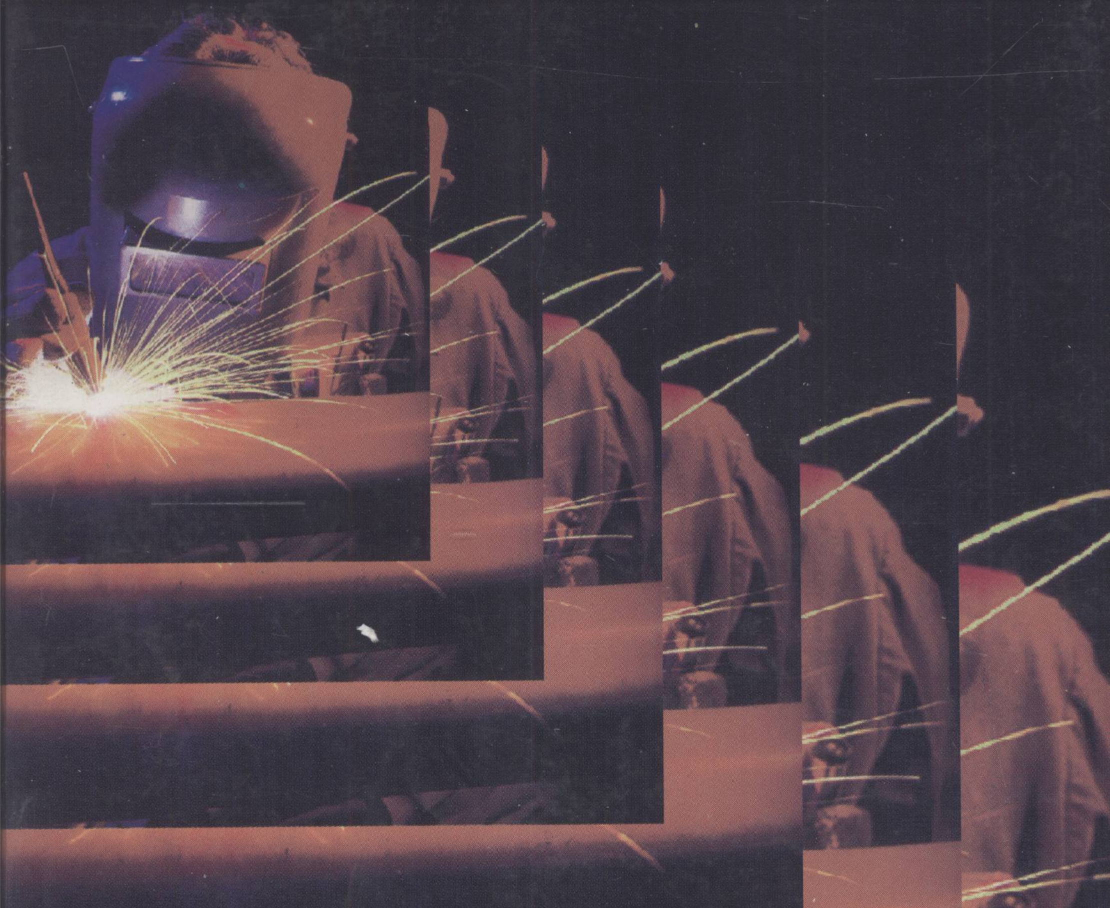

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Preface

Welding is one of the major and principal activities in today's shipbuilding and offshore industry. The performance of these industries as regards productivity, meeting delivery schedule, the product quality, etc. depends very much on the structural designs and welding technology adopted in these yards as well as the distortion control measures implemented during fabrication.

It may be of interest to note here that whether it is a ship or an offshore structure, huge subassemblies and assemblies are put together to get the final product. In the entire process, welding plays a very important role as far as productivity and quality of the end product is concerned.

Weld induced distortion is one of the major problem areas in ship and offshore construction. The problem becomes acute in case of thin panel fabrication. Naval vessels with weight restriction are using more and more of high tensile steels leading to the use of thinner plates. Unless suitable distortion control measures are taken, the fabricated components suffer substantial distortions rendering them unacceptable without fairing.

Hence the welding techniques and the associated weld distortion problems encountered in shipbuilding industries are very typical and they are to be dealt with from a view point of shipbuilding requirements. The welding and structural design engineers in a shipyard thus face a real challenge to deliver a distortion-free product and to minimize the post weld fairing requirement.

High performance vessels like planing craft, high speed catamarans, hydrofoil craft, etc. and naval vessels with weight restriction call for a material having high strength to weight ratio. Aluminum alloy is one such material which is being widely used for this purpose.

To achieve quality performance it is not merely enough to have suitable equipment but a clear understanding of the entire process is also required. To satisfy class requirements procedure approval is a must. Now to lay down a procedure, effects of the various welding parameters on weld quality and the cost effectiveness of the same are to be considered.

Unlike steel welding, aluminum welding is far more complicated because of the inherent thermo-physical properties of aluminum. Hence to achieve quality and class approved welding in aluminum, stringent process control is necessary. This can be achieved only through proper and adequate knowledge of all the process variables.

This book is the outcome of my experience of teaching Ship Construction and Welding Technology, and Marine Construction and Repair Techniques as regular courses in undergraduate and graduate curricula and various short term courses and projects carried out by me during the past 12 years. While teaching and working in this field, I felt the lack of a suitable book covering the detail aspects of welding and distortion control in the context of shipbuilding and offshore industry. This inspired me to get on this job and provide the practising engineers and students of welding technology with a comprehensive book on welding and distortion control in shipbuilding. The contents of the book have been logically organized and spread over five chapters.

Chapter 1 provides brief background and general introduction to arc welding and weld induced distortions.

Chapter 2 introduces the various aspects of arc welding processes. It deals with different types of power sources, various welding parameters and their effects, effect of edge preparation and shielding gases. The different welding methods as used in shipbuilding, namely SMAW, GMAW, GTAW, SAW and Electro-slag welding have been discussed at length. Also single side and multi-electrode welding techniques have been presented.

Chapter 3 covers welding distortions. It starts with explaining the distortion mechanism and subsequently introduces the various types of distortions encountered and their prediction methods. Suitable distortion prediction tools are needed to provide for the adequate allowances in the design dimensions to take care of possible weld induced distortions during fabrication.

Chapter 4 presents various distortion control mechanisms. The effect of design on weld induced distortions, implementation of shrinkage allowances, various distortion control measures like controlled heat input, structural fit-up, welding sequence, thermal tensioning and heat sink as applicable in ship construction are discussed in detail with real life examples. This will help the welding engineers and structural designers to implement effective distortion control measures and make production-friendly designs to achieve the goal of near zero distortion in the fabricated structures .which will eliminate to a great extent the tedious post weld fairing work.

Chapter 5 has dealt with aspects of residual stresses. The problem of predicting residual stress due to welding has long been recognized by ship designers and fabricators as very important but at the same time as a very difficult one to analyze. It thus becomes evident that the practising engineer would like to have a design tool to account for residual stresses and their effects. It is not the intent of the author to present in detail all the mathematics involved in the discussed methodologies. The interested reader is referred to other sources for this purpose. The emphasis is rather on how the ship designers and fabricators can effectively use the state-of-the-art methodologies available today for solving the residual stress problem.

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CHAPTER 1

Welding in Shipbuilding

1.1 INTRODUCTION

Shipbuilding is primarily an assembling industry. It consists of assembling precut plates and shapes into subassembly units. These units are subsequently assembled together into a much larger unit before being transferred to the erection berth. The assembly operations at every stage essentially mean fitup, alignment and welding. The quality of welding is not restricted only to the work done by the welder but depends on many other factors, viz. welding parameters, shielding medium, working environment, etc. Before the actual welding is done, all the earlier steps such as layout, plate edge preparation, fitup and alignment should be well planned with regard to achieving desired product quality.

From the standpoint of welder's comfort as well as weld soundness, adequate shelter must be provided during welding operations. Welding with shielded metal arc and any of the gas shielded processes where high winds prevail is likely to produce excessive porosity because of the disturbance of the arc shielding.

Selection of process and filler metal to be used depends on material to be welded, welding position, joint accessibility, joint design, accuracy of edge preparation, sequencing of work, suitability of welding equipment, and finally welder skill. To ensure consistency in welder skill, thorough training regarding the characteristics of the various types of electrodes and the preferable welding techniques for each is essential. A welding process and filler metal should be selected so that the weld deposit will be compatible with the base metal and will have mechanical properties similar to those of the parent metal. Generally, nothing like a standardized procedure exists, and procedures usually may not be transferred from one shipyard to another. Hence every shipyard should develop their own procedure to achieve the common goal of high productivity with highest quality.

Classification Societies require welding procedure qualification and welding performance qualification prior to performing any production welding.

The normal procedure for fabrication of subassemblies in shipyards is to lay the plates on a horizontal platform for flat panels or on a skid for curvilinear panels. The seams are welded on one side, the plate assembly turned over and the seams are finish welded on the second side, many a time after additional gouging operation. Assembly turning over and root gouging can be avoided by implementing single sided welding using suitable backing strip. In modern shipyards, all flat plate seams and many of the stiffening members are automatically welded.

To arrive at the proper overall dimensions, the subassemblies are fabricated by one of the two methods. In one case, the plates may be cut to finish size before they are welded into the assembly. In this case suitable allowance for shrinkage must be made for subsequent welding. In the other method, the plates are prepared with green material usually 25 to 50 mm around the periphery of the finished assembly. Subsequently the subassembly is trimmed to size after welding. This may be done in the shop or is done at site in the erection berth after necessary alignment. Depending on the erection location of a subassembly and its design, either of these methods can be used.

The quality of the welded subassemblies and assemblies depends not only on the quality of welding alone but also on its dimensional accuracy. The maintenance of good weld quality depends on the organization of welding operations as well as on the methods of inspection. A close cooperation among tradesmen, supervisors, welding engineers and designers is therefore essential to creating conditions suitable for producing sound welds.

Quality assurance in an organization starts at the top and the responsibility for it lies with the shipyard's top management. Quality can not be inspected into a product. Trained personnel and appropriate procedures must be in place prior to start of work. Suitable consumables, proper welding equipment and correct processes and procedures must be selected. The use of various welding processes and techniques may produce defects which are usually associated with a given process or technique. It is important to consider how the change in variables and techniques of a welding procedure can affect the probability of occurrence of certain types of defects. The regulatory agencies and the classification societies require the shipbuilder to inspect the hull and its components by various inspection methods to meet the required acceptance standards.

High strength and low alloy steels are being increasingly used in naval vessels as well as in some of the merchant ships. Initial qualification of both the welding procedure and the welders is required for these materials.

The panels, subassemblies and assemblies being welded are subjected to a thermal cycle of heating followed by cooling. This phenomenon gives rise to structural distortion and residual stresses. Their effect is more prominent in case of structures made of thinner plates. Extensive use of thin plates are made in naval vessels because of their stringent weight restriction. This leads to a difficult problem of distortion-free fabrication. Unless suitable measures are taken both at the design and production stages one can observe the so-called hungry-horse look on the hull of such naval vessels. Also excessive undulations of decks and superstructure bulkheads may take place.

Apart from the aesthetics point of view, the hull distortion may also adversely affect the hydrodynamic performance of a vessel. The deck and bulkhead undulations may give rise to problem of equipment installation. These weld-induced distortions may also cause the bows and sterns of ships to lift off the keel blocks by several centimeters. Suitable distortion control measures are therefore very much essential to produce ships with zero or minimum distortion.

CHAPTER 2

Arc Welding

Welding is a joining process by which two separate parts can be joined to make one integral part. Ideally there should be complete continuity between the parts and the joint area should be indistinguishable from the parent metal of the individual parts. This ideal situation is never achieved. However welds can be made in many ways, which give satisfactory service. Not every welding process is equally suitable for all types of metals or all types of joints. It is the knowledge base of an welding engineer which helps him to decide the appropriate welding process which will satisfy all the essential and necessary fabrication requirements.

The joining of two parts can be achieved if the electrons can be shared by the atoms across the interface. This will result in an ideal welded joint. Hence the simplest welding process would be the one in which the two parts to be joined will be machined with atomic precision. When these two surfaces are brought together in vacuum, bonding between the atoms across the interface takes place. In this case the welding process might be very simple, but the surface preparation with the degree of precision and the required vacuum for the level of cleanliness is not practically feasible in case of industrial structures. However this process might become feasible in space where ultra-high vacuum is already there.

In situations of heavy construction as in shipyards, this problem of atomic contact between the parts to be joined is solved by applying external heat leading to fusion of the parts to be joined. Essentially all welding processes must satisfy four basic requirements:

- A supply of energy to achieve union by fusion or pressure.
- A mechanism for removing superficial contamination from the joint faces.
- Avoidance of atmospheric contamination.
- Control of weld metallurgy.

Welding process can be classified according to the way in which these four basic requirements are satisfied. Here only the fusion welding process using electrical energy will be dealt with.

2.1 ARC WELDING POWER SOURCES

Arc welding power sources can be as varied as the welding processes. To meet the unique electrical requirements of various arc welding processes many types of power sources are necessary. The power sources needed for Shielded Metal Arc (SMAW), Gas Metal Arc (GMAW), Flux Cored Arc (FCW), Gas Tungsten Arc (GTA), Submerged Arc (SAW), and Electro Slag (ESW) are described.

The line voltage available is too high to use directly in arc welding. Arc welding involves low-voltage, high current arcs between an electrode and the work piece. Therefore the first function of arc welding power source is to reduce the high line voltage to a suitable voltage range of usually 20 to 80 V. Either a transformer, solid-state inverter or a motor-generator set can be used to obtain this rated terminal or open circuit voltage appropriate for arc welding. The same power source also provides a high welding current generally ranging from 50 to 1500A. The typical output of a power source may be alternating current (ac) or direct current (dc). The output power may have characteristics of either constant-current, constant-voltage or both. It may also provide a pulsing output mode. A schematic presentation of the basic elements of an arc welding power source is shown in Fig 2.1

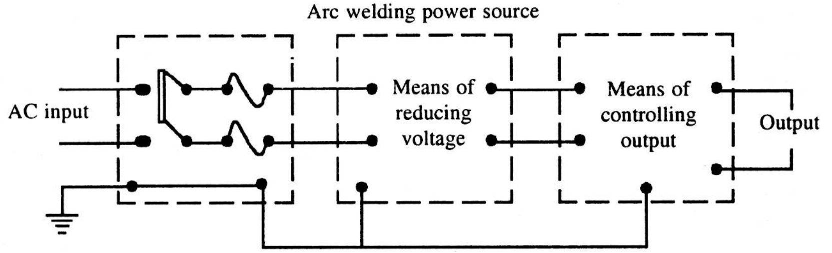

Fig. 2.1 Basic element of an arc welding power source

Apart from the welding processes that use pulsed current, welding power sources are commonly classified as constant-current or Drooping and constant-potential or Flat. Such classifications are based on the static volt-ampere characteristics of the power supply and not on the dynamic characteristics. Generally, the word 'constant' is partially true. Constant-potential power sources are usually much closer to constant-voltage output than constant-current sources are to constant-current output. However specialized power sources are available which can hold the outputs truly constant. The fast response solid-state sources can provide power in pulses over a broad range of frequencies. These are known as pulsed power sources.

Volt-Ampere Characteristics

The effectiveness of all welding power sources is determined by two kinds of operating characteristics, each of which affects welding performance differently. They are defined as static and dynamic characteristics. Both affects arc stability but in different ways depending on the welding process. Static output characteristics can be readily measured under steady state conditions by conventional test procedures using resistive loads. A set of output-voltage versus output-current characteristics curves also known as volt-ampere curves are usually used to describe the static characteristics.

The dynamic characteristics of an arc welding power source is determined by measuring the transient variations in the output current and voltage that appear in the arc. These characteristics describe instantaneous variations. Their occurrence is very short of the order of 0.001 s.

In general welding arcs operate in changing conditions. In particular, transients occur,

- During the striking of an arc,
- During rapid changes in arc length,
- During the metal transfer across the arc,
- In the case of AC welding, during arc extinction and reignition in each half-cycle.

These arc transients can occur in 0.001 s, the time interval during which significant change in ionization of arc column occurs. The power source must respond rapidly to these demands. This makes it important to have a dynamic characteristics control of the power source. The static volt-ampere characteristics have little significance in determining dynamic characteristics of an arc welding system. The dynamic characteristics of an arc welding power source are influenced by the following design features,

- Local transient energy storage, such as dc series inductance or parallel capacitance circuits,
- Feedback controls in automatically regulated systems,
- Modifications of waveforms or circuit operating frequencies.

Controlling these characteristics results in improvement in arc stability which leads to,

- Improvement in uniformity of metal transfer,
- Reduction in metal spatter,
- Reduced weld pool turbulence.

Manufacturers of welding power supplies give the static volt-ampere characteristics, however there is no universally accepted method by which dynamic characteristics can be specified.

2.1.1 Constant-Current Power Source

The typical volt-ampere characteristics of a conventional constant current power supply is shown in Fig. 2.2. This is also known as drooping power source because of the drooping nature of the volt-ampere curve. These power sources may have open circuit voltage adjustment in addition to output current control. By changing either of these controls, the slope of the ampere curve will change. Constant-current power sources are typically used for SMAW, GTAW and SAW. These machines can be inverters, transformer rectifier or generators.

The open circuit voltage of constant-current, rectifier type power sources vary depending on the intended welding application. They range from 50V to 100V. The effect of the slope of the V-A curve on power output is shown in Fig. 2.2. The curve-A indicates an open circuit voltage of 80V. An increase in arc

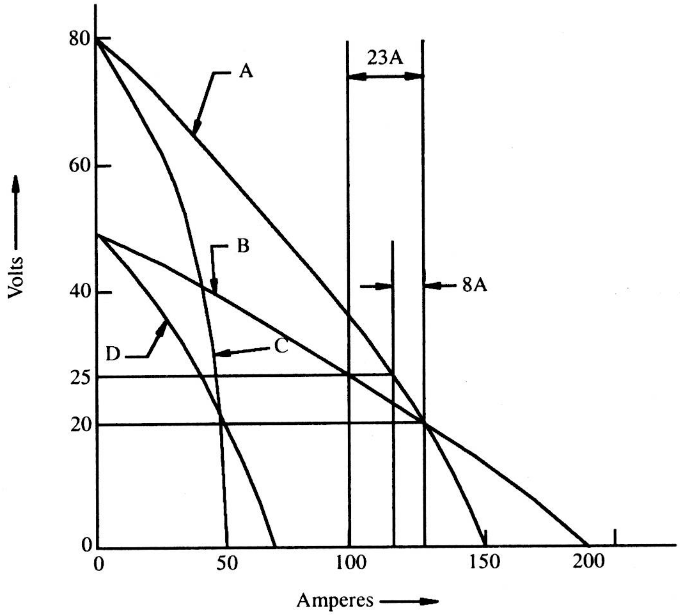

Fig. 2.2 Typical Volt-ampere characteristics of a "Dropping" power source with adjustance open circuit voltage

voltage from 20V to 25 V i.e. for a 25% change, it would result in a decrease in current from 123 A to 115 A, i.e. 6.5%. The relative change in current is much smaller. Therefore in case of SMAW, a small change in the arc length due to manual operation resulting in a change in arc voltage will lead to a much smaller change in welding current. The net effect is electrode melting rate remains fairly constant. If the open circuit voltage is set at 50V (curve-B), for the same change of arc voltage, i.e. from 20V to 25V, the change in current would be from 123 A to 100 A, i.e. 19%, which is much higher than the previous case. Hence, a less skilled welder would prefer a power source with much steeper V-A curve, so that the current remains more or less constant even if there are fluctuations in arc length. However, a skilled welder might prefer a power source with much flatter V-A curve, because he can substantially vary the welding current hence the metal deposition by changing the arc length. This could be useful in case of out-of-position welding because a welder could control the electrode melting rate and molten pool size.

Current control, as shown by curves C and D, is used to provide lower power output. It would result in V-A curves with higher slope resulting in a more constant-current output for greater changes in voltages.

2.1.2 Constant Voltage Power Source

A typical volt-ampere (V-A) curve for a constant-voltage power source is shown in Fig. 2.3. Ideally the V-A curve should have been flat, i.e. parallel to current axis. However because of internal electrical impedance there is a minor drop in the output voltage with increasing current. This leads to a V-A curve with slight

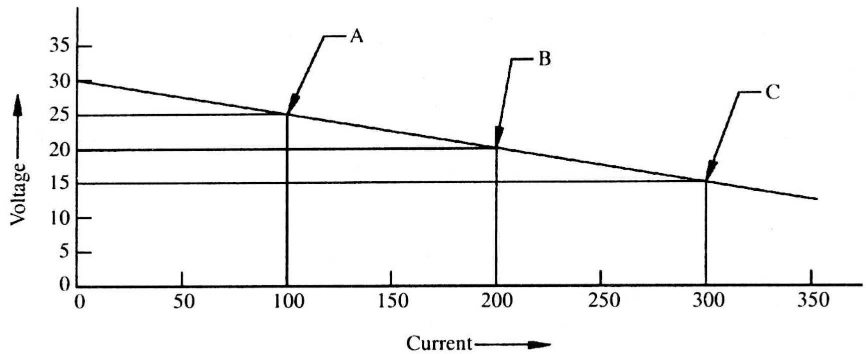

Fig. 2.3 Volt-Ampere characteristics for a constant Voltage Power Source

downward slope. This slope therefore can be changed by changing the internal impedance.

It can be seen from Fig. 2.3 that with increase or decrease in arc voltage to A or C i.e. ±5V or 25% change, will produce a much larger change in current (±100A or 50%). Hence welding processes having constant electrode feeding mechanism, such as gas metal arc (GMAW), submerged arc (SAW) or flux cored arc (FCAW) maintaining constant arc length are suitable for constant-voltage power sources.

A slight change in arc length will cause a substantial change in welding current. This will automatically increase or decrease the electrode melting rate to regain the desired arc length. This effect is known as self regulation. The difference between static and dynamic characteristics of a power supply can be explained from Fig. 2.3. For example during short circuiting metal transfer in GMAW, the welding electrode tip touches the weld pool, causing a short circuit. At this point the arc voltage almost drops to zero and there is a rapid increase in current. However this rapid increase in current gets limited by the circuit inductance. If the power supply responded instantly, very high current would immediately flow through the welding circuit quickly melting the short-circuited electrode tip and freeing it with an explosive force. This would result in dispelling the weld metal as spatter. Dynamic characteristics designed into these power sources control the rate of current change, thus decreasing the explosive force.

A typical constant-voltage (constant-potential or Flat) power source has a negative slope of 1-2V/100A. Machines with V-A curves having slopes upto 8V/ 100A are still referred to as constant-voltage power supplies.

2.1.3 Pulsed Mode Power Source

Pulsed power supply is used to reduce the arc power while retaining the desirable spray transfer. The concept is based on the fact that metal transfer from the electrode wire takes place in either of the two following ways;

- **Spray transfer**
  In this mode when the current exceeds a critical level, metal transfer takes place in the form of a few hundred drops per second.

- **Globular transfer**
  In this mode when the welding current is below the critical level, the metal transfer takes place in the form of less than 10 drops/s.

This critical current at which transition from globular to spray transfer takes place is known as transition current. By pulsing the current between these two regions, the desirable quality of spray transfer can be achieved while reducing the average current significantly. This also reduces deposition rate. Because of this GMAW with pulsed power supply can be used to weld in all positions as well as thinner plates even sheet metal. The current level during the globular transfer interval is kept sufficiently low so as to avoid any metal transfer however high enough to sustain ionization in the arc region. This current is more commonly known as 'background current' which helps in keeping the arc alive. Whereas in the spray interval, the current is raised above the transition current for sufficient time, enough to allow transfer of one or two droplets. This current is known as 'pulse current'. Power supplies are designed with necessary controls to deliver the controlled output for pulsed GMAW.

With solid-state power sources such as inverters, it is now possible to have a control over all the pulse variables, viz. peak current, background current, peak current time and background current time (Fig. 2.4). By controlling these variables it is possible to have a total control of metal transfer, allowing only single drops to transfer per pulse, while retaining the background current.

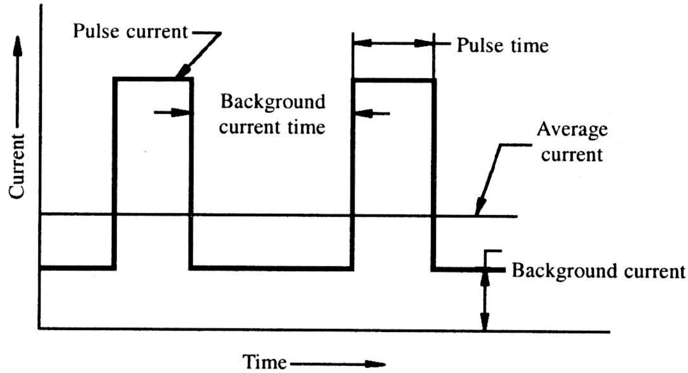

Fig. 2.4 Pulsed power source variable

One of the major drawbacks of a pulsed power source is, it is difficult to set the variables for a given welding requirement. Once the variables are set, it is also difficult to reset them should any of the variables needs to be changed. For example, a number of variables need to be reset if the wire feed speed is changed. Such problems can be overcome by having electronic and microprocessor controls to set the optimum pulse conditions for a given wire feed speed setting.

Figure 2.5 is a diagrammatic representation of the circuit elements of a typical synergic pulsed power source. The word 'synergic' means 'several things acting as one'. In synergic pulsed GMAW machines, the pulse variables are set automatically based on the required wire feed speed for a given joint geometry.

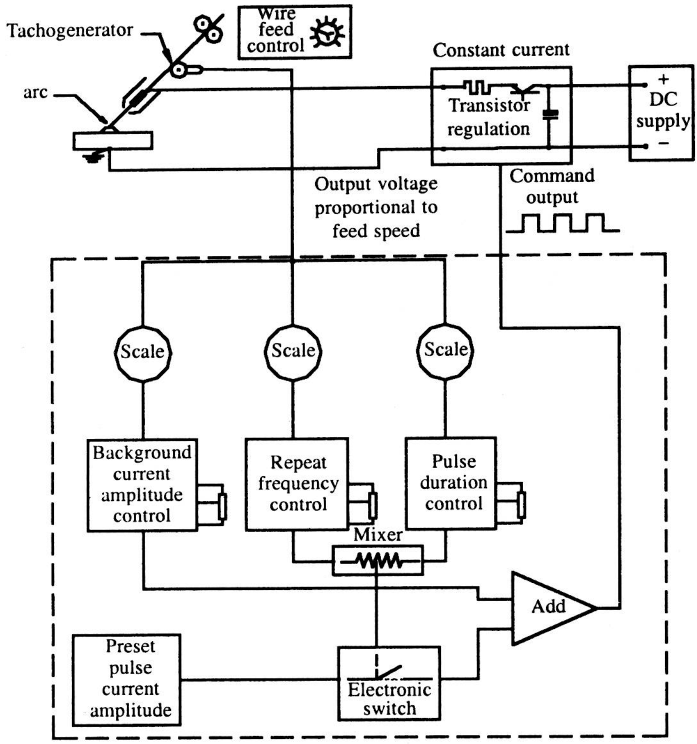

Fig. 2.5 Basic circuit for synergic pulse operation

Through the use of electronic controls, it is possible to choose a variety of synergic curves to satisfy particular applications. Synergic power supplies can be so designed that it can transfer single drops with each pulse by making instantaneous adjustments of the pulse frequency and width depending on the voltage sensed across the arc. Pulsed GMAW power sources typically range up to 500A peak current and the frequency various from 60 to 200 Hz.

Review Questions

1. What common welding processes are most likely to use a DC constant current power source?
2. What common welding process is most likely to use a DC constant voltage power source?
3. Would you use a constant current or a constant voltage DC power source for GTAW? What about SMAW? Would you most likely use a constant voltage or constant current DC power source for GMAW welding? Name one welding process that might use constant current DC, constant voltage DC, or an AC machine.
4. What effects do electrons have upon the penetration of the arc into the base metal?
5. What is straight polarity? Reverse polarity?