1924

A discussion of electric welding

Peter Fergus Thompson

A DISCUSSION OF ELECTRIC WELDING

BY

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A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree Of

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

Rolla, Mo.

1924

Approved by I. H. Lovett

Associate Professor of Electrical Engineering.

Thesis: A discussion of electric
welding. Thompson. 1924.

A DISCUSSION OF ELECTRIC WELDING

This thesis deals with the different processes, methods and uses of Electric Arc Welding; and tests made in the laboratory with Direct and Alternating Current.

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ELECTRIC WELDING (HISTORY).

The application of electrical energy has occupied the minds of some of the foremost inventors during the past forty years and the development that has taken place in this branch of engineering has been remarkably rapid. One of the most interesting developments of electrical energy is that of electric welding.

All electric welding may be divided into two general classes- arc welding and resistance welding. Precussion welding is a form of resistance welding and was developed in 1905. In each class there are a number of ways of obtaining the desired results.

Arc welding is the older process and was first used in 1881 for uniting parts of storage batteries. The work was connected to the positive pole of a current supply capable of maintaining an arc. The other pole was connected to a carbon rod. An arc was struck by touching the carbon rod to the work and withdrawing it slightly. The heat generated fused the metal parts together, the arc being applied in a way similar to that of the flame of the modern gas torch. Of the several early methods of arc welding, there are the Zerner, the Bernardos, the Slavianoff and the

Strohmenger- Slaughter processes, as well as some modifications. Slavianoff substituted a metal electrode for the carbon electrode. This method is known as the metallic-electrode process. The Strohmenger-Slaughter, or covered electrode, process is similar to the Slavianoff except that a coated metallic electrode is used; either direct current or alternating current may be used for energy.. The resistance or incandescent process, was conceived by Elihu Thomson some time in 1881, but was not developed until 1883 to 1885 when he developed and built an experimental machine. Some of the greatest manufacturing industries in the world have been built up on the basis of the invention made in the electrical field; and, furthermore, the practical application and uses of the electric current are by no means limited to the fields it has already invaded. One of the many uses of electric energy in the metal working trades is found in its application to electric welding. Although the electric welding processes passed out of the experimental and into the practical stage many years ago, the subject is one that is still rather vague in the minds of most mechanics. Electric welding, however, plays an important part in the

industries at the present time, and several large manufacturing plants are operating, that devote their entire attention to the manufacture of articles adapted to the use of electric welding as a basic procedure in the production of these goods.
Without the methods of electric welding, many of these products would have to be manufactured in an entirely different way and, in many cases, at a greatly increased cost.

ELECTRIC ARC WELDING.

Electric arc welding is the transformation of electrical energy into heat through the medium of an arc for the purpose of melting and fusing together two metals, allowing them to melt, unite, and then cool. The fusion is accomplished entirely without pressure. The heat is produced by the passage of an electric current from one conductor to another through air which is a poor conductor of electricity, and offers a high resistance to its passage. The heat of the arc is the hottest flame that is obtainable, having a temperature estimated to be between 3,500 and 4,000 degrees Centigrade (6,332 to 7,232 degrees Fahrenheit). The metal to be welded is made one terminal of the circuit, the other terminal being the electrode. By bringing the electrode into contact with the metal and instantly withdrawing it a short distance, an arc is established between the two. Through the medium of the heat thus produced, metal may be entirely melted away or cut, added to or built up, or fused to another piece of metal as desired. A particularly advantageous feature of the electric arc weld is afforded through the concentration of this intense heat in a small area, enabling it to be applied just where it is needed. Direct-current is now more generally used for arc welding than alternating-current. When using direct-current, the metal to be welded is made the positive terminal of the circuit, and the electrode is made the negative terminal.

Regarding alternating-current it is obvious that an equal amount of heat will be developed at the work and at the electrode, while with direct-current welding we have considerably more heat developed at the positive terminal. Also in arc welding the negative electrode determines the character of the arc, which permits of making additions to the weld in a way that is not possible with alternating-current. Since the work always has considerably greater heat absorbing capacity than the electrode, it would seem only reasonable that the direct-current arc is inherently better suited for arc welding work. Electric arc welding is inherently a low voltage application for electric power. For example an arc drawn between a metal plate and a carbon electrode will under most conditions operate at a potential of 35 to 50 volts, whereas an arc drawn between a metal plate and a metal electrode will operate at a potential of 15 to 35 volts. The high thermal efficiency of the electric arc for welding purposes is due to the fact that the heat is produced largely in the metal of the positive electrode which is from 3 to 10 times the thermal efficiency of a combustion flame used for the same purpose, owing to the fact that in the combustion flame a large part of the heat is wasted by conduction and deflection of the flame from the point at which molten metal is required. There are two systems of electric arc welding, based on the type of electrode used, known as the carbon (or graphite) and the metallic electrode processes. The latter process is also sub-divided into those using the bare and the covered metallic electrode.

ELECTRODES.

Metallic Electrodes.

The use of metallic electrodes for arc welding has proved more satisfactory than use of carbon or graphite electrodes which necessiate feeding the new metal into the arc by means of a rod or wire which is melted. The chief reason for this is that when the metallic electrode process is used, the end of the electrode is melted, the molten metal being carried through the arc and deposited at the other end of the arc on the material being welded; at which point the material is in a molten state produced by the heat of the arc, thereby producing a perfect union or fusion with the new deposited metal. In metal electrode welding a very wide variety of metal electrodes are used. Practically any dead soft iron or steel wire can be used for the metal electrode process provided it is given a coating of whitewash before being used. Whether dead soft steel is covered with whitewash or not the general results obtained by using it for the metal electrode process are about the same, regardless of the impurities present or the relative percentages of the various constituents of the metal. As the percentage of impurities such as carbon, manganese and nickel are increased in the welding wire the tendency is to increase the tensile strength of the metal in the weld. However, in bare wire welding there is practically no difference in the material added regardless of what the original analysis of the electrode might have been, so far as ductility is concerned.

The use of covered electrodes permits the use of alloy steels for the metal electrodes. Under certain conditions the use of the covering on the electrode will give an appreciable degree of ductility to the metal deposited by the electric arc welding process. The presumption is that this is due to the fact that the oxygen and nitrogen of the atmosphere is to a certain extent excluded from the hot metal during the welding process. Covered electrodes are of two general classes. The first class being the electrode which has a heavy covering of scientifically prepared slag which contains a deoxidizer and which most completely protects the molten metal from the action of the gases in the atmosphere. The second class of covered electrodes is the type which has a very thin covering on the wire. The attempt is made with the thin covering to obtain the same results as far as protection is concerned without the disadvantage of manipulating the heavy coating of slag during the welding operation.

Wire for metallic arc welding must be uniform, homogeneous structure, free from segregation, oxides, pipes and seams. The size, in diameter, ordinarily required are 1/8 in., 5/32 in., and 3/16 in. and occasionally 3/32 in. The proper size of electrode is determined from the size of the piece to be welded, class of work and the current to be used. The composition of the mild steel electrodes, commonly used, is around 0.18 per cent carbon, and manganese not exceeding 0.05 per cent, with only a trace of phosphorus, sulphur and silicon.

Carbon Electrodes.

Where carbon electrodes are used for welding purposes it has been found that the graphite electrode as distinguished from the hard carbon electrode, yields longer life than any other. The current density used in an electrode depends largely upon the character of the work done. It has been found that high current density in a carbon electrode adds to the stability of the arc and makes it more easy for the operator to control. On the other hand, a low density in the electrode means longer life and less heating of the electrode holder. The difference between carbon electrode welding and metal electrode welding arises from the fact that the arc is drawn between the carbon electrode and the work and also that the melt bar is fed into the arc separately, that it does not carry the arc's current as is the case in metal electrode welding. Carbon electrode welding practice is in every way similar to welding with oxy-acetylene flame.

The use of metallic electrodes for arc welding has proven more satisfactory than the carbon or graphite electrodes. In the hands of an experienced and careful welder, very good results can be obtained with the carbon electrode process. However, if the operator is inexperienced or careless, he is liable to fail to produce good fusion continuously due to feeding in the new metal too rapidly. As a result, the new metal will flow over portions of the work which have not been brought to the molten or fusing state. Probably the chief field of usefulness for the carbon electrode is that of cutting or for rapid repair welding where strength of the weld is not as important as the speed of doing the work. In the carbon electrode process, the negative terminal or electrode is a carbon pencil from 6 to 12 inches in length and from 1/4 to 1-1/2 inches in diameter. It is not practical to weld with the carbon electrode in overhead work or on a vertical surface, but there are many classes of work which can be profitably done by this process. Having electrode material of proper physical, chemical and electrical characteristics is one of the chief requisites in welding mild steel.

Electric Arc Welding Machines.

Direct Current Machines.

As the alternating-current arc varies from a maximum to a minimum at each current reversal, it was formerly not thought suitable for welding. The direct-current arc, on the other hand, is practically steady; so direct-current is used; only a low voltage is required. The metallic arc requires from 15 to 25 volts, while the carbon arc requires from 35 to 50 volts according to the equipment used. Special welding equipment in the form of generators and control apparutus is used only in order to obtain current at the required voltage economically. As far as welding is concerned, work can be done with almost any direct-current voltage up to 550 volts having the necessary resistance ballast. As this is done by inserting resistance in series with the arc to absorb the excess voltage, it is plainly an inefficient process, as the voltage absorbed by the rheostat is wasted. In order to avoid these losses, therefore, the various manufactures of electric welding apparutus have developed special low-voltage generators and methods of control that give the maximum of efficiency combined with flexibility and current protection.

There are three types of direct-current equipment on the market, which may be described as the constant-voltage, variable voltage, and the constant-current types.

The constant-voltage type is a motor-generator set that takes power from the mains and delivers on the generator end a practically constant low-voltage. The resistance is used between the generator and the welding arc to determine the current and to limit the current at short circuit. The power used in the resistance is wasted. Plate I is a diagram of the connections for an C.& C. Electric & Mfg. Company constant-voltage circuit. The generator is a flat compound 60 volt generator. This circuit gives automatic control of the welding current at all times. When the operator brings his electrode into contact with the work, the current is limited by all the resistance in the circuit, but when he draws his arc, the automatic contactor cuts out part of the resistance and allows the current to come up to the amount required for welding. Should the operator attempt to use more current than has been determined to be proper for the job, a self closing circuit-breaker acts immediately, interrupting the circuit, but permits resumption of welding, without it being necessary to close the circuit mannually. Welding circuits and control of welding circuits differ according to the make of the welding outfit.

The variable-voltage type is a motor-generator set in which the voltage supplied by the generator is variable, the generator delivering practically the voltage required by the arc. Plate II is a diagram of the connections of a Lincoln Variable Voltage welding outfit. This type of equipment was the first successful type eliminating the resistance ballast from the circuit entirely. The generator field is separately excited series field "bucking". The open circuit voltage may be anything between 40 and 100 volts. The reduction in voltage to that required by the arc is brought about by the "bucking" series field and armature reaction. Adjustment of the amount of current in the arc circuit is made by diverting current from the "bucking" series field. Additional stability of the arc is insured by the stabilizer, this being a high inductive low-resistance coil connected in the welding circuit and serving to correct momentary fluctuations of current.

The constant-current type is also a motor-generator set that takes power from the shop mains and delivers on the generator end the current required for welding without the use of resistance ballast. The essential characteristic of the generator is such that the short-circuit current is limited without the use of resistance ballast; inductive ballast being used to stabilize the arc. The constant-current type of welder has been developed to meet the demand for an outfit that will produce a welding current of constant value, regardless of the length of arc, and that can be installed at any desired location in the shop. Machines of this type are so made that the voltage varies automatically as operating conditions change, thereby, making apparatus of this type suitable for all kinds of shops.

A constant-current closed circuit arc welding machine is made by the Arc Welding Machine Company. This set consists of two units: The generator proper which furnishes the energy for welding, and the regulator which automatically maintains the current at a constant value. The regulator is excited from a separate source, and, by varying its excitation with an ordinary field rheostst, the main welding current may be set at any value within the range of the machine that is desired, and once set it will automatically maintain that value. This method has the advantage of a series distribution, namely, the size of wire is uniform throughout the system and carries a uniform current, independent of the length of the circuit as well as of the number of operators.

Plate III is a simple schematic welding circuit of a variable-voltage machine made by the Westinghouse Electric and Manufacturing Company.

Alternating Current Machines.

The development of alternating-current machines has not been as rapid as that of direct-current machines, due to the theory that there is more heat in the positive electrode for iron arcs. But this has been proven untrue by scientific authorities. Direct-current machines strive for either a constant voltage or constant current, but the heat of the arc is the product of both the current and the voltage, across it. The ideal conditions being the constant product of the current-volts. In alternating-current machines the wattage of the product of the current and the voltage, is held constant. This constant wattage, hence constant heat, should be varied to suit the different conditions of metals, electrodes and work. The alternating-current machine holds this wattage without moving parts; hence the heat is substantially constant for any given setting, and it is claimed that as soon as any person becomes accustomed to the sound and sight of the arc and can deposit the molten metal where he desires ,it is impossible to burn the metal from too much heat or make cold-shut welds from too little heat. The amount of heat generated is controlled by means of an adjusting handle on the transformer together with taps arranged on a plugging board. Almost all alternating-current welding is done with metallic electrodes and very little carbon electrode. welding has been done up to the present time.

Plate IV is a diagram of an alternating-current welding circuit with series resistance. With a voltage of 120 volts or higher a resistance is used in the circuit to reduce this pressure to approximately 20 volts at the arc. Welding under these conditions is done by using coated or special electrodes of the various types. This method is very inefficient from the standpoint of power input to the power delivered to the arc,and it is always necessary to ground one side of the circuit unless the work is insulated from the ground. However, when welding has to be done in locations where circuits are not provided to care for the operation of motor-generator type machines, this method can generally be used to advantage and good welding can be done under these conditions.

Plate V is a diagram of an alternating-current welding circuit with series reactance. By use of a simple reactance, either from 110 or from 220-volt alternating-current circuit, usually sixty cycles, (as welding is very difficult where the frequency is 25 cycles or lewer) good welding can be done. It has the same disadvantage as the series resistance method, that is, unless the work is insulated it is necessary to ground one side of the circuit. It is very desirable to use covered electrodes when possible in welding from a 110-volt circuit, but with 220-volt circuit any type of electrode can be used.

Plate VI is a drawing of the transformer and connections of an alternating-current arc welding machine made by the Electric Arc Cutting and Welding Company.

The machine consists of a transformer with no moving parts, and there is nothing to prevent its lasting indefinitely, except accidental mechanical injury or abuse. Different metals, electrodes, and conditions in the shop require various amounts of heat, and varying temperature and these adjustments are obtained by an adjustment handle on the transformer together with taps on the plugging board. The largest set is a 60-cycle type weighing about 200 pounds., which places it in the portable class. The set can be made single phase, two phase three wire, two phase four wire, to operate across the outside wires of the two phase system or from a three phase power supply.

This outfit can be made especially for welding and for cutting or for combination of welding and cutting and can make use of bare wire, slag covered, gaseous fluxed or carbon electrodes.

Some of the advantages of this machine are: Low first cost, low cost of operation, greater speed, greater penetration, portability, flexibility, practically no maintenance, low cost of installation and any type of electrode can be used.

APPLICATION OF ELECTRIC ARC WELDING.

The field for electric arc welding is unlimited. Practically every industry employing iron or steel, or other alloys, can utilize it to advantage. The process is used not only for joining two pieces of metal, but also for cutting metal, building on or adding to other metal parts. New fields for the sucessful application of electric arc welding are being discovered every day.

Electric Arc Welding in Manufacturing Plants.

The electric arc welding has become a well reconized process in manufacturing plants for repairs and reclamation work. It is also being used as a manufacturing process, superseding riveting and other means of joining metal parts. Some fâmiliar examples of this class of work are: ship construction, manufacture of pressure vessels, steel barrels, caskets, tanks boilers and automobile frames. And excellent economies have been affected by the use of the arc process, especially when employed in quantity production.

Machine Shops.

Arc welding makes it possible to rectify errors in machining or to build up worn parts of equipment by welding on additional metal and then re-machining. Sometimes, defects develop in castings after considerable machining has been done; in such cases, the casting may be saved by use of the electric arc. One of the most important economices in arc welding is that of welding small sections of high speed tool steel to a shank of ordinary machinery steel.

Steel Mills.

There are many places in steel mills where the arc welding process can be employed with a saving of time and expense over the old methods. The ends of driving spindles, pinions, or wobblers which have become badly worn, and would have to be scrapped, can readily be built up to their original size, machined and put back into service. An important application of the electric arc in this industry is its use to burn out tap-holes in the blast furnace.

Foundries.

Broken and defective steel castings can be reclaimed by arc welding. Steel castings found defective from sand spots, blow holes or shrinkage cracks can be quickly repaired with satisfactory results. When these defects develop in machining, they can be filled up without removing the casting from the machine and the work continued with little loss of time. The risers and sink-heads can be cut off castings quickly and more cheaply than by any other method.

Railroad Shops.

Arc welding finds an extensive field of application in railroad shops. Worn or broken parts of cars such as truck frames, brake hangers, journal boxes, drawheads and underframing, can nearly always be repaired without taking the truck from under the car. Locomotive frames can be welded and tires built up without removal or dismantling of the locomotive. Flues are welded in and the results obtained are more satisfactory than any other method of welding.The arc welding process is capable of effecting many economices in railroad work on account of the numerous repairs which can be made to the rolling stock without the necessity of dismantling it. There is practically no end to the application of arc welding in railroad shops.

Shipyards.

There has been more advance recently of arc welding in ship building than any other industry. Formerly it was used only for incidental work on repairs of boilers and engine room equipment, it is now being applied to all parts of ship construction, and will shorten the time and reduce the expense of ship construction.

Metals That Can be Welded.

Theoretically it is possible to weld any two metals; practically, there are limitations. The metals that are more commonly welded by the electric arc process are: wrought iron, rolled steel, cast steel and cast iron. Many others metals as, copper, aluminum, bronze and brass have been welded..

Wrought Iron and Rolled Steel.

Wrought iron and rolled steel are the metals best adapted to electric arc welding, and under proper conditions they can be welded with unvarying success. The carbon and metallic electrode processes have both been used with equal suceess.

Cast Steel.

The metal electrode process offers the easiest solution to the welding of cast steel for the reason that the effect of expansion and contraction is minimized with this process. It is never necessary to pre-heat a casting if the welding is to be done by the metallic electrode process. Due to internal stresses set up in cast steel due to welding it is hard to weld cast steel.

Cast Iron.

Cast iron offers the greatest difficulty to the welding operator of any metal he has to weld commercially. Cast iron owing to its low cost is used in building machines more than any other metal. But due to the fact that cast iron has a low ductility and a inappreciable degree of elasticity, the number of breaks in cast iron castings is high. In welding cast iron the metal electrode process is used, using soft steel or iron electrodes. The advantage of this practice lies in the fact that the welding can be done without pre-heating. Many times heavy machine parts can be welded in place thus saying the cost of taking it out and pre-heating it as would be necessary with the carbon arc process. A large number of cast iron welding jobs have been done successfully.

The most important application of welding in the other metals is that, of welding copper bonds to street railway tracks. The rest of the metals have been welded but not to any commercial degree.

Test made in the Laboratory.

A welding circuit was set up as shown in the diagram on plate VII. Direct and alternating-current circuits being used as a source of supply.

Direct Current Circuit.

The circuit was set up as shown in drawing on plate VII. A 110-volt, 44 ampere, motor-generator being used as the source of supply. A variable resistance and a ammeter were placed in series with the arc, and a voltmeter was placed across the arc to read the drop across the arc. Metal electrodes were used; one a bronze covered steel electrode and the other a nickel steel electrode. The readings as listed in table I were obtained from the experiment, they are not very accurate due to the fact that the arc could not be held steady. It takes an experienced operator to weld and keep a constant current. The results obtained from this experiment show that with any source of direct-current that welding can be done. But this method of welding is very inefficient and should only be used in case a welding machine is not available.

Alternating Current Circuit.

The wiring diagram for the alternating current circuit test was the same as that for the direct current test as shown in Plate VII, except that the source of power was taken from a 110-volt alternating current circuit. No readings were taken as it was impossible with the conditions present to obtain a welding heat at all times. A bronze covered steel electrode was used in this test. The failure of this test may have been due to the electrode used or to the product of the volts and current across the arc not being sufficient for a welding heat. Although it is very difficult to weld with alternating-current unless one is experienced in welding. The results obtained from these experiments were satisfactory, in that, it shows that welding can be done without the use of special machines.

TABLE No.I

Line volts.	Volts across arc.	Current.
84	25	7.5 amp.
90	40	10 "
84	30	10.5 "
84	32	15 "
84	30	12 "
115	32	19.5 "
115	25	22 "
115	16	25 "
115	30	32 "
115	40	27 "
115	50	25 "
115	40	32 "
115	30	33 "
111	40	27 "
111	36	35 "
111	41	32 "
112	40	30 "
115	30	34 "

Conclusions.

The principal advantages of arc Welding.

Low cost. The cost of welding by electric arc process in its field of application is lower than any other process with which it can be compared. The reason for this is the high temperature produced by the electric arc within a given area. Comparative costs made on the performance of the same work by means of the oxy-acetylene method show the arc process to be invariably from one-half to one-third cheaper than the oxy-acetylene process.

The ease and convenience of its application is another big advantage which has brought arc welding into popular favor to such a great extent during the recent years. The fact that it is possible to do overhead work with the metal electrode process widens its application considerably. It can be applied whereever electric current is available and can be carried to the work.

Less skilled labor is required due to the numerous manufacturing and repair operations in which arc welding has superseded other processes, it has been possible to dispense with the skilled mechanics and operators formerly required. This applies particularly to the riveting process where a helper is always required. A man of ordinary intelligence can learn to operate a welding machine in a short time with proper instructions.

It is possible to weld a great deal faster with the arc process because of the ease of application and the intense heat produced by the arc within a limited area. In many cases it is not necessary to remove the material to weld it, saving the delay of removing it.

Not only has the arc welding process demonstrated its value as to the cost and time saving but reliable results are assured. The number of satisfactory welds made is enough to assure its reliablilty.

Electric arc welding is essentially a low voltage operation as the drop across the arc will not exceed 20 to 30 volts and the maximum open circuit potential for best results, should not be over 60 volts. Therefore, danger from this source is elimated. Protective devices are provided which insure the operator against any injurious effects from the glare.

This discussion deals only with the electric arc welding. There are other forms of electric welding as the resistance welding, where pressure is used to weld the two metals together. There is a large field of application for resistance welding in the manufacture of duplicate of production work. There is also a great number of different machines made for resistance welding.

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" " "	" 7.
" " "	" 8.
" " "	" 9.

PLATE I

CONSTANT VOLTAGE ARC WELDING CIRCUIT.

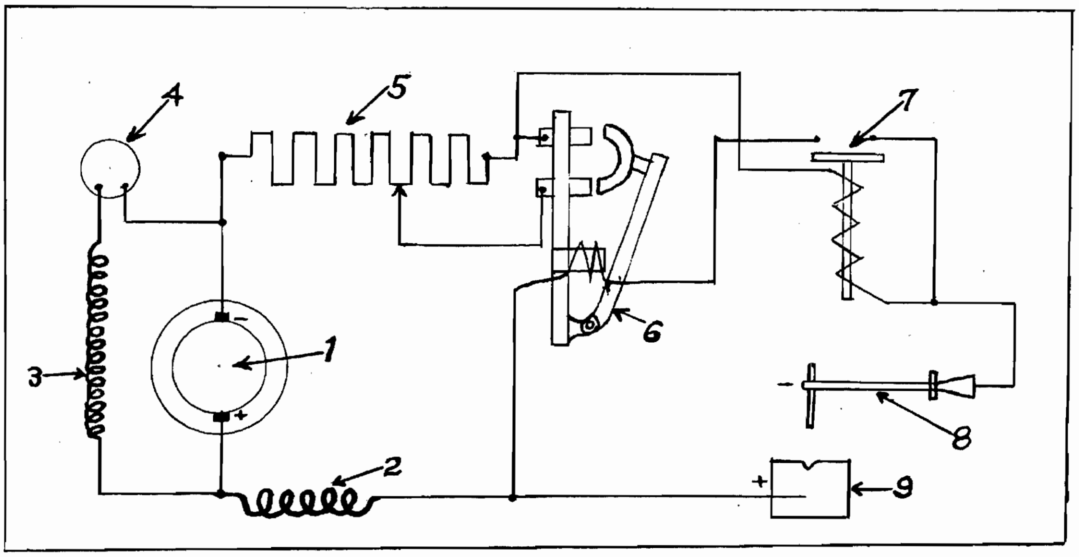


Diagram of Connections for C & C Electric & Mfg. Co. Arc-welding Equipment.

1.Generator.

2.Series Field.

3.Shunt Field.

4.Rheostat.

5.Adjustable Resistance.

6.Contactor.

7.Series Realy.

8.Electrode Holder.

9.Job.

PLATE II

LINCOLN VARIABLE VOLTAGE

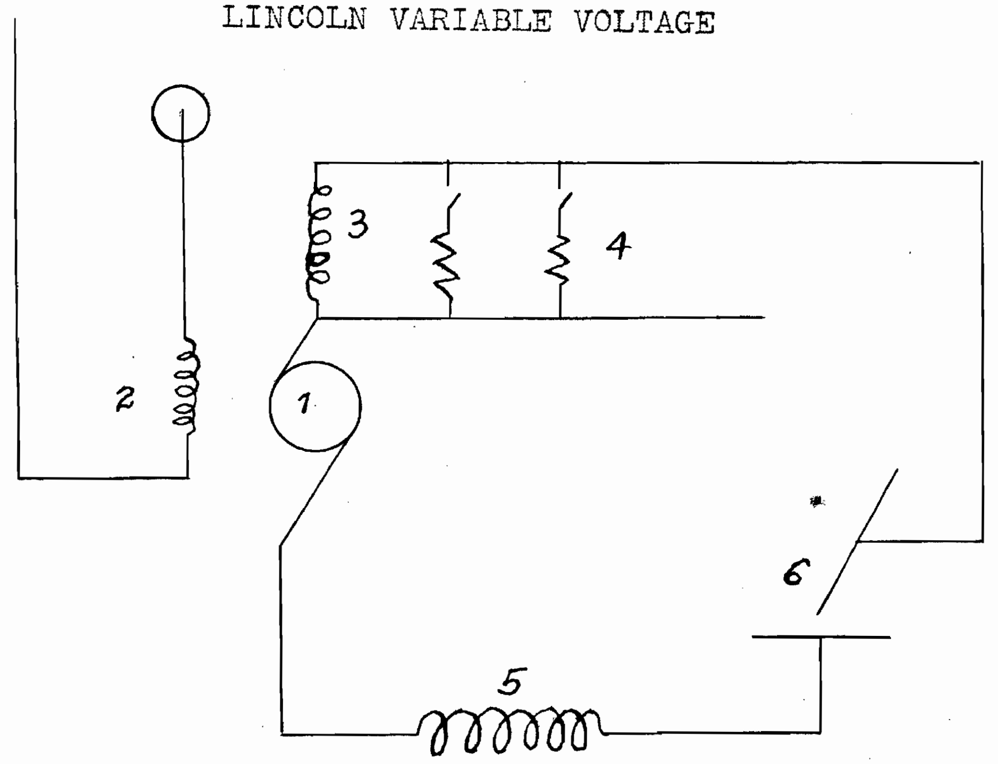


Diagram of the Lincoln variable voltage welding outfit.

1. Generator.

2. Separately excited field.

3. Series field.

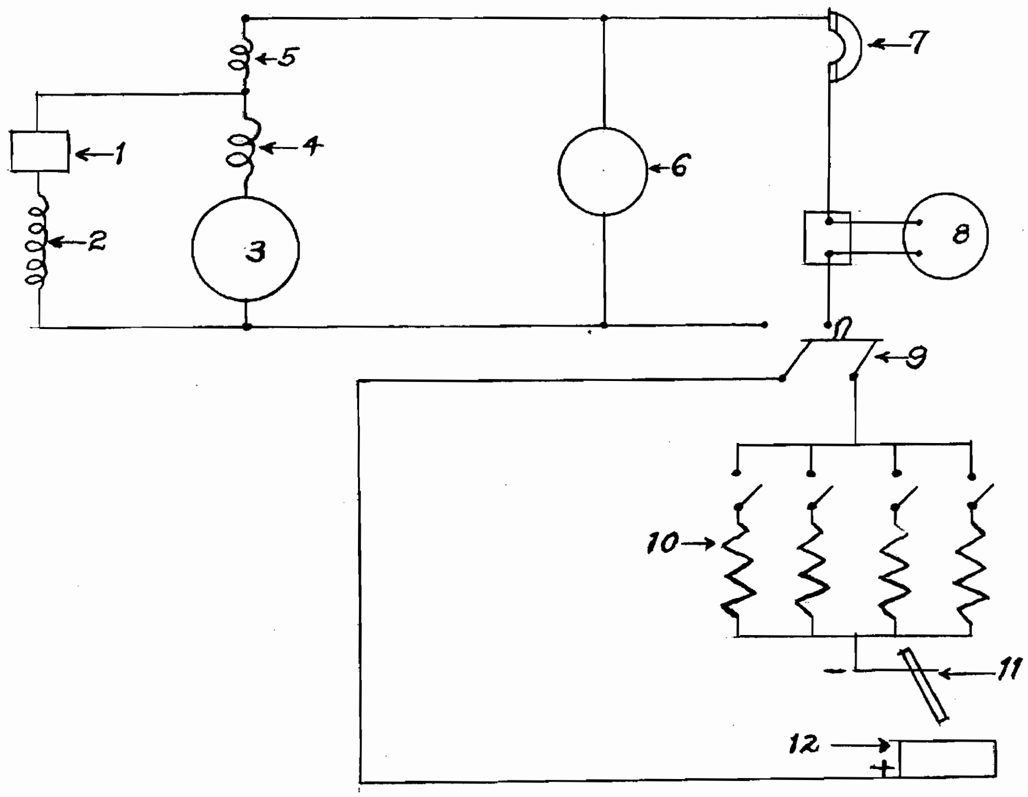
4. Diverters.

5. Stabilizer.

6. Electrode and work.

PLATE III

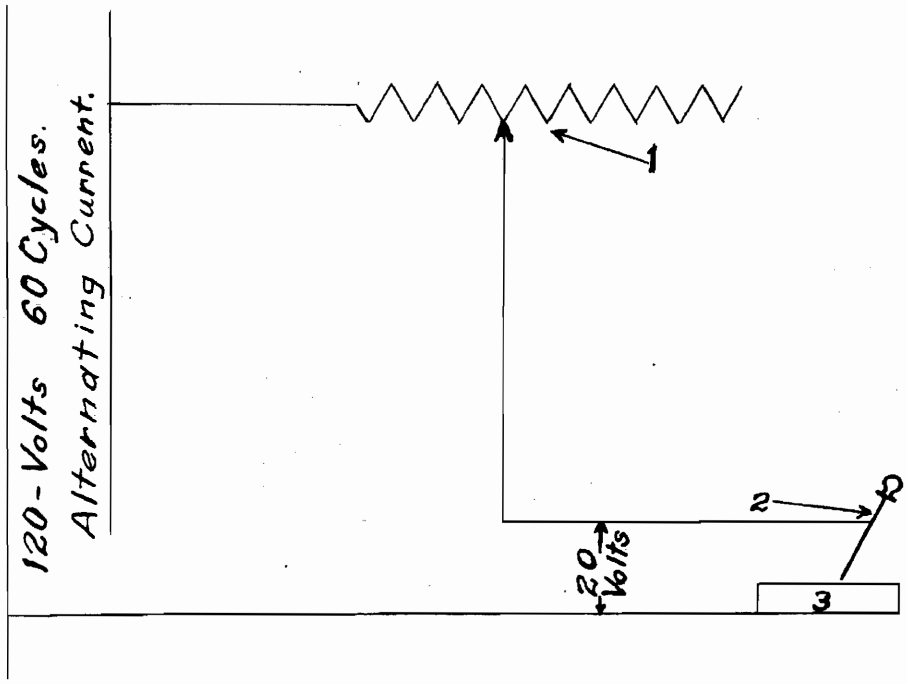
SIMPLE SCHEMATIC WELDING CIRCUIT.



1. Rheostat.
2. Shunt Field.
3. Generator.
4. Commutating Field.
5. Series Field.
6. Voltmeter.
7. Circuit Breaker.
8. Ammeter.
9. Service Switch.
10. Grid Resistors.
11. Electrode.
12. Work.

PLATE IV

WELDING CIRCUIT WITH SERIES RESISTANCE.



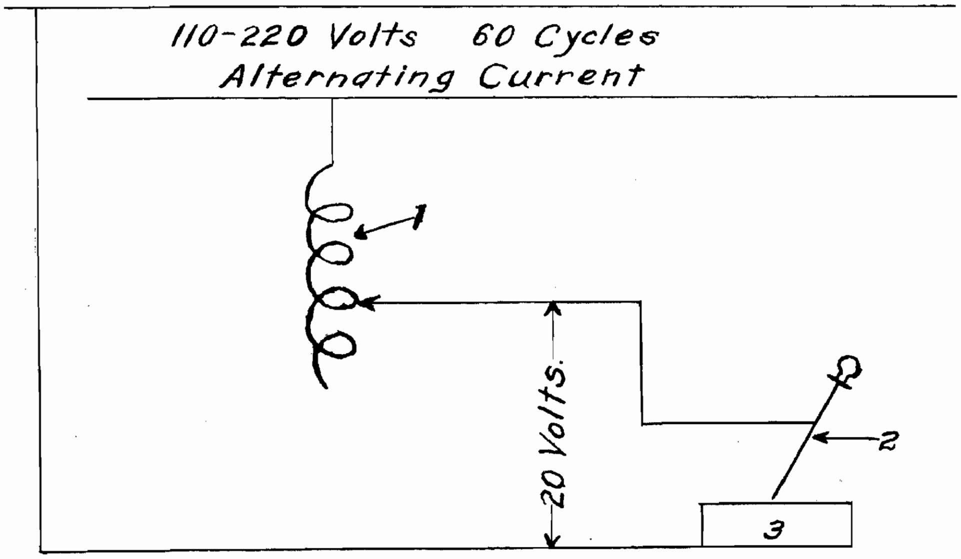
1.Variable Resistance.

2.Electrode.

3.Work.

PLATE V

WELDING CIRCUIT WITH SERIES REACTANCE.



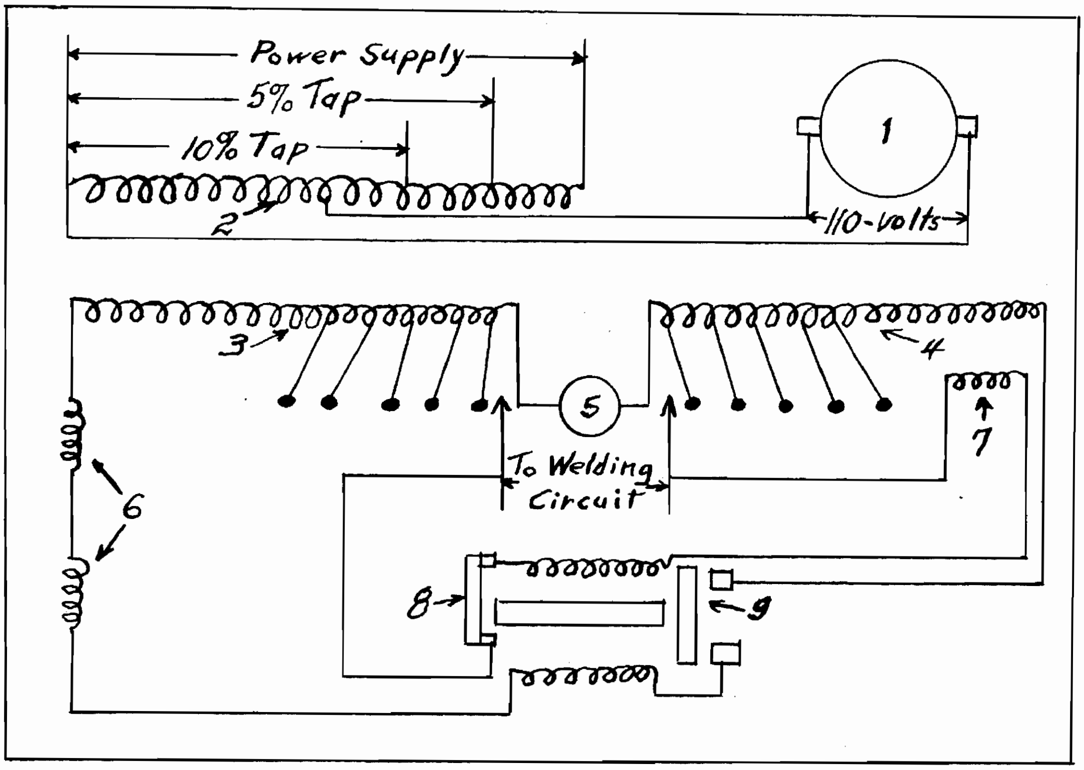
1. Variable Reactance.

2. Electrode.

3. Work.

PLATE VI.

TRANSFORMER DIAGRAM OF ELECTRIC ARC CUTTING AND WELDING MACHINE.



Wiring diagram of an Electric Arc Cutting and Welding Company's Standard Machine.

1.Generator. 5.Pilot lamp.

2.Primary coil. 6.Yokes.

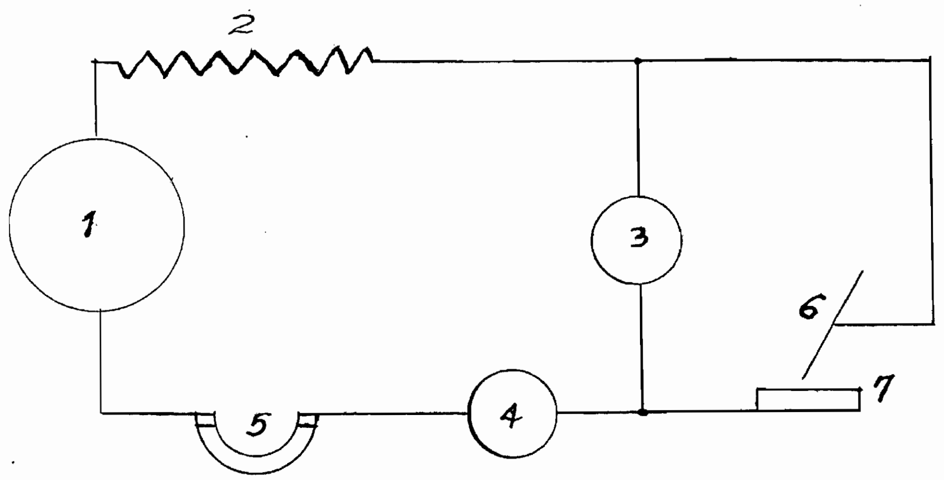
3.Main secondary. 7. 30-volt coil for contactor.

4.Auxiliary secondary. 8.Auxiliary contacts.

9.Main contacts.

Plate VII.

Drawing of a simple welding circuit as used in the Laboratory to make test.



1.Generator.

2.Variable resistance.

3.Voltmeter.

4.Ammeter.

5.Circuit breaker.

6.Electrode.

7.Work.

INDEX.