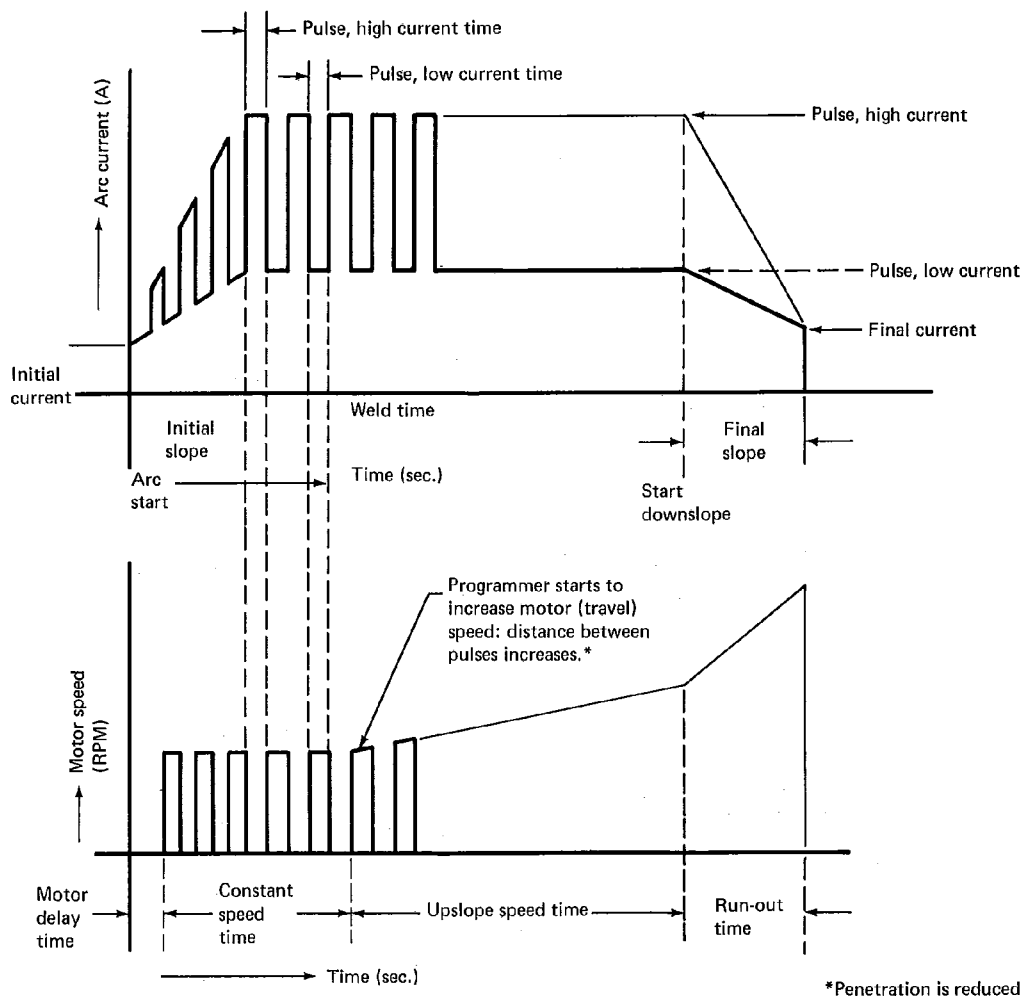
In welding long seams, the welding arc should be precisely positioned over the joint to be welded. The following seam tracking techniques have been developed to suit specific applications.

Table 3
Types of tungsten electrodes

AWS classification	Type of tungsten (avg. alloy)	Color code	Available finish*	Remarks
EWP	Pure	Green	Cleaned and ground	Provides good arc stability for ac welding. Reasonably good resistance to contamination. Lowest current-carrying capacity. Least expensive. Maintains a clean balled end.
EWZr	Zirconia, 0.15 to 0.40%	Brown	Cleaned and ground	Preferred when tungsten contamination of weld is intolerable. Excellent for ac welding due to favorable retention of balled end, high resistance to contamination, and good arc starting.
EWTh-1	Thoria, 0.8 to 1.2%	Yellow	Cleaned and ground	Easier arc starting. Higher current capacity. Greater arc stability. High resistance to weld pool contamination. Difficult to maintain balled end on ac.
EWTh-2	Thoria, 1.7 to 2.2%	Red	Cleaned and ground	
EWTh-3	Thoria, 0.35 to 0.55%	Blue		Designed primarily for ac welding to improve balled end.

*Clean finish designates electrodes that are chemically cleaned and etched. Ground finish designates electrodes with a centerless ground finish to provide maximum smoothness. Centerless ground tungsten electrodes are used where minimum resistance loss at the collet-electrode contact point is desired.

14 / RECOMMENDED PRACTICES FOR GAS TUNGSTEN ARC WELDING



*Penetration is reduced

Fig. 11 — Step pulse programmer

(1) Stylus. A stylus with a suitably shaped tip is mounted ahead of the welding torch, and the tip rides inside the joint to be welded. Variations are translated into electrical control signals, causing a servomechanism to adjust the welding torch so it accurately positions over the joint.

(2) The required servocontrol signal can also be obtained by using joint sensing techniques based on:

(a) Variations in electrical capacitance caused by a variation of distance of the weld joint in relation to the sensor element

(b) Variations in magnetic reluctance

(c) Variations in the frequency of a timed circuit formed between the sensing element and the weld joint

(d) Variations in the location of a reference line drawn parallel to the joint to be welded as observed by an optical sensing element

(e) Variations in the location of a reference type shim mounted parallel to the joint to be welded as observed by a mechanical sensing element

(f) Variations in the location of the joint to be welded as observed through a closed-circuit television camera

2.7 Tungsten Electrode

2.7.1 Type. Tungsten is employed as an essentially nonconsumable electrode for the GTAW process. Tungsten has melting point of 6160° F (3392° C) and a boiling point of 10 700° F (5906° C). It is virtually impossible to vaporize a tungsten electrode during welding, provided the electrode is used within the current-carrying capacity range for its specific type (see Table 4) and diameter, with sufficient inert shielding gas. Tungsten retains its hardness even at red heat.

Table 4
Typical current ranges for tungsten electrodes ^a

		DCSP, A	DCRP, A	High frequency unbalanced wave, ac, A			High frequency balanced wave, ac, A		
Electrode diam., in. mm		EWP EWTh-1, EWTh-2, EWTh-3	EWP EWTh-1, EWTh-2, EWTh-3	EWP	EWTh-1, EWTh-2, EWZr	EWTh-3	EWP	EWTh-1, EWTh-2, EWZr	EWTh-3
0.010	0.25	up to 15	b	up to 15	up to 15	b	up to 15	up to 15	b
0.020	0.5	5-20	b	5-15	5-20	b	10-20	5-20	10-20
0.040	0.1	15-80	b	10-60	15-80	10-80	20-30	20-60	20-60
1/16	1.6	70-150	10-20	50-100	70-150	50-150	30-80	60-120	30-120
3/32	2.4	150-250	15-30	100-160	140-235	100-235	60-130	100-180	60-180
1/8	3.2	250-400	25-40	150-210	225-325	150-325	100-180	160-250	100-250
5/32	4.0	400-500	40-55	200-275	300-400	200-400	160-240	200-320	160-320
3/16	4.8	500-750	55-80	250-350	400-500	250-500	190-300	290-390	190-390
1/4	6.4	750-1000	80-125	325-450	500-630	325-630	250-400	340-525	250-525

a. All values are based on the use of argon as the shielding gas. Other current values may be used, depending upon the shielding gas, type of equipment, and application.

b. These particular combinations are not commonly used.

Tungsten electrodes are commercially available in diameters from 0.010 to 1/4 in. (0.25 to 6.4 mm) and in lengths to 24 in. (610 mm). Electrodes may be pure tungsten or tungsten alloyed with zirconia or thorium. Table 3 lists the various types of tungsten electrodes commonly used along with their AWS classifications, color codes, available finishes, and normal applications.

2.7.2 Factors Affecting Electrode Life. Although the tungsten electrode is considered nonconsumable, electrode life is determined by operating conditions. The life of any tungsten electrode is shortened by excessive welding current, metal contamination, and atmospheric contamination.

2.7.2.1 Excessive Current. Good practice requires use of an electrode diameter consistent with the operating current being used. Table 4 lists various types of tungsten electrodes with typical current ranges for each. Currents greater than the recommended range for a respective electrode size and type will cause melting and vaporization of the electrode tip. The molten weld metal may be contaminated and possibly alloyed with tungsten as a result. A given size electrode has greatest current-carrying capacity with DCSP; less with ac; and still less with DCRP.

2.7.2.2 Metal Contamination. The most common type of electrode contamination is metal contamination. The metal may come from the filler metal, the molten weld pool, or the base metal being welded. Particularly in manual welding, the welder may dip the electrode into the weld pool or touch the electrode with the filler metal being added. The contaminated surface of the electrode must be removed. If a specific electrode geometry is used, the electrode must also be reprepared so that clean tungsten is available for welding. When contamination of the electrode occurs, the welding arc becomes more diffuse. This change in arc action is obvious to the operator and indi-

cates metal contamination.

2.7.2.3 Atmospheric Contamination. The most common causes of atmospheric contamination are insufficient gas flow, excessive electrode extension, or insufficient postweld purge time. The gas flow rates will vary widely, depending upon the shielding gas used, nozzle size, and specific welding conditions. Manual welding requires flow rates of at least 15 cubic feet per hour (7.05 liters per minute) with argon. Helium requires slightly higher rates. The effectiveness of the gas shielding, even with adequate flow, can be greatly diminished with excessive electrode extension. A rule-of-thumb for electrode extension is: the electrode should extend beyond the nozzle a *maximum* of one times the diameter of the nozzle; i.e., when using a number 6 nozzle (3/8 in. [9.5 mm]), the tungsten electrode should extend not more than 3/8 in. (9.5 mm) beyond the nozzle. Also, the effectiveness of a gas shield can be increased with the use of a gas lens attachment. A too short shielding postflow may also cause atmospheric contamination. The postflow should be sufficiently long to allow the tungsten to cool below its oxidizing temperature.

Water can be another source of electrode contamination. Water contamination may result from leaks in the water-cooled torch caused by loose connections, pinched O-rings, defective seals, etc. Also, water contamination as a result of condensate forming in the welding torch head can occur with no leaks in the torch. Condensate can occur when cold water coolant is circulated through the torch during warm, humid days. This problem can be corrected by using warm cooling water.

Tungsten electrode contamination, by either atmosphere or water, is apparent by the color change on the electrode. The color may range from a bright blue or purple to black. If the tungsten has a blue-black color, the

16 / RECOMMENDED PRACTICES FOR GAS TUNGSTEN ARC WELDING

oxidized portion of the electrode must be removed and the cause of contamination determined and corrected before welding is continued.

2.7.3 Electrode Preparation and Tip Geometry. The tungsten electrode may be used with no end preparation, with the end beveled to a specific included angle, or with the electrode end "balled." Various electrode tip geometries affect the weld bead shape and size.^{1 2} For example, with DCSP at 90 A welding on 1/4 in. Alloy 600 plates, changing the end bevel or included angle from 30 degrees to 120 degrees (going from a pencil point to a blunt tip) will increase the width of the weld bead and decrease weld penetration. However, as the welding current magnitude is increased, the opposite is true. For example, when welding 1500 A285 alloy steel at 300 A DCSP, changing the electrode tip included angle from 30 degrees to 120 degrees will decrease weld bead width by a factor of 2 and increase weld penetration by 45 percent. The degree of taper or beveling of the electrode tip also influences the tungsten's erosion rate. Tapers over a length of 2 to 3 times the diameter will minimize electrode erosion.

When electrode geometry is achieved by grinding methods, the grinding should be with a special fine grit hard abrasive wheel, used *only* for preparing tungsten electrodes. The electrode may be contaminated with particles from wheels used for grinding other materials. The electrode should be held at right angles to the abrasive wheel face during grinding so that the grinding direction is 90 degrees to its length (see Fig. 12).

Another method of tungsten preparation is to set the welding power source amperage specified in Table 4 for the specific electrode type and size. An arc is then initiated with a high frequency arc-starting mechanism on a water-cooled copper block. As soon as the arc is established, the electrode end will show a bright orange color. As the current is increased, the color will change to a brilliant white and the electrode will melt, forming a ball on the end of the electrode. At this point, the current is shut off and a uniform diameter ball will remain on the end of the electrode.

Regardless of the type of the electrode geometry selected, the most important factor is that a *consistent* electrode geometry be used once a welding procedure is established. Since changes in electrode geometry can have a significant influence on weld bead shape and size, electrode tip preparation is a welding variable that should be included in the welding procedure.

2.8 Filler Metal.

2.8.1 Composition. The filler metal compositions used for GTAW are in general the same as those used for gas metal arc welding (GMAW). These filler metals normally have compositions similar to the base metals being welded. However, for some considerations, such as corro-

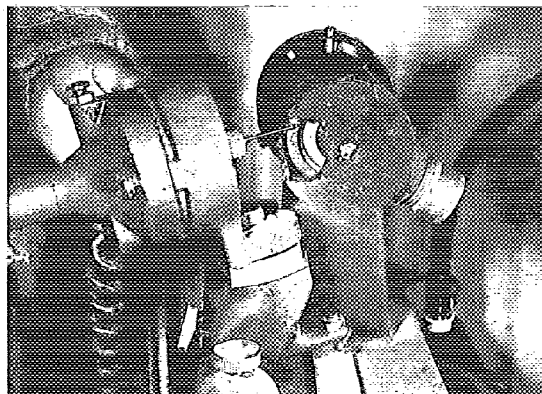


Fig. 12—Tungsten electrode grinding setup

sion resistance, strength, and surface appearance, the recommended filler metal may be a composition completely different from the base metals. Section IV, 6th edition of the AWS *Welding Handbook*, "Metals and Their Weldability," should be consulted for a detailed discussion of metals, their weldability, and proper filler metal selection. Table 5 lists the AWS specifications for various filler metals.

Table 5
AWS Filler metal specifications

Filler metal	AWS Specification
Carbon steel	A5.18
Copper	A5.7
Chromium and chromium-nickel	A5.9
Nickel	A5.14
Aluminum	A5.10
Titanium	A5.16
Surfacing	A5.13

The filler metals are usually alloyed to resist porosity and fissuring in the weld deposit due to high arc currents, high pool temperatures, and pool agitation. Filler metals for welding carbon and low alloy steels are alloyed with manganese and silicon. Titanium is most often used to control porosity for welding the stainless steels and high nickel alloys. Manganese, columbium, molybdenum, or a combination of these can be used to control cracking.

2.8.2 Quality and Identification. The wire surface must be free of all drawing lubricants and oxides to ensure high quality welds with the correct composition filler metal. Nearly all manufacturers supply filler metal that has been properly cleaned, packaged, and identified. However, once the filler metal has been received by the user, its proper storage and care become an in-house function. Opened packages, dirty gloves, and greasy or dirty welding equipment are all poor shop practices which may

1. The Effect of Electrode Geometry in Gas Tungsten-Arc Welding, *Welding Journal*, November 1965.
2. Investigation, *Welding Journal*, April 1975.

contaminate the filler metal and result in defective welds.

Good shop practice is to keep the filler metal in a clean, dry cabinet which is well identified so that filler metals will not become mixed. Filler metal should always be returned to the proper storage cabinet when not in use.

In instances where special cleaning, packaging, or identification of filler metals is desirable, a specification may be prepared by the user for purchasing the needed filler metal.

2.8.3 Feeding Techniques. The three methods of introducing filler metal into a weld joint are: (1) hand feeding by the welder; (2) automatic feeding by a wire feeder; and (3) preplacing the filler metal, either as a consumable insert or as a filler metal overlay.

The torch should be held at between 75 and 90 degrees to the work for all manual welding. A slight inclination in the forehand position is necessary for good visibility. An acute angle can cause aspiration of air into the shielding gas and thus contaminate the weld.

The filler metal should be carefully added at the leading edge of the molten weld pool to avoid contact with the electrode. The hot end of the filler metal should always be kept in the protective atmosphere of the shielding gas. Excessive agitation of the molten pool should be avoided; it should be kept as quiet as possible to prevent vaporizing the deoxidizing elements. In manual welding, the filler metal is introduced much the same as the filler metal is added in oxyacetylene welding. In automatic welding, the wire is fed mechanically into the leading edge of the weld pool. Preplaced filler metal, such as a consumable insert, is often used, particularly in pipe welding applications. Once the insert is tacked into place, the welder need concentrate only on fusing the filler metal to the workpiece.

Regardless of the method of filler metal addition, it should be remembered that these filler metals contain elements specifically added to resist hot cracking and porosity. Maximum benefit from those elements is achieved when the completed weld consists of at least 50 percent filler metal.

2.8.4 Filler Metal Size and Shape. Filler metal is available either as straight lengths, normally 18 or 36 in. (460 or 900 mm) long, or on spools or reels. Spool size will vary from a 2 lb (0.9 kg) spool for the very small diameter filler metals to 12 and 25 lb (5.4 and 11.3 kg) spools and 50 to 60 lb (23 to 27 kg) reels. The diameter range is from 0.020 to 1/4 in. (0.5 to 6.4 mm). The sizes most often used are 1/16, 3/32, and 1/8 in. (1.6, 2.4, and 3.2 mm) nominal diameters.

Filler metal shapes other than round wire are usually in the form of preformed rings or rectangular wires. The preformed filler metal insert is of the same composition as other forms and is fused into the weld joint during the first weld pass. The advantages of preforms are uniformity of results and precise control over the chemical composition of the weld deposit. Pipe welding is an example of a preformed shape providing for uniformity of the internal weld condition.

Other examples of preforms are T-rings or Y-rings, which are roll-formed and then machined to close tolerances for components that require precision welding, such as certain aerospace or nuclear applications. Machined preforms are normally used in conjunction with the automatic welding systems, where precise control of the welding variables can be maintained.

2.9 Fixturing

2.9.1. Principles Governing Fixture Design

2.9.1.1 General. The decision to use fixturing for the fabrication of a weldment is generally governed by economics. Close tolerance requirements for exceptionally high quality work may also dictate fixturing. A decision not to build fixturing usually means that the part to be welded can be hand fitted and tack welded together and will be entirely self-supporting during the welding operation and that the resulting distortion can be tolerated or corrected by straightening operations.

Some functions of a weld fixture are:

- (1) To locate parts relative to the assembly
- (2) To maintain alignment during welding without excessive restraint (should not promote weld cracking)
- (3) To control distortion in the weldment

The size of the weldment in itself may require that supporting fixturing be made, or a large number of small assemblies might be produced more economically with locating and clamping fixturing.

The fixturing decision is even more complex when the welding process application is considered. Selection of the most economic process to meet the quality requirement might require movement of an extremely large weldment, with very high fixturing costs. Selection of another welding process (more expensive in itself) might permit welding progression by the weld station alone, with the large part stationary. Thus, once it is determined that fixturing is required, economics of fixture construction will determine whether to move the work or the torch. The GTAW process is readily adapted to all the foregoing considerations.

2.9.1.2 Effect of Heat Sink. Achieving an acceptable GTA weld generally means that a stable, reproducible thermal pattern was produced. The heat received into the molten weld pool goes initially to melting base metal and preheating ahead of the weld. Nearly all of the heat is initially dissipated through the base metal, and thermal gradients are established, depending upon the geometry, the mass involved, and base metal diffusivity. If metallurgical or quality considerations dictate higher thermal gradients and chill rates than the weld assembly configuration will furnish, then supplemental chilling can be accomplished with the addition of chill bars. The influence of these bars depends upon their mass, location, and diffusivity. Also, the condition of the metallic interface between the chills and the base metal is of major importance. Oxides and foreign material can reduce heat transfer by making intimate contact impossible. The chills should be flexible and ductile and held in place by uniform unit pressure of sufficient magnitude.

18 / RECOMMENDED PRACTICES FOR GAS TUNGSTEN ARC WELDING

High chill configurations can be difficult to weld, since they demand more of the arc heat for preheating. When welding speed is lowered to increase heat input, heat utilization becomes even less efficient. Erratic high chill systems produce variable nugget and heat-affected zones, since the heat available for melting is not stable. Low chill systems are sometimes used to eliminate these problems.

Whatever chill approach is taken, it must be compatible with the welding conditions that are developed.

2.9.2 Clamping. Pressures required for thermal considerations can be a factor in weld consistency. Pressures required to align and hold parts before, during, and after welding have largely been determined by trial and error and are not usually a problem to a tool designer. Well-formed parts generally require only nominal pressures for alignment and containment during the expansions and contractions of welding. Weld tooling can be classified as tool supported or part assembly supported. Tools that support as well as clamp are normally heavy and capable of producing more than enough closing force, while assemblies with self-contained tooling are held with lower pressures. These concepts have come to be loosely known as "hard" and "soft" tooling. On large structures, soft tooling has economic advantages but usually requires a low chill utilization of the clamping surfaces to maintain weld bead consistency. Preweld dimensional control of parts is usually stringent with the soft tooling approach. The GTAW process yields excellent results with either chill concept. Welding variables will usually be different between hard and soft tooling to account for heat sink differences.

Clamping or closing a tool can be a tedious manual operation (such as turning down a number of C-clamps), or simply engaging a lever or pushing a button on automatic systems. Generally, pneumatic or mechanical-pneumatic systems are quick closing, while completely mechanical systems take longer. Pneumatic systems usually are directly expanding, with hoses between the tool and the chills. Pressures up to 100 psi (69 kPa) are common in the hoses. Very uniform mating pressures can be obtained with these systems. Mechanical-pneumatic systems may consist of a series of levers, one arm to a work contact shoe and the other to a portion of an expandable hose. These systems can use various lever arm ratios for mechanical advantage and apply high clamping or alignment forces.

2.10 Welding Schedule and Procedure (See Tables 6 & 7.)

2.10.1 Establishing Welding Activities. The majority of industrial welding activities are governed by predetermined welding schedules and procedures. Establishing these procedures and schedules may be quite involved, depending upon the application and specification requirements. The following definitions are listed to distinguish between a welding schedule and a welding procedure.

(a) Welding procedure: "The detailed methods and

practices, including all joint welding procedures, involved in the production of a weldment." Usual information to be considered for a welding procedure specification includes:

- Base metal and filler metal
- Amperage
- Voltage
- Welding speed (travel speed)
- Wire feed speed and number of passes
- Shielding gas type and flow rate
- Backup gas type and flow rate
- Tungsten size, type, and electrode tip preparation
- Arc length
- Joint design
- Fixture type (if used)

(b) Welding schedule: "A chronological listing of welding sequence and related activities which must be followed in their respective order for the purpose of reproducing the desired weld." The welding procedure will reference the welding schedule for the specific information.

(c) Certain factors must be declared prior to the establishment of the welding schedule or procedure. These factors directly relate to the level of effort that will be placed on schedule and procedure establishment, and will include but are not limited to the following:

- Quality of weld required (level of quality to which the weld must be tested and accepted)
- Specification requirements (personnel qualifications, procedure qualifications)
- Production schedule
- Tooling ability or capacity

The welding schedule and procedure may be established after determining the above factors. The procedure and schedule may be quite involved, depending upon the influencing factors, or may be minimal in the case of a manually produced weld.

2.10.2 Monitoring and Recording. Instrumentation for monitoring and recording welding activities has become increasingly important with the mechanization of the weld system. The cost of commercially available equipment varies from a few hundred dollars for a single-channel monitor up to several thousand dollars for a multiple-channel recorder. Increased demands for quality control measures require incorporating these recording instruments into weld systems in order to compare weld information with known standards.

Recorders are used to provide accurate data regarding shielding gas flow, backup gas flow, weld travel speed, shielding gas moisture content, weld temperatures, and amperage and voltage values.

The need for a recording instrument is dependent upon the weldment specification or the degree of necessary quality control measures. Also, recorders used with automated weld programs provide definite and useful quality measurement.

2.11 Welding Equipment Setup. GTAW equipment is

Table 6
Typical welding procedure for manual
gas tungsten arc welding of carbon steel

Material thickness, in. (mm)	1/16 - 1/8 (1.6 - 3.2)	1/8 - 1/4 (3.2 - 6.4)	1/4 - 1/2 (6.4 - 12.7)
Joint design	Straight butt	Single-V-groove	Double-V-groove
Current, A	50-100	70-120	90-150
Polarity	DCSP	DCSP	DCSP
Arc voltage, V	12	12	12
Travel speed	As required	As required	As required
Electrode type	EWTh-2	EWTh-2	EWTh-2
Electrode size, in. (mm)	3/32 (2.4)	3/32 (2.4)	1/8 (3.2)
Filler metal type	E70S-3	E70S-3	E70S-3
Filler metal size, in. (mm)	1/16 or 3/32 (1.6 or 2.4)	3/32 or 1/8 (2.4 or 3.2)	3/32 or 1/8 (2.4 or 3.2)
Shielding gas	Argon	Argon	Argon
Shielding gas flow rate, cfh (liter/min)	20 (9.4)	20 (9.4)	25 (11.8)
Purging gas	Argon	Argon	Argon
Purging gas flow rate, cfh (liter/min)	5-7 (2.4 - 3.3)	5-7 (2.4 - 3.3)	5-7 (2.4 - 3.3)
Nozzle size	3/8 (9.5)	3/8 (9.5)	1/2 (12.7)
Nozzle-to-work distance, in. (mm)	1/2 (12.7) max	1/2 (12.7) max	1/2 (12.7) max
Preheat, min	60° F (16° C)	60° F (16° C)	60° F (16° C)
Interpass temp., max	500° F (260° C)	500° F (260° C)	500° F (260° C)
Postweld heat treatment	None	None	None
Welding position	F, H, V, OH	F, H, V, OH	F, H, V, OH

Table 7
Typical welding procedure for manual
gas tungsten arc welding of stainless steel

Material thickness, in. (mm)	1/16 - 1/8 (1.6 - 3.2)	1/8 - 1/4 (3.2 - 6.4)	1/4 - 1/2 (6.4 - 12.7)
Joint design	Straight butt	Single-V-groove	Double-V-groove
Current, A	50-90	70-120	100-150
Polarity	DCSP	DCSP	DCSP
Arc voltage, V	12	12	12
Travel speed	As required	As required	As required
Electrode type	EWTh-2	EWTh-2	EWTh-2
Electrode size, in. (mm)	3/32 (2.4)	3/32 (2.4)	3/32 (2.4)
Filler metal type	ER-308	ER-308	ER-308
Filler metal size, in. (mm)	1/16 or 3/32 (1.6 or 2.4)	3/32 or 1/8 (2.4 or 3.2)	3/32 or 1/8 (2.4 or 3.2)
Shielding gas	Argon	Argon	Argon
Shielding gas flow rate, cfh (liter/min)	20 (9.4)	20 (9.4)	25 (11.8)
Purging gas	Argon	Argon	Argon
Purging gas flow rate, cfh (liter/min)	5-7 (2.4 - 3.3)	5-7 (2.4 - 3.3)	5-7 (2.4 - 3.3)
Nozzle size, in. (mm)	3/8 (9.5)	3/8 (9.5)	1/2 (12.7)
Nozzle-to-work distance, in. (mm)	1/2 (12.7) max	1/2 (12.7) max	1/2 (12.7) max
Preheat, min	60° F (16° C)	60° F (16° C)	60° F (16° C)
Interpass temp., max	500° F (260° C)	500° F (260° C)	500° F (260° C)
Postweld heat treatment	None	None	None
Welding position	F, H, V, OH	F, H, V, OH	F, H, V, OH

20 / RECOMMENDED PRACTICES FOR GAS TUNGSTEN ARC WELDING

designed to perform numerous functions controlling weld quality, described and analyzed in the discussion of process variables. The number of variables controlled by the operator during welding depends upon the welding equipment setup. The basic variables include welding current, arc voltage, travel speed, wire feed, and inert gas coverage of the molten pool.

Refinements of manual GTAW include foot controls for welding current, travel speed controls, wire feed manipulators, and on-off switching.

Automatic GTAW is extensively used. The degree of mechanization varies from simply mounting the torch in a bracket that moves over the workpiece to an automatic operation for the total welding cycle. The degree of mechanization is usually determined by the number of identical welds and the speed and quality desired. The aerospace and the nuclear industries use automatic GTAW extensively, not necessarily because of the large quantities of production parts involved, but because the weld quality required can often only be achieved with the control inherent in automatic welding.

A workable weld process operation has to be carefully analyzed and available welding equipment studied to determine the degree of automation possible for a welding application.

2.11.1 Electrical Design Variables. Feedback control has been used to establish the basis for analysis of the required degree of automation in the electrical design of welding equipment. Feedback control can be established in open-loop or closed-loop systems if a value for comparison with a reference or desired value is present for the variable to be controlled.

In an open-loop control system, the static correspondence between the controlled variable (system output) and the reference quantity (system input) is a function of the calibration of the control mechanism. In a closed-loop system, the amount of corrective response is determined by the controlled variable as well as the input command. Therefore, the static correspondence between the output and input is more even in a closed-loop system than in an open-loop system.

Control devices may be further subdivided on the basis of functional area and the nature of the input.

Some GTAW process variable controls are designed for the specific purpose of maintaining a correspondence between the controlled variable and an input which changes infrequently. A system of inert gas flow control may be considered an example of an open-loop control system. The output is caused to change infrequently in accordance with the input (state of flow rate and pressure control devices). The flow of inert gas is in no way affected by the welding arc and does not differ from that called for by the inert gas control. Such an open-loop control system is properly termed a "regulator," since its purpose is merely to adjust the output to a desired constant value.

Other controls are designed to make the controlled

variable follow relatively rapid variations in the input over a fairly wide range, as well as to conform with the input in the presence of load disturbances. Such a system must contain a closed loop. An automatic arc voltage control system is an example. This type of control system is classified as a servomechanism and is defined as "an error-sensitive, follow-up, amplifying system permitting a wide range of input command remotely located from the element being controlled." This type of servomechanism is employed by the new feedback controls generally described as adaptive controls.

There is need for a means of compensation for uncontrollable input variables even with a properly functioning GTA weld quality monitoring system. For example: In the welding of a large booster, mismatch, gapping, tack welds, and heat sink variation caused a variation in arc penetration, even though the process was controlled with very close accuracy. The problem demonstrated a need to automatically close the loop (or feed back information) between the work and the welding equipment; i.e., find a way to feed back signals that could change weld setting automatically. Potential solutions required automatic compensation (1) to increase the welding current when a local increase of heat sink was taking heat away from the weld area, thereby reducing penetration; (2) to reduce the weld current when penetration increased (due to the varying gap width between joint faces); and (3) to increase the welding current when a mass of tack weld was approached, and then reduce current when leaving the vicinity of the tack weld.

Several designs of adaptive controls are in use. Each adaptive control uses a sensor that continuously derives information concerning the dynamic penetration of the weld in progress. A second element constitutes a simple computer, which accepts information from the sensor and increases or decreases the welding current a proper amount to assure uniform preset weld penetration. A block diagram of an adaptive GTAW penetration control system is illustrated in Fig. 13. Additional information on adaptive control systems is published in "Automation of the Gas Tungsten Arc Welding Process" by E. P. Vilkas, *Welding Journal*, 45 (5), pp. 410-416 (1966).

2.11.2 Mechanical Design Variables. Measurability has been used as the recommended basis for mechanical design. Mechanical measurability is vital to automatic GTAW. Measurability of the mechanical welding machine variables can be broadly classified as static and dynamic. Positioning of the parts to be welded is almost as important as the mechanism of a wire feeder, a wire guide, and the arc length control dynamic response in many applications.

The setup for automatic GTAW may be simple or complex, as dictated by the configuration of the component parts and the alloys being fused. In tube and pipe welding (without the addition of filler metal) the setup is relatively simple and allows the entire welding operation to be completed without constant observation and adjustment of

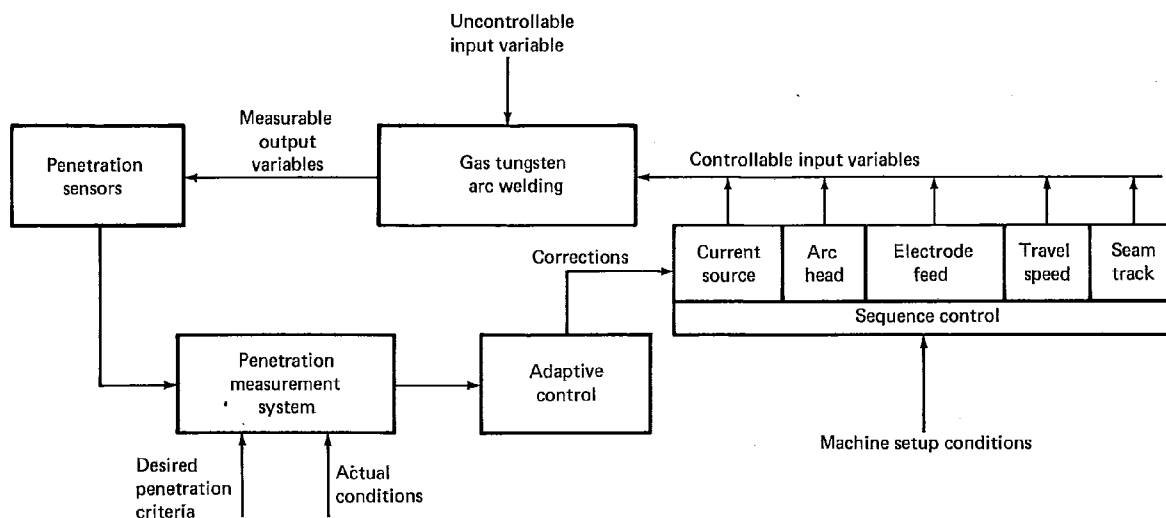


Fig. 13—Block diagram of adaptive GTAW penetration control system

mechanism or controls by an operator. GTAW of hydraulic, pressurant, fuel, and instrumentation lines in the aerospace and nuclear industries is performed automatically. The automatic weld sequence with correct weld settings eliminates human error in tube welding applica-

tions. Reproducibility of tungsten electrode position with respect to the weld joint is assured by measurability of all mechanical variables.

The basic elements in the tube or pipe welding system are illustrated in the block diagram in Fig. 14.

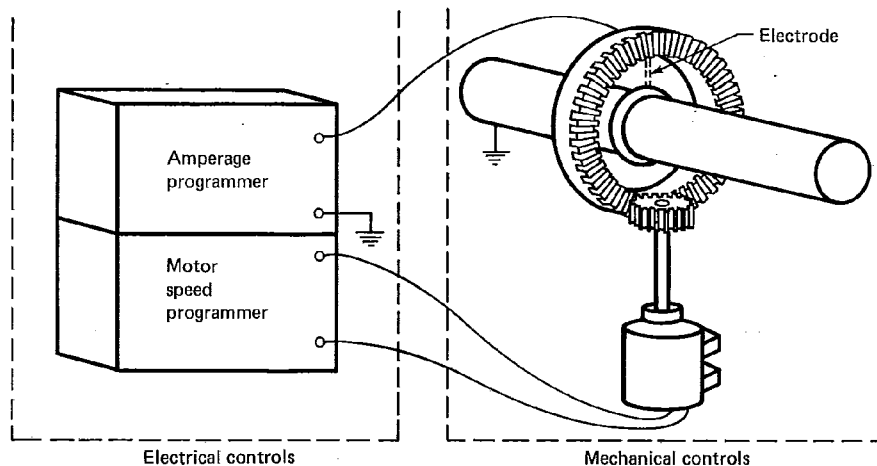


Fig. 14—Diagram of basic elements in tube or pipe welding

22 / RECOMMENDED PRACTICES FOR GAS TUNGSTEN ARC WELDING

The mechanical variables are controlled by the following means:

(1) Tube or pipe outside diameter tolerances and alignment of two tube ends. Spring type, replaceable tube clamp inserts accommodate tube OD tolerances and accurately and positively position and align tube ends without deformation.

(2) Mechanical guidance of the ring type electrode holder. A split type precision housing of high heat and wear resistant material insulates and contains the electrode holder. The split type electrode holder accurately maintains the electrode-to-joint spacing alignment and is driven around the joint by a miniature high torque dc gear motor, with tachometer, mounted within the welding head handle.

Another GTAW application with a high degree of measurability is arc spot welding of automotive components.³

The more complex assemblies may be welded automatically or semiautomatically but require elaborate tooling, fixtures, and the techniques of a skilled machine operator who can make applicable machine adjustments.

Semiautomatic pipe welding with filler metal addition is not especially complex. Pipes may be welded in place if clearances allow the weld head to travel around the pipe circumference. Otherwise, a manual weld with the aid of mirrors and unrealistic positions is required. Setups requiring such manual welding are more likely to contain defects that can be avoided with semiautomatic pipe welding.

Automatic GTAW may be easily adapted for high production of either simple or complex small assemblies. These types of assemblies have included electronic components, hydraulic assemblies, power plant parts, and instrumentation closures, among others. The welding setup has provided for automatic loading and unloading of parts, the necessary purging with inert gas, and the welding operations. The various operations may also be performed in an atmospheric chamber, to accommodate the inert gas requirements either for welding or in the filling and sealing of inert gas within the component assembly being welded.

2.11.3 Environmental Design Variables. Gas shielding has been used as the basis for analysis and design of equipment setup with respect to environmental variables. Manual GTA welding of many complicated assemblies is best performed in so-called dry boxes or chambers.

High quality inert gas atmosphere in a chamber is achieved by means of vacuum pumps evacuating the atmosphere and inert gases back-filling the chamber. The size of the chambers used depends upon the requirements. For example, in nuclear applications, room size chambers have been used. Mechanized welding is usually employed for small assemblies, such as nuclear fuel rods, which must be welded in a chamber and can be rotated.

3. Vilkas, E. P., Automation of the Gas Tungsten Arc Spot Welding Process. *Welding Journal*, January 1966.

Changing from manual to mechanized welding usually requires a sound knowledge of welding, a sophisticated machine design, and a high initial investment. Nevertheless, GTAW is readily adapted for automation through the availability of a wide variety of mechanical and electrical controls.

Also, in tube or pipe GTAW, a unique nozzle design creates a miniature chamber. The nozzle surrounds the weld joint with inert gas without creating any gas pressures during the complete weld cycle. This allows the welding of such difficult-to-weld reactive materials as titanium and others. The gas purges solely through a designed clearance between the nozzle and the outside of the tube.

Many GTA welding process variables, such as material, inert gas, and electrode quality, are regulated by material quality specifications and are relatively constant. However, material preparation, including cleaning procedure or process controls, eliminates many weld defects if provided with a closed loop feedback feature.

3. Welder and Welding Engineer

3.1 Welder Training and Qualification. The type and quality of work which the individual is expected to perform dictates the extent to which a welder or welding operator should be trained. The welder responsible for joining nuclear pressure vessels and pipes requires more training than one responsible for flat position fillet or lap welds only.

The training program is by one or a combination of two general methods: (1) within the plant itself, and (2) by outside schools. The training program should be geared to the company's needs and be a mixture of basic theory and practice. Minimum requirements for the training of welders are listed in AWS E3.1-75.

Once the individual has been allowed sufficient practice time (which varies depending upon the particular assignment) and has attended a training program, a qualification test is usually given.

Welder qualification tests are primarily given to the individual to determine that person's ability to produce sound welds that meet the requirements of the particular code or specification involved. There are several types of qualification tests, and many companies have their own test which the welder must pass. A qualification test should be designed to represent the type of work the welder will be required to do, even though no one test can apply to all types of work.

3.2 Areas of Responsibility. Responsibilities of the welder, the welding engineer/technologist, and the welding technician vary, depending upon the company and its product. Generally, these responsibilities are as shown in the following chart.

Responsibilities	Welding engineer/ technologist	Welding technician	Welding operator, manual welder
Prepare welding specifications	*		
Purchase equipment (prepare specifications)	*		
Prepare welding procedures	*	*	
Recommend NDE activities and assist when necessary	*	*	
Provide up-dating training sessions on new processes	*		
Provide feedback (improvements, suggestions)		*	*
Follow-up shop work	*	*	
Provide plant assistance and troubleshooting	*	*	
Establish work priorities for new weld development	*		
Qualification and testing of weld personnel		*	
Oversee preventive maintenance of equipment		*	
Produce welds per approved procedure			*

4. Quality Control

4.1 Inspection and Test Methods. GTA welds are inspected by the same methods used for other fusion processes. The as-welded surface of GTA welds is generally adequate for inspection without conditioning.

Visual inspection is one of the most valuable inspection methods and should include all factors affecting the quality of the weld such as edge preparation, cleaning, and alignment, as well as the visible condition of the completed weld surface. Common weld defects disclosed by visual inspection are incorrect weld size, inadequate joint penetration, undercutting, surface porosity, and cracking. The welder should detect these conditions and take corrective action to prevent rejection in the final stages of product fabrication.

Other inspection methods used, depending upon the required product quality level, are liquid penetrant, magnetic particle, ultrasonic, eddy current, and radiographic. Section I, 6th edition, of the *AWS Welding Handbook* and *AWS Welding Inspection* include information on these methods of inspection.

4.2 Specifications. The purpose of any inspection is to ensure a predetermined quality level in the finished product. Since the quality requirements may vary widely with service conditions, design factors, and economics, each

producer must establish a quality level that applies to the specific product. The producer's specification must define the test procedure and the acceptance standards to assure uniformity in testing and evaluating the product.

5. Typical Equipment for Process Applications

5.1 Manual Gas Tungsten Arc Welding

5.1.1 General. Manual GTAW is most applicable where complex shapes preclude the use of automatic methods. Manual electrode holder manipulation is generally used for irregularly shaped parts that require short welds or for welding in difficult-to-reach areas. The GTAW equipment required for manual welding is illustrated in Fig. 15.

Arc striking may be accomplished as discussed in Section 2.3.

Once the arc is started, the electrode holder (torch) is held with the electrode positioned at an angle of about 75 degrees to the weld pool surface. To start welding, the arc is usually moved in a small circle until a suitable size pool of molten metal is obtained. When adequate fusion is achieved at any one point, a weld is made by gradually moving the electrode along the parts to be welded in order

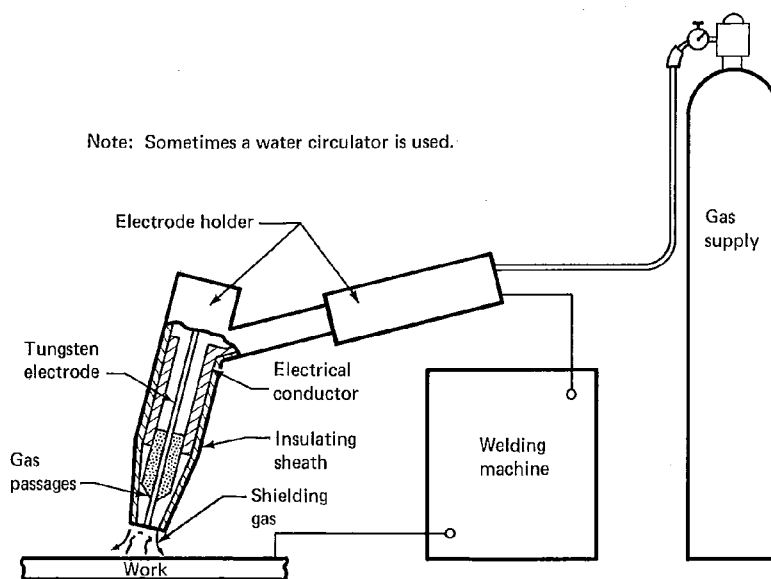


Fig. 15—Schematic diagram of gas tungsten arc equipment

to progressively melt the adjoining edges. Solidification of the molten metal follows progression of the arc along the joint and completes the welding cycle.

Welding is stopped either by gradually withdrawing the electrode from the workpiece or by tapering off the current. The former system is used often when dc power is employed. The latter is more common with ac welding, since the high frequency oscillators normally used with alternating current usually require on-off switching for control of the high frequency spark. Foot controls for current and on-off switching are used for high quality ac and dc welding.

The metal thickness and joint design, together with metallurgical properties, determine whether filler metal need be added to the joints. Filler metal, if added, is applied by manually feeding the filler rod into the pool of molten metal in the arc region, in much the same manner as in oxyacetylene welding. One of the most frequently used techniques for feeding filler rod is illustrated in Fig. 16.

The filler rod is usually held at an angle of about 15 degrees to the surface of the work and slowly fed into the weld pool. The filler rod must not be removed from the protection of the inert gas shield during welding. Another method is to press the filler rod in line with the weld and melt it along with the joint edges. This method is often used for the root pass in multiple-pass welding of V-groove joints. A method used frequently in weld surfacing and in making large welds is to feed filler metal continuously into the weld pool by oscillating the filler rod and arc from side to side. The filler rod moves in one direction while the arc

moves in the opposite direction, but the filler rod is at all times near the arc and feeding into the weld pool within the shielding gas blanket.

All the standard type joints, such as square and V-groove, T, and lap joints, may be welded by this process.

The GTAW electrode holder must have sufficient welding current capacity to prevent overheating. Collets must be available to accommodate the correct sizes of tungsten electrodes. Each diameter and type of tungsten electrode has a recommended welding current range (see Table 4). The nozzles of an electrode holder are made from various heat resistant materials in different diameters, shapes, and lengths. Length and shape are selected on the basis of joint accessibility and the required clearance between the nozzle and the work. The nozzle should be large enough to provide complete inert gas coverage of the molten weld metal.

5.2.2 Power Source and Welding Current. The power source is chosen to provide the type of welding current needed for the metal under consideration. The welding current may be ac, DCSP, or DCRP. The welding current magnitude is adjusted to provide the desired amount of heat. Alternating current is usually preferred for the manual GTA welding of magnesium, aluminum, and their alloys because of the cleaning action (oxide removal) that takes place in the electrode positive half-cycle of the alternating current. Power sources have been designed to produce a balanced wave alternating current (half-cycles of equal magnitude) for the welding of aluminum and its alloys. The balanced wave increases the

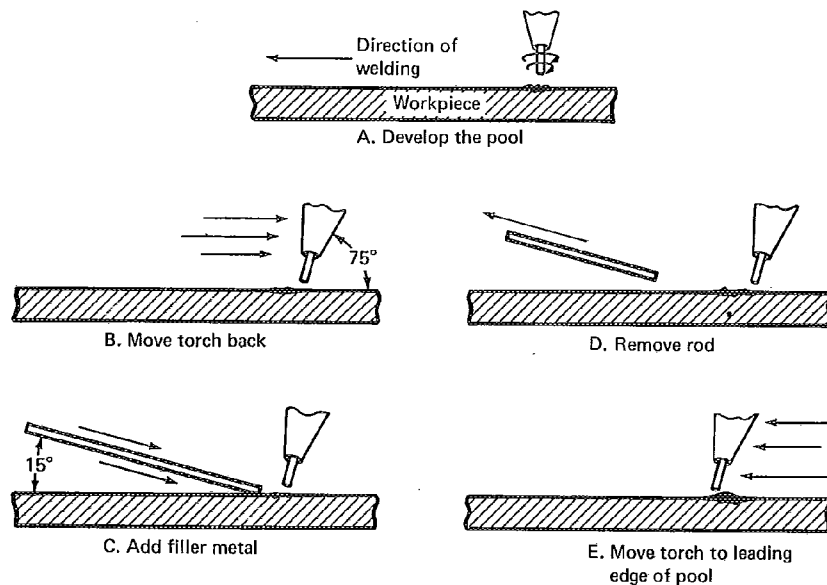


Fig. 16—In gas tungsten arc welding, filler metal is fed manually in a manner similar to that used in oxyacetylene welding

cleaning action. Ac or dc power sources normally used for welding with covered electrodes may be used for manual welding. Special dc or ac power sources that are designed specifically for use in GTA welding are available with automatic means for controlling the flow of gas and water and the start and stop of welding. (For further detail, refer to *Welding Handbook*, 7th ed., Vol. 2, Chapter 1, Arc Welding Power Sources.)

5.2 Semiautomatic Gas Tungsten Arc Welding. Semiautomatic gas tungsten arc welding is defined by AWS as welding with equipment which controls only the filler metal feed. The advance of the welding is manually controlled.

Semiautomatic electrode holders for gas tungsten arc welding were introduced about 1952 but were never widely used. A semiautomatic electrode holder is an assembly of a handheld, water-cooled electrode holder with an attachment that brings the filler wire into the arc area. The filler wire is fed to the arc through the flexible conduit by a motor-driven wire feeder. The filler wire fed ahead of the arc helps guide the electrode holder and establish travel speed. The filler metal is then melted by the arc and deposited in the joint.

Figure 17 shows a filler metal delivery system used with semiautomatic cold wire feed GTAW. With this system the welder does not have to feed filler metal into the weld pool. The system delivers filler metal to the welding arc in adjustable increments to suit the metal welded and the welding configuration. The filler wire is fed at a preset constant feed rate that can be operated continuously or

intermittently by the arc welding gun trigger. Filler metal feed is controlled by adjusting feed speed, feed time interval, and dwell time between feed intervals. Since each feed interval can be used with any of four dwell times, these variables can be adjusted to deliver the right amount of filler metal at the right time.

Semiautomatic GTA spot welding equipment is an assembly of a pistol-like electrode holder, a water-cooled gas nozzle, a tungsten electrode concentrically positioned

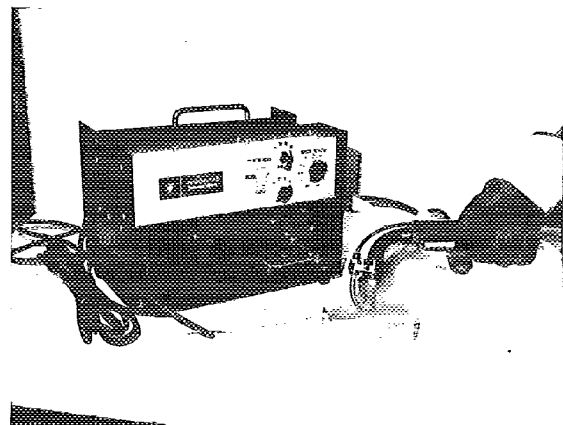


Fig. 17—Semiautomatic electrode holder and feeder

with respect to the nozzle, a miniature filler wire feeder with wire guide arrangement, and a trigger switch for sequence start. The filler wire addition to the arc is electronically controlled in conjunction with the spot weld programmer controls. There is a slight time delay while the molten spot is established (filler metal added), then the filler wire is retracted a precise distance as the spot weld current starts the downslope time. The retraction is necessary to avoid freezing the filler wire with the spot weld metal.

The nozzle configuration is varied to fit the contour of the weldment. Arc penetration is controlled by adjustment of arc length and the amount and time of current flow.

Multiple pulses of current are preferred to one long sustained pulse in some applications. Variations in shear strength, nugget shape, and penetration of the spot weld can be minimized with precision control of all variables (including tungsten electrode tips and pressure of the nozzle on the weldments). For additional information refer to A. Lang and T. Rutkay, "Gas Tungsten Arc Spot Welding 2219 Aluminum on S-1C Booster Program," *Welding Journal*, 45 (6), 1966.

5.3 Automatic Gas Tungsten Arc Welding. The amount of automation or mechanization applied to GTAW depends upon the quantity of identical welds, the accessibility, quality control requirements, degree of perfection required in the weldment, and available funding. GTAW can be controlled with various devices that accept information about the desired values of the process variables on punched tape or cards. In some devices, the input data are stored on a memory drum. Less sophisticated controls that make use of cam-actuated pressure or mechanical switches are also available.

The aerospace industry uses automatic GTAW extensively, not necessarily because of large quantities of production parts, but because the quality required for aerospace designs often can be achieved only with the control inherent in automatic welding. A typical example is the fabrication of large diameter rocket motor cases where longitudinal and girth welds are made by automatic GTAW.

Longitudinal seamers, often called stake welding fixtures, are designed to locate and clamp both sides of a straight butt joint, as shown schematically in Fig. 18. The butt joint may be between two plates, or it may be the longitudinal seam of a flat, conical, circular, or rectangular workpiece. A longitudinal seamer consists of a base that contains a weld backing bar to which the work is clamped by hold-down fingers and an upper beam structure (not shown in Fig. 18) that supports a traveling carriage and track carrying the welding head, wire-feed mechanism, and clamping fingers. The upper beam structure is cantilevered, secured to the base, and hinged at one end for support, with the opposite end remaining open to permit loading and unloading of the workpieces. A pivoted locking latch is provided at the loading end to restrain the cantilevered upper beam when the clamping force is applied.

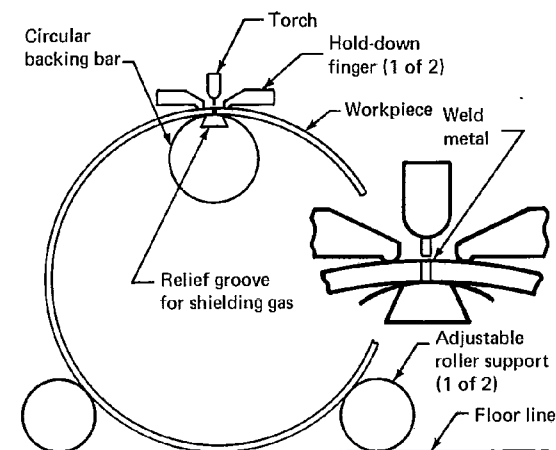


Fig. 18—Setup for automatic welding of longitudinal butt joints

The clamping mechanism is composed of two rows of hold-down fingers that firmly hold the workpiece during welding. Each row may be independently actuated by means of manual or foot-operated valves that control mechanical, magnetic, hydraulic, or pneumatic pressure systems. The intensity of clamping force may be controlled by a pressure regulating device.

The backing bars are removable to permit use of variously contoured groove openings for different thicknesses and types of metal. The bars may also contain relief grooves that permit flow of shielding gas to the underside of the weld (as in Fig. 18) and may have provision for thermostatically controlled heating or cooling.

Pedestal boom manipulators can be used for rapid positioning and welding in any direction to produce internal or external longitudinal or circumferential (girth) welds. This equipment is suitable for use with power rolls or headstock-tailstock welding positioners on tanks, vessels, pipes, and similar weldments. Rotating positioners, to which fixtures or other work-holding tooling devices are mounted, are readily adapted to use with pedestal boom manipulators for small production runs or special fabrications.

Power supplies, filler metal supplies, portable coolant tanks, automatic welding heads, and remote controls can be mounted on a pedestal boom manipulator. A typical pedestal boom manipulator that includes some of these features is shown in Fig. 19. Pedestal boom manipulators can be moved manually on integral wheeled bases to the work location, or they can be powered to travel at welding speeds on rails.

Skate welding machines are lightweight motorized travel carriages on which seamtracking devices, a filler metal feed system, and the automatic welding head are mounted. The skate welding machine shown in Fig. 20

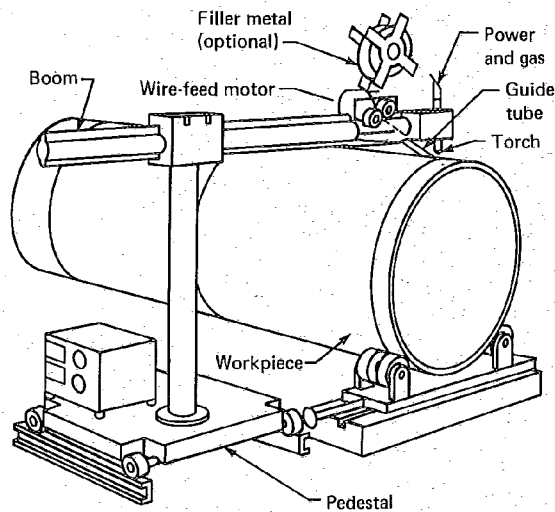


Fig. 19—Use of a pedestal boom manipulator for making a circumferential girth weld

enables precision welding of massive structures that cannot be handled by conventional rotating positioners and longitudinal seamers. Straight or curved track sections are attached directly to the workpiece by bolting or by suction cups, permitting movement of the welding carriage in a continuous path along the weld seam. The skate carriage can be operated in horizontal and vertical directions for out-of-position welds.

In skate welding large assemblies, a mobile service carriage that contains the power supply, the gas supply, all the control elements, and the operator is synchronized to travel with the moving skate carriage during welding. Such equipment (shown in Fig. 21) is satisfactory for long duty cycles on large assemblies.

Rotating positioners are probably the most adaptable type of fixtures for manual or automatic welding. The positioner worktable is a circular or square plate that has been machined to a flat surface and is fitted with T-slots for bolting down various jigs or work-holding tools. The worktable can be rotated for 360 degree circumferential welds in any plane from flat to 10 degrees past vertical. Variable rotational speeds and provision for smooth starting and stopping are mandatory for automatic welding operations. Pedestal boom manipulators (see Fig. 19) are used to position the automatic welding head over the joint, and the positioner worktable may be started manually or be sequenced to start automatically.

The automatic GTAW process may be programmed by N/C (numerical control). Control information is received from a 1 in. (25 mm) wide, eight channel tape that is punched in a binary coded decimal (BCD) format. The information is transmitted in the form of electrical commands to servomechanisms on each machine axis, as well as those provided for the various welding functions. Feedback devices are used to relay actual conditions to the machine control unit, which corrects for any differences between command and actual values. Such a system is capable of providing relative motion between the torch and workpiece in as many as eight axes, delivering up to twenty controllable welding functions. Lineal axis move-

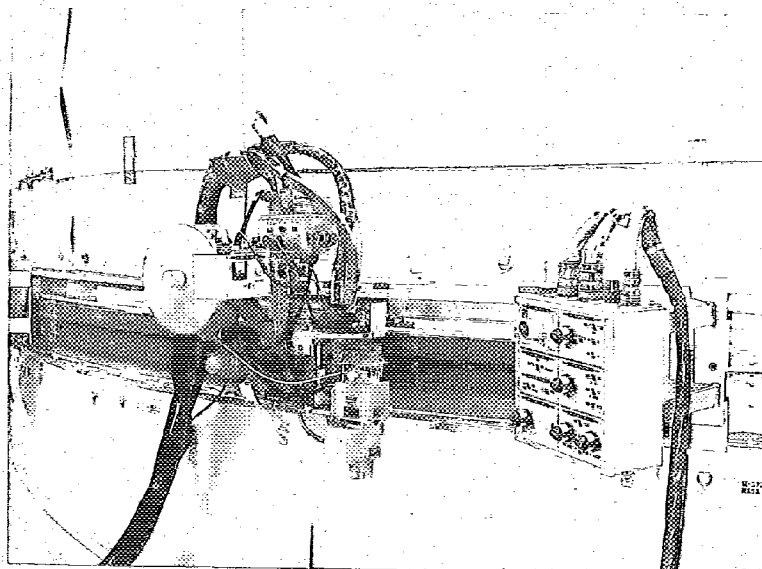


Fig. 20—An example of the skate welding technique

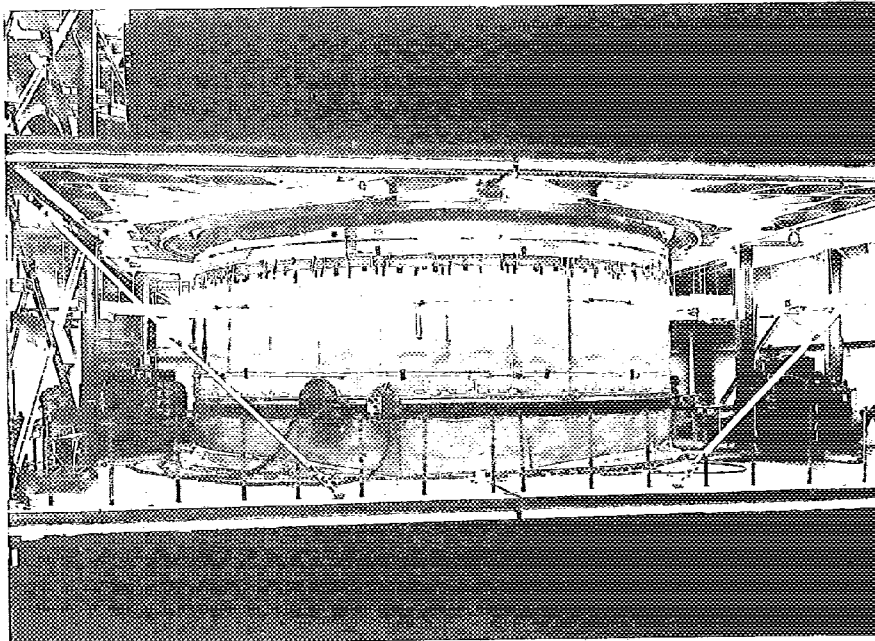


Fig. 21 — Two skate welding machines used on Saturn S-11

ment is programmable to an accuracy of 0.0002 in. (0.005 mm), and rotary motion to an accuracy of 0.001 degree. The welding functions can be programmed by t-codes in increments as fine as 0.4 A of welding current, 0.03 volts of arc voltage, and 0.1 in./min (0.04 mm/s) of wire feed speed. Depending upon the type of tape reader and means of execution and electrical storage, the welding variables can be changed anywhere in a welding sequence as frequently as 0.15 seconds. They may not be changed simultaneously, however. This in-process change capability is quite essential for such situations as weld starts, weld overlaps, tapered sections, changing joint mass conditions, welding around radial corners, backstepping, variations in fillet size, and combined weld types. For more information, see "Advancement of the Numerically Controlled Gas Tungsten Arc Welding Process," G. R. Stoeckinger, et al., *Welding Journal*, 49 (3), pp. 183-193, (March 1970).

Some specific applications where automatic GTAW is being used in industry are presented below.

Automatic Tube and Pipe Welding

Development of better equipment has increased the usage of automatic GTA pipe welding. Completely programmed pipe welding systems are available to weld pipes in the fixed position up to 40 in. (1.02 m) in diameter, using wire feed additions, arc oscillation, and arc voltage control. Power supplies using current pulsation and variable speed control have helped adaptation of the GTAW process to out-of-position welding.

One type of portable welding head for small diameter 1/4 to 4 in. (6.4 to 102 mm) O.D. pipe is shown in Fig. 22. This welding head is used in one application for complete joint penetration welds with a uniform inner bead, in stainless steel pipelines of 0.109 in. (2.8 mm) and 0.154 in. (3.9 mm) wall thickness. The welding programmer in this instance is up to 100 ft (30.5 m) away from the point of welding, and the welding variables are monitored by a multi-channel recorder for the quality assurance program requirements.

The ability to reproduce quality welds with a minimum of personnel is the primary advantage of this type of pipe welding equipment. Others are that only small clearances are required around the stainless or carbon steel pipe and that wall thicknesses up to 0.154 in. (3.9 mm) can be welded in one fusion pass without wire addition (see Fig. 23).

Automatic Pressure Vessel Welding

Various types of equipment may be adapted for circumferential (girth) welds. The major limiting factors for automating the welding operation are the ingenuity of the personnel assigned to the task and the funding available.

One automatic welding operation utilizing equipment from several manufacturers is shown in Fig. 24. The welding head is mounted on a long side beam carriage that can be easily adjusted vertically for different vessel diameters. The welding head uses arc voltage control, hot wire feed, and arc oscillation to weld formed heads to

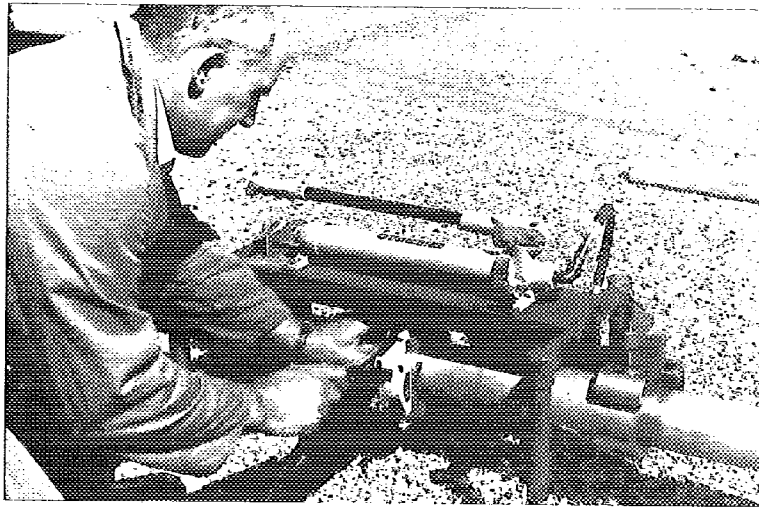


Fig. 22— Automatic pipe welding

pressure vessel shells. Hot wire feed permits high deposition rates comparable to other weld processes, and the welds easily meet the stringent radiographic soundness requirements. The drive rolls that support and rotate the vessels are sequenced to start with arc initiation. The welding operator is required to monitor the welding arc and make the minor adjustments needed during the weld

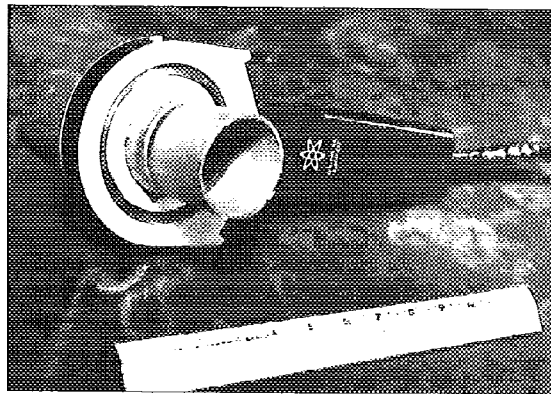


Fig. 23— Programmed gas tungsten arc welding head in operation

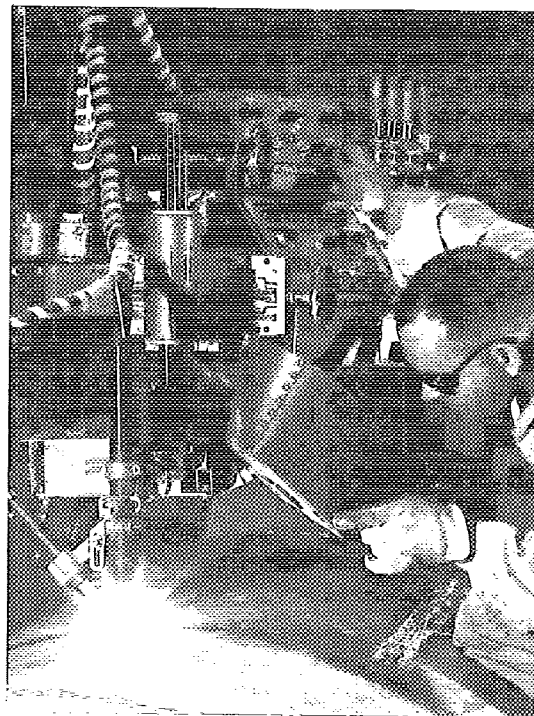


Fig. 24— Automatic pressure vessel welding

30 / RECOMMENDED PRACTICES FOR GAS TUNGSTEN ARC WELDING

cycle. This type of complete system may reduce the welding costs by as much as fifty percent.

Automatic Nuclear Waste Container Welding

Remote welding applications of automatic GTAW in the nuclear field are growing. One example is the use of this process to remotely weld the top cap on containers containing remotely loaded radioisotopes. These high quality welds are simply made by the GTAW process, using equipment incorporating commercially available current pulsation and weld programming features. As shown in Fig. 25, the mechanical equipment for holding and centering during welding is designed to meet specific needs. In this particular case, the GTAW torch was also shop built to allow tungsten replacement by remote manipulator control.

This demonstrated flexibility of the process and the associated equipment is partially responsible for the continuous growth and acceptance of its use in nearly all types of industry.

Automatic Tube-To-Tube Sheet Welding

Various designs of heat exchangers are in use throughout industry. Fastening the tubes to the tube sheets in these heat exchangers is often accomplished by mechanical expansion of the tube into a small ring groove machined into the tube sheet holes. Automatic GTAW of the tube ends to the tube sheet minimizes leakage when using corrosive

fluids within the tube bundle.

In one method of GTAW, the tubes are recessed below the surface of the tube sheet approximately the same distance as the wall thickness of the tube, and the tungsten electrode melts the corner or edge of the tube sheet as it progresses around the tube periphery. Filler metal may be present either as a tube sheet overlay or wire addition. This creates a weld throat or minimum leak path equal to the tube wall thickness.

Figure 26 shows the operator centering the machine over a tube hole by using a mechanical centering device. After centering, the device is removed and the weld torch is lowered to the workpiece, and the automatic cycle, which includes programmed current and speed controls, is started. On tube heat exchangers of this size, the welding sequence is important to minimize tube sheet distortion.

Certain codes may require a weld throat dimension greater than the wall thickness. In this situation, filler wire additions are made automatically after the first fusion pass is completed.

Automated Pipe Welding

Automated pipe welding equipment represents a technological improvement over conventional manual processes. It was developed to satisfy the increasing demands for an improved method of achieving consistently high integrity welds for the critical requirements of nuclear pipe

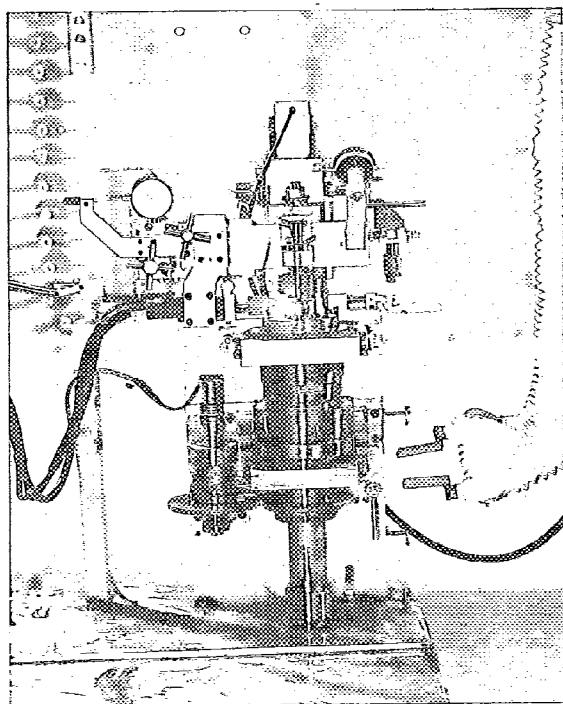


Fig. 25—Automatic nuclear waste container welding

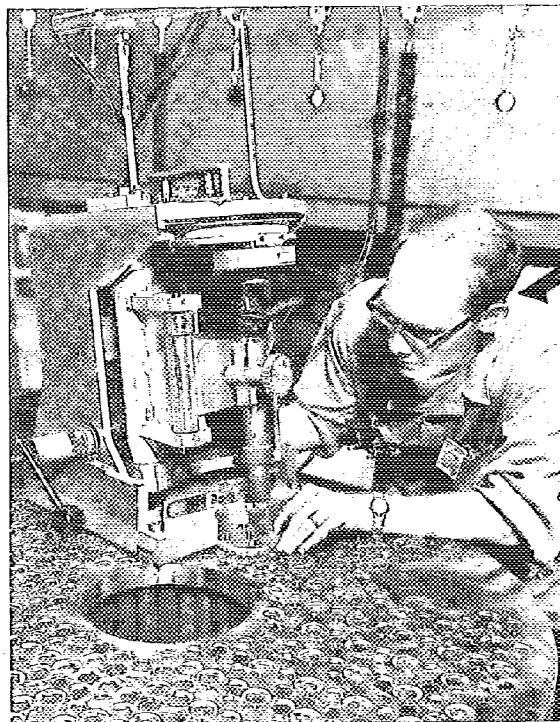


Fig. 26—Automatic tube-to-tube sheet welding.

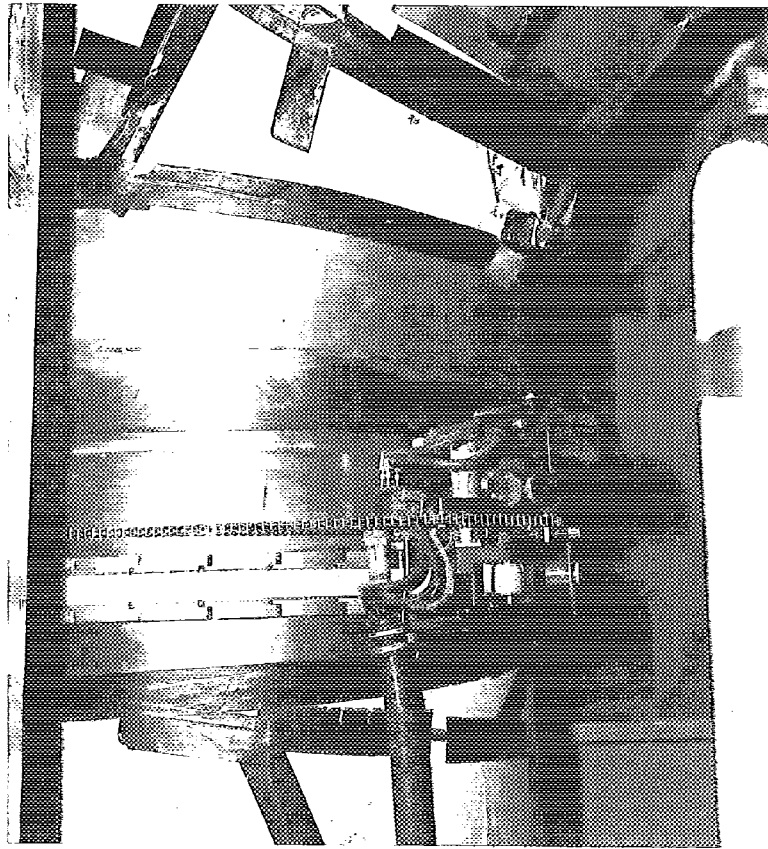


Fig. 27 — Automated pipe welding head and guide ring and safety chain on primary loop closure piece joint at steam generator

fabrication (see Fig. 27).

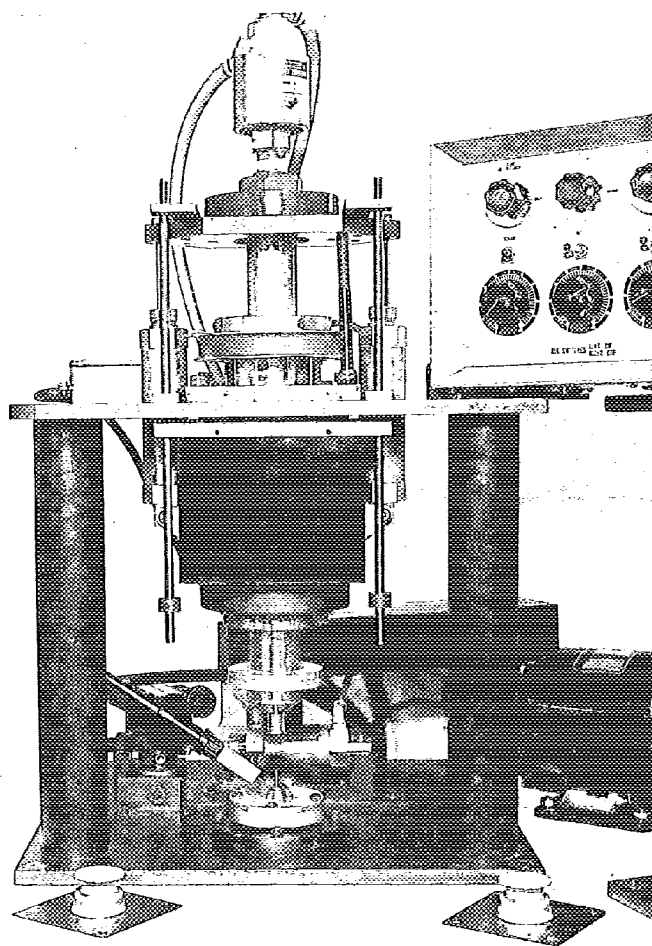
All-position installation and removal of the welding head is accomplished in a few minutes, and the head is precisely guided around the pipe by rigid or segmented belt guide rings. The independently adjustable dwell time at oscillator excursion limits and the precise relationship of the filler wire to the electrode tip permit extremely rapid filler wire addition. Control of penetration (root) passes for all types of joint designs and high quality fill passes is ensured by the accuracy and repeatability of the controls

and ease of operation of the welding heads. Direct reading control settings, easily accessible manual adjustments, and a clear view of the weld zone contribute to minimum operator training time and allow compensation for uneven wall thickness, offset joints, uneven lands, and weld bead sag.

Typical Equipment and Applications

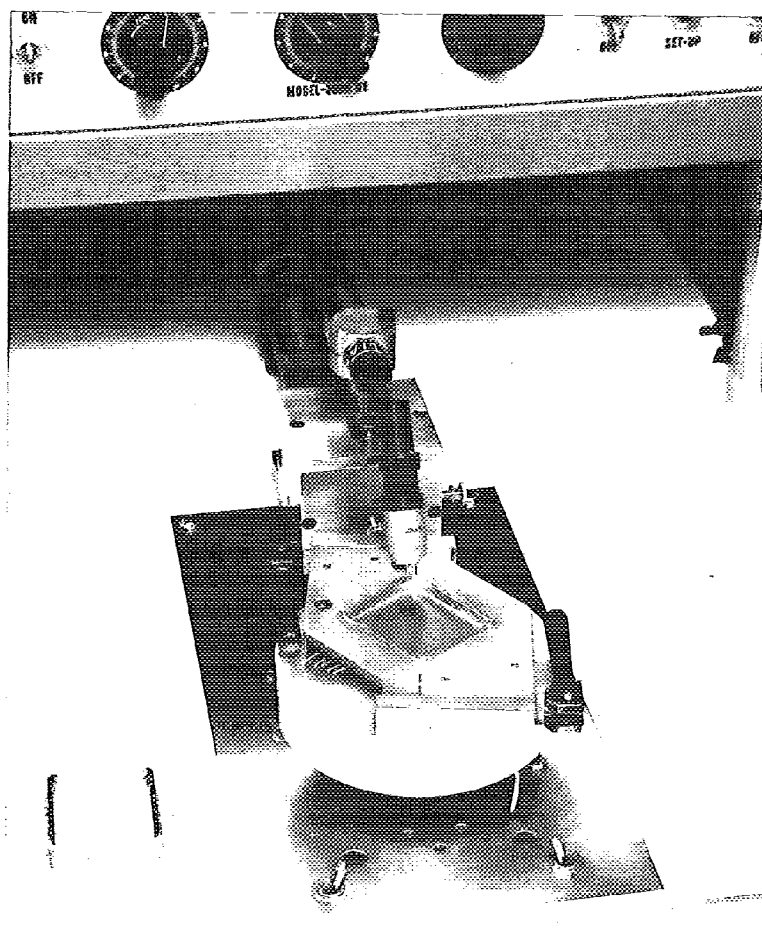
Figures 28 through 35 were chosen to illustrate automatic GTAW equipment and types of product application.

32 / RECOMMENDED PRACTICES FOR GAS TUNGSTEN ARC WELDING



Typical welding system integrating power supply, automatic weld programmer, torch holder, and parts for semiautomatic welding, medium volume production.

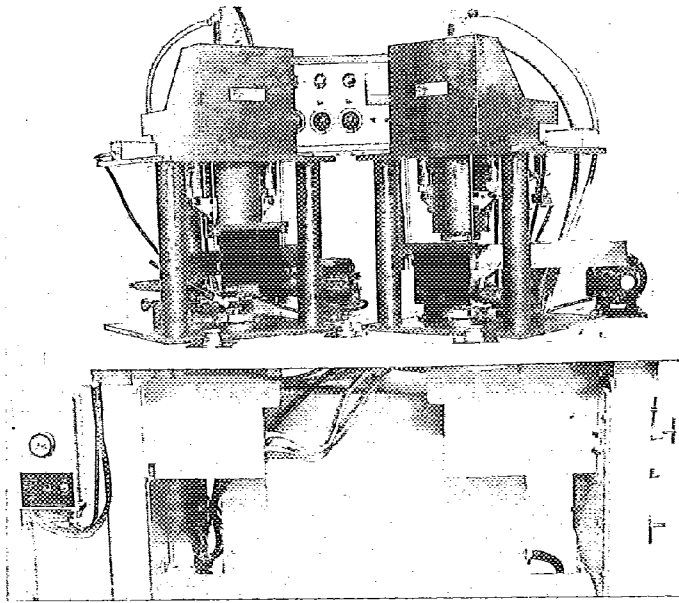
Fig. 28 — Semiautomatic GTA welding station



2 x 2 in. (51 x 51 mm) semiconductor case edge welded for a hermetic seal.
The torch automatically tracks the shape.

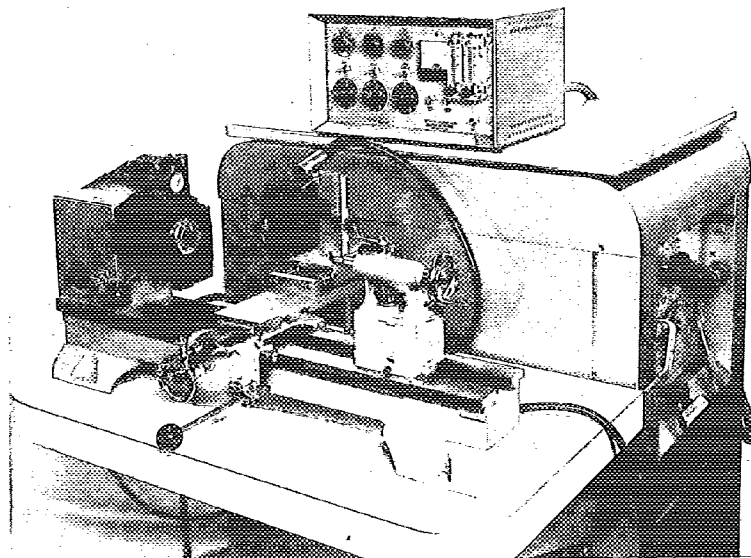
Fig. 29 — Automatic GTA welding station

34 / RECOMMENDED PRACTICES FOR GAS TUNGSTEN ARC WELDING



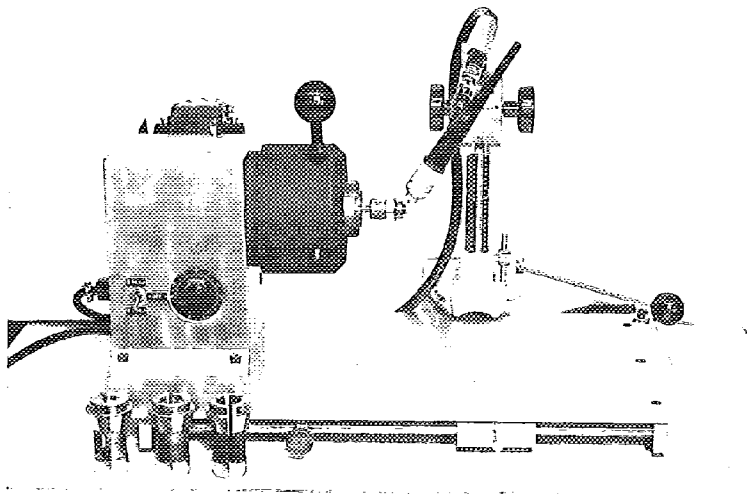
One programmer with power source system enables one operator to alternately load 0.6 in. (7 mm) O.D. capsule into fixture every 6 seconds. Welding labor per part, only 3 seconds; welding amperage switched electronically from one torch to the other. Fixture has water-cooled clamps, common drive for alignment, automatic torch retraction, and complete weld program.

Fig. 30—Two station automatic GTA welding station



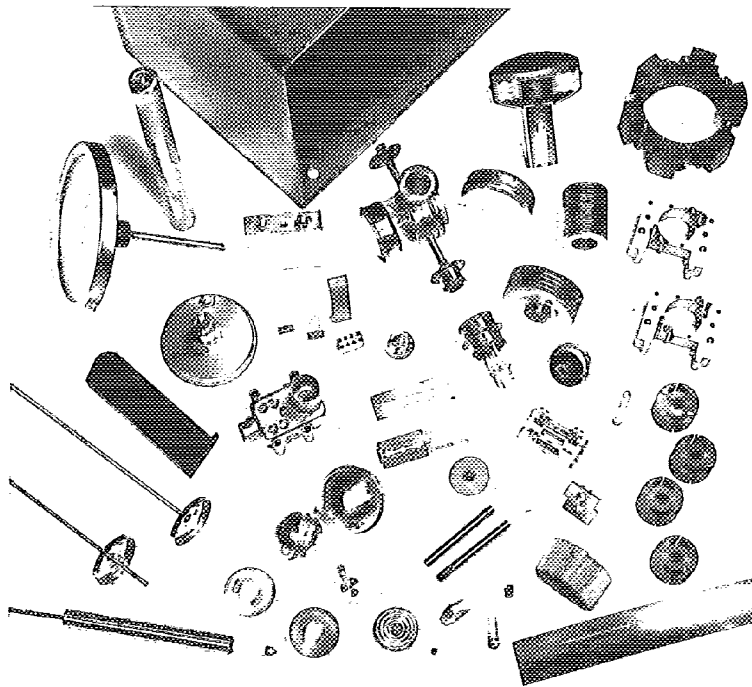
Simple fixture provides method of locating parts and torch precisely for each weld.

Fig. 31—Circumferential welding system



Typical welding system integrating power supply, automatic weld programmer, torch holder, and parts for semiautomatic welding, medium volume production.

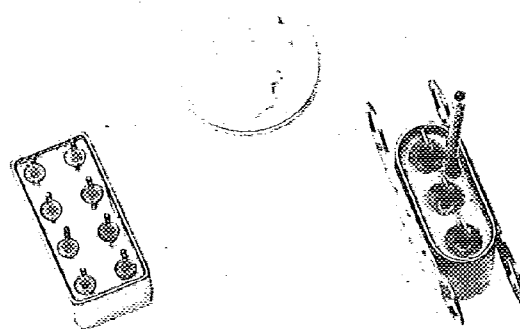
Fig. 32 — Semiautomatic GTA welding machine



Small thin parts welded on welding fixtures as well as automatic machine welding makes GTAW an economical production process. This is an assortment of small thin parts, production welded. Note 25-cent piece in the center for relative size.

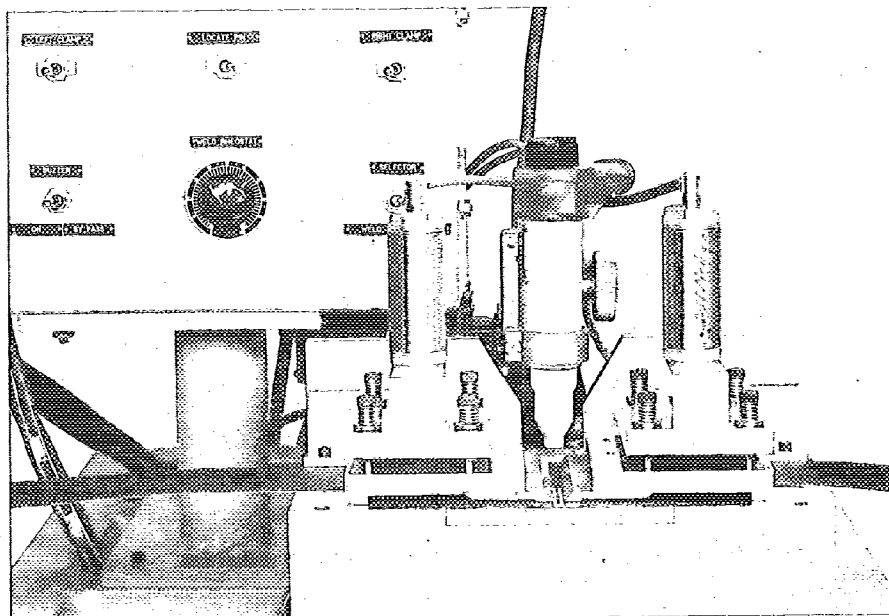
Fig. 33 — Typical production pieces

36 / RECOMMENDED PRACTICES FOR GAS TUNGSTEN ARC WELDING



Two 4 x 8 in. (102 x 20 mm) crystal can relays edge welded CRS header lip to cupro nickel case. Note size of welded assembly in comparison to dime at top of picture.

Fig. 34—Glass beaded headers to cases for small hermetic relays and switches



Coil ends being butt welded together with no increase in strip thickness.

Fig. 35—GTA welding machine

6. Safe Practices

6.1 Introduction. The general subject of safety and safe practices in welding, cutting, and allied processes is covered in ANSI Z49.1,⁴ "Safety in Welding and Cutting" (published by the American Welding Society), and ANSI Z49.2,⁵ "Fire Prevention in Use of Welding and Cutting Processes." Welding personnel should be familiar with the safe practices discussed in these documents.

In addition, there are other potential hazard areas in arc welding and cutting (besides fumes, gases, and radiant energy), such as noise and the handling of cylinders and regulators, which warrant consideration. Those areas that may be associated with the GTAW process are briefly discussed in this section.

6.2 Safe Handling of Shielding Gas Cylinders and Regulators. Compressed gas cylinders should be handled carefully. Knocks, falls, or rough handling may damage cylinders, valves, or safety devices and cause leakage or accident. Valve protecting caps, when supplied, should be kept in place (handtight) except when cylinders are in use or connected for use. For further information, see CGA Pamphlet P-1, "Safe Handling of Compressed Gases in Containers."⁶

6.3 Cylinder Use. The following should be observed when setting up and using cylinders of shielding gas.

(1) Before connecting a regulator to the cylinder valve, the valve should be opened momentarily and closed immediately ("cracking"), to clear the valve of dust or dirt that otherwise might enter the regulator. The person opening the valve should stand to one side of the cylinder outlet, never in front of it. Then, the cylinder should be secured.

(2) After the regulator is attached, the adjusting screw should be released (by turning it counterclockwise). Then the cylinder valve should be opened slowly to prevent a too rapid surge of high pressure gas into the regulator.

(3) When the weld area is left untended, the source of the gas supply should be shut off.

6.4 Gases. The major toxic gases associated with welding are ozone, nitrogen dioxide, and carbon monoxide. Phosgene gas could be present as a result of thermal or ultraviolet decomposition of chlorinated hydrocarbon cleaning agents, such as trichlorethylene and perchlorethylene, located in the vicinity of welding operations. **Degreasing or other cleaning operations involving chlorinated hydrocarbons should be so located that vapors from these operations cannot be reached by radiation from the welding arc.**

6.4.1 Ozone. The ultraviolet light emitted by the weld-

ing arc acts on the oxygen in the surrounding atmosphere to produce ozone. The amount of ozone produced will depend upon the intensity and the wave length of the ultraviolet energy, the humidity, the amount of screening afforded by the welding fume, and other factors. The ozone concentration will generally be increased with an increase in welding current, by the use of argon as the shielding gas, and when aluminum is welded. Test results, based upon present sampling methods, indicate the average concentration of ozone generated in the GTAW process does not constitute a hazard under conditions of good ventilation and welding practice. (See ANSI Z49.1 for welding conditions requiring ventilation and particularly when welding is accomplished in confined spaces.)

6.4.2 Nitrogen Dioxide. Some test results show that high concentrations of nitrogen dioxide are found only within six inches of the arc. Natural ventilation reduces these concentrations quickly to safe levels in the welder's breathing zone, so long as the welder keeps his head out of the plume of fumes (and thus out of the plume of weld gases). Nitrogen dioxide is not thought to be a hazard in GTAW.

6.5 Metal Fumes. The welding fumes generated by the GTAW process can be controlled by natural ventilation, general ventilation, local exhaust ventilation, or by respiratory protective equipment as described in ANSI Z49.1. The method of ventilation required to keep the level of toxic substances in the welder's breathing zone within acceptable concentrations is directly dependent upon a number of factors, among which are the material being welded, the size of the work area, and the degree of confinement or obstruction to normal movement where the welding is being done. Each operation should be evaluated on an individual basis in order to determine what will be required. Acceptable levels of toxic substances associated with welding and designated as time-weighted average threshold limit values (TLVs) and ceiling values, have been established by the American Conference of Governmental Hygienists and by the Occupational Safety and Health Administration. Compliance with these acceptable levels can be checked by a sampling of the atmosphere under the welder's helmet or in the immediate vicinity of the helper's breathing zone. The maximum allowable particulate matter (welding fume) which may be present (as measured over an eight hour period for a forty hour weekly exposure) within the welder's breathing zone is listed in Table 8. Sampling should be in accordance with AWS F1.1, Method for Sampling Airborne Particulates Generated by Welding and Allied Processes.⁷

6.6 Radiant Energy. Any personnel within the immediate vicinity of the welding arc should have adequate protection from the radiation produced by the welding arc. Generally, the highest ultraviolet radiant energy intensities are produced when an argon shielding gas is used and when aluminum is welded.

7. See also AWS *Fumes and Gases in the Welding Environment*.

4. ANSI Z49.1 is available from the American Welding Society, 2501 N.W. 7th St., Miami, FL 33125

5. ANSI Z49.2 is available from the American National Standards Institute, 1430 Broadway, New York, NY 10018

6. CGA P-1 is available from the Compressed Gas Association, Inc., 500 Fifth Avenue, New York, NY 10036

Table 8
Particulate matter with possibly significant
fume concentrations in the welder breathing zone

Material being welded	Particulate matter
Aluminum and aluminum alloys	Al, Mg, Mn, Cr
Magnesium alloys	Mg, Al, Zn
Copper and copper alloys	Cu, Be, Zn, Pb
Nickel and nickel alloys	Ni, Cu, Cr, Fe
Titanium and titanium alloys	Ti
Austenitic stainless steels	Cr, Ni, Fe
Carbon steels*	Fe, Cu, Mn

*Also Cd and Zn for plated materials.

The filter glass shades recommended for GTAW, as presented in ANSI Z 49.1 as a guide, are:

	Shade ⁸
When welding ferrous material	12
When welding non-ferrous material	12
Flash goggles	2

Leather or wool clothing that is dark in color (to reduce reflection which could cause ultraviolet burns to the face and neck underneath the helmet) is recommended for GTAW. The greater intensity of ultraviolet radiation will cause rapid disintegration of cotton clothing.

6.7 Noise and Hearing Protection. Personnel shall be

8. The choice of a filter shade may be made on the basis of visual acuity and may therefore vary widely from one individual to another, particularly under different current densities, materials, and welding processes. However, the degree of protection from radiant energy afforded by the filter plate or lens, when chosen to allow visual acuity, will still remain in excess of the needs of eye filter protection. Filter plate shades as low as shade 8 have proven suitably radiation-absorbent for protection from the arc welding processes.

9. See also AWS *Arc Welding and Cutting Noise*.

protected against exposure to noise generated in welding and cutting processes, in accordance with paragraph 1910.95, entitled "Occupational Noise Exposure" of the Occupational Safety and Health Standards, Occupational Safety and Health Administration, U.S. Department of Labor.⁹

6.8 Safe Handling of Welding Equipment

6.8.1 No welding should be done until all electrical connections, power supply, welding leads, welding machines, and work clamps are secure, and the welding power source frame is well grounded.

6.8.2 The work clamp must be securely attached to the work before any welding is carried on.

6.8.3 Welding cables and hoses should be kept free of grease and oil. The line supply disconnect switch should be placed in the "OFF" position when the welding power source is left unattended.

6.8.4 The positions of all power source controls for initial start or resetting the disconnect switch should be checked.

6.8.5 The insulation on the electrode lead cable, gun, and electrode holder should be in good condition.