

Recommended Practices for Gas Tungsten Arc Welding



American Welding Society



Documents

Document Sharing Hub

Key Words—Gas tungsten arc welding, GTAW, TIG, training, process, qualification, equipment, quality, safe practices, WIG, Heliarc®

AWS C5.5/C5.5M:2003
An American National Standard

Approved by
American National Standards Institute
June 4, 2003

Recommended Practices for Gas Tungsten Arc Welding

Supersedes AWS C5.5-80

Prepared by
AWS C5 Committee on Arc Welding and Arc Cutting

Under the Direction of
AWS Technical Activities Committee

Approved by
AWS Board of Directors

Abstract

This document is designed to assist anyone who is associated with gas tungsten arc welding (GTAW). This includes welders, welding technicians, welding engineers, quality control personnel, welding supervisors, purchasing personnel, educators, and students.

This document discusses welding principles, equipment, gas shielding, and techniques for manual and automatic GTAW. Welding safety, troubleshooting, and related items are included for understanding by all types of personnel in establishing better production welding operations.

Educators will find this publication a handy reference for teaching all aspects of gas tungsten arc welding. It can become a quick reference for students after their graduation or during their employment.



American Welding Society

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



Documents

Document Sharing Hub

Statement on Use of AWS American National Standards

All standards (codes, specifications, recommended practices, methods, classifications, and guides) of the American Welding Society (AWS) are voluntary consensus standards that have been developed in accordance with the rules of the American National Standards Institute (ANSI). When AWS standards are either incorporated in, or made part of, documents that are included in federal or state laws and regulations, or the regulations of other governmental bodies, their provisions carry the full legal authority of the statute. In such cases, any changes in those AWS standards must be approved by the governmental body having statutory jurisdiction before they can become a part of those laws and regulations. In all cases, these standards carry the full legal authority of the contract or other document that invokes the AWS standards. Where this contractual relationship exists, changes in or deviations from requirements of an AWS standard must be by agreement between the contracting parties.

International Standard Book Number: 0-87171-715-8

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

© 2003 by American Welding Society. All rights reserved

Printed in the United States of America

AWS American National Standards are developed through a consensus standards development process that brings together volunteers representing varied viewpoints and interests to achieve consensus. While AWS administers the process and establishes rules to promote fairness in the development of consensus, it does not independently test, evaluate, or verify the accuracy of any information or the soundness of any judgments contained in its standards.

AWS disclaims liability for any injury to persons or to property, or other damages of any nature whatsoever, whether special, indirect, consequential or compensatory, directly or indirectly resulting from the publication, use of, or reliance on this standard. AWS also makes no guaranty or warranty as to the accuracy or completeness of any information published herein.

In issuing and making this standard available, AWS is not undertaking to render professional or other services for or on behalf of any person or entity. Nor is AWS undertaking to perform any duty owed by any person or entity to someone else. Anyone using these documents should rely on his or her own independent judgment or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstances.

This standard may be superseded by the issuance of new editions. Users should ensure that they have the latest edition.

Publication of this standard does not authorize infringement of any patent. AWS disclaims liability for the infringement of any patent resulting from the use or reliance on this standard.

Finally, AWS does not monitor, police, or enforce compliance with this standard, nor does it have the power to do so.

On occasion, text, tables, or figures are printed incorrectly, constituting errata. Such errata, when discovered, are posted on the AWS web page (www.aws.org).

Official interpretations of any of the technical requirements of this standard may be obtained by sending a request, in writing, to the Managing Director, Technical Services Division, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126 (see Annex A). With regard to technical inquiries made concerning AWS standards, oral opinions on AWS standards may be rendered. However, such opinions represent only the personal opinions of the particular individuals giving them. These individuals do not speak on behalf of AWS, nor do these oral opinions constitute official or unofficial opinions or interpretations of AWS. In addition, oral opinions are informal and should not be used as a substitute for an official interpretation.

This standard is subject to revision at any time by the AWS C5 Committee on Arc Welding and Arc Cutting. 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 that may be of use in improving this standard are required and should be addressed to AWS Headquarters. Such comments will receive careful consideration by the AWS C5 Committee on Arc Welding and Arc Cutting and the author of the comments will be informed of the Committee's response to the comments. Guests are invited to attend all meetings of the AWS C5 Committee on Arc Welding and Arc Cutting to express their comments verbally. Procedures for appeal of an adverse decision concerning all such comments are provided in the Rules of Operation of the Technical Activities Committee. A copy of these Rules can be obtained from the American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

Photocopy Rights

Authorization to photocopy items for internal, personal, or educational classroom use only, or the internal, personal, or educational classroom use only of specific clients, is granted by the American Welding Society (AWS) provided that the appropriate fee is paid to the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, Tel: 978-750-8400; online: <http://www.copyright.com>.

Personnel

AWS C5 Committee on Arc Welding and Arc Cutting

<i>J. R. Hannahs, Chair</i>	Edison Community College
<i>N. A. Sanders, 1st Vice Chair</i>	Hypertherm, Incorporated
<i>D. B. Holliday, 2nd Vice Chair</i>	Northrop Grumman Corporation
<i>P. Howe, Secretary</i>	American Welding Society
<i>*E. R. Bohnart</i>	Welding Education and Consulting
<i>H. A. Chambers</i>	TRW Nelson Stud Welding Division
<i>C. Connelly</i>	Poly-Weld, Incorporated
<i>J. DeVito</i>	ESAB Welding and Cutting Products
<i>R. M. Dull</i>	Edison Welding Institute
<i>D. A. Fink</i>	The Lincoln Electric Company
<i>I. D. Harris</i>	Edison Welding Institute
<i>*R. T. Hemzacek</i>	Consultant
<i>G. K. Hicken</i>	Sandia National Laboratory, Retired
<i>K. Y. Lee</i>	The Lincoln Electric Company
<i>R. P. Munz</i>	The Lincoln Electric Company
<i>S. R. Potter</i>	SRP Consulting Services
<i>*B. L. Shultz</i>	The Taylor-Winfield Corporation
<i>R. L. Strohl</i>	Tweco-Arcair Corporation
<i>*E. G. Yevick</i>	Weld-Met International Group
<i>L. Yost</i>	The Lincoln Electric Company

AWS C5C Subcommittee on Gas Tungsten Arc Welding

<i>G. K. Hicken, Chair</i>	Sandia National Laboratories, Retired
<i>R. D. Campbell, Vice Chair</i>	Purity Systems, Incorporated
<i>P. Howe, Secretary</i>	American Welding Society
<i>E. A. Benway</i>	Swagelok Company
<i>*E. R. Bohnart</i>	Welding and Education Consulting
<i>*C. Connelly</i>	Poly-Weld, Incorporated
<i>D. E. Destefan</i>	High Current Technologies, Incorporated
<i>R. W. Diesner</i>	Retired
<i>J. C. Downey</i>	Retired
<i>T. W. Edwards</i>	American Welding and Engineering, Incorporated
<i>*J. R. Hannahs</i>	Edison Community College
<i>*L. M. Hellemann</i>	General Electric Aircraft Engines
<i>E. J. LaCoursiere</i>	EJL & Associates
<i>P. C. McClay</i>	Pratt and Whitney
<i>D. E. Spragg</i>	Pratt and Whitney
<i>*J. S. Thrower</i>	Optimum Engineering Manufacturing, Incorporated
<i>D. A. Wright</i>	Zephyr Products, Incorporated
<i>*B. Young</i>	Westinghouse Savannah River Company, Retired

*Advisor

This page is intentionally blank.

Foreword

(This Foreword is not a part of AWS C5.5/C5.5M:2003, *Recommended Practices for Gas Tungsten Arc Welding*, but is included for informational purposes only.)

Gas tungsten arc welding (GTAW) was introduced as a practical fabricating process in the 1940s. In the decades since then, advances have been made in the equipment and in the development of techniques for automatic applications. GTAW is now accepted as the only practical joining method in some metal joining applications.

These recommended practices were first prepared by the AWS C5 Committee on Arc Welding and Arc Cutting and the AWS C5C Subcommittee on Gas Tungsten Arc Welding in 1980. The 1980 edition was reaffirmed in 1989. The current AWS C5 Committee on Arc Welding and Arc Cutting and the current C5C Subcommittee on GTAW have prepared these recommended practices to present the basic practices and methods of GTAW and to expand the document to include the latest advancements in this process. These recommended practices are based on present uses of GTAW in the metal fabricating industry, along with research and development and new applications of the process.

We should all encourage our younger generation to consider welding and welding related fields as places to become involved with the high rewards and challenges to be encountered in the future. We should also be willing and pleased to share our prior experiences and knowledge that could help new members excel in this occupation.

The description of GTAW and its features are 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 GTAW process and, thus, to higher quality and performance standards.

Comments and suggestions for the improvement of this standard are welcomed. They should be sent to the Secretary, AWS C5 Committee on Arc Welding and Arc Cutting, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126.

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

This document will be reviewed periodically to assure its success in serving all parties concerned with its provisions. Revisions will be issued when warranted.

This page is intentionally blank.

Copyright American Welding Society

Table of Contents

	Page No.
<i>Personnel</i>	iii
<i>Foreword</i>	v
<i>List of Tables</i>	x
<i>List of Figures</i>	xi
1. Scope and Introduction	1
1.1 Scope	1
1.2 Introduction to the Gas Tungsten Arc Welding (GTAW) Process	1
1.3 History	1
2. Normative References	4
2.1 American Conference of Governmental Industrial Hygienists Standards	5
2.2 AWS Standards	5
2.3 ISO Standards	6
2.4 OSHA Standards	6
3. Definitions	6
4. GTAW Principles	9
4.1 Process Description	9
4.2 Process Advantages	9
4.3 Process Limitations	11
4.4 Process Variables	12
4.5 Related Variables	17
5. Equipment and Supplies	18
5.1 Welding Power Sources (Used for GTAW)—Introduction	18
5.2 Controllers	20
5.3 Pulse Controllers	22
5.4 Weld Sequence Controllers	22
5.5 Arc Welding Torches	23
5.6 Wire Feeders	30
5.7 Arc and Torch Oscillators	31
5.8 Arc Initiation Equipment	32
6. Tungsten Electrodes	33
6.1 General	33
6.2 Classifications of Electrodes	34
6.3 Surface Finishes	37
6.4 Electrode Sizes and Current Capacities	37
6.5 Electrode Tip Configurations	38
6.6 Electrode Cutting	41
6.7 Factors Affecting Electrode Life	41
6.8 Removing Contamination	42
6.9 Grinding Dust	42
6.10 Storage	43
7. Gas Shielding, Purging, and Backing	43
7.1 Torch Shielding Gas	43

7.2	Purging	50
7.3	Shielding and Purging Gas Purity	62
7.4	Shielding and Purging Gas Economics	65
7.5	Purifiers	65
7.6	Purging Gas Safety	67
8.	Fixturing and Tooling.....	68
8.1	Material Selection	68
8.2	Tooling/Fixturing Considerations.....	68
8.3	Temporary (Soft)/Permanent (Hard) Tooling.....	69
9.	Welding Techniques	71
9.1	General	71
9.2	Manual and Semiautomatic Welding	71
9.3	Mechanized Welding.....	80
9.4	Automated Welding.....	83
10.	Joint Design, Preparation, and Welding Positions	85
10.1	Introduction	85
10.2	Basic Joint Configurations and Welding Positions	85
10.3	Edge Preparation and Surface Cleaning.....	85
11.	Welding Characteristics of Selected Alloys	85
11.1	Introduction	85
11.2	Carbon and Alloy Steels.....	89
11.3	Stainless Steels and Iron-Based Superalloys.....	89
11.4	Aluminum Alloys	90
11.5	Magnesium Alloys	91
11.6	Beryllium.....	91
11.7	Copper Alloys	91
11.8	Nickel Alloys.....	92
11.9	Cobalt Alloys.....	92
11.10	Refractory and Reactive Metals	92
11.11	Cast Irons.....	92
11.12	Welding Dissimilar Materials.....	92
11.13	Filler Metals	92
12.	Qualification of Procedures, Welders, and Welding Operators.....	94
12.1	Introduction	94
12.2	Welding Program.....	95
12.3	Establishing Welding Requirements	95
12.4	Welding Procedure Specifications (WPS).....	95
12.5	Procedure Qualification Records (PQR)	95
12.6	Welder and Welding Operator Qualification Tests.....	95
13.	Quality Control	96
13.1	Introduction	96
13.2	Weldment Quality.....	96
13.3	Specifications	96
14.	Troubleshooting	97
14.1	General	97
14.2	Electrical.....	97
14.3	Inert Shielding Gas Troubleshooting	102
14.4	Water Cooling Systems	105
14.5	Tools and Fixtures	106

	Page No.
14.6 Filler Material.....	106
14.7 Design of Welded Assemblies.....	106
14.8 Weld Joint Fit-up.....	108
15. Safety	108
15.1 Hazards.....	108
15.2 Electrical Shock.....	108
15.3 Arc Radiation and Burns	108
15.4 Welding Environment.....	109
15.5 Oxygen Deficiency	110
15.6 Noise.....	110
15.7 Safe Handling of Cylinders	110
15.8 Fires And Explosions	110
15.9 Common Sense.....	110
15.10 Grinding Dust.....	110
<i>Nonmandatory Annexes</i>	<i>113</i>
<i>Annex A—Guidelines for Preparation of Technical Inquiries for AWS Technical Committees.....</i>	<i>113</i>
<i>Annex B—Suggested Reading List and Other References</i>	<i>115</i>
<i>List of AWS Documents on Arc Welding and Arc Cutting</i>	<i>117</i>

List of Tables

Table	Page No.
1 Welding Process Comparison Based on Quality and Economics	11
2 Comparison of Typical Current Ratings for Gas-Cooled and Water-Cooled GTAW Torches.....	25
3 Typical Welding Cable Capacities	29
4 Guide for Selecting the Size of Cable Based on the Welding Current.....	30
5 Chemical Composition Requirements for Tungsten Electrodes	34
6 Typical Current Ranges for Tungsten Electrodes and Recommended Gas Cup Sizes	35
7 Comparison of Surface Finish Designations.....	37
8 Recommended Types of Current, Tungsten Electrodes, and Shielding Gases for Welding of Various Metals and Alloys	39
9 Tungsten Electrode Tip Shapes and Examples of Current Ranges	39
10 General Properties of Gases	44
11 Thermodynamic Properties of Gases	44
12 Dew Point Conversions	45
13 Advantages of Shielding Gases.....	46
14 Typical Argon Flow Rates.....	50
15 Gas Purity Specification by Industrial Grade.....	62
16 Purity Requirements for Gaseous Argon	62
17 Purity Requirements for Gaseous Helium	63
18 Purity Requirements for Gaseous Hydrogen	63
19 Welding Equipment or Components	72
20 AWS Specifications Related to Gas Tungsten Arc Welding	88
21 Troubleshooting	98
22 Guide for Shade Numbers.....	109

List of Figures

Figure

Page No.

1	Early Gas Tungsten Arc Welding Torches and Accessories, Circa 1943, with a Torch Body and an Early Flowmeter	2
2	Early Gas Tungsten Arc Welding Torches	2
3	SMAW Power Source Used for Early Gas Tungsten Arc Welding	3
4	Motor-Generator SMAW Power Source Used for Early Gas Tungsten Arc Welding	3
5	Gas Tungsten Arc Welding Power Source—Pulsed	4
6	Gas Tungsten Arc Welding Power Source	4
7	Stylized Representation of the Gas Tungsten Arc Welding Process	9
8	Gas-Cooled GTAW Torch and Stylized Representation of Typical Gas Tungsten Arc Welding Equipment	10
9	Clean Weld Beads Typical of Properly Shielded GTAW Welds	11
10	Characteristics of Current Types Used for Gas Tungsten Arc Welding	13
11	Relationship Between Arc Pressure and Pulse Frequency	14
12	Programmed (Modulated) Current without Polarity Reversal	15
13	Characteristics of Variable Polarity (Programmed) Weld Current	16
14	Arc Shape and Fusion Zone Profiles as a Function of Electrode Tip Geometry in Pure Argon Shielding Gas	17
15	Typical Volt-Amp Characteristic Curves for GTAW Power Sources	18
16	Typical Inverter Power Source Components	20
17	Typical Wire Feeder	22
18	Typical GTAW Sequence for Non-Pulsed DC Welding	23
19	Typical GTAW Sequence for Pulsed DC Current and Pulsed Wire Feed	24
20	Typical Water-Cooled GTAW Torch (Cross-Sectional View)	25
21	Examples of GTAW Torches	26
22	Orbital Weld Head with Wire Feeder	27
23	Components of a Typical GTAW Torch, Including Gas Nozzle/Cup, Gas Lens, Collet Body, Torch Body, Collet, and Electrode	27
24	GTAW Torch Without a Gas Lens (Left) and with a Gas Lens (Right)	28
25	GTAW Torch with Cold Wire Feed	31
26	Schematic of GTAW with Hot Wire Feed	31
27	Magnetically Deflected Arc Laying a Stringer Bead in a Deep Groove Weld	32
28	Cross Sections of Welds Made in 1/2 in. [13 mm] Thick Stainless Steel; (A) with Magnetic Arc Oscillation, and (B) without Magnetic Arc Oscillation	32
29	High-Frequency Arc Starting	33
30	Balled Tip on the End of a Pure Tungsten Electrode Used for AC Welding	36
31	Ground Tapered Tip on End of Doped Tungsten Electrodes	38
32	Ground Electrode Tip Geometry	39
33	Typical Preparation Method of Tungsten Electrodes Used for GTA Welding, Including Tip Truncation, Grinding, and Cutting	40
34	The Desired Surface Finish of a Ground Electrode	41
35	Proper Cutting of Tungsten Electrodes with a Diamond Cut-Off Blade	42
36	GTA Weld Bead Shape as a Function of Shielding Gas Composition and Electrode Tip Geometry (on 304 Stainless Steel)	47
37	GTA Voltage—Current Relationships with Argon and Helium Shielding Gases for Different Arc Lengths	48

38	Improved Surface Cleanliness on Monel ^{®1} Welds Produced with the 5% Hydrogen Mixture in Argon Shielding Gas with GTAW	49
39	The Effects of Shielding Gas Contamination on Titanium Weldments (Color Chart for Titanium Welding Acceptance).....	51
40	GTAW Weld Underbead Contamination with Various Levels of Oxygen Contents in the Purging Gas.....	52
41	Purging Times for Various Pipe Sizes	54
42	Purging a Piping System with Open Ends Blanked	55
43	Purging of a Piping System with Appropriate Venting to Eliminate Dead Air Pockets	55
44	Purging with Removable Plugs	56
45	Purging with Removable Chamber	56
46	Purge Distributor Ring	56
47	Purging with Water Soluble Paper Dams	57
48	Purging with a Backing Channel.....	57
49	Purging with a Gas Distributor (Diffuser).....	58
50	Typical Inert Gas Glove Box Chamber	58
51	Flexible Plastic Purge Bag	59
52	Trailing Shields—Bottom View of Inert Gas Trailing Shield Fabricated Using Stainless Porous (100 micron) Tubing (Shown with High Temperature Tape).....	60
53	Trailing Shields—Inert Gas Trailing Shield Fabricated Using Stainless Porous (100 micron) Tubing (Shown with High Temperature Tape)	60
54	Trailing Shields—Inert Gas Trailing Shield Fabricated Using Stainless Porous (40–100 micron) Sheet Metal	61
55	Shielding with the Use of a Backing Tape	61
56	Point-of-Use (POU) Purifiers (Waferpure ^{®2} Reactive Resin Type) Below a Welding Fixture	66
57	Point-of-Use Gas Purifier (Heated Metal Getter Type)	67
58	Cylinder Status Tag (The Use of a Simple Tagging System Can Be Very Helpful)	68
59	Weld Distortion in Ti-6Al-V Bead-on-Plate (Sheet) Weld	69
60	Tooling for GTAW of Fuel Cell Components to Control Distortion of Weldment	70
61	Run-On/Run-Off Tabs Used for Welding Ends of Strip Material.....	70
62	Walking-the-Cup Technique	74
63	Dragging-the-Finger Technique	74
64	Folding Fingerstall Technique.....	75
65	Brace Technique Showing Wrist in Contact with Workpiece to Stabilize the Torch.....	75
66	Small Rotary Positioner Used for Workpiece Manipulation.....	76
67	Mechanical Manipulation in a Mechanized Welder.....	76
68	Gas Tungsten Arc Welding Torch with Wire Feeders [(A) and (B)] for Spooled Wire.....	78
69	Cross Sections of Typical Consumable Inserts	79
70	Lathe-Type Welding Setup.....	81
71	Orbital GTAW Weld Head	84
72	Basic Joint Types.....	86
73	Weld Joint Edge Preparation (U-Groove, J-Groove, and V-Groove).....	87
74	Effects of Sulfur Content on Bead-on-Plate Weld Bead Shape in 304L Made with the Same Parameters	90
75	GTAW in 6061-0 Aluminum Showing the Surface Contours with Pulsed Direct Current Straight Polarity (DCEN).....	91
76	High Quality Welds in Inconel ^{®1} 718, Original Scale 5X	93
77	High Quality Welds in Cobalt Alloy HS188, Original Scale 5X	93
78	Manual GTAW of Titanium in an Inert Gas Chamber (Glove Box)	94
79	Criteria for Acceptable GTAW in Titanium via Tack Welds Only	104

1. Monel and Inconel are registered trademarks of Special Metals Corporation.

2. Waferpure is a registered trademark of Mykrolis Corporation.

Recommended Practices for Gas Tungsten Arc Welding

1. Scope and Introduction

1.1 Scope. This document presents recommended practices for the gas tungsten arc welding (GTAW) process.¹ Its purpose is to provide a fundamental explanation of the process, describe basic practices and concepts, and outline some advanced methods and applications of GTAW. These should enable welding personnel to determine the best applications of this process and evaluate its use compared with other joining processes.

The section covering principles of operation will help the reader understand how the process works, the general types of equipment needed, and the advantages and limitations of the gas tungsten arc welding process. The basic concepts and practices include both general and specific recommendations and technical data for equipment, consumables, procedures, variables, applications, and safety considerations.

This standard makes use of U.S. Customary Units. Approximate mathematical equivalents in the International System of Units (SI) are provided for comparison in brackets [] or in appropriate columns in tables and figures.

1.2 Introduction to the Gas Tungsten Arc Welding (GTAW) Process. Welding as an occupation and a career is a very “special” and rewarding choice to pursue. It is one of the most interesting manufacturing disciplines as it involves both art and science. This is illustrated by manual gas tungsten arc welding (GTAW) because a person’s manual dexterity, hand-eye coordination, and self-discipline in combination with the correct welding procedure(s) are paramount to its success. The “art” portion is most evident when an individual welder expresses their unique signature to the manually applied welds. Exam-

ples of this would be certain welded metal sculptures and/or a “perfectly” welded part or assembly. The “science” end of the spectrum would include recent developments such as fully automated robotic welding cells that could include through-the-torch vision that allows real-time viewing of the weld as well as real-time weld joint tracking. Also, weld parameter data acquisition and feedback control are routinely accomplished in real-time.

1.3 History. Although arc welding was first developed in the 1880s, its commercial use in the United States did not commence until the first decade of the 1900s. The years of the First World War brought the initial large-scale commercial use of arc welding, when shielded metal arc welding (SMAW) began to replace riveting as the means of joining in the manufacture of ships.

During the 1920s, H. M. Hobart and P. K. Devers performed preliminary work on using inert gases to shield the carbon or metallic electrode’s welding arc and molten weld pool. In 1926 they applied for patents² on the use of an electric welding arc in which an inert gas was independently supplied around the arc, thus replacing flux as the shielding method. Other investigators experimented with both helium and argon as shielding gases, but because of the high costs associated with these inert gases, very little commercial use was made of them at that time.

By the onset of the Second World War, shielded metal arc welding had become the dominant welding process. However, there was a need within the aircraft industry for welds made with better shielding than that provided by SMAW when joining reactive metals such as aluminum and magnesium. Also, in the aircraft industry there was a need to develop an acceptable welding process to replace riveting for joining of thin gage materials. These needs led to the first commercial development of gas tungsten arc welding equipment.

1. Gas tungsten arc welding is defined as an arc welding process that uses an arc between a tungsten electrode (nonconsumable) and the weld pool. The process is used with shielding gas and without the application of pressure. (Ref. AWS A3.0, *Standard Welding Terms and Definitions*.)

2. H. M. Hobart, U.S. Patent 1,746,081, 2/4/1930 and P. K. Devers, U.S. Patent 1,746,191, 2/4/1930.

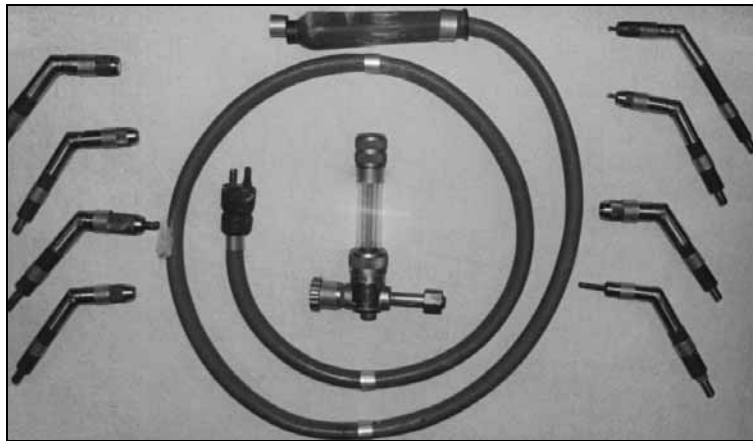


Figure 1—Early Gas Tungsten Arc Welding Torches and Accessories, Circa 1943, with a Torch Body and an Early Flowmeter

In 1941, R. Meredith and V. H. Pavlecka developed the first practical electrode holders (torches) using a nonconsumable electrode made from tungsten. These first torches were simply shielded metal arc welding electrode holders that had been modified to provide the shielding gas flow. A 1/8 in. [3 mm] diameter tungsten electrode was held in a copper tube through which the inert helium gas flowed to protect the electrode, weld pool, and adjacent heated areas of the workpiece. Helium was elected to provide the necessary shield because, at the time, it was the only readily available inert gas. Tungsten inert gas torches and accessories typical of that period are shown in Figures 1 and 2.³ A patent was issued for this process in 1942.⁴

This arc welding process was initially named “Heliarc®,”^{5,6} welding because helium was used as the shielding gas. It has also been called nonconsumable electrode welding, tungsten inert gas (TIG) welding, wolfram inert gas (WIG) welding⁷ and tungsten-arc welding. However, the proper AWS terminology for this process is gas tungsten arc welding (GTAW), because shielding gas mixtures containing inert gases other than helium, or gases which are not inert, are sometimes used.

Using a tungsten electrode and direct current power source, a stable, efficient heat source (the arc) was used

to produce acceptable welds. The inert shielding gas provided full protection of the arc and weld pool, which was imperative in welding of aluminum and magnesium, because even a small amount of air could contaminate the weld. The process also allows for better control over the heat input, thus making it easier to weld thin materials.



Figure 2—Early Gas Tungsten Arc Welding Torches

3. Reprinted with permission from “Modern Welding Technology,” H. B. Cary, 2nd Edition, Prentice Hall, NJ 1989, Figure 1-9, p. 8.

4. R. Meredith, U.S. Patent 2,274,631. 2/24/1942.

5. Registered trademark of ESAB.

6. “Heliweld” was the Airco description of the process.

7. Wolfram is the German name for tungsten.



Figure 3—SMAW Power Source Used for Early Gas Tungsten Arc Welding

When the GTAW process was first developed, SMAW was being performed utilizing direct current with electrode positive (DCEP or reverse polarity). The same power sources (DC generators of the rotating type) were thus used for the early gas tungsten arc welding process. Photographs of early GTAW/SMAW power sources are shown in Figures 3 and 4. One of the major benefits of DCEP was the tremendous cathodic cleaning action of the workpiece surface for aluminum and magnesium. However, overheating of the electrode and subsequent splitting, melting, and transfer of tungsten particles into the weld limited the useful current range. Since these early torches were air-cooled, they had only a 75 A current capacity. As a result, it soon became apparent that DCEP was not the best polarity to use for this process.

By making the electrode negative, overheating was avoided and weld penetration was improved. Use of DC electrode negative (DCEN or straight polarity) proved acceptable for welding of stainless steels. How-



Figure 4—Motor-Generator SMAW Power Source Used for Early Gas Tungsten Arc Welding

ever, because it did not provide the cleaning action like DCEP, it was not acceptable for welding of aluminum or magnesium, which have tenacious surface oxides that must be removed before acceptable welds can be produced.

To obtain the cleaning action of DCEP along with the improved penetration characteristics and lower electrode heating of DCEN, alternating current (AC) welding power sources were developed. A high-frequency, high-voltage current was superimposed over the basic welding current to stabilize the arc during current reversals. This method was successfully applied to GTAW of aluminum and magnesium.

By the early 1950s, GTAW had gained acceptance in the welding industry. Argon was the most widely accepted shielding gas, followed by helium. However, because of the high cost of argon and helium gases, carbon dioxide and nitrogen were investigated as shielding gases. Since that time, numerous other gases and mixtures of gases have been used with this welding process to provide improved welding performance for some metals. These include argon-helium mixtures, argon-hydrogen mixtures, and argon-nitrogen mixtures.

As a tool for increasing deposition rates beyond that of the commonly used cold wire feed during gas tungsten arc welding, the hot wire feed method⁸ of filler metal addition was introduced. This allowed the high quality

8. A. F. Manz, U.S. Patent 3,122,629, File 2562, issued 2/25/1964.

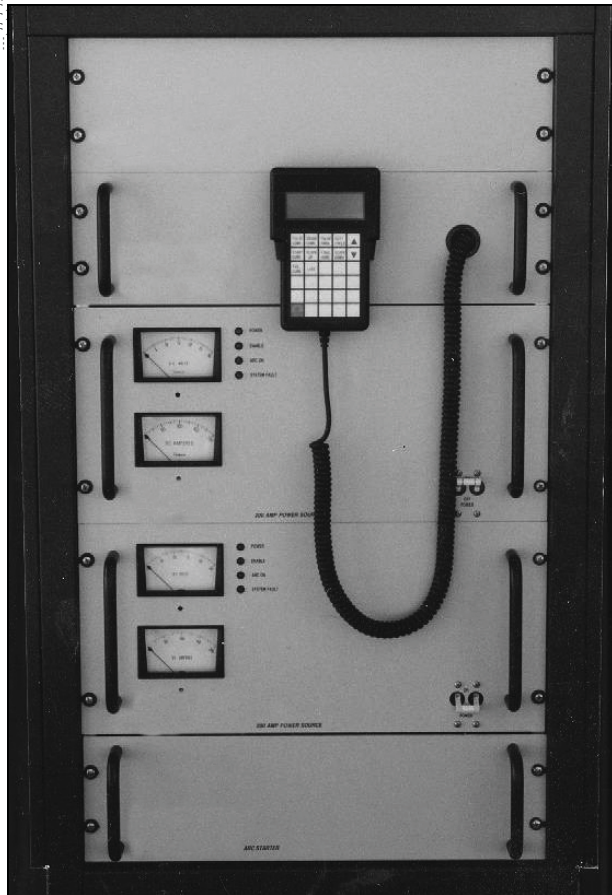


Figure 5—Gas Tungsten Arc Welding Power Source —Pulsed

welds produced by the GTAW process without incurring the spatter produced by the consumable electrode processes.

Over the last several decades, numerous improvements have been made to the GTAW equipment, process and controls. Welding power sources have been developed specifically for the GTAW process (see Figures 5 and 6). Some provide pulsed direct current and others produce variable polarity alternating welding current. Automatic arc starting systems, automatic arc length/voltage controls, vision and penetration sensors, and positioning equipment are all commercially available. Computer controls, automatic sequence controls, and data acquisition systems are readily available to allow data recording and statistical process control. Water-cooled torches were developed, which allow welding currents of up to 1500 A. Different tungsten electrode



Figure 6—Gas Tungsten Arc Welding Power Source

compositions have been developed for improved arc starting, arc stability, and electrode life. GTAW systems are available with several tungsten electrodes positioned around the part to be welded, or impinging on a single weld pool.

2. Normative References

If a code or other standard is cited without a date of publication, it is understood that the latest edition of the document referred to applies. As codes and other standards undergo frequent revision, the reader is encouraged to consult the most recent edition. If a code or other standard is cited with the date of publication, the citation refers to that edition only, and it is understood that any future revisions or amendments to the code or standard are not included.

2.1 American Conference of Governmental Industrial Hygienists Standards⁹

(1) ACGIH, *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*

2.2 AWS Standards¹⁰

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

(2) AWS A1.1, *Metric Practice Guide for the Welding Industry*

(3) AWS A3.0, *Standard Welding Terms and Definitions*

(4) AWS A5.7, *Specification for Copper and Copper Alloy Bare Welding Rods and Electrodes*

(5) AWS A5.9, *Specification for Bare Stainless Steel Welding Electrodes and Rods*

(6) AWS A5.10/A5.10M, *Specification for Bare Aluminum and Aluminum Alloy Welding Electrodes and Rods*

(7) AWS A5.12/A5.12M, *Specification for Tungsten and Tungsten Alloy Electrodes for Arc Welding and Cutting*

(8) AWS A5.13, *Specification for Surfacing Welding Electrodes for Shielded Metal Arc Welding*

(9) AWS A5.14/A5.14M, *Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods*

(10) AWS A5.15, *Specification for Welding Electrodes and Rods for Cast Iron*

(11) AWS A5.16, *Specification for Titanium and Titanium Alloy Welding Electrodes and Rods*

(12) AWS A5.18/A5.18M, *Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding*

(13) AWS A5.19, *Specification for Magnesium-Alloy Welding Electrodes and Rods*

(14) AWS A5.21, *Specification for Bare Electrodes and Rods for Surfacing*

(15) AWS A5.22, *Specification for Stainless Steel Electrodes for Flux Cored Arc Welding and Stainless Steel Flux Cored Rods for Gas Tungsten Arc Welding*

(16) AWS A5.24, *Specification for Zirconium and Zirconium Alloy Welding Electrodes and Rods*

(17) AWS A5.28, *Specification for Low Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding*

(18) AWS A5.30, *Specification for Consumable Inserts*

(19) AWS A5.32, *Specification for Welding Shielding Gases*

(20) AWS B2.1, *Specification for Welding Procedure and Performance Qualification*

(21) AWS B2.1-1-002, *Standard Welding Procedure Specification (WPS) for Gas Tungsten Arc Welding of Carbon Steel, (M-1/P-1, Group 1 or 2), 3/16 through 7/8 inch, in the As-Welded Condition, With or Without Backing*

(22) AWS B2.1-1-007, *Standard Welding Procedure Specification (SWPS) for Gas Tungsten Arc Welding of Galvanized Steel (M-1), 18 through 10 Gauge, in the As-Welded Condition, with or without Backing*

(23) AWS B2.1-1-008, *Standard Welding Procedure Specification (SWPS) for Gas Tungsten Arc Welding of Carbon Steel (M-1, P-1, or S-1), 18 through 10 Gauge, in the As-Welded Condition, with or without Backing*

(24) AWS B2.1-1-009, *Standard Welding Procedure Specification (SWPS) for Gas Tungsten Arc Welding of Austenitic Stainless Steel (M-8, P-8, or S-8), 18 through 10 Gauge, in the As-Welded Condition, with or without Backing*

(25) AWS B2.1-1/8-010, *Standard Welding Procedure Specification (SWPS) for Gas Tungsten Arc Welding of Carbon Steel to Austenitic Stainless Steel (M-1, P-1, or S-1 to M-8, P-8, or S-8), 18 through 10 Gauge, in the As-Welded Condition, with or without Backing*

(26) AWS B2.1-22-015, *Standard Welding Procedure Specification (SWPS) for Gas Tungsten Arc Welding of Aluminum (M/P/S-22 to M/P/S-22), 18 through 10 Gauge, in the As-Welded Condition, with or without Backing*

(27) AWS B2.1-1-021, *Standard Welding Procedure Specification (WPS) for Gas Tungsten Arc Welding Followed by Shielded Metal Arc Welding of Carbon Steel (M-1/P-1/S-1, Group 1 or 2), 1/8 through 1-1/2 inch Thick, ER70S-2 and E7018, As-Welded or PWHT Condition (primarily for pipe applications)*

(28) AWS B2.1-8-024, *Standard Welding Procedure Specification (WPS) for Gas Tungsten Arc Welding Followed by Shielded Metal Arc Welding of Austenitic Stainless Steel (M-8/P-8/S-8, Group 1), 1/8 through 1-1/2 inch Thick, ER3XX and E3XX-XX, As-Welded Condition, Primarily Plate and Structural Applications.*

(29) AWS B2.1-8-025, *Standard Welding Procedure Specification (WPS) for Gas Tungsten Arc Welding of Austenitic Stainless Steel (M-8/P-8/S-8, Group 1), 1/16 through 1-1/2 inch Thick, ER3XX, As-Welded Condition, Primarily Plate and Structural Applications.*

(30) ANSI/AWS B2.1-1-207, *Standard Welding Procedure Specification (WPS) for Gas Tungsten Arc Welding of Carbon Steel (M-1/P-1/S-1, Group 1 or 2), 1/8 through 1-1/2 inch Thick, ER70S-2, As-Welded or PWHT Condition, Primarily Pipe Applications*

(31) ANSI/AWS B2.1-1-209, *Standard Welding Procedure Specification (WPS) for Gas Tungsten Arc Welding Followed by Shielded Metal Arc Welding of Carbon Steel (M-1/P-1/S-1, Group 1 or 2), 1/8 through 1-1/2 inch Thick, ER70S-2 and E7018, As-Welded or PWHT Condition, Primarily Pipe Applications*

9. Available through American Conference of Governmental Industrial Hygienists, 1330 Kemper Meadow Drive, Cincinnati, OH 45240-1634.

10. Available through Global Engineering Documents, Handling Services Group, 15 Inverness Way East, Englewood, CO 80112-5776, (800) 854-7179 (303) 397-7956, Fax (303) 397-2740, Internet: www.global.ihs.com.

(32) AWS B2.1-1-210, *Standard Welding Procedure Specification (WPS) for Gas Tungsten Arc Welding with Consumable Insert Root of Carbon Steel (M-1/P-1/S-1, Group 1 or 2), 1/8 through 1-1/2 inch Thick, INMs-1 and ER70S-2, As-Welded Condition, Primarily Pipe Applications*

(33) AWS B2.1-1-211, *Standard Welding Procedure Specification (WPS) for Gas Tungsten Arc Welding with Consumable Insert Root followed by Shielded Metal Arc Welding of Carbon Steel (M-1/P-1/S-1, Group 1 or 2), 1/8 through 1-1/2 inch Thick, INMs-1, ER70S-2, and E7018, As-Welded or PWHT Condition, Primarily Pipe Applications*

(34) AWS B2.1-8-212, *Standard Welding Procedure Specification (WPS) for Gas Tungsten Arc Welding of Austenitic Stainless Steel (M-8/P-8/S-8, Group 1), 1/16 through 1-1/2 inch Thick, ER3XX, As-Welded Condition, Primarily Pipe Applications*

(35) AWS B2.1-8-214, *Standard Welding Procedure Specification (WPS) for Gas Tungsten Arc Welding followed by Shielded Metal Arc Welding of Austenitic Stainless Steel (M-8/P-8/S-8, Group 1), 1/8 through 1-1/2 inch Thick, ER3XX and E3XX-XX, As-Welded Condition, Primarily Pipe Applications*

(36) AWS B2.1-8-215, *Standard Welding Procedure Specification (WPS) for Gas Tungsten Arc Welding with Consumable Inserts of Austenitic Stainless Steel (M-8/P-8/S-8, Group 1), 1/8 through 1-1/2 inch Thick, IN3XX and ER3XX, As-Welded Condition, Primarily Pipe Applications*

(37) AWS B2.1-8-216, *Standard Welding Procedure Specification (WPS) for Gas Tungsten Arc Welding with Consumable Insert Followed by Shielded Metal Arc Welding of Austenitic Stainless Steel (M-8/P-8/S-8, Group 1), 1/8 through 1-1/2 inch Thick, IN3XX, ER3XX and ER3XX-XX, As-Welded Condition, Primarily Pipe Applications*

(38) AWS B2.1-4-217, *Standard Welding Procedure Specification (WPS) for Gas Tungsten Arc Welding of Chromium-Molybdenum Steel (M-4/P-4, Group 1 or 2), ER80S-B2, 1/8 through 1/2 inch Thick, As-Welded Condition, 1/8 through 1-1/2 inch Thick, PWHT Condition, Primarily Pipe Applications*

(39) AWS B2.1-4-219, *Standard Welding Procedure Specification (WPS) for Gas Tungsten Arc Welding followed by Shielded Metal Arc Welding of Chromium-Molybdenum Steel (M-4/P-4, Group 1 or 2), 1/8 through 1/2 inch Thick, As-Welded Condition, 1/8 through 1-1/2 inch Thick, PWHT Condition, ER80S-B2 and E8018-B2, Primarily Pipe Applications*

(40) AWS B2.1-4-220, *Standard Welding Procedure Specification (WPS) for Gas Tungsten Arc Welding (Consumable Insert Root) of Chromium-Molybdenum Steel (M-4/P-4, Group 1 or 2), 1/8 through 1/2 inch Thick, As-Welded Condition, 1/8 through 3/4 inch Thick, PWHT Condition, IN515 and ER80S-B2, Primarily Pipe Applications*

(41) AWS B2.1-4-221, *Standard Welding Procedure Specification (WPS) for Gas Tungsten Arc Welding (Consumable Insert Root) followed by Shielded Metal Arc Welding of Chromium-Molybdenum Steel (M-4/P-4, Group 1 or 2), 1/8 through 1/2 inch Thick, As-Welded Condition, 1/8 through 1-1/2 inch Thick, PWHT Condition, IN515 and ER80S-B2, and E8018-B2, Primarily Pipe Applications*

(42) AWS B2.1-5A-222, *Standard Welding Procedure Specification (WPS) for Gas Tungsten Arc Welding of Chromium-Molybdenum Steel (M-5A/P-5A), ER90S-B3, 1/8 through 1/2 inch Thick, As-Welded Condition, 1/8 through 3/4 inch Thick, PWHT Condition, Primarily Pipe Applications*

(43) AWS B2.1-5A-224, *Standard Welding Procedure Specification (WPS) for Gas Tungsten Arc Welding followed by Shielded Metal Arc Welding of Chromium-Molybdenum Steel (M-5A/P-5A), 1/8 through 1/2 inch Thick, As-Welded Condition, 1/8 through 1-1/2 inch Thick, PWHT Condition, ER90S-B3 and E9018-B3, Primarily Pipe Applications*

(44) AWS B2.1-5A-225, *Standard Welding Procedure Specification (WPS) for Gas Tungsten Arc Welding (Consumable Insert Root) of Chromium-Molybdenum Steel (M-5A/P-5A), 1/8 through 1/2 inch Thick, As-Welded Condition, 1/8 through 3/4 inch Thick, PWHT Condition, IN521 and ER90S-B3, Primarily Pipe Applications*

(45) AWS B2.1-5A-226, *Standard Welding Procedure Specification (WPS) for Gas Tungsten Arc Welding (Consumable Insert Root) followed by Shielded Metal Arc Welding of Chromium-Molybdenum Steel (M-5A/P-5A), 1/8 through 1/2 inch Thick, As-Welded Condition, 1/8 through 1-1/2 inch Thick, PWHT Condition, IN521 and ER90S-B3, and E9018-B3, Primarily Pipe Applications*

(46) AWS B2.1-1/8-227, *Standard Welding Procedure Specification (SWPS) for Gas Tungsten Arc Welding of Carbon Steel (M-1/P-1/S-1, Groups 1 or 2) to Austenitic Stainless Steel (M-8/P-8/S-8, Group 1), 1/16 through 1-1/2 inch Thick, ER309(L), As-Welded Condition, Primarily Pipe Applications*

(47) AWS B2.1-1/8-229, *Standard Welding Procedure Specification (SWPS) for Gas Tungsten Arc Welding followed by Shielded Metal Arc Welding of Carbon Steel (M-1/P-1/S-1, Groups 1 or 2) to Austenitic Stainless Steel (M-8/P-8/S-8, Group 1), 1/8 through 1-1/2 inch Thick, ER309(L) And ER309(L)-15, -16, or -17, As-Welded Condition, Primarily Pipe Applications*

(48) AWS B2.1-1/8-230, *Standard Welding Procedure Specification (SWPS) for Gas Tungsten Arc Welding with Consumable Insert Root of Carbon Steel (M-1/P-1/S-1, Groups 1 or 2) to Austenitic Stainless Steel (M-8/P-8/S-8, Group 1), 1/16 through 1-1/2 inch Thick, IN309 and ER309(L), As-Welded Condition, Primarily Pipe Applications*

(49) AWS B2.1-1/8-231, *Standard Welding Procedure Specification (SWPS) for Gas Tungsten Arc Welding with Consumable Insert Root followed by Shielded Metal Arc Welding of Carbon Steel (M-1/P-1/S-1, Groups 1 or 2) to Austenitic Stainless Steel (M-8/P-8/S-8, Group 1), 1/8 through 1-1/2 inch Thick, IN309 and ER309, and E309-15, -16, or -17, or IN309, ER309(L), and ER309(L)-15, -16, or -17, As-Welded Condition, Primarily Pipe Applications*

(50) AWS C5.10, *Recommended Practices for Shielding Gases for Welding and Plasma Arc Cutting*

(51) AWS D1.1, *Structural Welding Code—Steel*

(52) AWS D1.2, *Structural Welding Code—Aluminum*

(53) AWS D1.2, *Structural Welding Code—Stainless Steel*

(54) AWS D10.11, *Recommended Practices for Root Pass Welding of Pipe Without Backing*

2.3 ISO Standards¹¹

(1) ISO6848, *Tungsten Electrodes for Inert Gas Shielded Arc Welding, and for Plasma Cutting and Welding*.

2.4 OSHA Standards¹²

(1) Code of Federal Regulations (OSHA), *Title 29 Labor, Parts 1910.1 to 1910.1450*

3. Definitions

The terms and definitions are divided into two categories:

(1) general welding terms (highlighted by **bold print**) compiled by the AWS Committee on Definitions and Symbols (which can be found in the latest AWS A3.0, *Standard Welding Terms and Definitions*); and,

(2) terms or definitions (highlighted by **bold italics**) defined by the AWS C5C Subcommittee on Gas Tungsten Arc Welding, which are defined as they relate to this Recommended Practice, or are additions or modifications to AWS A3.0 terms or definitions.

air cooled torch. A nonstandard term for a gas-cooled torch.

arc postheating. The intense heat of an arc can be used to reduce the cooling rate of a weld after a fusion weld has been made. This is primarily a nonmelting pass.

arc preheating. An arc that does not melt the base metals is sometimes used to remove the chill or significantly raise the temperature of the weld joint. This can be used to remove moisture or light residues of oils. This can be accomplished by a first pass or a second leading arc.

arc welding torch. A device used to transfer current to a fixed welding electrode, position the electrode, and direct the flow of shielding gas.

automatic welding. Welding with equipment that requires only occasional or no observation of the welding, and no manual adjustment of the equipment controls.

backing or back-up bars. Plates or bars that are in contact with the workpieces on either the root or the face side of the welds should be located so as not to contaminate the weld or base metal or cause gas or flux (if used) entrapment. These accessories are usually made of copper or stainless steel.

brace-technique. A technique used in manual welding of vessels, sheet metal and structures. In this welding technique, the welder stabilizes the torch by resting his wrist, arm or elbow as far away from the weld zone as possible and sliding the wrist in the direction of welding.

direct current electrode negative (DCEN). The arrangement of direct current arc welding leads in which the electrode is the negative pole and the workpiece is the positive pole of the welding arc.

direct current electrode positive (DCEP). The arrangement of direct current arc welding leads in which the electrode is the positive pole and the workpiece is the negative pole of the welding arc.

dragging-the-finger. A technique used in manual welding of all types of joint configurations. It can be used when welding all diameters of pipe and tubing. In this welding technique a fingerstall is made by overlapping a “sleeve” of fiberglass material approximately 8 in. [200 mm] long. The fingerstall is placed over the middle finger and should extend approximately 1 in. [25 mm] beyond the end of the finger. The fingerstall is used to stabilize the hand holding the torch as it is slid along during welding.

dressing pass. The weld bead shape can be changed or improved by the use of a cosmetic pass after the weld has been completed. This is primarily accomplished by remelting of the solidified weld bead surface. This is frequently accompanied with transverse oscillation of the arc or torch. Sometimes a small amount of filler metal is added.

electrode holder. A device used for mechanically holding and conducting current to an electrode during welding. See ***arc welding torch***.

11. Available through ISO Central Secretariat, International Organization for Standardization (ISO) 1, rue de Varembe, Case postale 56, CH-1211 Geneva 20, Switzerland; Online: <http://www.iso.ch/iso/en/ISOOnline.frontpage>.

12. Available through U.S. Government Printing Office, Superintendent of Documents, P.O. Box 371954, Pittsburgh, PA 15250-7954.

fixture. A device designed to hold and maintain parts to be joined in proper relation to each other.

freehand technique. The free hand technique is a method where welding is accomplished without the benefit of stabilization of hand and welding torch. It is the most difficult way to effect a weld and is not recommended unless no other option is available.

gas cup. A nonstandard term for **gas nozzle**.

gas nozzle. A device at the exit end of the torch that directs shielding gas.

gas tungsten arc welding (GTAW). An arc welding process that uses an arc between a tungsten electrode (nonconsumable) and the weld pool. The process is used with shielding gas and without the application of pressure. Filler metal may or may not be used.

Heliarc[®] welding. A nonstandard term for **gas tungsten arc welding**. It refers to the earliest use of the process when only the inert gas helium was utilized as the shielding method.

hold down and backing bars. Fixtures which provide the means to clamp and position the weldment, and supply backing support and/or shielding gas to the underside of the weld bead. Backing bars usually contain passages to facilitate inert gas purging. When grooved backing bars are used, the grooves should be shallow to minimize melt through and to limit the height of root reinforcement. Grooves in backing bars should have rounded corners to be elliptical in shape to prevent entrapments and to minimize stress raisers relative to underbead shape. These devices usually extend the full length of the weld.

machine welding. A nonstandard term when used for **mechanized welding**.

manual welding. Welding with the torch held and manipulated by hand. Accessory equipment, such as part motion devices and manually controlled filler-material feeders may be used.

mechanized welding. Welding with equipment that requires manual adjustment of the equipment controls in response to visual observation of the welding, with the torch held by a mechanical device.

opposing arcs. This is a welding process employing two arcs. Each arc is located on opposite sides of the weld joint. The purpose is to equalize stresses on plates to reduce the tendency for warping or distortion.

reverse polarity. A nonstandard term for **direct current electrode positive**.

run-off weld tab. Additional material that extends beyond the end of the joint, on which the weld is terminated.

run-on/off tabs. Additional material (devices) used mostly on butt and lap joints to facilitate starting and extinguishing the arc.

semiautomatic welding. Manual welding with equipment that automatically controls one or more of the welding conditions.

straight polarity. A nonstandard term for **direct current electrode negative**.

tandem arcs. To increase the speed or increase penetration in single pass welds, closely spaced arcs can be employed. Two to five arcs in tandem can be employed with three arcs common. This multiple arc process is primarily employed for high-speed tube or pipe welding. It can also be employed for sheet and plate splicing.

tooling. Weld tooling can be a variety of devices (fixtures) that are associated with the welding operation and their use assists in producing a weldment that meets all specified requirements. Weld joint backing and/or chill bars are examples of weld tooling.

torch. See **arc-welding torch**.

tungsten-arc welding. A nonstandard term for **gas tungsten arc welding**.

tungsten electrode. A non-filler metal electrode used in arc welding, arc cutting, and plasma spraying, made principally of tungsten.

tungsten inert gas (TIG) welding. A nonstandard term for **gas tungsten arc welding**. It refers to the early use of the process when only the inert gases argon and helium were utilized as the shielding method.

walking-the-cup. A technique for manipulating the torch when manually welding groove and fillet welds. With this technique, the electrode extension is adjusted to allow the proper arc length while the edge of the cup rests on the side of the joint. The torch is manipulated in a manner to swing the tip of the tungsten back and forth across the side of the joint by “walking-the-cup” on each edge of the joint. The left or right edge of the gas nozzle/cup is in constant contact with the members giving the cup a walking motion on the weld joint.

welding fixture (also see fixture). A device designed and built to hold parts to be joined in proper relationship with each other. Chill bars are often used to help cool the weld area rapidly and usually result in controlling weld shrinkage and workpiece distortion.

4. GTAW Principles

4.1 Process Description. The GTAW process and equipment are illustrated in Figures 7 and 8. GTAW produces fusion (coalescence caused by melting) of base metals from the heat generated by an electric arc. The arc is established between the tip of a nonconsumable tungsten or tungsten alloy electrode and the workpiece (also called base metal). The electrode is held in an arc welding torch, either water-cooled or gas-cooled, through which shielding gas is fed. The shielding gas provides the required arc characteristics by becoming a plasma (ionized), and also shields the electrode, filler metal end, and the molten weld pool from contamination by the atmosphere. Once the arc and weld pool are established, the torch is moved along the joint and the arc progressively melts the faying surfaces (surfaces to be joined). Filler wire, when used, is added to the weld pool to fill the joint. Filler wire is usually added to the leading edge of the weld pool, but may be added to the trailing edge, or both.

To avoid weld contamination, the nonconsumable electrode requires special arc initiation techniques. There are two main methods utilized.

(1) One method involves arc starters such as high-frequency generators or capacitor discharge starters, which provide a high voltage across the arc gap. This causes the shielding gas to ionize and thus makes it conductive, allowing the arc to initiate.

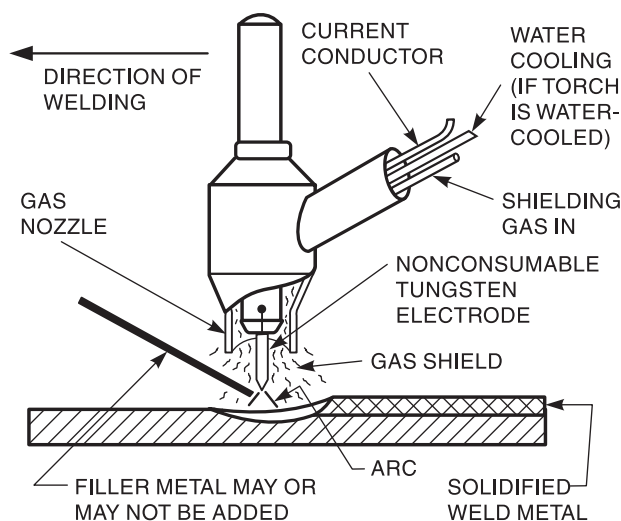


Figure 7—Stylized Representation of the Gas Tungsten Arc Welding Process

(2) The other method involves touch or contact starting where the tungsten electrode is brought in contact with the base metal and then withdrawn to initiate the arc. The electrode is then retracted to the proper arc gap.

Note: It is considered good practice, when the touch starting system is used, to initiate the arc in a location that will be consumed in the subsequent weld metal. The initiation point is termed an arc strike or arc burn and, if visible after welding, is cause for rejection by a number of specifications.

The GTAW process is adaptable to manual, semi-automatic, mechanized, and automatic applications. It can be used to produce continuous welds, intermittent welds, and spot welds. Unlike other arc welding processes, the GTAW process can be used to produce autogenous (no filler wire) welds because the electrode is nonconsumable. For many applications, the addition of filler wire is desirable or necessary.

The process can be used to produce welds on essentially all joint designs and geometries. It can be used to weld a wide range of thicknesses and sizes of plate, sheet, pipe, tube, and other structural shapes. The GTAW process can be successfully used in any welding position.

4.2 Process Advantages. GTAW has become indispensable as a tool for many industries. If properly utilized, the GTAW process will produce the high quality welds required for the aerospace, nuclear, pharmaceutical, semiconductor and other industries. As illustrated in Figure 9, weld beads produced with the GTAW process typically are cleaner than with any other arc welding process because no slag or spatter is present. Visual and non-destructive inspecting of GTAW welds is thus easier.

The combination of GTAW for root pass welding with either shielded metal arc welding (SMAW) or gas metal arc welding (GMAW) for the fill passes is particularly advantageous for welding pipe. The GTAW process produces a smooth, uniform root pass weld while the fill passes are made with a higher deposition rate (more economical) process. Table 1 presents an overview of GTAW, GMAW, and SMAW processes for different base materials.

The following are some advantages of the GTAW process:

- (1) capable of producing superior quality welds, generally free of defects
- (2) is free of the spatter which occurs with most other arc welding processes
- (3) can be used with or without filler metal as required for the specific application
- (4) allows excellent control of root pass weld penetration
- (5) can produce inexpensive autogenous welds at high speeds

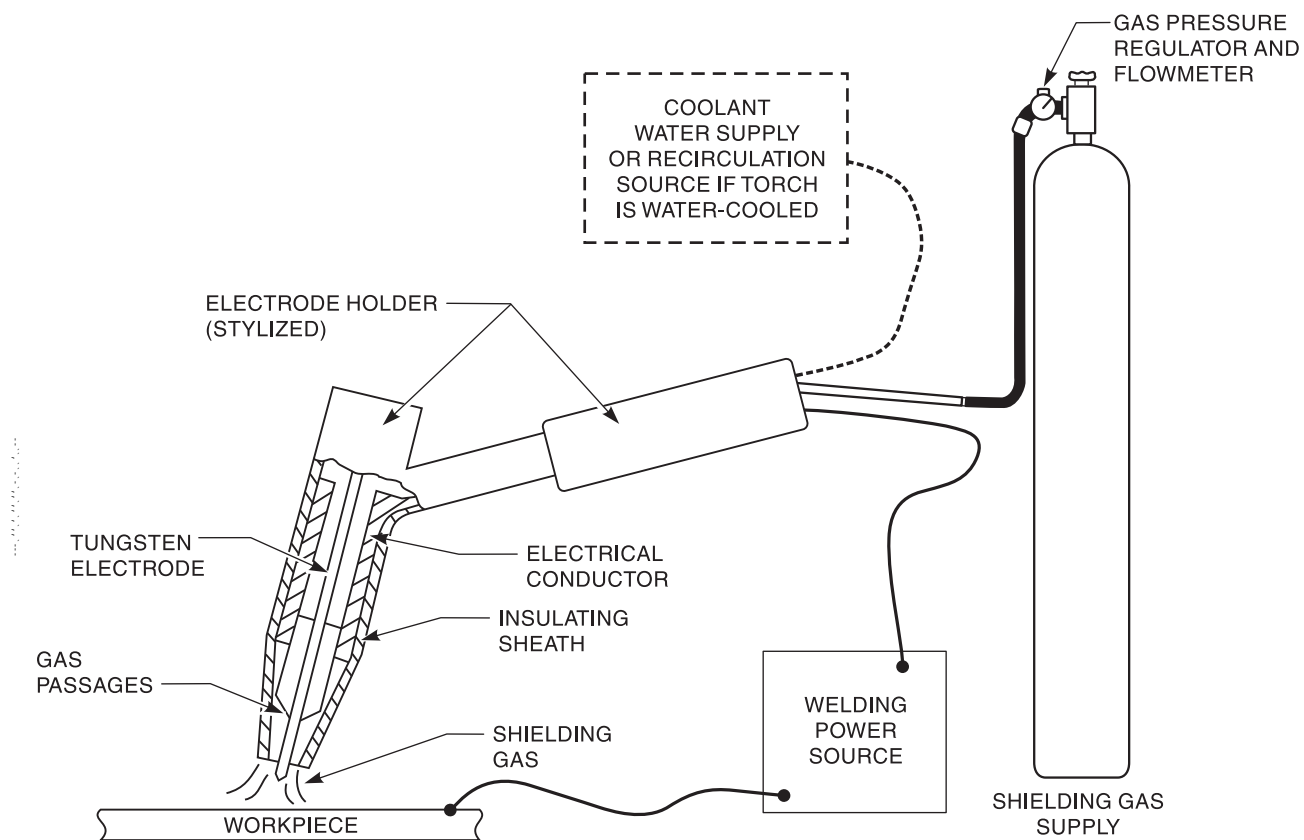


Figure 8—Gas-Cooled GTAW Torch and Stylized Representation of Typical Gas Tungsten Arc Welding Equipment



**Figure 9—Clean Weld Beads
Typical of Properly Shielded
GTAW Welds**

- (6) can use inexpensive power sources
- (7) allows precise control of the welding variables
- (8) is very good for joining thin base metals because of the excellent control of heat input
- (9) can be used to weld almost all metals, including dissimilar metal joints
- (10) is especially useful for joining aluminum and magnesium, which form refractory oxides
- (11) is probably the most used process for reactive metals like titanium
- (12) allows the heat source and filler metal additions to be controlled independently

4.3 Process Limitations. The GTAW process requires continuous and efficient weld metal shielding. Backup shielding or enclosed 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 (outdoor) welding is also readily accomplished.

**Table 1
Welding Process Comparison Based on Quality and Economics**

Applications	Welding Processes ⁽¹⁾ and Ratings ⁽²⁾ (All Positions)		
	GTAW	GMAW	SMAW
Carbon steel plate >3/16 in. [5 mm]	G	E	E
Carbon steel sheet ≤3/16 in. [5 mm]	E	E	G
Carbon steel structural	F	F	E
Carbon steel pipe ≤3 in. [75 mm] IPS	E	F	F
Carbon steel pipe >3 in. [75 mm] IPS	G	G	G
Stainless steel plate >3/16 in. [5 mm]	G	E	G
Stainless steel sheet ≤3/16 in. [5 mm]	E	G	F
Stainless steel pipe ≤3 in. [75 mm] IPS	E	F	F
Stainless steel pipe >3 in. [75 mm] IPS	G	G	F
Aluminum plate >3/16 in. [5 mm]	G	E	NR
Aluminum sheet ≤3/16 in. [5 mm]	E	G	NR
Aluminum structural	E	G	NR
Aluminum pipe ≤3 in. [75 mm] IPS	E	NR	NR
Aluminum pipe >3 in. [75 mm] IPS	E	F	NR
Nickel and nickel alloy sheet	E	F	F
Nickel and nickel alloy tubing	E	NR	NR
Nickel and nickel alloy pipe ≤3 in. [75 mm] IPS	E	F	NR
Nickel and nickel alloy pipe >3 in. [75 mm] IPS	E	F	NR
Reactive metals—titanium—sheet, tubing, pipe	E	NR	NR
Refractory metals—Ta and Cb—sheet, tubing	E	NR	NR

Notes:

(1) GTAW = Gas Tungsten Arc Welding (TIG).

GMAW = Gas Metal Arc Welding (MIG).

SMAW = Shielded Metal Arc Welding (Stick).

(2) E = Excellent, G = Good, F = Fair, NR = Not Recommended on basis of cost, usability, or quality.

4.3.1 Limitations. The following are some limitations of the GTAW process:

(1) Deposition rates are lower than the rates possible with the consumable electrode arc welding processes unless used with hot-wire additions. Therefore, it can be less economical than the consumable electrode arc welding processes for thicker sections (greater than 3/8 in. [10 mm]).

(2) For manual welding, there is a need for slightly more dexterity and welder coordination than with gas metal arc welding or shielded metal arc welding.

(3) Shielding the weld zone properly in drafty environments is difficult.

4.3.2 Potential Problems. Potential problems with the process include:

(1) Tungsten inclusions can occur if the electrode is allowed to contact the weld pool or if the electrode is overheated.

(2) Contamination of the weld metal can occur if proper shielding of the filler metal by the gas stream is not maintained or if the torch shielding gas does not properly protect the weld pool.

(3) There is low tolerance for contaminants on filler or base metals.

(4) Possible contamination or porosity can be caused by coolant leakage from water-cooled torches, as with other processes.

(5) Arc blow or arc deflection can be a concern, as with other arc welding processes.

4.4 Process Variables. The primary variables in GTAW are welding current, arc voltage (arc length), travel speed, electrode (condition, shape, and alloy), and shielding gas. Additional input parameters include wire feed rate, electrode orientation, travel angle, arc deflections (magnetic and mechanical arc oscillations), and pulsing parameters. The main issue that these variables affect is the energy transferred from the power source through the arc and into the work, and the rate and control of that energy transfer. Variation in chemical composition of the base metal and filler metals as well as condition of the joint design, joint preparation (including fixturing and tooling), and welding position must also be considered.

4.4.1 Arc Current. Weld penetration is directly proportional to arc current, i.e., as the current is increased, the weld penetration increases. Arc current also effects the voltage as a function of the power source characteristic and from the forces (pressure, Lorentz, buoyancy) acting on the weld pool to change the pool's position under the arc. For this reason, it is necessary to change the voltage setting when the current is adjusted to keep a fixed arc length in automatic welding. For some materials, such as stainless steels and nickel alloys, certain trace elements (such as sulfur and oxygen) alter the surface tension and

change weld pool fluid flow. If present in low levels (less than 30 parts per million [ppm]) in these materials, increasing arc current can produce a dramatic increase in weld width without much increase in penetration. If sulfur content is greater than 50 ppm, an increase in arc current can produce a dramatic increase in penetration.^{13, 14}

4.4.1.1 Current Polarity. Three basic categories of welding current are available: direct current (DC), alternating current (AC), and programmed current. Programmed current is a category combining some of the features of AC and DC. Variable polarity (VP) can be considered as a subset of programmed current and is replacing AC and balanced AC in many applications.

There are two polarities or directions in which the current can flow in the welding circuit; direct current electrode negative [DCEN, so-called straight polarity, see Figure 10(A)] and direct current electrode positive [DCEP, so-called reverse polarity, see Figure 10(B)]. When using direct current, the tungsten electrode may be connected to either the negative or positive terminal of the power source. When the electrode is negative (cathode), the electrons flow from the electrode to the work and the ions move from the work to the electrode. When the electrode is positive (anode), the electrons flow from the work to electrode and the ions move from the electrode to the work. The choice of whether to use DC, AC, VP, or programmed current depends largely on the material to be welded.

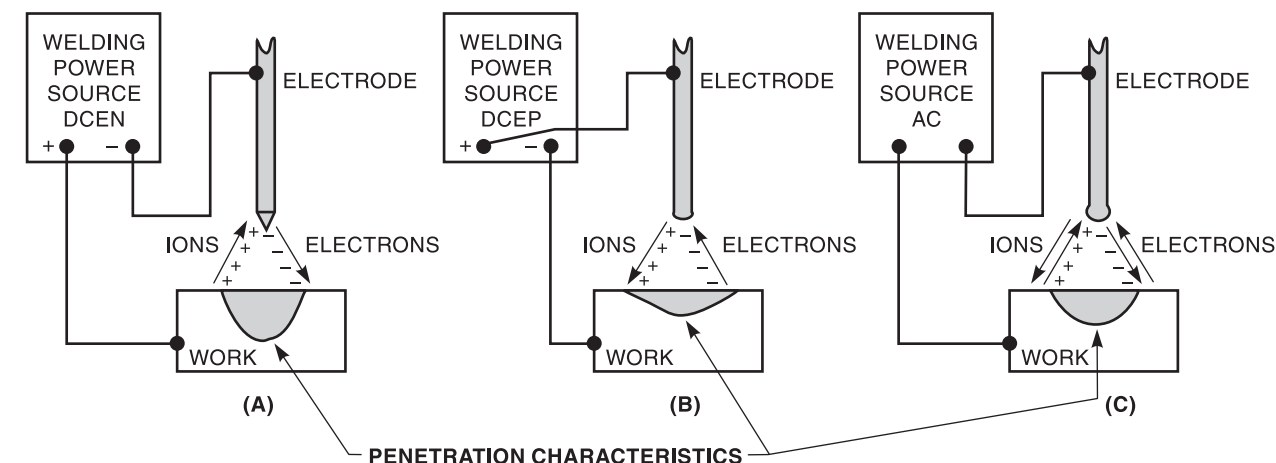
4.4.1.2 Direct Current with Respect to Polarity.

The two types of direct current GTAW to be considered are direct current electrode negative (DCEN), and direct current electrode positive (DCEP). Each type has its own characteristics and areas of application.

Direct current electrode negative (DCEN) when combined with a thermionic electrode (e.g., tungsten) generates approximately 70% of the heat at the anode (work) and approximately 30% of the heat at the cathode (electrode). Since DCEN produces the greatest amount of heat at the workpiece, this offers the advantage of deep penetration and fast welding speeds. DCEN is the most common configuration used in GTAW, and is used with argon, helium, or a mixture of gases to weld most metals. Helium and helium mixes are frequently the gases of choice for mechanized welding because of helium's higher thermal conductivity. Additions of helium or hydrogen to argon are also frequently used for mechanized welding because these produce a "hotter" arc.

13. Burgardt, P. and Campbell, R., 1992, Chemistry Effects on Stainless Steel Weld Penetration, Ferrous Alloy Weldments, Trans Tech Publications, Switzerland.

14. Burgardt, P., and Heiple, C., Interaction Between Impurities and Welding Variables in Determining GTA Weld Shape, *Welding Journal*, Vol. 65, No. 6, June 1986, pp. 150-s–155-s.



CURRENT TYPE	DCEN (A)	DCEP (B)	AC Balanced/Variable Polarity (Programmed) (C)
ELECTRODE POLARITY	Negative	Positive	Negative and Positive
OXIDE CLEANING ACTION	No	Yes	Yes, Once Every Half Cycle
HEAT BALANCE IN THE ARC (APPROXIMATE)	70% at Work 30% at Electrode	30% at Work 70% at Electrode	50% at Work, 50% at Electrode (Varies with Program Setting)
PENETRATION	Deep, Narrow	Shallow, Wide	Medium
ELECTRODE CAPACITY	Excellent, e.g., 1/8 in. [3 mm]: 400 A	Poor, e.g., 1/4 in. [6 mm]: 120 A	Good, e.g., 1/8 in. [3 mm]: 225 A

Figure 10—Characteristics of Current Types Used for Gas Tungsten Arc Welding

With direct current electrode positive (DCEP), a cathodic cleaning action is created at the surface of the workpiece. This cathodic cleaning at the work surface can be beneficial in removing oxides present on the surface of some metals. In practice, this method is not used as frequently as DCEN, AC, or Variable Polarity (VP) because of the overheating of the electrode that occurs, but it does have a particular advantage of surface cleaning on metals whose oxides cause problems to the welding operation. For example, this cleaning action is beneficial for the welding of aluminum and magnesium. This same action occurs in the reverse polarity half cycle of AC and VP welding. In practice, alternating current (AC) or variable polarity (VP) schemes are usually used when cathodic cleaning action is needed.

Unlike DCEN, in which the electrode tip is cooled by the evaporation of electrons, when the electrode is used as the positive pole (i.e., DCEP), its tip is heated by the bombardment of electrons as well as by its resistance to their passage through the electrode. Therefore, to reduce

resistance heating and increase thermal conduction into the electrode collet, a larger diameter electrode is required for a given welding current when using DCEP (reverse polarity) to reduce electrode tip melting. DCEP is sometimes used for thin cross sections to reduce heat input.

4.4.1.3 Alternating Current with Respect to Polarity. The condition existing when the welding current polarity is periodically alternated from electrode positive to electrode negative is called alternating current [AC, see Figure 10(C)]. AC combines the work cleaning action of electrode positive (reverse polarity) with the deep penetration characteristic of electrode negative (straight polarity).

Conventional AC welding power sources produce a sinusoidal open circuit voltage output. 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.

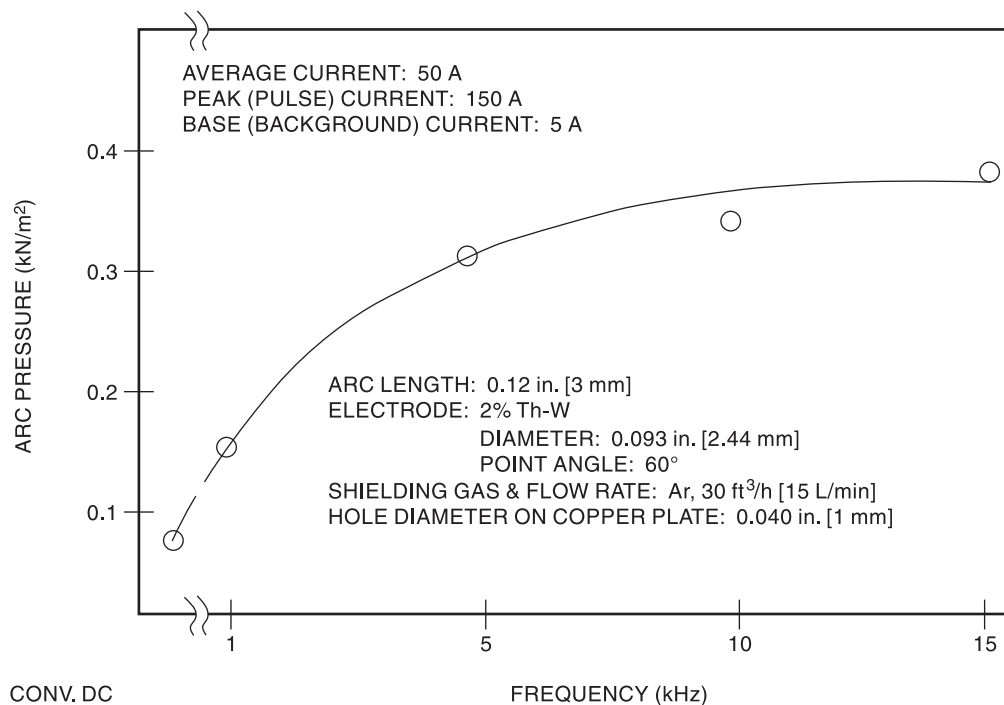


Figure 11—Relationship Between Arc Pressure and Pulse Frequency

Some means of maintaining the arc during the voltage reversal is required with conventional sinusoidal welding power sources. This has been done by using high open circuit voltage power sources; by discharging capacitors at the appropriate time in the cycle; by using high-voltage high-frequency generators in parallel with the arc; and by using power sources with a square wave output.

4.4.1.4 Pulsed DC Welding. Pulsed GTAW is characterized by a repetitive switching between a peak (high) current and a background (low) current. Alternate melting and solidification are obtained by switching between high and low currents. The high (peak) current (5 A–200 A) is normally higher than continuous DC welding to ensure rapid full penetration, after which switching to a low (background) current (1 A–15 A) allows the molten pool to solidify but maintains a pilot arc for application of the next pulse.¹⁵

There are three broad categories of pulsing: low frequency (0.5 Hz–20 Hz), sometimes called “thermal pulsing”; intermediate frequency (>20 Hz–500 Hz); and, high frequency (>500 Hz up to 16 kHz or more).

In pulsed DC welding, the peak current level is typically set at 2 to 10 times the background current level. This condition provides the benefits of the driving, forceful arc characteristics of high current with the low heat input of low current. The pulse current is used to obtain the good fusion and penetration while the background current maintains the arc and allows the weld area to cool and/or solidify. Low-frequency DC pulsing of the weld current can be thought of as a moving series of overlapping spot welds.

There are several advantages of pulsed current. The effect of high-frequency switching is to produce a “stiff” welding arc. Arc pressure is a measure of arc stiffness. As shown in Figure 11,¹⁶ as the switching frequency nears 10 kHz, arc pressure increases to nearly four times that of a steady DC arc. As arc pressure increases, there is a reduced effect by magnetic fields (such as arc blow), shielding gas movement (wind), etc.

For a given average current level, greater penetration can be obtained by pulsing the current compared with continuous current. This is useful on metals sensitive to

15. *Pulsed Arc Welding*. J. A. Street, Abington Publishing, p. 11, (1990).

16. Refer to AWS Welding Handbook, 8th Edition, Volume 2: Welding Processes, Chapter 3, “Gas Tungsten Arc Welding,” Figure 3.12, and p. 86 for more information.

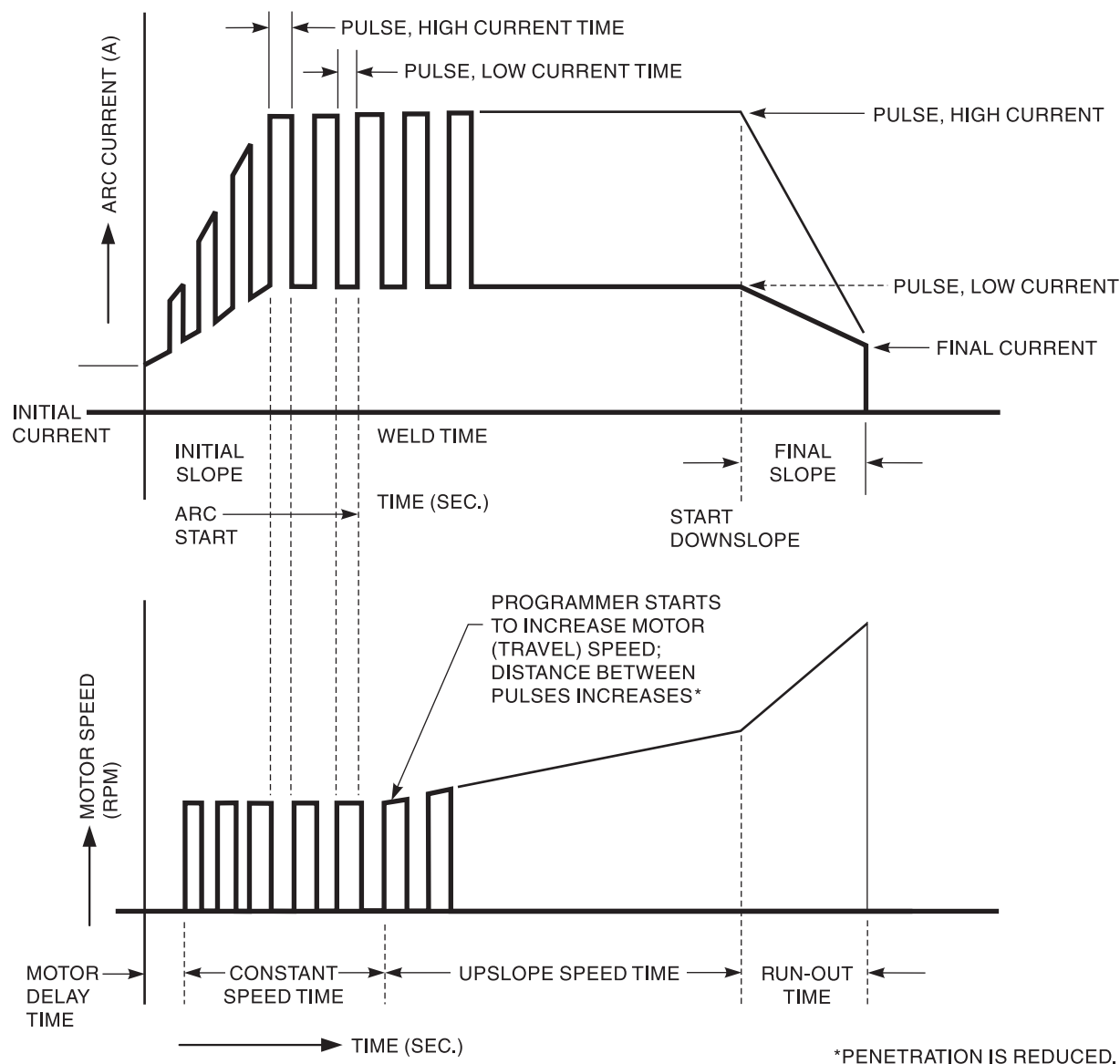


Figure 12—Programmed (Modulated) Current without Polarity Reversal

heat input and for distortion control. Also, because there is insufficient time for significant heat flow during the current pulse, metals of vastly dissimilar thickness respond nearly equally and thus nearly equal penetration can be achieved. For a similar reason, very thin metals can be joined with pulsed DC. In addition, one set of welding parameters can be used on a joint in all positions, such as a circumferential weld in a horizontal pipe. Pulsed DC is also useful for bridging gaps in open root joints and for welding with consumable inserts. A disadvantage of pulsed DC current is that the welding power

source and controller are more sophisticated and relatively more expensive.

4.4.1.5 Programmed Current. Welding power sources have also been developed that are capable of providing various types of modulated current with or without actual polarity reversal. See Figure 12¹⁷ for an example. These current pulsation techniques have been

17. References: AWS Welding Handbook, 8th Edition, Volume 2: Figure 3.10, p. 85; Muncaster, Figure 4.2, p. 37.

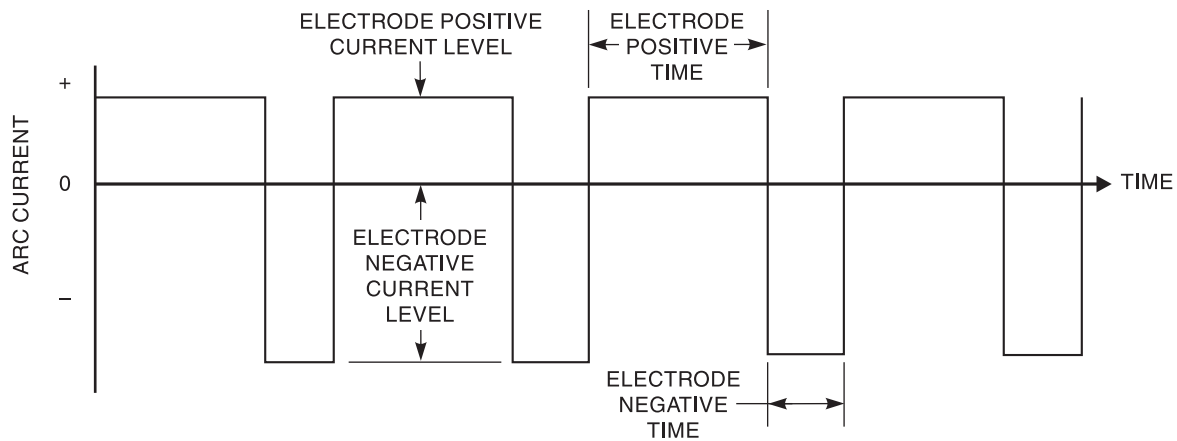


Figure 13—Characteristics of Variable Polarity (Programmed) Weld Current

developed to increase weld penetration, to reduce heat input, and to control or improve weld root and bead contour, grain size, and out-of-position welding capabilities. Two such programmed current techniques are square wave AC pulsation and pulsating DC. Variable polarity can be thought of as a subset of programmed current.

4.4.1.6 Variable Polarity. The term variable polarity describes an alternating welding current that is asymmetrical about the zero current level. This is shown in Figure 13. The symmetry of the current above and below zero is controlled by the current balance adjustment on the power source.

The variable polarity power source was developed to meet the criteria established for effective plasma “key-hole” welding of aluminum, especially in heavy sections. While primarily used for plasma arc welding (PAW) it also is used for certain GTAW applications. This direct current (DC) machine produces cyclic changes of DCEN and DCEP polarities with independent control of the current amplitude and the duration.

4.4.2 Arc Voltage. The voltage measured between the tungsten electrode and the work is commonly referred to as the arc voltage. The arc voltage is changed by the effects of the other variables, and is used in describing welding procedures only because it is easy to measure. Since the other variables such as the shielding gas, electrode, and current have been predetermined, the arc voltage becomes a way to control the arc length. The arc length is a critical variable that is difficult to monitor without appropriate equipment. Arc length is important with this process because it affects the width and depth of the weld pool. The arc voltage is a function of gas composition and arc gap length. The weld width is

directly proportional to the arc length, while the pool depth is inversely proportional to the arc length. Therefore, in most applications the desired arc length is as short as possible.

4.4.3 Travel Speed. Travel speed affects both the width and penetration of a gas tungsten arc weld. However, its effect on width is more pronounced than on penetration. Travel speed is important because of its effects on cost and weld quality.

High travel speeds minimize distortions caused by thermal expansions and contractions during welding. On the other hand, alloys prone to cold cracking are usually not welded at high speeds, since the associated steep thermal gradients and rapid cooling rates would contribute to crack formation. Lower welding speeds are applied to circumvent this cracking problem (often used in combination with preheating the base metal to further reduce the possibility of cold cracks and decrease the cooling rates).

4.4.4 Electrodes. The shape of the tungsten electrode tip is an important process variable in GTAW. The tungsten electrodes may be used with a variety of tip configurations and preparation methods. Electrode tip configuration is a welding variable that should be studied during the welding procedure development. It is important that consistent electrode geometry be used once a welding procedure has been established. Changes in electrode geometry can significantly influence the weld bead shape and size as shown in Figure 14.¹⁸

18. Reference: Key, J., “Anode/Cathode Geometry and Shielding Gas Interrelationships in GTAW,” *Welding Journal*, Vol. 59, No. 12, Dec. 1980, Figure 1, p. 265-s.

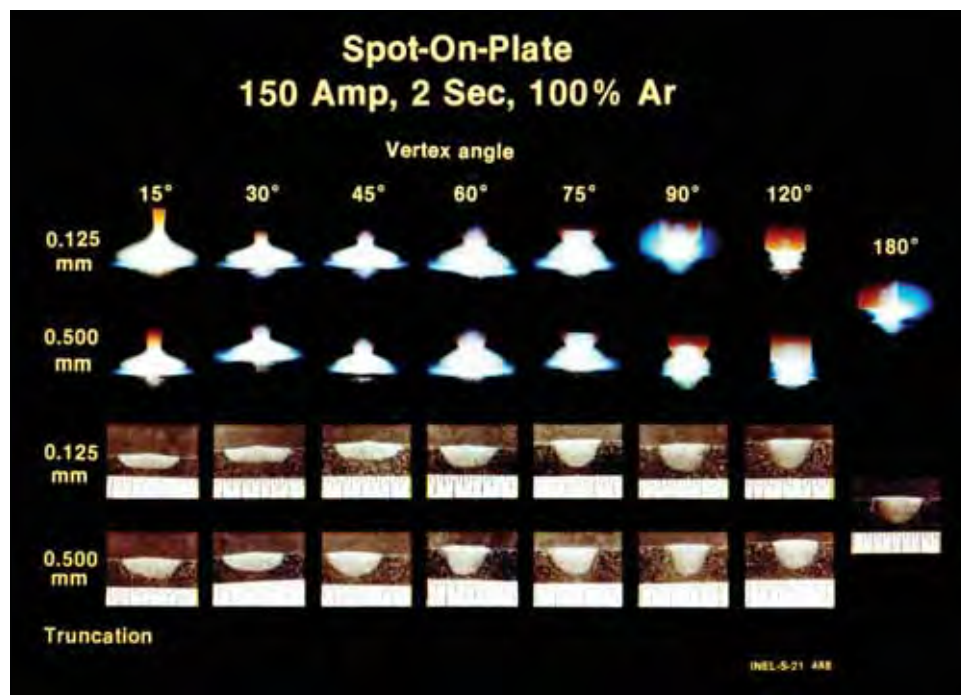


Figure 14—Arc Shape and Fusion Zone Profiles as a Function of Electrode Tip Geometry in Pure Argon Shielding Gas

4.4.5 Shielding Gas. As mentioned previously, the shielding gas has several influences on the GTAW process. Attention should be paid to the gas quality (purity), to its voltage-current characteristic, and to its thermal conductivity. Shielding gases will be covered in detail in Section 7.

4.5 Related Variables. A number of variables can have a pronounced effect upon GTAW quality and speed. These include filler metal (type, size, feed mechanism), joint design, material composition, and tooling. In addition, electrode orientation and arc deflections must be considered.

4.5.1 Electrode to Work Angle and Position. The forces exerted on the weld pool vary with the angle of the torch (electrode) with respect to the vertical and the direction of travel.

In manual welding the welder may use this to:

- (1) Properly distribute weld deposit relative to the joint being welded, e.g., fillet or groove weld.
- (2) Affect multipass or stringer beads that may overlap one another.
- (3) Control the amount of weld penetration or drop through (root reinforcement) and/or weld bead shape.

In mechanized or automated welding the electrode (torch) angle can be an important parameter to counter the effects of arc drag or to force changes to the shape of the pool (and thus change the resultant solidification) by redirecting the arc force either into or away from the direction of travel.

4.5.2 Arc Motion and Deflections. Several variations of arc deflection have been applied in attempts to modify the resultant fusion zone, including grain refinement. These techniques include weld pool stirring, arc oscillations and arc modulations/pulsations. One of the more popular techniques is magnetic arc deflections or oscillations. The application of one or more magnetic poles is used to stabilize the arc column and minimize the effects of local magnetic disturbances that result in arc blow. Fixed and/or variable electromagnetic poles have been applied in a similar manner to stabilize or to oscillate the arc column. Stable arc deflections can be used to counter the effects of arc drag during higher speed welding.¹⁹

19. Hicken, G. K. and Jackson, C. E., 1966, "The Effects of Applied Magnetic Fields on Welding Arcs," *Welding Journal*, Vol. 45, No. 11, Nov. 1966, pp. 515-s-524-s.

Another variation of arc deflection is the weaving or mechanical motion of the torch (electrode) side to side, to be sure that a full fusion weld is achieved.

5. Equipment and Supplies

5.1 Welding Power Sources (Used for GTAW)—Introduction. Constant-current type power sources are normally used for GTAW. Power required for both AC (alternating current) and DC (direct current) GTAW can be supplied by inverter, transistor, or transformer-rectifier power sources or from rotating AC or DC generators. A description of the types of currents is found in Section 4. Advances in semiconductor electronics have made transformer-rectifier, and more recently, transistor and inverter type power sources popular for both shop and field GTAW. Engine driven power sources continue to be widely used in the field.

In constant current power sources the weld current remains nearly constant with variations in output voltage, as shown in Figure 15. It is the goal of the power source manufacturer to provide power sources that produce the desired type of current (e.g., DC, pulsed DC, AC, etc.) and maintain the current at the desired level regardless of external influences such as power line voltage fluctuations. The components used for each type of power

source are a compromise of cost, weight, size, type of input or primary power, performance, and the type of current to be used in the welding process.

Selecting the correct power source, of course, depends upon process requirements. The first step is to determine the electrical requirements of the welding process with which it will be used. Other factors to consider include such things as future requirements, maintenance, economic considerations, portability, environment, available skills, safety, manufacturer's support, code compliance, and standardization. Most electronically controlled power sources offer rapid dynamic response; i.e., can change from one level to another. As a result, these power sources can be used to provide pulsed welding current. Series linear regulator and switched secondary designs provide DC welding current from rectified single or three-phase input power. Silicon controlled rectifier (SCR) designs can provide AC and DC current from single-phase power and DC current from three-phase power. Depending on the design, inverter power sources can provide AC and DC output from single or three-phase input power. Inverter power sources are the most versatile, with many offering multi-process capabilities and variable welding current waveform output. Inverters are also lighter and more compact than standard 60 Hz transformer-rectifier power sources of equivalent current rating.

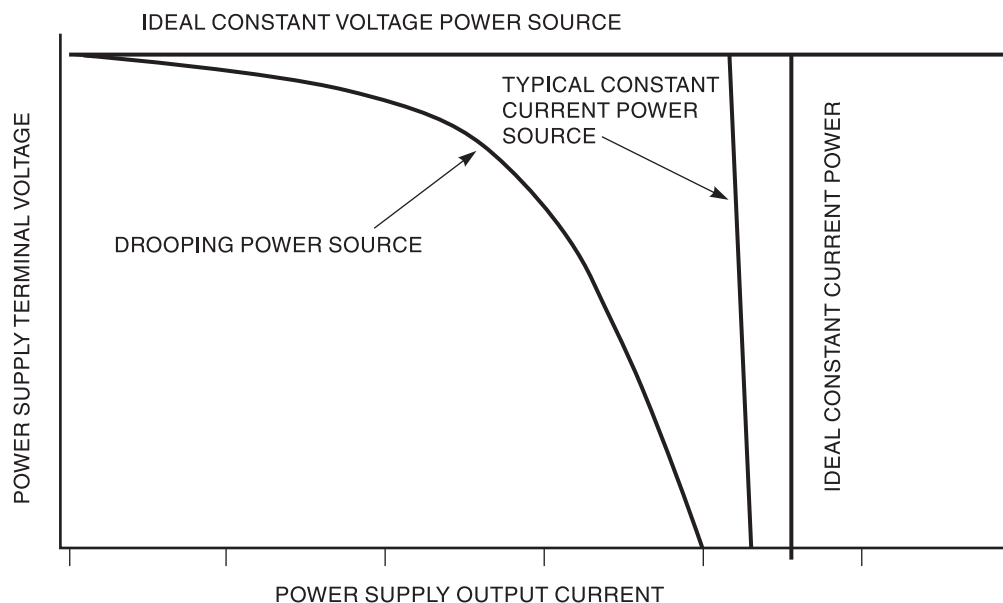


Figure 15—Typical Volt-Amp Characteristic Curves for GTAW Power Sources

It is important to select a GTAW power source based on the type of welding current required for a particular application. The types of welding current include AC sine wave, AC square-wave, DC, and pulsed DC. The following sections have more information on the types of power sources. Many power sources are available with a variety of additional controls and functions such as water and shielding gas control, wire feeder and travel mechanism sequencing, current up-slope and down-slope, and multiple-current sequences.^{20, 21}

5.1.1 Transformer Rectifier Power Sources. One of the most common types of GTAW power sources utilizes transformers and some form of rectification. The rectification can be provided by simple inexpensive diodes or SCRs. The purpose of the transformer in this power source design is to reduce the incoming line voltage and increase the current to a level that is more closely needed for the welding process. For example, a welding power source using 480 V supply voltage needs to be reduced to a voltage in the range of 30 V–80 V, and the current is increased proportionally to the reduction in voltage. Single rectifiers, also known as diodes, can be connected to create a single polarity of voltage, i.e., direct current. The SCRs are simply controllable diodes that improve the ability of the electronics to control current. Prior to the use of SCRs this type of control had been accomplished using mechanically driven magnetic control techniques and saturable reactor magnetic controls. The magnetic type of control was relatively slow and had many mechanically related deficiencies.

5.1.2 Generator Power Sources. Generators are most commonly used for field applications or in industrial settings where sufficient power is not available from the existing power system (mains). The generator-type power sources convert mechanical energy into electrical power suitable for arc welding. The mechanical power can be obtained from an internal combustion engine, an electric motor, or from a power take-off from other equipment. For welding, two basic types of rotating power sources are used: the generator and the alternator. Both have a rotating member normally called a rotor or an armature, and a stationary member, called a stator. A system of excitation is needed for both types. Alternators are used to produce alternating currents while generators are used to produce direct currents. The speed of rotation, the winding configuration and external excitation

currents are the major determining factors in the voltages and currents that each of these devices generate.²²

5.1.3 Transistorized Power Sources. The transistorized power source derives its name from the fact that the output of the welding power source utilizes transistors. The transistorized source takes the DC created by a transformer and diodes and uses the transistors to control the power source output current. The use of transistors allows for very fast and precise control of the output current, which is especially advantageous in pulsed GTAW applications. The two common types of transistorized designs are referred to as series linear regulators and secondary switchers.

The transistorized power source has a very stable output and is fast to respond to control signals. Advanced design methods make it possible to obtain a modulated signal whereby the output current is proportional to the input control voltage. The fast response of the power source when combined with the modulation capability makes it possible to generate sine wave, thermal pulsed DC, and high-frequency pulsed DC all from the same power source by simply changing the input control voltage or modulation signal.

5.1.4 Inverter/Converter Power Sources. The inverter power source was originally developed for the military to provide significant reduction in weight and size of the power source relative to the other types of sources described thus far in this text. The welding inverter power source provides a weight reduction factor of 4 to 5. The inverter design is also electrically more efficient and the output more stable than SCR power source design technologies. This is primarily accomplished by the reduction of the transformer size. This reduction in transformer size is possible by increasing the frequency used in the transformer section. The transformer section of the inverter power source is utilized in the many thousands of Hertz as opposed to 60 Hz in other power source designs.

The inverter power source is a type of GTAW power source that takes AC input power, typically at 60/50 Hz, and changes it to DC, which is converted to higher frequency AC and then rectifies the higher frequency AC to obtain the desired output current. Several variations of the inverter design are available. An example of the design schematic is shown in Figure 16. This higher frequency is in the range of 1 kHz–125 kHz. The size of a transformer is indirectly proportional to the frequency of the voltage. That is, as the frequency increases the size

20. Refer to AWS Welding Handbook, 8th Edition, Volume 2: Welding Processes, Chapter 1, “Arc Welding Power Sources,” for more detailed information.

21. Grist, F. J., Farrell, W. and Lawrence, G. S. 1993. *Power Sources*. *ASM Handbook*, 9th Edition, Volume 6, Welding, Brazing and Soldering, pp. 36–44.

22. For additional information, see AWS Welding Handbook, 8th Edition, Volume 2: Welding Processes. Also see *ASM Handbook*, 9th Edition, Volume 6: Welding, Brazing, and Soldering.

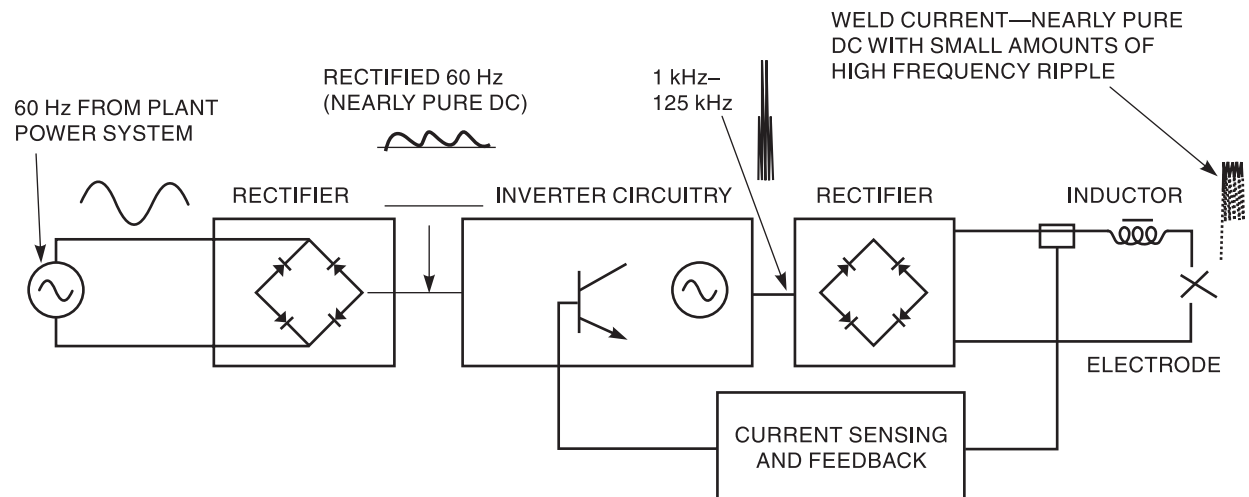


Figure 16—Typical Inverter Power Source Components

and weight of a transformer decreases. Since the voltage being transformed is very high in frequency, the size of a transformer is significantly less, as noted above, when compared to a transformer for the same application used at 60 Hz. Thus significant size and weight reduction is possible. The inverter power source also has a very fast response time compared to many other types of power sources, e.g., transformer-rectifiers. The fast response time is useful in pulsed welding applications.

5.2 Controllers. The term controller is used throughout industry and has many meanings. In the welding field there are two common types of controllers. The first is the controller used to control a single process variable. The second type of controller is the weld sequence controller that orchestrates all of the individual process variables so that each weld variable is set to the proper level at the proper time during the weld cycle.

The most common weld sequence controller is time based. That is, the control is programmed in time relative to the arc start or the pre-flow of electrode shielding gas. It is also possible to have a position based weld sequence controller. In this type of controller the sequencing of the process variables is determined or programmed using the relative position or location of the torch with respect to the part, e.g., a change in speed.

5.2.1 General Control Concepts. Each process variable in the GTAW process is set to an appropriate level to produce desired weld characteristics (e.g., the desired weld width, penetration). The variables that are commonly measured and/or controlled are called process variables. The desired weld characteristics are not being

measured and controlled, but rather the major process variables that affect heat input and torch position are measured. Control of the process variables improves process consistency, but does not ensure consistent welds under all conditions.

Although the actual weld characteristics cannot typically be controlled, it is possible to precisely control a majority of the process variables that drastically affect weld quality and consistency (repeatability). These variables include arc voltage, weld current, travel speed, wire feed speed, shielding gas flow, and multiple axes of position.

There are two categories of controls used in most GTAW processes. The first is the open loop control system. In the open loop control system the process variable is generated and no corrections are made to this setting to maintain the desired set point, even if the output value is not correct. A closed loop control assures the set point value is maintained regardless of the outside influences. A sensor measures the process variable and sends this signal back to the comparison circuitry, i.e., feedback. The circuitry compares the actual variable value to the desired set point (reference) value. If the actual value is lower than the reference value then the signal to correct is increased. This process continues until the reference value is achieved. The ability to maintain a process variable at the desired or set point value, however, is greatly affected by whether or not the system is governed by open or closed loop control methods.

Besides the open loop and closed loop control methods, either of these types of control can be based on analog or digital principles. The analog controller typically

uses “circuitry” to perform the necessary set-point and output comparisons. Such functions are, in many cases, easily performed using transistor or integrated circuit designs. In other situations it is more desirable to implement the control functions using digital circuits, microprocessors, or some other digital computation system such as a personal computer.

In all of the following process variable control discussions it must be remembered that the open loop and closed loop implementations are possible, and, the control may be implemented using digital or analog techniques or a combination of digital and analog methods. The following provides a brief discussion of typical individual process variable controls.

5.2.1.1 Current. The desired current from the power source is set either using front panel adjustments, hand or foot controller, or through an external signal that may come from a computerized weld controller or a dedicated weld sequence controller. If closed loop control is implemented, a current sensor is used to monitor the actual current that is produced by the power supply.

5.2.1.2 General Motion Control. Motion control is a general term that refers to control of linear or rotational speed or position, or a combination of these. In general, for motion to occur there must be some drive source, such as a motor. If there is feedback involved then there must be some type of sensor to complete the feedback loop and appropriate electronics for the feedback.

There are three major types of motors used for motion in GTAW. The first and most common is the DC motor. The second type sometimes used is the stepper motor. The stepper motor is a digitally controlled motor and can be used with or without feedback. The third, and less common is the AC motor, which is also used for larger applications.

5.2.1.3 Travel Speed. Travel speed is simply an implementation of a general motion control, but instead of using position feedback sensors, a speed or velocity sensor is used with appropriate modification to the controls to assure that speed is controlled instead of position. Travel speed in GTAW applications normally refers to the relative motion between the part and the torch.²³ In many GTAW applications, the part is moved with the torch remaining in a fixed position. In other cases it is easier to move the torch with the part remaining fixed.

23. LaCoursiere, E. J., A. H. Farnham, D. G. Howden, L. Zhang. 1993. “Requirements for High-Speed (GTA) Welding, Controller Response Time and Speed Resolution,” in the “International Conference Proceedings on Modeling and Control of Joining Processes,” edited by T. Zacharia, Oak Ridge National Laboratory. American Welding Society, December 8–10, 1993, pp. 500–509.

The simplest and most common travel speed implementations are the simple linear torch movement or the constant rotation speed of a part. These are examples of a single axis of motion. On the other extreme of complexity is the robotic movement of a torch that may involve many axes of rotation and linear motion to weld a complex part.

5.2.1.4 Wire Feed Speed. For mechanized and automatic gas tungsten arc welding, wire feeders (see Figure 17) are often used to deposit filler metal into a weld joint. The wire must be deposited at a constant volumetric rate so as to not overfill or underfill the weld joint. The typical wire being fed into the joint by the wire feeder comes from a supply spool of wire. In most cases, the wire that is fed to the weld is stiff and the amount of force needed to uncoil or feed the wire is not constant during the feeding process. Friction forces inside the conduit, that guide the wire to the arc, vary considerably as the conduit is manipulated during the weld process.

Since the force required to feed the wire is not constant, there must be provisions made in the design of wire feeders to assure constant wire feed rates. In some of the less expensive designs the speed of the electric motor used to feed the wire is reduced or the motor speed is geared such as to achieve mechanical advantage to reduce the effect of the varying force on the speed of the motor. Feedback control methods can also be used to assure the constant wire feed rate. The latter provides the best assurance of constant wire feed rate.

As with other controllers, the wire feed rate may be set using front panel control knobs, signals from computers, or weld sequence controllers. The motors used most often for this application are DC motors, but digital stepper motors or AC motors can also be used.

For many welding processes the wire feed rate is continuous throughout the welding sequence. That is, the wire feed rate is maintained at one level throughout the portion of the welding sequence that requires weld wire. In thermal pulsed GTAW wire may be fed only during the peak pulse current time. This requires synchronization of the wire feed command signal to the power source current control signal. This places additional demands on the controllers and wire feed motor systems to accomplish this task.

In addition to the speed and synchronization of the wire feed there are two additional variations for feeding wire in the GTAW process. These variations are hot and cold wire feeders as described in more detail in 5.6.

5.2.1.5 Gas. The torch gas flow rate is most often manually preset using variable area flowmeters, also commonly known as rotameters. This is the floating ball in a tube-type indicator commonly seen on welding equipment. Gas flow is then started and stopped using

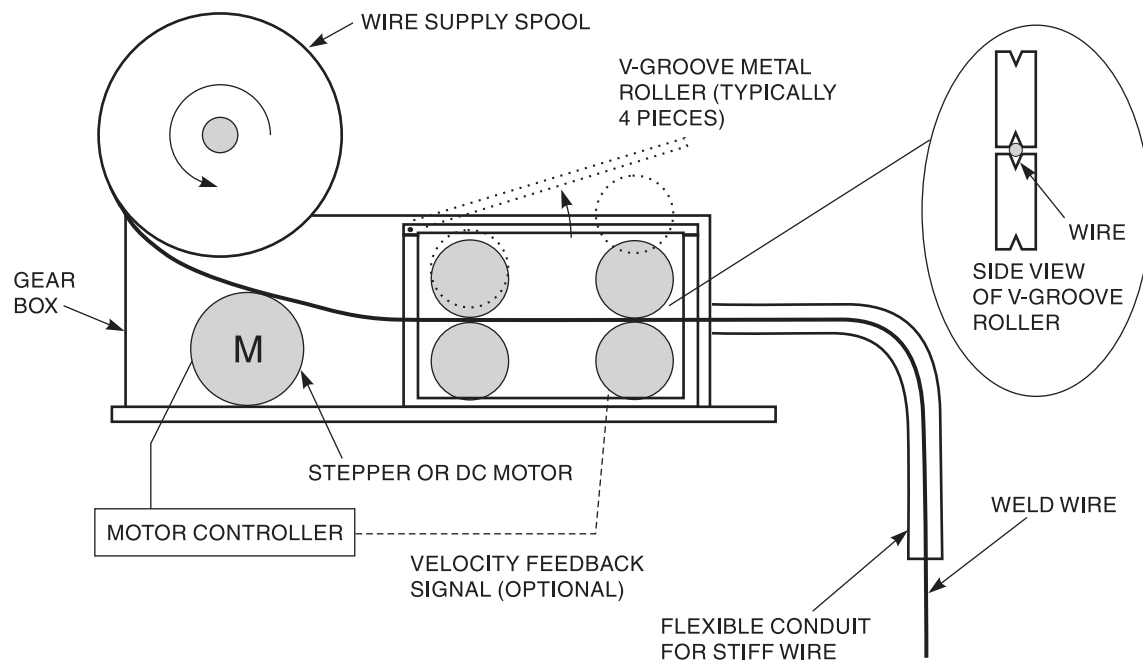


Figure 17—Typical Wire Feeder

electrically controlled solenoid valves. The solenoid valves are most often activated at the appropriate time by the weld sequence controller. The flow rate is adjusted manually on most variable area flowmeters. Flowmeters that can be preset are available. In cases where it is desired to actually measure or control gas flow, controllers are available for this purpose. The most common of these is the mass flow meter and controller. For reasons of cost, it is not common to use mass flow meters and controllers except for cases where flow rates must be remotely controlled or for the most accurate control of flow.

5.2.1.6 Arc Voltage and Arc Length Controllers.

Arc voltage controllers (AVC) can be used in mechanized and automated GTAW welding to maintain arc length. In this case, the arc itself is the sensor, since its voltage is a function of its length. A comparison is made between the actual arc voltage and the desired arc voltage. The difference in voltage is used by the AVC to determine which direction (i.e., closer to or further away from) and at what speed the welding electrode will be moved.

In pulsed welding the current varies between the peak and background values. This causes corresponding increases and decreases in arc voltage for a given arc length. If this fluctuating arc voltage is presented to the

AVC a hunting or continual adjustment of the arc length will occur. Some manufacturers provide an additional option for AVC to prevent this unwanted variation, unless some electronic filtration is used. The option allows the controller to measure the arc voltage only during the high or peak current times.

It must be remembered that it is the relationship between arc length and arc voltage that makes the use of AVC possible. Once a weld is developed, it is assumed that this relationship will remain constant over time for production runs. However, many variables can change the arc voltage vs. arc length relationship. For example, use of helium provides greater sensitivity than argon gas.

5.3 Pulse Controllers. There are numerous types of pulse controllers available. These may be added to appropriate power sources as an option or integrated as part of a power source. In either of these cases, the pulse control options may be set and controlled via computer or by manual selector settings. These controllers provide the necessary additional controls required to set pulse time, pulse current, background current and background time variables.

5.4 Weld Sequence Controllers. The weld sequence controller provides the capability to synchronize the operation of many individual process variable controls so that the proper weld sequence may occur. For instance a

weld sequence controller may execute the following steps:

- (1) pre-flow torch gas for 5 seconds,
- (2) start the welding arc,
- (3) after the arc is successfully started slope the current from 10 amps to 100 amps in ten seconds, etc.

The weld sequence controller can have many forms. The simplest form is a multi-channel timer that simply starts the various individual process variable controllers at the required time. For example, the pre-flow of torch gas may be started by opening a solenoid valve, the timer then signals the arc starter, and when the arc is initiated it simply maintains a current for a predetermined length of time. In the simplest form, relative torch motion may be provided manually by the operator.

On the other extreme of capability is the sophisticated computerized weld controller. This may be a dedicated microprocessor or computer system. All process variable control values and functions are handled by this one weld controller. Figure 18 shows a nonpulsed weld sequence and Figure 19 shows a pulsed weld sequenced schematic.

5.5 Arc Welding Torches. GTAW torches hold the tungsten electrode, which conducts welding current to the arc, and provide a means for conveying shielding gas to the weld zone. Torches are rated in accordance with the maximum welding current and duty cycle that can be used without overheating. Most torches are designed to accommodate a range of electrode sizes and different types and sizes of gas cups/nozzles. The heat generated in the torch during welding is removed by shielding gas cooling and/or water-cooling. Reflected heat can reduce the duty cycle rating.

5.5.1 Types of Torches. Several types of welding torches are available and will be briefly described.

5.5.1.1 Gas-Cooled Torches. Gas-cooled torches (a nonstandard term is air-cooled torches) provide cooling by the flow of a relatively cool shielding gas through the torch. Gas-cooled torches are limited to a maximum current of about 200 A at 60% duty cycle. Gas-cooled torches may be used at high current settings for low-duty cycles, short weld lengths with frequent starts and stops,

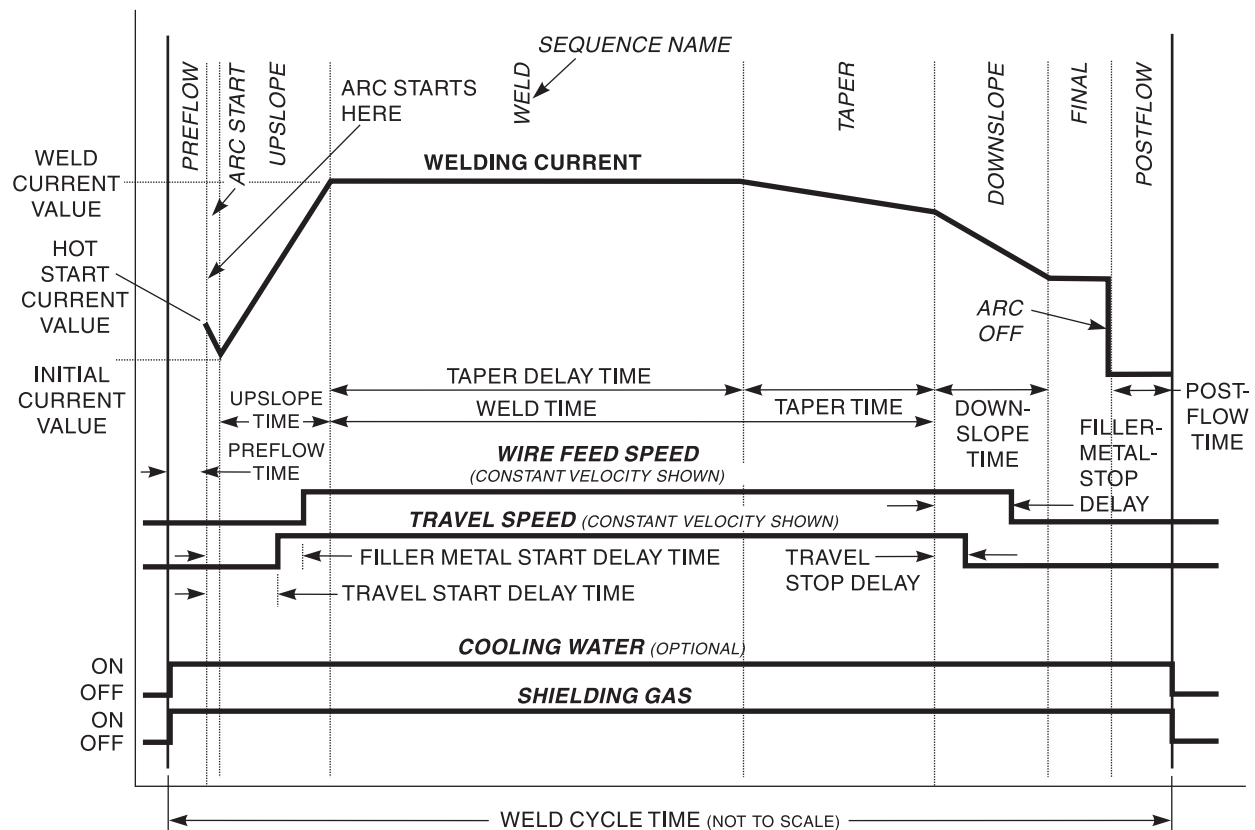


Figure 18—Typical GTAW Sequence for Non-Pulsed DC Welding

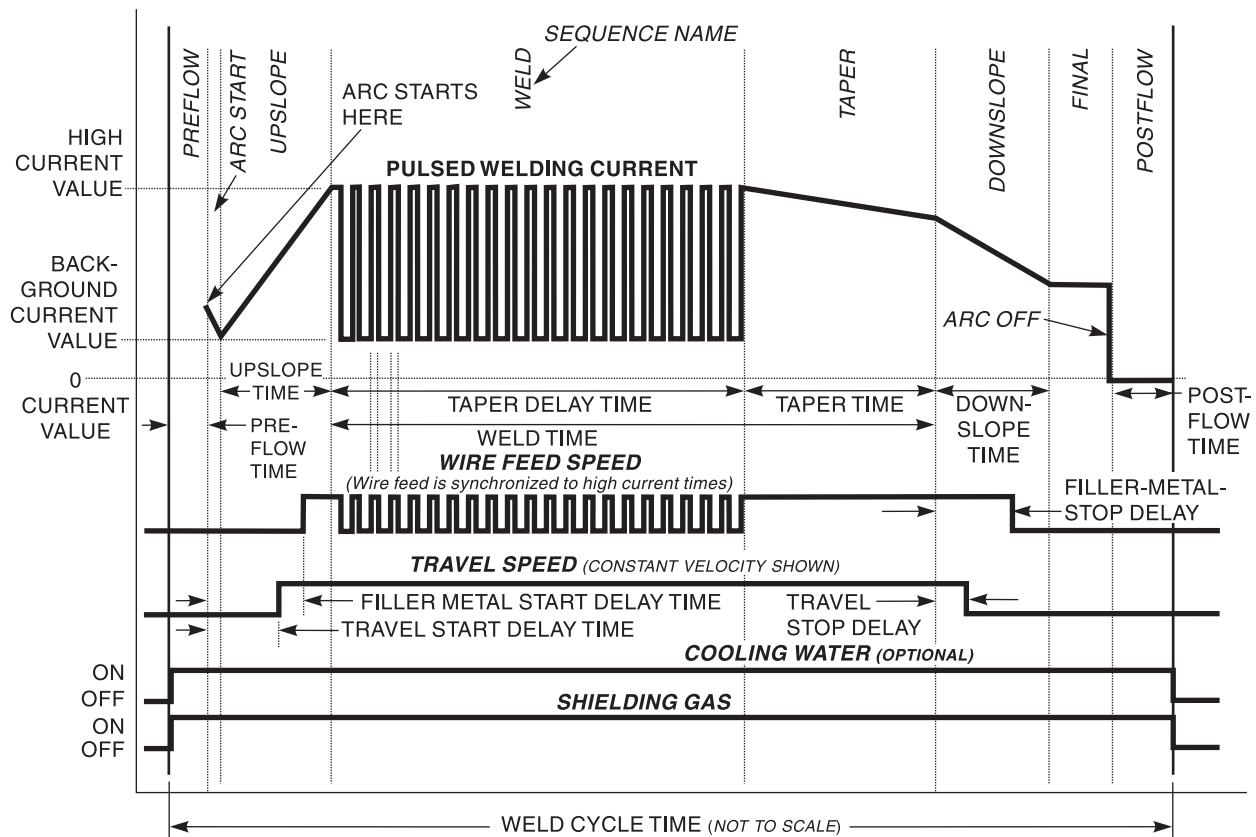


Figure 19— Typical GTAW Sequence for Pulsed DC Current and Pulsed Wire Feed

and tacking of heavy materials. A gas-cooled torch is illustrated in Figure 8.

5.5.1.2 Water-Cooled Torches. Water-cooled torches are cooled by the continuous flow of water through passageways in the holder. As illustrated in Figure 20,²⁴ cooling water enters the torch through the inlet hose, circulates through the torch, and exits through an outlet hose. The power cable from the power source to the torch is typically enclosed within the cooling water outlet hose.

Water-cooled torches are designed for use at higher welding currents and duty cycles than gas-cooled torches. Typical welding currents of 300 A to 500 A can be used, although some torches have been built to handle welding currents up to 1500 A. Most machine or automatic welding applications use water-cooled torches.

Water-cooled torches typically use a water-propylene glycol mixture in a closed system with a recirculator (see 5.5.5 on Water Coolers). This is especially needed for systems employing high-frequency arc stabilization and high-frequency arc starts. This reduces mineral build-up in the torch from tap water, as well as conserving water. However, tap water is sometimes used when it does not interfere with the high-frequency system.

A comparison of typical current ratings for gas-cooled and water-cooled torches is shown in Table 2.²⁵

5.5.1.3 Manual Torches. Torches for manual applications have a head angle (angle between the electrode and handle) of 90°, 100°, or 120°. Torches are also available with adjustable angle heads and straight-line (pencil type) heads. Manual torches often have auxiliary switches, valves, and controls built into their handles for controlling current and shielding gas flow.

24. AWS Welding Handbook, 8th Edition, Volume 2: Welding Processes, Chapter 3: Gas Tungsten Arc Welding. Figure 3.4, p. 78.

25. AWS Welding Handbook, 8th Edition, Volume 2: Welding Processes, Chapter 3: Gas Tungsten Arc Welding. Table 3.1, p. 77.

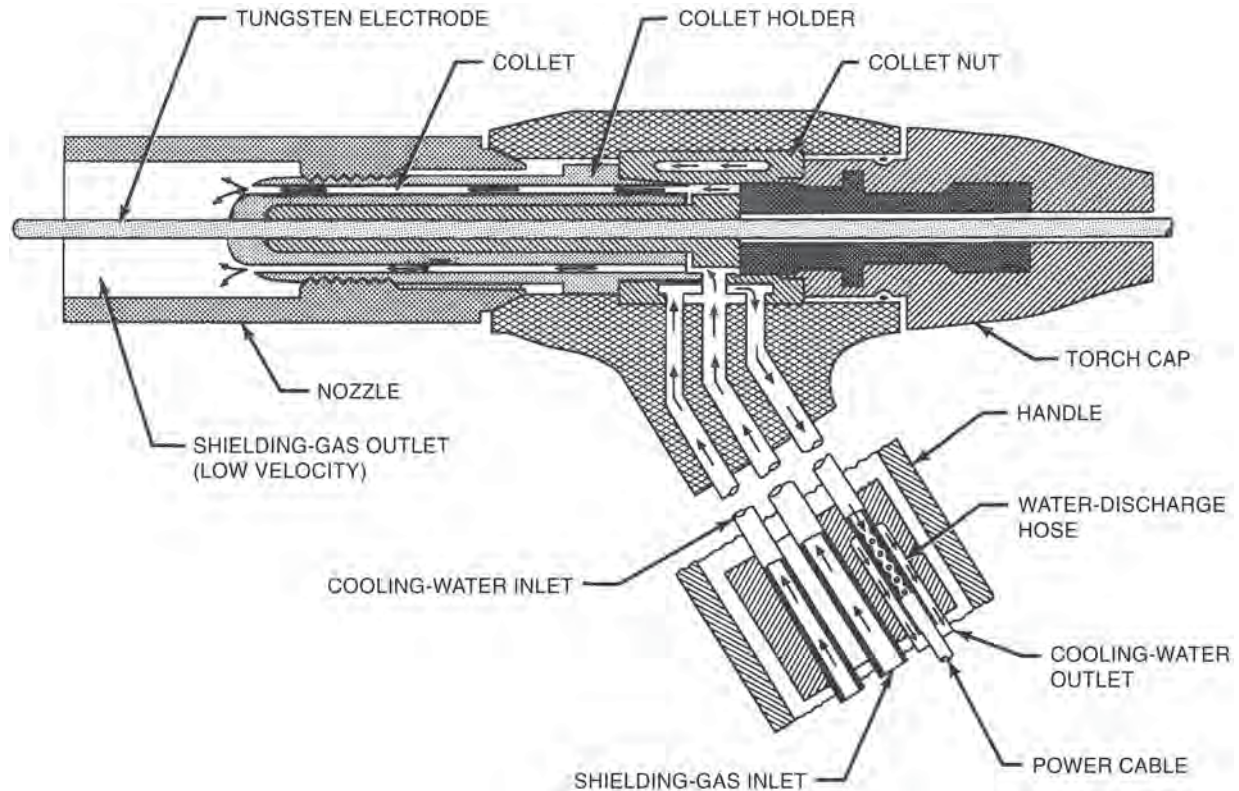


Figure 20—Typical Water-Cooled GTAW Torch (Cross-Sectional View)

Table 2
Comparison of Typical Current Ratings for Gas-Cooled and Water-Cooled GTAW Torches⁽¹⁾

Torch Characteristics	Torch Size		
	Small	Medium	Large
Maximum Current (100% duty cycle), A	200	200–300	500
Cooling Method	Gas	Water	Water
Electrode Diameters accommodated, in. [mm]	0.020 to 3/32 [0.5 to 2.4]	0.040 to 5/32 [1.0 to 4]	0.040 to 1/4 [1.0 to 6]
Gas Cup Diameters accommodated, in. [mm]	1/4 to 5/8 [6 to 16]	1/4 to 3/4 [6 to 19]	3/8 to 3/4 [10 to 19]

Note:

(1) AWS Welding Handbook, 8th Edition, Volume 2: Welding Processes, Chapter 3, Gas Tungsten Arc Welding, Table 3.1, p. 77.

The welder prefers the lightest torch possible for any application because of the tiring effects of positioning and manipulating the torch with relationship to the weld pool. The angle of the torch head is usually dependent on the type of welding to be performed. A 120° torch head is preferred when making fillet welds and a 100° torch head is preferred when making butt welds. Figure 21²⁶ shows typical GTAW torches.

26. Photo courtesy of CK Worldwide.

5.5.1.4 Mechanized and Automated Torches.

The basic mechanized or automatic torch has a straight-line (pencil type) head (see Figure 21). The torch is either rotated mechanically around a joint to be welded, mounted on a tracking device for longitudinal welds or on a robot for all configuration welds.

5.5.1.5 Orbital Weld Heads.

Integral electrode holders are often used in orbital weld heads. With closed-head types, the electrode is held in a planetary gear housing that rotates around the stationary workpiece (see



Figure 21—Examples of GTAW Torches

9.4.1.2 for further details). Open head types feature the torch mounted on a gear that rotates around the workpiece (see Figure 22²⁷). Shielding gases are contained within the weld head for closed head types and are provided through the torch in open head types.

5.5.2 Collets. Electrodes of various diameters are secured in the torch by appropriately sized collets or chucks. Collets are typically made of a copper alloy. The electrode is gripped by the collet when the torch cap is tightened in place. Good contact between the electrode and the inside diameter of the collet is essential for proper current transfer and electrode cooling.

5.5.3 Gas Nozzles/Cups. Shielding gases are directed to the weld zone by gas nozzles, which fit onto the head of the torch as illustrated in Figure 23. Nozzles are more often called by the nonstandard term gas cup. Also incorporated in the torch body are diffusers or carefully patterned jets or holes that feed the shield gas to the gas nozzle (cup). Their purpose is to assist in producing a laminar flow of the exiting gas shield (see 5.5.3.3 for gas lenses). Gas nozzles are made of various heat-resistant materials in different shapes, diameters, and lengths. These gas nozzles are either threaded to the torch or held by friction fit.

5.5.3.1 Gas Nozzle/Cup Materials. Shielding gas nozzles are made of ceramic, metal, metal jacketed ce-

ramic, fused quartz, lava, or other materials. Ceramic cups are the least expensive and most popular, but are brittle and must be replaced often. Fused quartz cups are transparent and allow better vision of the arc and electrode. However, contamination from metal vapors from the weld can cause them to become opaque, and they are also brittle. Water-cooled metal nozzles have longer life and are used mostly for machine and automatic welding applications where welding currents exceed 250 A.

5.5.3.2 Sizes and Shapes of Gas Nozzles (Cups).

The gas nozzle (cup) must be large enough to provide shielding gas coverage of the weld pool area and surrounding hot base metal. The gas nozzle diameter must be appropriate for the volume of shield gas needed to provide protection and the stiffness needed to sustain coverage in drafts. A delicate balance exists between the gas nozzle diameter and the flow rate. If the flow rate for a given diameter is excessive, the effectiveness of the shield is destroyed because of turbulence. High flow rates without turbulence require large diameters; these are essential conditions at high currents. Size selection depends on electrode size, type of weld joint, weld area to be effectively shielded, and access to the weld joint.

Suggested gas nozzle sizes for various electrode diameters are covered in Section 6. Use of the smallest gas nozzle permits welding in more restricted areas, and offers a better view of the weld. However, use of too small a gas nozzle may cause shielding gas turbulence and jetting, as well as melting of the lip of the gas nozzle.

27. Photo courtesy of Arc Machines Incorporated.

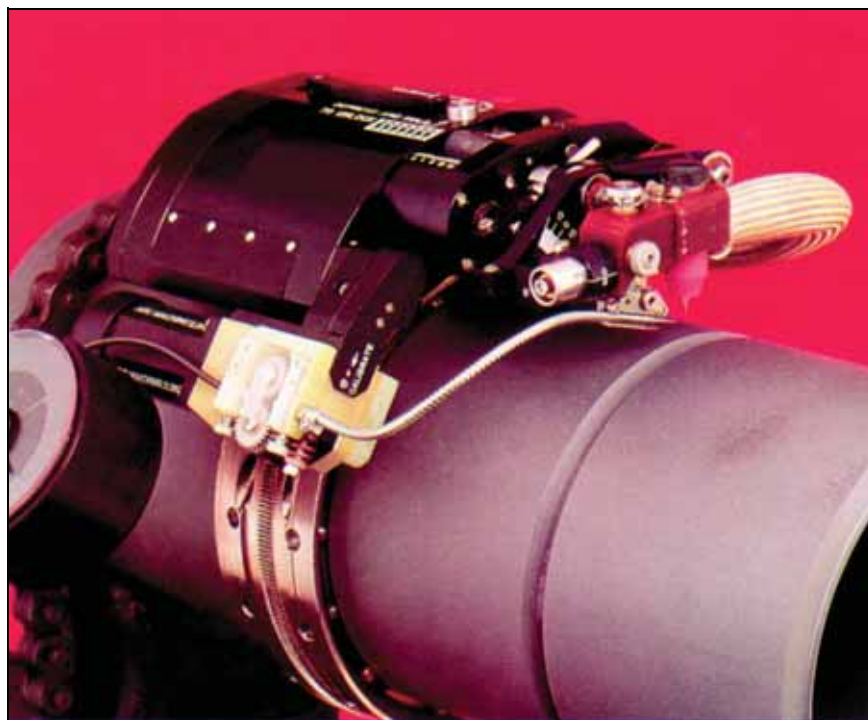


Figure 22—Orbital Weld Head with Wire Feeder

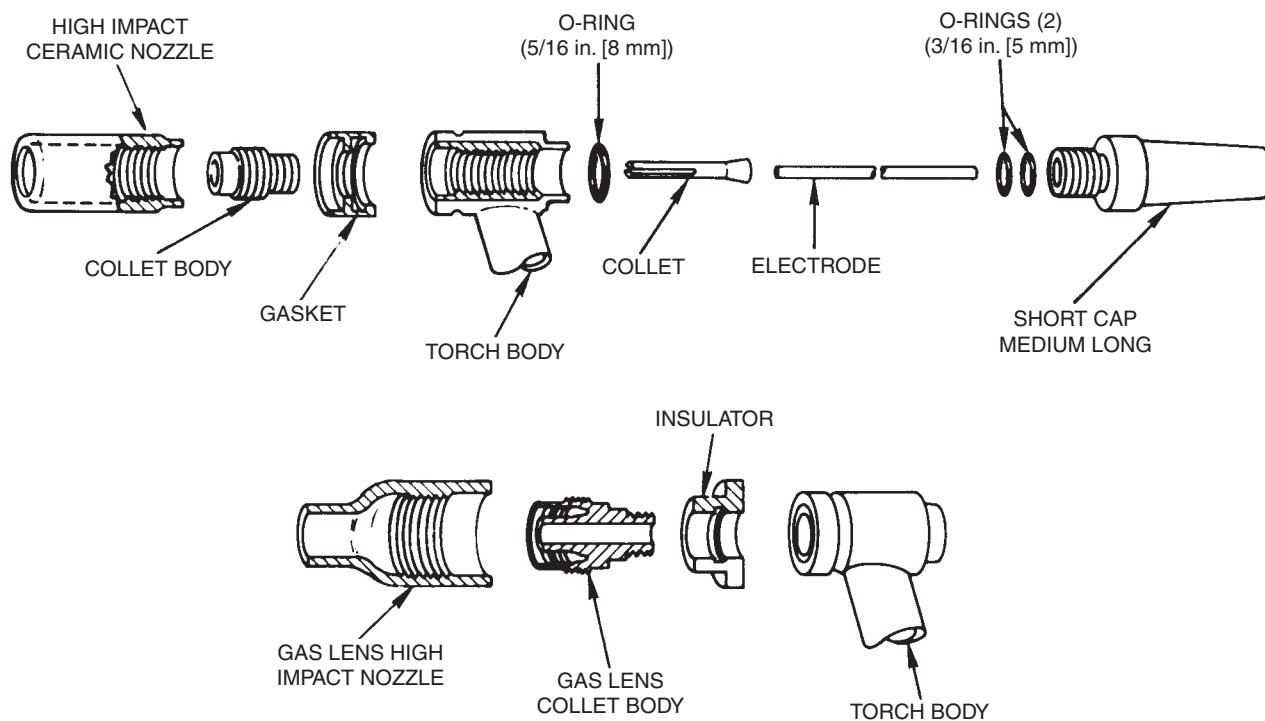


Figure 23—Components of a Typical GTAW Torch, Including Gas Nozzle/Cup, Gas Lens, Collet Body, Torch Body, Collet, and Electrode