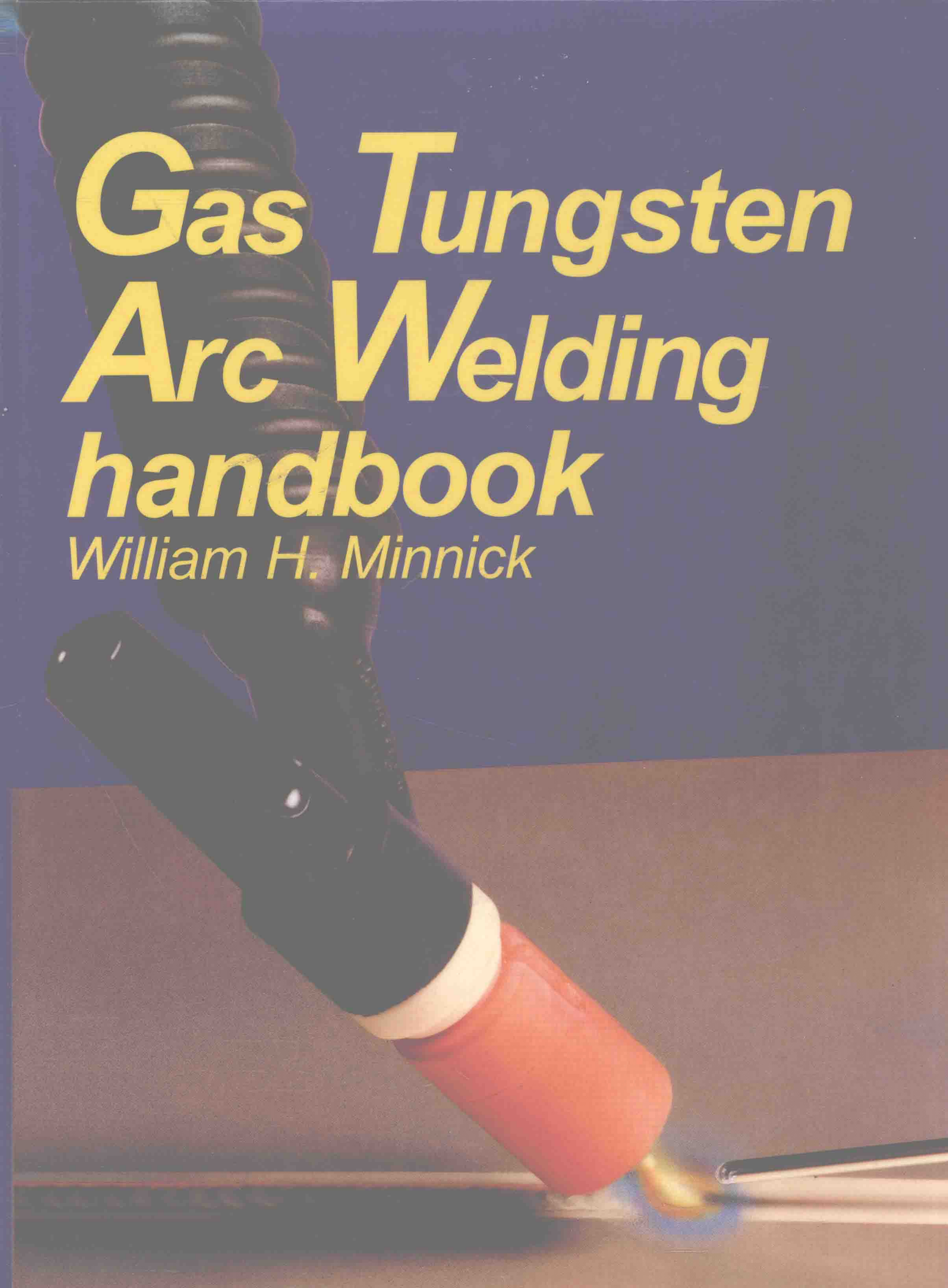
Gas Tungsten Arc Welding handbook

William H. Minnick



Gas Tungsten Arc Welding handbook

William H. Minnick

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About the Author

Realizing the need for a specialized type of welding text for instructors and students, Bill Minnick has drawn on his many years of experience as a welder, welding engineer, and Community College instructor to develop this text for training future welders.

The author's career in industry moved from welder to welding process engineer to welding engineer supervisor. He has had experience welding on jet engines, missiles, pressure vessels, and nuclear reactors. During his industrial career, he developed the welding procedures and welded the first titanium pressure vessel for the Atlas missile program.

The author has written many technical papers for various welding publications. These articles included research and development for welding exotic materials and modification of existing welding processes for automatic and robotic applications. He is also the author of the **Gas Metal Arc Welding handbook** and the **Flux Cored Arc Welding handbook.**

Mr. Minnick developed welding certificate and degree programs and taught all phases of welding and metallurgy in community colleges for over twenty years. His vast experiences shine through in this useful text.

The Publishers

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INTRODUCTION

The **Gas Tungsten Arc Welding handbook** provides complete and thorough coverage of the gas tungsten arc welding (GTAW) field. Theory, fundamentals, equipment, and safety information are provided to teach you to make successful welds. Basic skills and proper procedures are presented in easy-to-understand language and combined with numerous illustrations to guide you in learning about GTAW.

The **Gas Tungsten Arc Welding handbook** is designed to teach the understanding and skills needed to enter the welding field. The sequence of chapters will lead you through GTAW principles and practices in logical order. You will be introduced to:

- the types of safe operation of GTAW equipment.
- setup and maintenance of equipment.
- types of welds, joint design, and tooling.
- welding techniques and procedures for various types of metals.
- semiautomatic and automatic welding systems.
- inspection practices and quality control.
- weld repair.
- qualification and certification.
- estimating cost.

Each and every weld that you will make bears your personal trademark and represents your skill as a welder. Take pride in your work and make each weld as if your career depends upon it. The **Gas Tungsten Arc Welding handbook** will give you the information you need to make that weld.

William H. Minnick

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CHAPTER 1 Gas Tungsten Arc Welding Process

The GAS TUNGSTEN ARC WELDING (GTAW) process fuses metals by heating them between a non-consumable (does not melt) tungsten electrode and workpiece. The heat necessary for fusion (mixing or combining of molten metals) is provided by an arcing electric current between the tungsten electrode and the base metal.

This type of welding is usually done with a single electrode. However, it may be done with several electrodes. The tungsten electrode and the weld zone (area being welded) are shielded from the atmosphere (air around it) by an inert gas, such as argon or helium. Filler metal may or may not be used.

The discovery of the GTAW process is credited to two Americans, Russell Meredith and V.H. Pauleka who developed a method for welding magnesium. They used a direct current arc for heat and helium gas to protect the molten metal from the atmosphere. From this combination, the name "Heliarc" was born. Meredith later sold it to the Linde Company which now uses the word Heliarc as a trademark on their equipment.

TIG OR GTAW?

At one time, the American Welding Society (AWS) called the process "tungsten inert gas welding." The letters "TIG" were used to designate the process. Later, the definition was changed to "gas tungsten arc welding" and the letters "GTAW" came into popular use. Today, both of the names and letters are used. However, the American Welding Society recommends the use of Gas Tungsten Arc Welding or GTAW. This book will follow current practice and refer only to GTAW.

A typical manual GTA weld is shown in Fig. 1-1. The entire weld area and the tungsten electrode is shielded by a flow of an inert gas through the specially designed welding torch and gas nozzle. The gas protects the tungsten, molten metal, and heat-affected area from contamination by oxygen, nitrogen, and hydrogen in the atmosphere. If the tungsten and the molten metal are not shielded properly, the atmosphere is absorbed into the weld and it becomes brittle and porous. Welds that have been contaminated do not usually have sufficient strength to carry the intended load or stress.

WELDING MODES

GTA welding may be done in any position and in manual, semiautomatic, or automatic modes. The method used depends on the equipment and the application. In the MANUAL MODE, the welder controls every part of the GTAW process that can vary. In addition, the welder manipulates (handles) the welding torch and then adds filler wire as needed.

In the SEMIAUTOMATIC MODE, the welding torch may be mounted on a special holder or on a tractor. In another variation, the part may move under a stationary (not moving) torch. The welder controls the process wherever it varies.

In the AUTOMATIC MODE, all of the welding variables, as well as the sequence of steps, are programmed into the welding machine. The operator monitors (oversees) the overall operation.

COMPONENTS AND ACCESSORIES

Basic equipment components (parts) and accessories (things that make the welding process work better) vary widely. The equipment selected depends upon:

1. The mode in which the process is used.
2. Type of material to be welded.
3. Number of welds needed.
4. Quality of the completed welds.

Each welding system must have a minimum of three major components. These three items include:

1. POWER SUPPLY for the type of desired current.

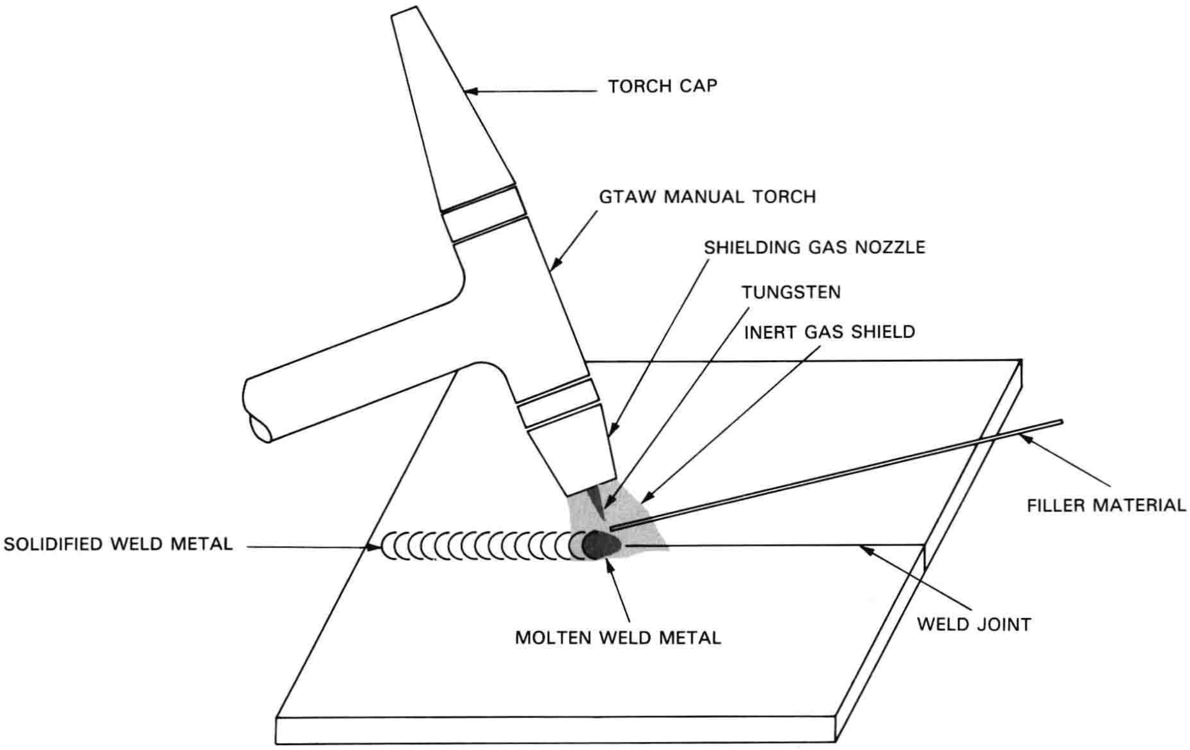

Fig. 1-1. The GTA welding torch is moved along the weld joint melting the base material. Filler material is added as needed by the operator.

2. INERT GAS SUPPLY and a flow control to regulate the flow of gas to the weld area.

3. GTAW TORCH, tungsten electrode, collect assembly, and gas nozzle.

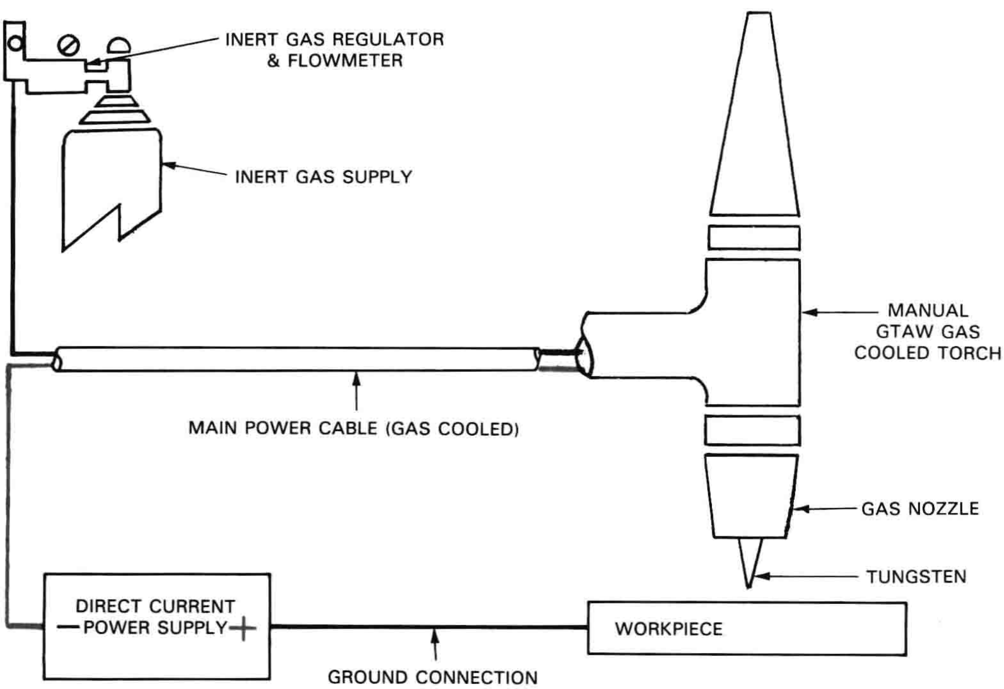

Fig. 1-2. Basic components for a simple GTAW system to weld steel, stainless steel, inconel, etc.

Basic Welding System

A basic welding system is diagramed in Fig. 1-2. It is for the manual welding of thin gauge steel, stainless steel, inconel, titanium, etc., using direct current from the power supply. This type of system is limited to thin gauge materials because of the amperage (heat) capacity of the welding torch.

Basic Welding System For Aluminum And Magnesium

A welding system for the manual welding of thin gauge aluminum and magnesium is illustrated in Fig. 1-3, using alternating current from the power supply. A high frequency voltage generator is required to maintain the arc to and from the workpiece, with this type of current. This type of system is limited to thin gauge materials because of the amperage (heat) capacity of the torch.

Basic Welding System For All Types of Metals

The system shown in Fig. 1-4 uses a power supply which will supply either alternating or direct current. A high frequency voltage generator is also required when using alternating current for welding. This type of system is limited to thin gauge materials because of the amperage capacity of the torch.

Basic Welding System For All Types of Metals and Thicknesses

The manual system shown in Fig. 1-5 can be used for all thicknesses of materials because the torch is water cooled. Heat which is generated in the tungsten electrode is removed by circulating water through the torch body and head.

Semiautomatic Longseam Welding System

The system diagramed in Fig. 1-6 can be used on all types and thicknesses of metal. A tractor for longitudinal travel is added to move the machine welding torch along the weld joint. The arc gap is maintained along the joint by raising or lowering the torch with a gear and rack adjustment wheel.

A wire supply and feeder assembly may be used in this system. The addition of material is for filling groove weld joints and making a crown on the top of the weld. Longitudinal welds in cones, cylinders, channels, and tubes are welded using this type of system.

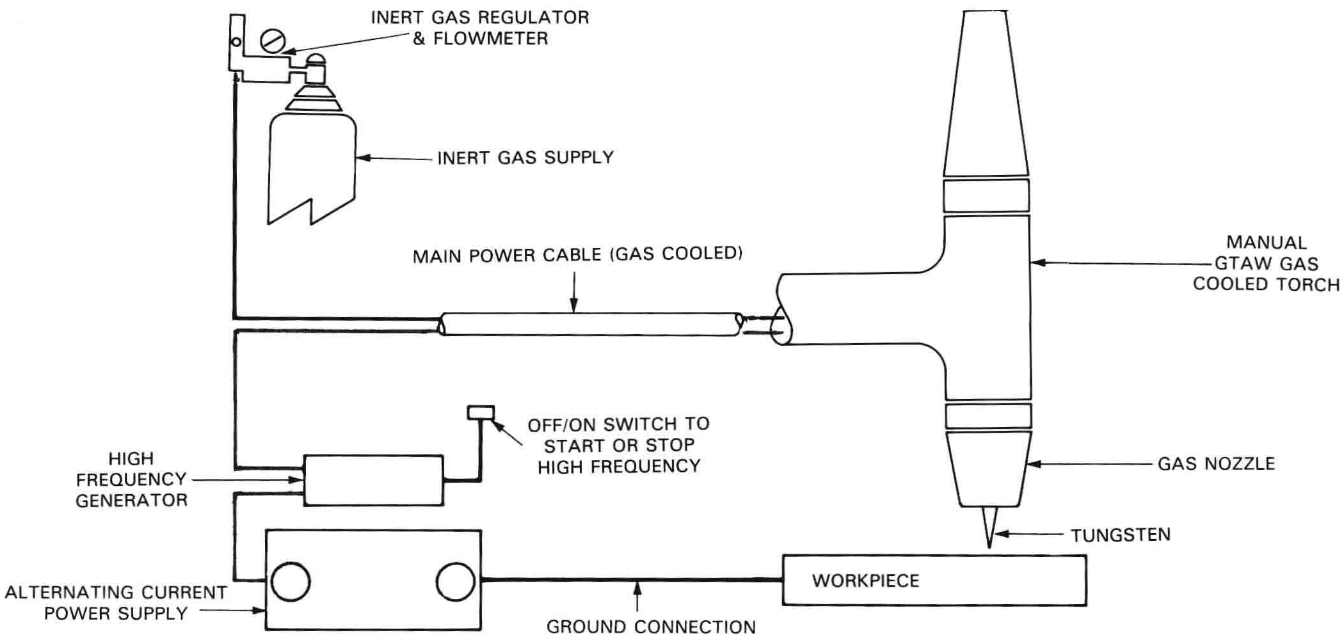

Fig. 1-3. An alternating current power supply and a high frequency voltage generator are required to weld aluminum and magnesium.

Semiautomatic Rotational Welding System

Fig. 1-7 shows a system used to make welds between round parts, such as rings and cylinders. The machine welding torch is mounted above the part. Manual adjustments maintain the proper gap between the torch and the part.

A positioner rotates the part at a set speed under the torch during the weld. Tilt table positioners are used where the weld joint must be angled to the welding torch. A wire supply and feeder assembly may also be added in this system.

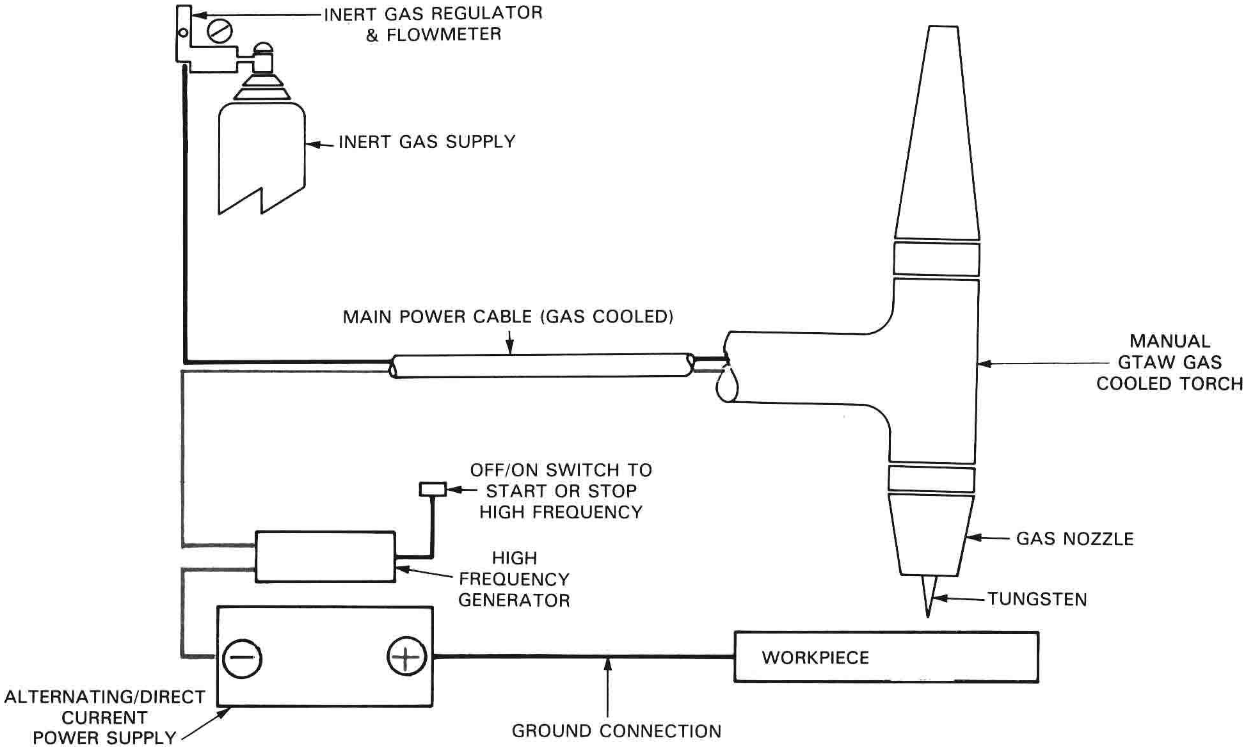

Fig. 1-4. Both aluminum and steel can be welded with a combination alternating and direct current welding power supply.

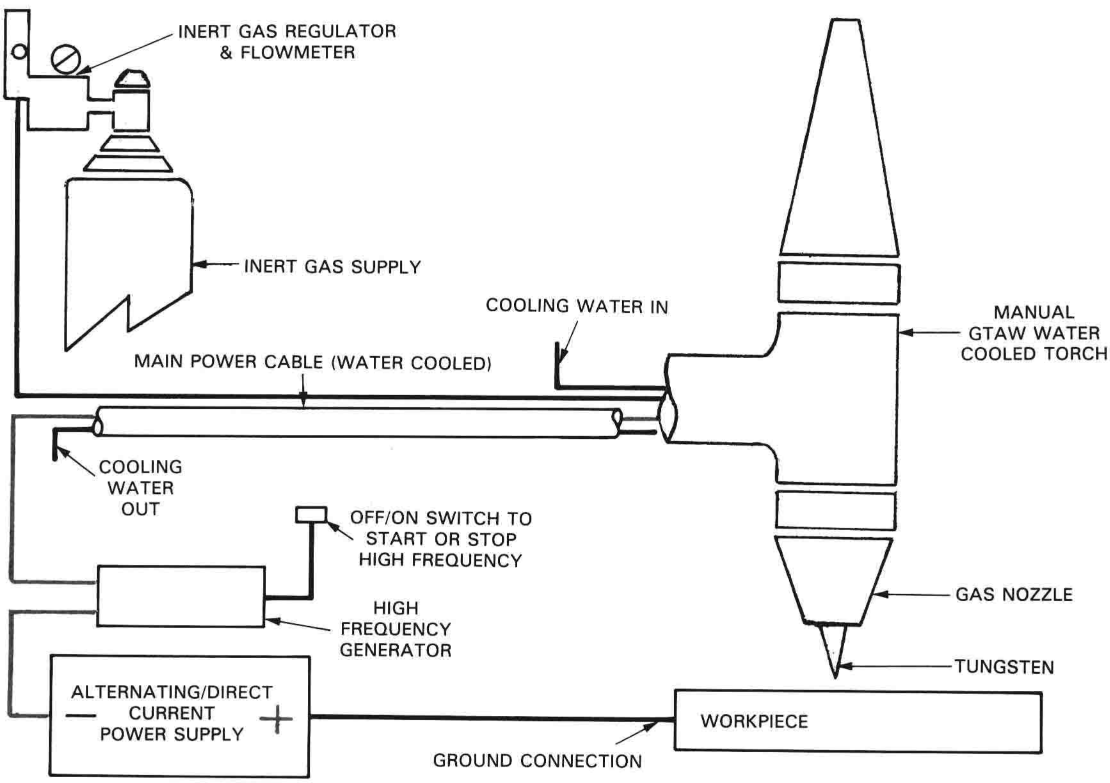

Fig. 1-5. Higher welding currents can be used in this GTAW system because the torch is water cooled.

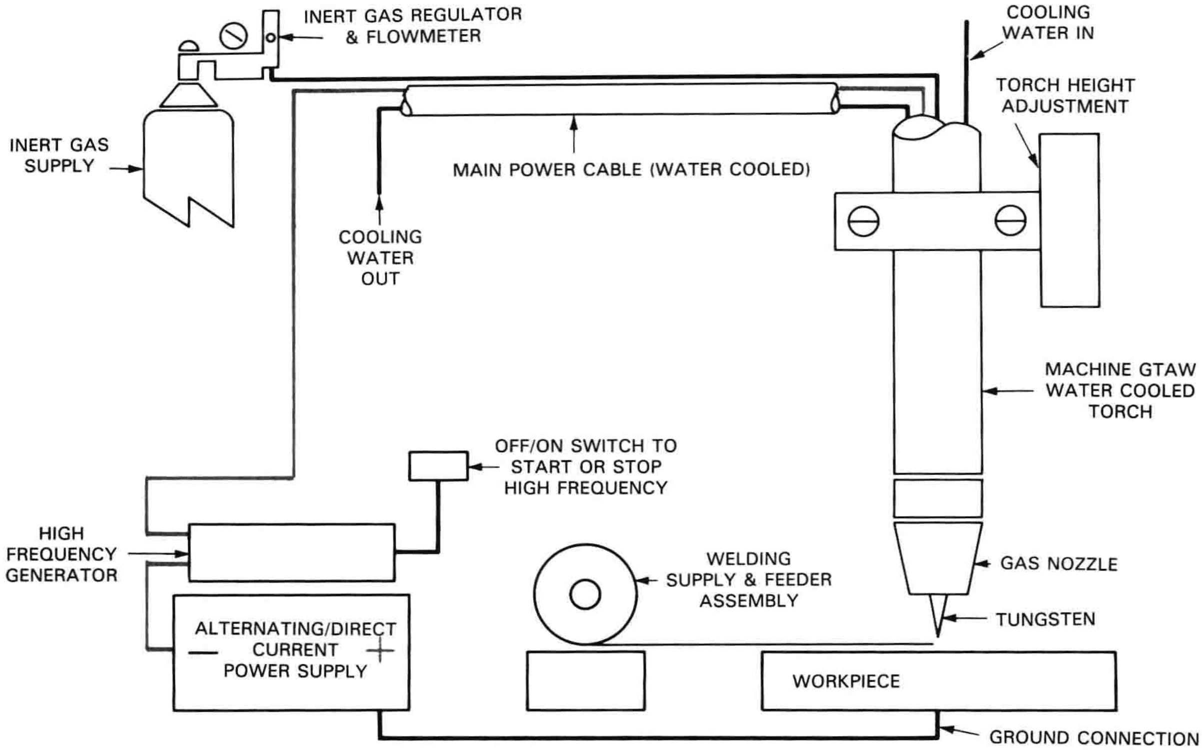

Fig. 1-6. Welds made with this semiautomatic type of equipment can be made much faster with less defects than manual welds. A wire supply and feeder assembly provide filler material.

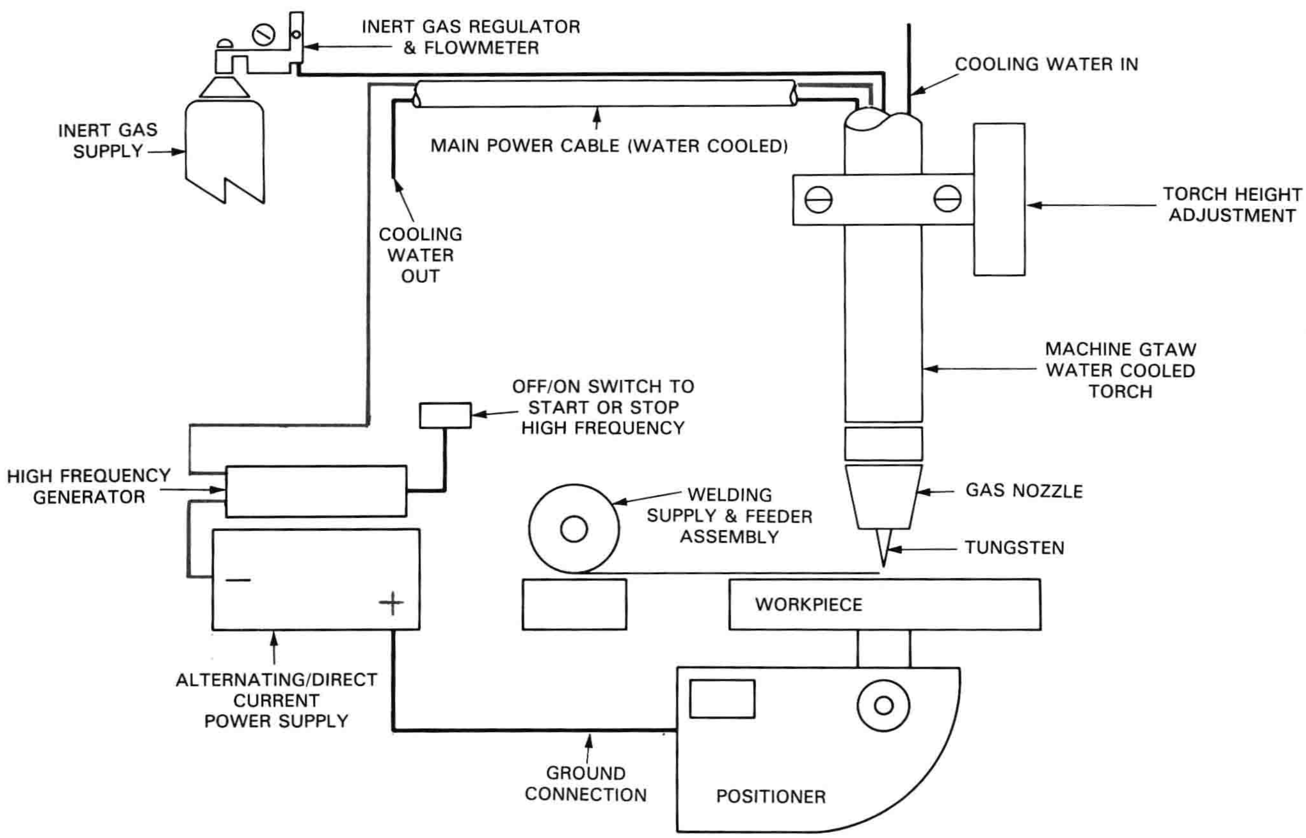

Fig. 1-7. Positioners are used to locate and rotate circular parts at an accurate speed to allow for semiautomatic rotational welding.

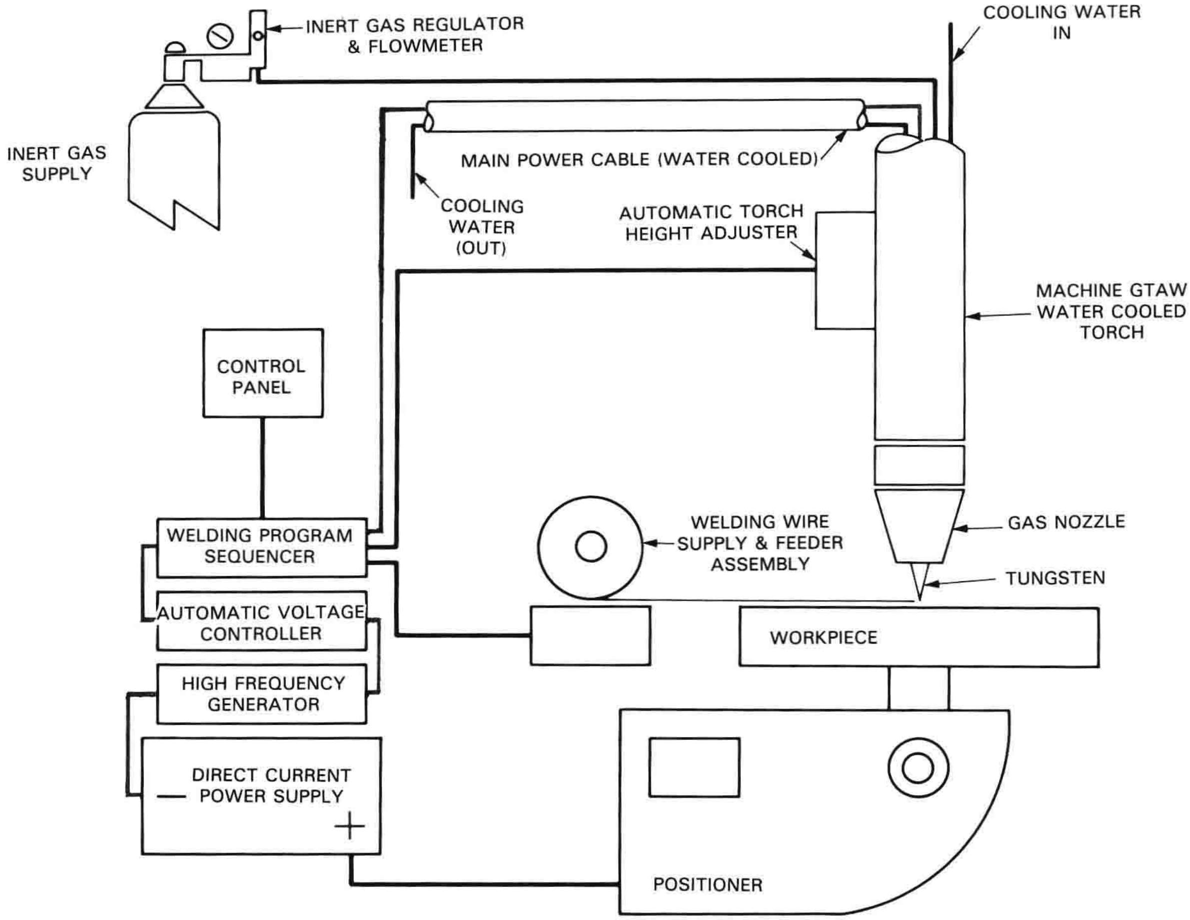

Fig. 1-8. Automatic welding systems are designed for high production rates and where high quality is required.

Automatic Welding System

The system shown in Fig. 1-8 may be used on longseam and/or rotational type welds. The components of the system are interconnected and programmed to operate as required during the operation. The welder oversees the operation and makes adjustments as required.

This type of equipment is typically very expensive and is used where high quality or high production welds are required.

Semiautomatic Spot Welding System

Spot welds may be used as an assembly tool to spot tack weld mating parts together. Spot welds may also be used as the main welding operation. Fig. 1-9 shows a basic spot welding system. In some cases, additional equipment may be required to start the arc or to add filler material to the weld puddle.

PROCESS APPLICATIONS

Applications of the GTAW process are virtually unlimited in modern fabrication industry. The nuclear power, aircraft, missile, food processing, chemical and oil refining industries, today employ thousands of welders producing components using the GTAW process. The major advantages of the process include:

1. The welds are very clean and have good quality.
2. Arc heat is intense and highly concentrated.
3. There is no smoke, fumes, spatter or slag.
4. Weld zone is highly visible.
5. Weld chemistry is easily controlled.
6. GTAW can be used to weld most industrial metals.

The disadvantages of the process include:

1. Slow welding speed.
2. Equipment is expensive.
3. Inert gases are costly.
4. Requires a highly skilled welder for manual welding.

REVIEW QUESTIONS

1. The GTAW process is a __________ welding process.
2. __________ current provides the heat for melting the base materials.

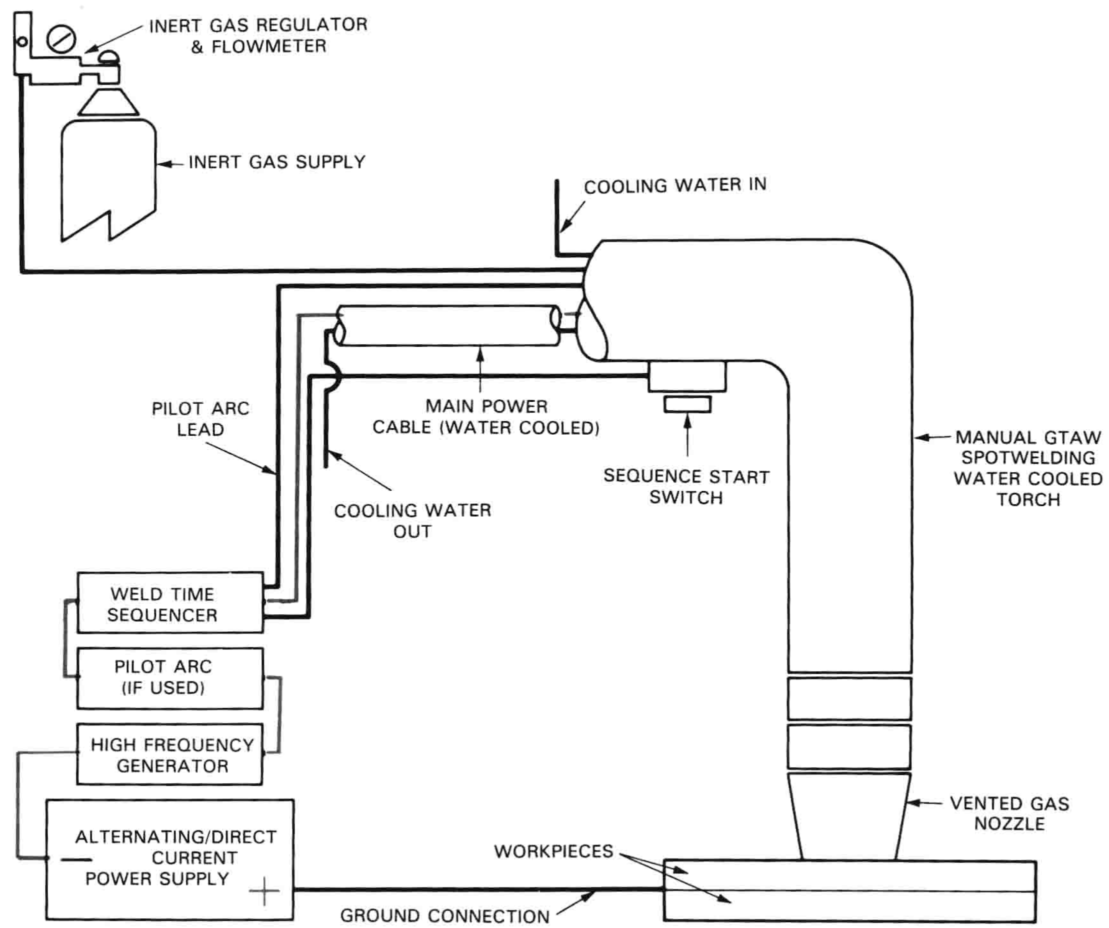

Fig. 1-9. Spot welding of overlapping materials is accomplished by heating the top plate and melting into the bottom plate.

3. __________ and __________ are typical gases used to shield the weld zone from the atmosphere.
4. The welding electrode is nonconsumable and is made from __________ material.
5. The original name for the GTAW was ______ .
6. The letters AWS stand for ________ ________ ________ .
7. The letters TIG mean __________ __________ __________ .
8. Weld metal that absorbs atmosphere become __________ and __________ .
9. Three contaminates in the atmosphere are ________, ________ and ________ .
10. In the __________ welding mode, the welder controls every part of the process that can vary.
11. In the automatic mode, the __________ oversee or monitors the entire operation.
12. Each welding system has a minimum of three major components. They are:
    1. ____________
    2. ____________
    3. __________
13. Another name for welding alternating/direct current is __________ .
14. Steel, stainless steel, and inconel are welded using __________ current from the power supply.
15. Aluminum and magnesium is welded using __________ current.
16. A __________ __________ __________ generator must be used with alternating current to maintain the flow of welding current.
17. Heavier thicknesses of material are welded with __________ cooled torches.
18. To fill groove weld joints and make crowns on welds using the semiautomatic system, a ________ ________ and a ________ ________ must be added to the system.
19. Welding torches mounted on tractors are used to make __________ type welds.
20. GTAW spot welding of overlapping materials is accomplished by heating the __________ plate and melting into the __________ plate.

CHAPTER 2 GTAW Process Operation and Safety

In gas tungsten arc welding, the welder applies the arc to two workpieces that are butted together. The heat of the arc melts the metal along the butted edges of the two workpieces. (Melted filler metal may be added.) As the molten (melted) metal cools it becomes solid and permanently joins the workpieces. This GTAW process is called FUSION WELDING. Fig. 2-1 shows a manual GTAW operation. The movement of the torch is controlled by the welder.

Note in Fig. 2-1 that the welder is wearing an approved molded helmet with an extra large lens for maximum visibility. A lens shade number of 10 to 14 is recommended for GTAW. Dark clothes are worn to cut down reflections and glare. Trousers worn by welders should not have cuffs. Protective gloves are worn to prevent "sunburn" of the hands and wrist. Good ventilation is extremely important to all welding operations.

PROCESS OPERATION

In the GTAW process, several components (parts) are combined to make welding systems. As you studied in Chapter 1, three items are required to produce GTAW results; a power supply for the type of desired current, an inert gas supply and a flow control to

Fig. 2-1. A 300 ampere AC/DC power supply is being used for this manual GTAW operation. Note the helmet, gloves, and dark clothing. (Miller Electric Manufacturing Co.)

regulate the flow of gas to the weld area, and the GTAW torch made up of the tungsten electrode, collet assembly, and gas nozzle. These components will be studied in more detail in this chapter.

When the systems are properly controlled, they will produce a carefully controlled arc. At the same time, a measured amount of inert gas will flow around the weld area.

Additional components may be used in semiautomatic or automatic systems. The added components are designed to:

1. Oscillate the torch. This means "move it back and forth."
2. Add filler wire.
3. Maintain the arc voltage.
4. Control other functions or aspects of the welding process.

Prior to welding, all the equipment must be set up to operate in a definite way. Each component in the system must be set to enter the operation and to work at the proper time. To properly set up the time and order of these events, a study must be made of the required weld. Definite characteristics are then determined before welding. These characteristics are called PARAMETERS and VARIABLES in the welding trade. These will vary depending on such items as types of metals, thickness of the weld joint, weld joint design and weld quality required.

Some of the major variables are:

1. Type of weld current.
2. Amount of weld current.
3. Arc voltage.
4. Power source characteristics.
5. Type of shielding gas.
6. Amount of gas flow.
7. Type of welding torch.
8. Electrode type.
9. Electrode diameter.
10. Electrode tip shape.
11. Gas nozzle size.

All of these variables will have to be carefully considered when setting up the components of any GTAW system.

POWER SUPPLIES

Power supplies are specially designed and manufactured for GTAW. They must produce a variable low voltage and a constant electrical current to the welding arc. The various types of power supplies used in GTAW are shown in the chart in Fig. 2-2.

The welding machines are rated for the amount of current and length of time they can operate without damage to the power supply. This rating is called the MACHINE DUTY CYCLE. They should never be operated beyond these limits.

WELDING CURRENT OUTPUT			
Machine Type	A/C ONLY	D/C ONLY	A/C or D/C
Transformer	X		
Transformer-Rectifier		X	X
Motor Generator	X	X	X
Motor Alternator	X	X	X
Inverter		X	X

Fig. 2-2. Five types of power supplies are used in Gas Tungsten Arc Welding.

Controls for a power supply may range from very simple to very complex. The simplest is a tap connection for changing the amount of welding current. One of the most complex is a series of controls that fully sequence the welding current throughout the entire operation.

Manual type industrial rated power supplies, like the one shown in Fig. 2-3, generally have two methods of controlling the arc welding current:

1. Machine mounted rheostat which is preset to the desired amperage prior to starting to weld.
2. Remote hand or foot rheostat which is adjusted by the welder during the operation to the desired current level. This control is very useful to the welder as the current may be started and ended at a very low level. This reduces the possibility of burn-through and craters at the start and end of the weld.

The remote amperage hand control used with a power supply is shown in Fig. 2-4. The remote amperage foot control used with a power supply is shown in Fig. 2-5.

The power supplies produce OPEN CIRCUIT VOLTAGE when started. They are ready to produce welding current as soon as the arc is struck. A CONTACTOR switch prevents accidental shortage of the arc welding current to the workpiece prior to the start of the weld. The contactor allows welding current to flow from the power supply to the torch.

The contactor is located in the power supply where it opens and closes the power circuit from the power supply to the torch. Switches located on the main power supply select desired modes (foot or machine) for amperage control and contactor operation. Refer to Fig. 2-3. Operation of the hand or foot control energizes the contactor and allows the arc to start.

Four major points to remember about the power

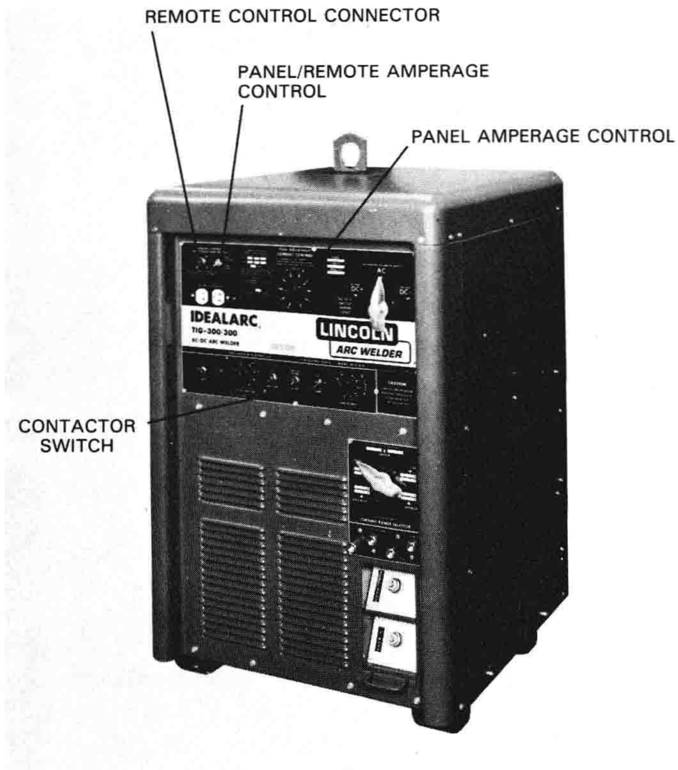

Fig. 2-3. This industrial type power supply has provisions for panel control of amperage or remote (hand or foot) control. (Lincoln Electric Co.)

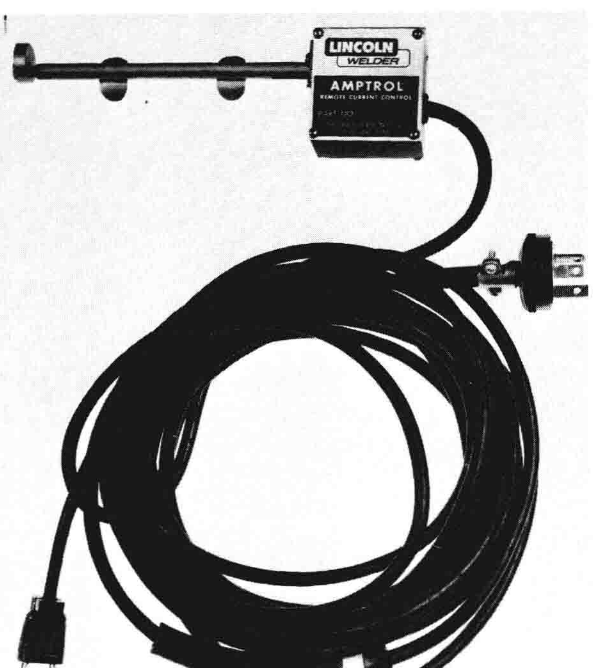

Fig. 2-4. The welder controls amperage by turning the shaft with a fingertip during welding. The assembly is mounted directly on the GTAW torch. (Lincoln Electric Co.)

Fig. 2-5. The welder can raise or lower amperage by movement of the foot pedal. (Lincoln Electric Co.)

supply include:

1. NEVER use the power supply above the rated load.
2. NEVER change an output lead during welding.
3. NEVER change the current type while welding.
4. NEVER change the current range switch during welding.

TYPES OF WELDING CURRENT

The GTAW process uses three types of current. Each is needed to weld different types of metals. ALTERNATING CURRENT is generally used for manual and semiautomatic welding of aluminum and magnesium. DIRECT CURRENT STRAIGHT POLARITY (DCSP), also referred to as Direct Current Electrode Negative (DCEN), is used to weld the steels, stainless steels, nickel, titanium, and many other materials. In some automatic welding of aluminum and magnesium, direct current straight polarity (DCSP or DCEN) is used with helium shielding gas. DIRECT CURRENT REVERSE POLARITY (DCRP) or Direct Current Electrode Positive (DCEP), type of current is usually used only on materials needing shallow penetration.

The American Welding Society has defined current flow as moving from the negative (−) terminal to the positive (+) terminal. When the current flows from the welding machine negative terminal to the electrode holder, across the arc gap, to the workpiece and back to the welding machine, the circuit is known as

DIRECT CURRENT ELECTRODE NEGATIVE (DCEN). This is the same as DIRECT CURRENT STRAIGHT POLARITY (DCSP). You will find many of the welders in the field use the DCSP markings, while newer equipment will be labeled as DCEN.

When the current flows from the welding machine to the workpiece, then across arc gap to the electrode, then back through the lead to the welding machine, the circuit is known as DIRECT CURRENT ELECTRODE POSITIVE (DCEP) or DIRECT CURRENT REVERSE POLARITY (DCRP).

These terms Electrode Negative and Straight Polarity will be used interchangeably in this book, as well as the terms Electrode Positive and Reverse Polarity.

ACHF Using An Unbalanced Wave Transformer

The letters "AC" indicate the welding current is Alternating Current. The letters "HF" indicate that a HIGH FREQUENCY voltage is used to maintain the alternating current arc. These letters are used often in specifications, blue-prints, and fabrication orders throughout the industry.

Power companies supply high voltage and low amperage current. The transformer of an alternating current welding machine changes the current to lower voltage and higher current or amperage for welding. The frequency remains the same at 60 cycles per second.

Each complete cycle of current contains a half cycle of straight polarity and a half cycle of reverse polarity. In the STRAIGHT POLARITY portion of the cycle, the welding current flows from the tungsten electrode to the workpiece. In the REVERSE POLARITY portion of the cycle, the welding current flows from the workpiece to the tungsten. Fig. 2-6 shows a sine wave form of one complete cycle of alternating current.

Normally, the current is unbalanced in GTAW. This happens because hot tungsten can emit (send out) electrons better than molten metal. The current flows more readily in one direction than the other. As a result of the unbalance, current flow during the reverse polarity part of the cycle will not equal the current flow during the straight polarity part of the cycle.

During each part of the current cycle, electrons will carry heat across the arc gap. Gas ions are formed from the inert gas. Ions are atoms positively or negatively charged as a result of having gained or lost one or more electrons. An ionized path develops through which the welding current flows. Fig. 2-7 shows the electron and gas ion flow for one complete cycle of alternating current.

In the straight polarity (SP) part of the cycle, the electrons leave the tungsten tip and impinge (strike) on the metal. Enough heat is created to melt the workpiece. The reverse polarity (RP) part of the cycle removes oxides from the surface of the material as the electrons flow from the surface of the metal to the electrode. This part of the cycle will also cause the tip of the tungsten to melt. The tip will then become rounded because most of the heat is directed to the tungsten.

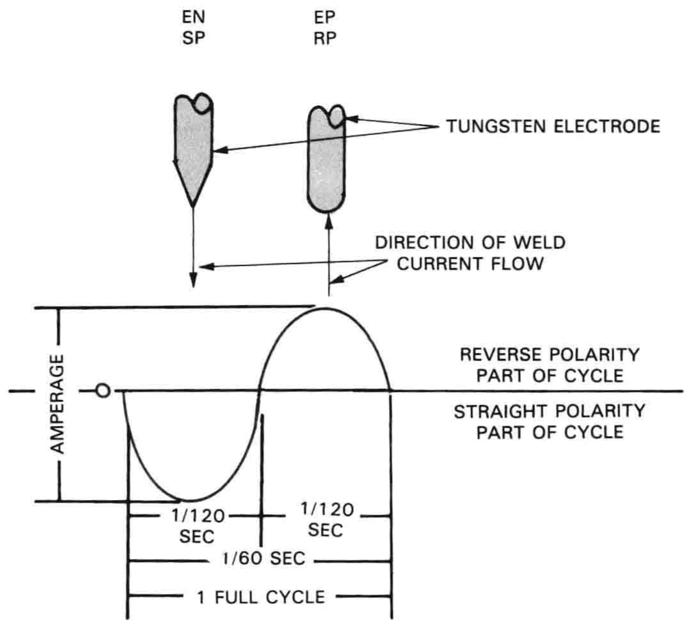

Fig. 2-6. The reverse polarity part of the cycle has less amperage output than the straight polarity part of the cycle in GTAW using AC. Alternating current will form a ball on the electrode on the reverse polarity part of the cycle.

Rectification

When alternating current flows across the zero amperage point, as in Fig. 2-6, it changes polarity. The arc will go out at this point. On the straight polarity portion of the cycle, electrode emission (sending out) of the electrons is sufficient to ignite the arc. All of the electrons are concentrated at the electrode tip. On the reverse polarity portion of the cycle, the electron flow is very poor because the electrons are scattered all over the workpiece surface. As a result, the arc may not ignite on that half cycle. When the arc does not restart because of the resistance of electron flow from a surface to a point, the condition is called RECTIFICATION. This condition may last for one or more cycles. Without the reverse polarity from the surface, the oxide will be absorbed into the weld. Welds containing oxides are usually porous and weak.

The HIGH FREQUENCY VOLTAGE GENERATOR was developed to provide the spark necessary to ignite the reverse polarity part of the cycle and to stabilize the arc. The high voltage causes the arc gap to become ionized, thus becoming a path for the electrons to flow.

ACHF Using a Balanced Wave Transformer

The balanced wave designation with this type of current means that the power supply has been changed. The sine wave form can now be changed from a normal unbalance of current to an even balance of current or any area inbetween. Fig. 2-8 shows a balanced wave form. A balanced flow of current is usually supplied by the use of series-connected condensors in the welding circuit. An alternative method is to place batteries in the circuit in such a way that the battery voltage will be additive to the reverse polarity half cycle. Balanced wave current flow will produce the following:

1. Best oxide cleaning action.
2. A more stable arc and uniform heating of the metal.
3. Minimum heating within the welding transformer.

Although sometimes desirable, a balanced wave is not essential for most manual welding applications. It is, however, desirable for many mechanized welding applications.

The electron flow is always from the tungsten to the workpiece. The gas ion flow is always from the workpiece to the electrode. In the DCSP or DCEN mode, the tungsten stays sharp or pointed and most of the heat is generated in the workpiece. See Fig. 2-7.

DCRP Direct Current Reverse Polarity

DCRP (DCEP) is the common abbreviation for this type of current. It is produced the same way as DCSP. The electron flow is always from the workpiece to the electrode. The gas ion flow is always from the electrode to the workpiece.

In the DCRP or DCEP mode, the tungsten electrode will receive most of the heat. A large tungsten electrode will be required. A ball will usually form on the tip of the tungsten. Fig. 2-7 shows the electron and gas ion flow for DCRP.

DCRP has limited use in GTAW, as most of the heat in the arc is directed to the tungsten instead of the workpiece. The penetration is shallow.

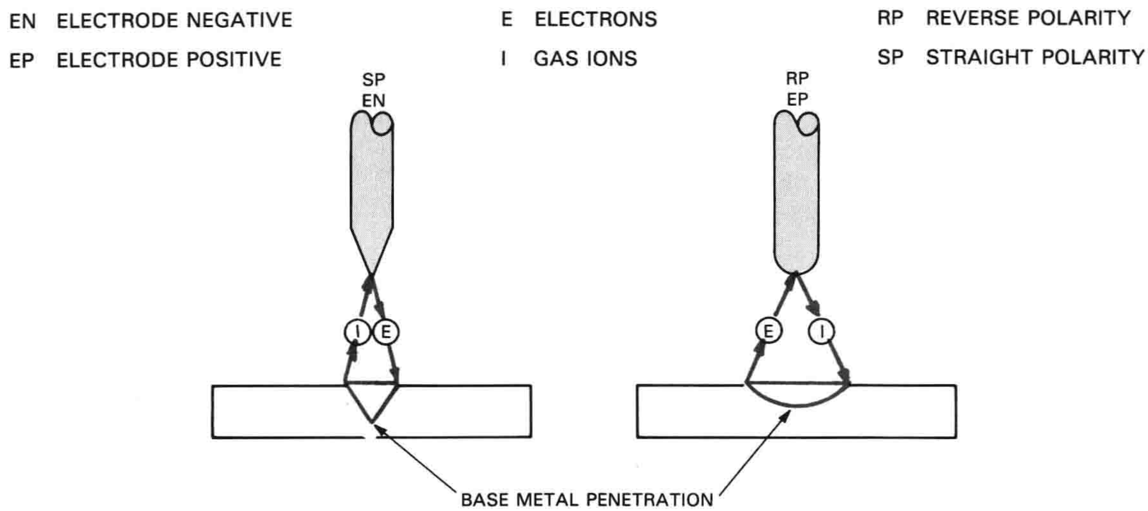

Fig. 2-7. Penetration into the base material is greater during the straight polarity part of the cycle. Electron flow is in the opposite direction of gas ion flow.

DCSP Direct Current Straight Polarity

DCSP (DCEN) is the common abbreviation for this type of welding current. Welding current produced by generators is direct current, and may be either straight or reverse polarity. Polarity changes are made by switches, or by changing the output leads of the machine.

Welding current produced by transformer-rectifiers starts out as alternating current. It is changed to direct current by rectifiers which allow only one polarity or one-half of the alternating current cycle to pass through as welding current.

STARTING THE ARC

How the arc will be started in GTAW depends on the system used and the type of power supply. Three methods are commonly used:

1. SCRATCH OR TAP START. This method is commonly used with motor generators or direct current rectifiers. The welder scratches or taps the workpiece creating a short circuit and an arc, allowing the current to flow. This type of arc start may contaminate the electrode or weld area if the