# Power Supply For Resistance Welding Machines

Prepared by the AIEE Subcommittee
on
Power Supply for Resistance Welding Machines
under the direction of the
AIEE Committee on Electric Welding

The Data Herein Are to Be Considered the Recommendations of a Committee and not as AIEE Standards

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## SUBCOMMITTEE ON POWER SUPPLY FOR RESISTANCE WELDING MACHINES

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# Power Supply for Resistance Welding Machines

## Section I

## SCOPE OF REPORT

The resistance welding process has been used to fabricate an almost infinite variety of metal parts so that machines of many designs and capacities have been developed. This report is intended to be a convenient and reliable reference to the accepted electrical engineering practices and standards in this field. It describes the various welders available; clarifies ratings, duty cycles, timers, controls, et cetera; and carries extensive tables, curves, and charts to assist in selecting and installing resistance welders.

An adequate power supply is essential for the successful use of resistance welders. The relatively high short-time demand and low duty cycle imposed by a welder requires considerable knowledge of the electrical constants of the power supply circuit. All of these electrical features which may, if neglected, cause poor or inconsistent welds, erratic operation of controls, or flickering lights are discussed in this report. It supplements in this special field the AIEE booklet "Electrical Power Distribution for Industrial Plants," known as the AIEE Red Book.

Ordinarily power company engineers are best able to calculate voltage drops on their own systems. The facilities within large factories can readily be laid out by the plant electrical engineers, using this report for handbook in most cases. In smaller factories, welder manufacturers' engineers, through experience with previous installations, can often be of assistance in layouts; or if there are special requirements or the cost of procuring adequate power seems high, it may be economical to bring in an electrical engineer who understands these special problems. In any event, close co-operation between the welder manufacturer, the power company, and the welder user is essential in assuring an adequate power supply for resistance welding equipment.

No general solution can be offered to cover all, or even the majority of cases. Each installation must be investigated individually and the solution based upon the merits of the case. Thus it is the hope of the Committee that this report will furnish convenient and reliable data for the development of many satisfactory electric welder installations.

## Section II

## GENERAL CONSIDERATIONS

### The Economic Approach

Because of unusual supply facilities required, it must be recognized that the introduction of resistance welding is not simply the connection of two supply conductors to a machine. The prospective user is faced with a complex economic problem, the major elements of which are:

1. The savings which accrue to the user from the introduction of the welding process.
2. The cost to the user of the welding machine together with the cost of reinforcing and rearranging the supply facilities on his side of the utility's meter.
3. The possible cost to the user of equipment which may be required to limit the electrical demand.
4. The cost of reinforcing and rearranging the electric utility system, particularly in those instances where the welding machine is located in sparsely populated territory at a point distant from supply sources.
5. The revenue produced for the utility by the welding machine and by the new supplementary equipment required by the manufacturing process.

Each of these elements must be evaluated by thorough study and mutual discussion when the welding installation is in the proposal stage. To do otherwise may lead to troublesome situations and financial penalty.

### The Co-operation Required

Providing an adequate and economical power supply for resistance welding is thus the problem not alone of the electric utility industry but also of the manufacturer of welding equipment and of the industrial user of such equipment. Each has a definite responsibility.

The manufacturer must supply:

1. A machine with efficient design characteristics, that is, one which will perform the required work with the least electrical demand.
2. A machine adequate to the work to be performed, but not one of high cost or excess capacity.
3. Complete basic electrical data.
4. Full operating and maintenance instructions.

The industrial user's responsibility lies in:

1. Installing plant wiring of ample capacity and designed for low voltage drop.
2. Employing welding techniques which avoid excessive electrical demand.
3. Consulting with the utility before machine purchase.

The utility has the responsibility:

1. To supply adequate capacity and voltage at the customer's meter.
2. To design the external supply system for minimum over-all cost to the customer and the company, and for minimum disturbance to existing customers.

## Section III

# POWER SUPPLY TERMINOLOGY

The sections which follow were written from differing viewpoints, and it is hence natural that the authors use words and phrases in the everyday parlance of their respective fields. Unfortunately, however, there may be a very considerable difference in the meaning of the same words as applied to, for instance, the utility field than when they are referred to the user's field. A brief explanation may be helpful to the full understanding of this report.

The term resistance is well understood and applies equally to a-c and d-c conductors. Reactance, however, looms as a large factor in welding applications; and reactance, which varies with the distance between conductors, as well as with frequency, is a characteristic of a-c conductors. Both of these quantities cause voltage drop as is more fully outlined in Section V. The square root of the sum of the squares of resistance and reactance is termed impedance, which is thus a measure of the total opposition to the flow of current.

Another term which may cause confusion in the layman's mind is that of kva. The product of current and voltage in a two-wire circuit is termed kilovolt-amperes, that is, thousands of volt-amperes, and is abbreviated kva. As with impedance, kva is the square root of the sum of the squares of two quantities. The first quantity is kilowatts which is a measure of the actual useful energy being supplied and the quantity normally recorded by the utility meter. The other quantity is reactive kilovolt-amperes, abbreviated rkva, and is a measure of the excess current, over that which is useful, which is drawn from the supply lines due to the reactance of the plant distribution system and of the devices connected to it. Since welders in general have low power factors, the rkva is a dominant element, greatly increasing the amount of current which must be supplied to the welder and thus increasing the voltage drop and the heating loss throughout the supply system. For a 30 per cent power factor load the total current will be more than three times as large as the useful current.

Voltage drop may generally be defined as the loss of voltage due to the passage of current through a circuit from generator to the load or through a portion of such a circuit. This drop is caused by the characteristics of electrical conductors, that is, resistance and reactance.

In a 3-phase supply circuit feeding numerous welders, there will be voltage drops along each of the line conductors but very little voltage drop in the neutral wire. However, a voltage drop along a line wire will cause a reduction in the voltage available between line wire and neutral conductor. A majority of utilities connect between line wire and neutral wire those transformers serving lighting loads; and since the voltage drop at the primary or high-voltage terminals of these transformers causes light flicker, the base of the utility's interest is in this phase-to-neutral voltage drop. On the other hand, the user of a welding machine is most vitally interested in the supply of adequate voltage for welding operations. Hence, voltage drop to the user is the voltage drop appearing at the welder terminals.

The voltage drop which affects the operation of the welder is not confined, however, to the reduction in voltage caused by the passage through the supply system of the current drawn by that welder, often referred to as self-drop. It will also be affected by the drop in voltage at its terminals, termed cross-drop, which is caused by the operation of other welders on the same circuit or in the same plant. The total drop at the welder terminals caused by its own current and that current of all other affecting devices is referred to as aggregate voltage drop.

The voltage drop appearing at the terminals of a welder due to its own operation is often referred to as regulation and is expressed in percentage. There are, however, other variations in voltage not covered by this term, as for instance, the departure of the normal operating voltage of the supply system from the nominal system voltage, as well as the hour-to-hour variation of voltage in the supply system caused by loads other than that in the user's plant.

The reader must therefore exercise caution and determine by reference to the foregoing and by context the meaning which the respective authors seek to convey.

## Section IV

# RESISTANCE WELDING MACHINES

Resistance welding is a production process for joining two or more pieces of metal in which the weld is formed by applying pressure to the point to be welded and heating the metals to fusing temperature. Heating is accomplished by-passing an extremely high current, seldom less than 5,000 amperes, sometimes more than 100,000, through the pressure area, then maintaining pressure until the fused metals solidify. The various types of resistance welds include spot, projection, seam, upset butt, and flash butt. Each is illustrated in Figure 1.

The basic function of a resistance welding machine is to furnish the pressure and the electric current which are the fundamentals of the resistance welding process. Mechanical designs may vary widely depending upon the welding operation which the machine is to perform. Electrical design of both the welder itself and of its associated controls also vary widely, according to the mechanical design, the requirements of the welding operation, or to the characteristics of the load which the welder will impose upon the power supply system.

Resistance welders are generally classified both as to mechanical construction or welding characteristics and as to electrical features. Mechanical classifications include rocker arm, press, seam, flash,

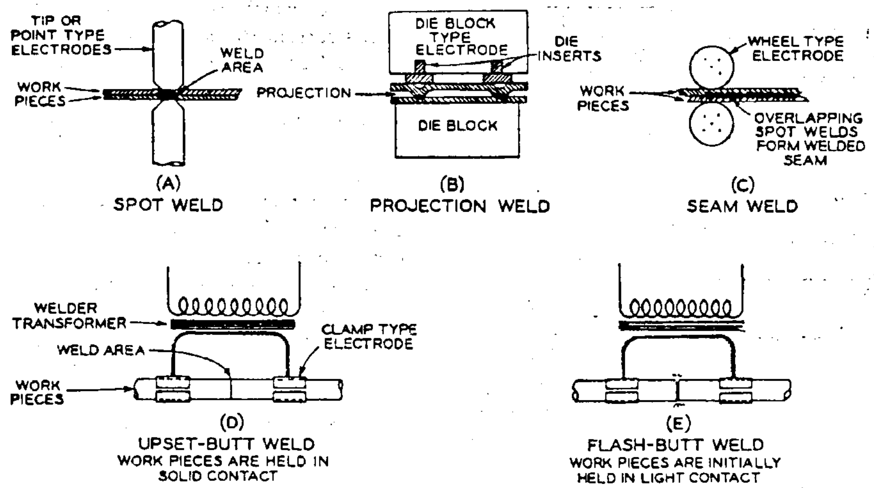



**Figure 1. Types of welds: (A) Spot, (B) Projection, (C) Seam, (D) Upset-butt, (E) Flash-butt**

butt, portable gun, fixture gun, ultraspeed, and hydromatic welders and multi-transformer welding presses. All except portable gun welders are intended for more or less permanent installation and in the welding operation the work is brought to the machine. When the work is too bulky to be taken to the welder, the welder must be taken to the work, and for this purpose portable gun welders are used.

Standard welders are manufactured for miscellaneous welding operations, or for specific operations which can be performed upon them. For special welding applications which cannot be performed upon a standard welder, or to obtain higher production, reduce the number of operators, improve the electrical load characteristics, or for various other reasons, special welders are often designed for specific applications. Special welders are often rebuilt or retired when the job is completed or when the work-piece is redesigned. Various types of welders are shown in Figures 5 through 13 inclusive.

The electric system of a resistance welder consists of two basic components, a power device such as a transformer or rectifier which takes energy from the power supply system at line voltage and frequency and delivers it to the work in the form of high current, low voltage power, and an auxiliary device or devices which turn the weld power on-and-off and synchronize it with the mechanical action of the welder. These auxiliaries are broadly known as welder controls.

The electric system may be designed for operation at any voltage or frequency. Some types of welders operate from a single-phase power supply and some are designed to operate from three phases. Unless especially designed for the purpose, a given welder will ordinarily operate properly only at the voltage and frequency for which it was designed.

The Resistance Welder Manufacturers Association (R.W.M.A.) is, as the name implies, an organization of manufacturers of resistance welding equipment. It has formulated and published standards for conventional general purpose welders which largely determine their electrical characteristics, and has specified the minimum information to appear on the welder nameplate. Familiarity with these standards will prove of assistance in the analysis of power supplies for resistance welders. They will be referred to from time to time in this report.

## Types of Resistance Welders

From a standpoint of power supply welders may be divided into two general classifications, direct energy which take power only during the time a weld is being made; and energy storage, which store energy either continuously or during the interval between welds, and release energy whenever a weld is made.

Welding technique usually requires that weld times be short, between 1 and 120 cycles on a 60-cycle-per-second base, and that the input of energy to the weld be relatively high during this time. Overall load factor or duty cycle is, in most cases, comparatively low. Direct energy welders impose upon the power supply system a load of relatively high kva demand, short duration, intermittent application and often low power factor and, if connected to a supply which has inadequate capacity to serve the load, may cause objectionable voltage fluctuations. Energy storage welders, because of the low over-all duty cycle at which welding is done, can store energy at a low and reasonably uniform rate, and consequently create no more of a power supply problem than a motor of the same power demand.

Direct energy welders include:

1. *Single-Phase Alternating Current.* This is the simplest, least expensive and most widely adaptable type of resistance welder. Unfortunately its load characteristics make it the most difficult to serve from a power supply standpoint. However its desirable features outweigh the undesirable load characteristics to the extent that over 90 per cent of all welders which have been built, which are being manufactured today, and which are in prospect for the future, are of this variety.

2. *Single-Phase Alternating Current Plus Correction to Reduce Kva Demand.* These are essentially conventional single-phase welders which are used in connection with some device which improves the inherent load characteristics of the welder. These devices include a motor generator set, the inertia of which absorbs the impact of the welder load and minimizes its effect upon the power system; a dummy load of approximately the same magnitude and power factor as the welder, which is controlled to come on between welds and so impose a continuous load upon the power system; and shunt or series capacitors, the capacitive reactance of which compensates for the inductive reactance of the welder so that the net load upon the power system is kilowatts only. Because the welder, controls, and corrective device must be properly co-ordinated, the welder manufacturer should always be consulted concerning the application of such a device.

The motor-generator set, because of high first cost and long delivery, and dummy loads and shunt capacitors because of technical difficulties are seldom used. Series capacitors are, however, entirely successful in some applications and will be discussed in more detail later.

3. *Load Distributing Welding Machines.* These welders are used for making a multiplicity of welds in a relatively large assembly, and include the hydromatic and ultraspeed welders and the multiple transformer welding press. Their controls may be arranged to lessen the instantaneous demand upon the power system by making the welds in sequence on one or more phases, or simultaneously on two or more phases.

4. *Frequency Converters and Dry-Disc Rectifier.* The frequency converter welder utilizes electronic tubes and associated control circuits to deliver the welding energy at a lower frequency than that of the power supply system, which reduces the inductive reactance of the welder electrical system and thus the kva demand of the load, and raises its power factor. Frequency converter welders are usually designed for 3-phase operation. The rectifier welder incorporates a dry disk rectifier unit to deliver direct current to the weld and is also ordinarily a 3-phase device. Some welders in this classification have, in addition to more desirable load characteristics, better

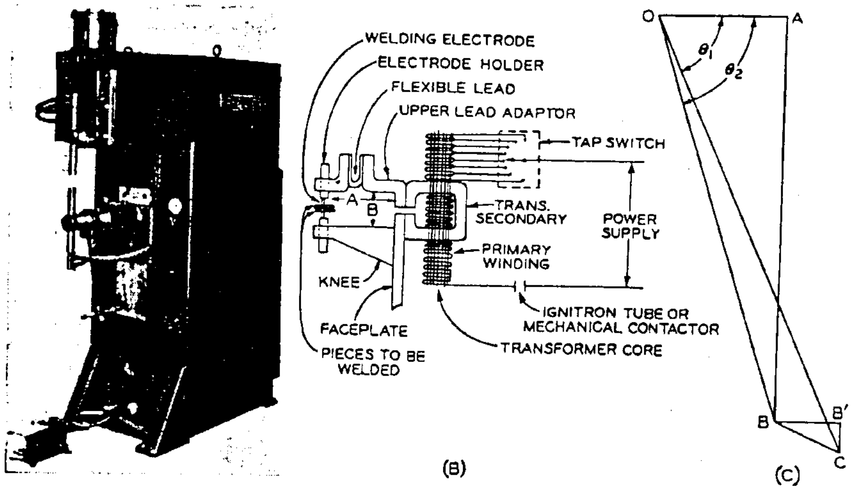



Figure 2(A) Courtesy Precision Welder & Machine Company.

**Figure 2(A). Press-type spot welder. 2(B). Diagram of electrical circuit. 2(C) Vector diagram**

welding characteristics for some applications. In general their disadvantages are higher first cost, and more and costlier maintenance than single-phase a-c welders.

Energy storage welders include:

1. The capacitor discharge welder, in which the energy is stored capacitor units.
2. The magnetic storage welder, in which the energy is stored in the iron core of the welder transformer.
3. The storage battery welder.
4. The homopolar generator welder.

## Basic Electrical Concepts of Resistance Welding

A clear understanding of the electrical aspects of the weld proper and of the machine which makes it, are important background for the proper analysis of a problem of power supply for resistance welder load.

The fundamental characteristic of resistance welding is that the pieces being joined are brought to the plastic state of weldability with the heat generated by the resistance $R$ of the weld area to the electric current $I$ which flows through it. The power required is $I^2R$ watts and the energy consumed is $I^2RT$ watt seconds. Welding technique requires that time $T$ during which the current is caused to flow be extremely short, usually between one and 120 cycles (one-sixtieth and two seconds). Resistance $R$ is usually in the order of micro-ohms and, since time $T$ must be very short, it follows that, in order to produce sufficient heat $I^2RT$ to bring the weld area to a plastic state, current $I$ must be extremely high, in the order of thousands of amperes. The voltage drop $IR$ across the weld, thousands of amperes times micro-ohms of resistance, is usually in the order of 1 volt or less. The impedance of the work is, in effect, largely resistance.

The conventional single-phase a-c spot welder is the simplest of resistance welding machines, incorporates the essentials of all types, comprises over 90 per cent of all units, and the characteristics of its load are such that it poses the most common as well as the most difficult problems in power supply. Discussion of the electrical characteristics of resistance welders may therefore properly begin with a description of a standard single-phase a-c spot welding machine. Because the frequency of most power supply systems in the United States is 60 cycles, a 60-cycle machine will be described and the difference between it and machines of other frequencies pointed out.

In a single-phase welder, the high welding current is produced by a transformer which, through a suitable switching device, can be connected to the power supply each time a weld is made. The output of this transformer is connected to the secondary circuit of the welder which conducts the welding current from the transformer through the welding electrodes into the weld area of the work. The secondary circuit consists of conductors having a large cross section which are often structural parts of the welder, a flexible lead to permit movement of one electrode so that the work can be inserted and removed and, when set up for welding, the electrode holders and electrodes between which the work is placed for welding. Figure 2(A) is an illustration of an R.W.M.A. size 1, air-operated press-type spot welder on which the knee, which is the conductor that carries current to the lower electrode, the flexible lead, and electrode holder and electrodes are shown. The transformer is located inside of the welder frame and is not visible. The upper electrode is connected, through a ram and piston rod, to the air cylinder on the top of the welder. The upper electrode can be raised to permit inserting and removing work by applying air pressure to the bottom side of the piston. The upper electrode is lowered against the work, and weld pressure is obtained by applying air pressure to the upper side of the piston. Other pressure systems such as motor driven cams, springs, or hydraulic fluids are also used.

Figure 2(B) is a diagrammatic sketch on which the parts of the transformer and of the secondary circuit are indicated. Dimension A is known as the throat depth and dimension B as the horn spacing of this welder. The area bounded by the secondary conductors, electrode holders and electrodes is known as throat area.

In any single-phase a-c welder, the welder transformer presents an impedance, consisting of resistance and inductive reactance. The secondary circuit also comprises an impedance, consisting of the resistance of the conductors and of inductive reactance resulting from their separation. Work pieces between the electrodes also add to the impedance of the secondary circuit. This condition is known as the welding impedance. The welding impedance for a given machine will vary somewhat depending upon the material, length and diameter of the electrode holders and electrodes, and upon the material and stock thickness of the work.

To eliminate these variables, the R.W.M.A. has specified that in rocker arm and press-type spot welders, impedance be based upon a condition in which the electrode holder and electrodes are replaced by a solid copper bar of the same diameter as the electrode holders. This condition is known as the short-circuit impedance and is used in all design calculations. R.W.M.A. also specifies the horn spacing upon which design calculations shall be based. For other types of standard welders, in which point type electrodes such as those shown in Figure 2(A), are not used, or where the replacement of electrodes and holders is not practical, R.W.M.A. has specified the type of short-circuiting device or the method of short circuiting to be used.

The maximum secondary amperes which a given welder is designed to produce is determined by the type of weld which it is to make and the material and maximum thickness of stock to be welded. According to Ohm's Law for an a-c circuit, voltage is the product of current times impedance. Therefore the secondary voltage for which a welder transformer is designed is the short-circuit secondary amperes times the short-circuit impedance.

Figure 2(C) is a vector diagram of the welder shown in Figure 2(A) in which short-circuit values, referred to the secondary are:

$OA$ = resistance = 0.000075 ohm
$AB$ = reactance = 0.000236 ohm
$OB$ = impedance = 0.000250 ohm

If this welder is to produce a maximum of 25,000 secondary amperes the secondary voltage required of the welder transformer would be: 25,000 amperes × 0.000250 ohms = 6.25 volts.

The short-circuit demand which the welder would create is:

$$\frac{E_2 \times I_2}{1{,}000} = \frac{6.25 \times 25{,}000}{1{,}000} = 156 \text{ kva}$$

The power factor is:

$$\frac{R}{Z} = \frac{0.000075}{0.000250} = 0.30$$

In any welder, the welding impedance is always greater than short-circuit impedance. Therefore maximum welding current and maximum welding kva demand are always less than maximum short-circuit current and maximum short-circuit kva demand. Because electrodes are smaller in diameter than the short-circuiting bar and are often of lower conductivity material; because of contact resistance between electrode holders and electrodes; and because of saturation of the work by the magnetic field of the high welding current, the welding impedance is at a higher power factor than short-circuit impedance. For voltage drop calculations when work is between the electrodes only and does not extend into the throat of the welder, and providing rated voltage is applied to the transformer, maximum welding current can be assumed to be 90 per cent of maximum short-circuit current, and welding power factor 10 per cent higher than short-circuit power factor.

In Figure 2(C), vectors $BB'$ and $B'C$ represent the increase in welding resistance and reactance respectively over short-circuit values, and

$OA + BB'$ represents welding resistance = 0.000114 ohm
$AB + B'C$ represents welding reactance = 0.000261 ohm
$OC$ represents welding impedance = 0.000285 ohm

The maximum welding current is therefore:

$$\frac{6.25 \text{ volts}}{0.000285 \text{ ohm}} = 22{,}000 \text{ amperes}$$

The maximum welding demand will be:

$$\frac{6.25 \text{ volts} \times 22{,}000 \text{ amperes}}{1{,}000} = 137 \text{ kva}$$

Load power factor is:

$$\frac{R}{Z} = \frac{0.000114}{0.000285} = 0.40$$

The welding of different materials and different thicknesses of stock of the same material require different amounts of heat. Heat is proportional to current squared. For a fixed impedance, current is proportional to voltage. It is therefore customary to provide some method of adjusting secondary voltage as a means of adjusting heat. One of the most common methods is to provide taps in the primary winding of the welder transformer as shown in Figure 2(B). R.W.M.A. standards for tapped transformers call for a voltage range of from maximum to 60 per cent of maximum in 4, 6, or 8 taps, depending upon the type and kva rating of the welder. Since heat varies as the square of the current, this range in voltage will provide a heat range of from maximum to 36 per cent of maximum.

In the above example the minimum secondary voltage would be: 6.25 × 0.60 = 3.75 volts.

Minimum short-circuit current would be:

$$\frac{3.75 \text{ volts}}{0.000250} = 15{,}000 \text{ amperes}$$

Minimum short-circuit kva would be:

$$\frac{3.75 \text{ volts} \times 15{,}000 \text{ amperes}}{1{,}000} = 56 \text{ kva}$$

Although the impedance of the welder transformer will be somewhat different on each tap, the ratio of transformer impedance to total secondary impedance is ordinarily small enough that load power factor may be assumed to be the same for all taps of the transformer.

Other methods of heat adjustment include the use of an autotransformer in conjunction with an untapped welder transformer, and phase-shift heat control which is described later.

On most standard rocker arm and press welders, the position of one side of the secondary circuit is fixed for any welding operation. The other side however is usually adjustable to permit adjusting the arm spacing of the welder if the welding operation requires it. When the throat area of a given welder is increased, the length of path over which the current flows and the spacing between going and return conductors are also increased. This increases the resistance, reactance and impedance of the circuit. For a given welder the secondary voltage is fixed by the turn ratio of the transformer and so, since increasing the throat area increases the secondary impedance, it follows that it will also decrease the current which the welder will produce with the transformer set on a given tap. Conversely, if throat area is decreased, the secondary impedance will be decreased and a higher secondary current will be obtained.

For estimating purposes the current at any throat area can be approximated by the equation:

$$I_B = I_A \sqrt{\frac{\text{throat area } A}{\text{throat area } B}}$$

in which $I_A$ is the known current at throat area $A$, and $I_B$ is the unknown current at throat area $B$.

Generally, power factor decreases as throat area increases.

Because welding impedance is greater than short-circuit impedance, it follows that welding current, for any setting of the machine is less than short-circuit current. Although in standard spot welders, work impedance is ordinarily small in relation to circuit impedance and may be neglected, it should not be overlooked because high work impedance may reduce current which the transformer can force through the circuit to a value which is inadequate for welding.

In deep throat welders the existence of magnetic metal work pieces in the throat increases the effective impedance and reduced the current which flows in the secondary circuit. If the operation is such that the work is moved into the throat, the current will become progressively less as the work moves into the throat until it may become insufficient to weld. Automatic devices known as current regulators can under some conditions be added to electronic controls to compensate for this condition. Such applications should be taken up with the welder or control manufacturer. If, however, the operation is reversed so that the work is moved out of rather than into the throat, and the first weld is made with the most work in the throat, the current will be least for the first, rather than the last weld. However, in each succeeding weld some of the current will be shunted through previous spots, and the difference in actual welding current between the first and last spots will not be as great as when the work is moved into the throat. If this procedure is

**Table I. Turn Ratio—Maximum and Minimum Turns**

| Secondary Volts | Primary Volts 220 Turn Ratio | 220 Turns | 440 Turn Ratio | 440 Turns | 550 Turn Ratio | 550 Turns |
|---|---|---|---|---|---|---|
| 3.75 | 59/1 | 59 | 118/1 | 118 | 147/1 | 147 |
| 6.25 | 35/1 | 35 | 70/1 | 70 | 88/1 | 88 |

used it is often possible to obtain satisfactory welds over the entire length of the work without the use of a current regulator.

The construction of the secondary circuit of a resistance welder precludes the use of a current transformer for metering secondary currents and at the present time there are no field instruments available for accurately metering these high currents.

The R.W.M.A. has therefore specified that secondary currents shall be computed by multiplying the metered primary current at rated voltage by the turn ratio of the welder transformer. Although this method introduces an error due to the fact that transformer magnetizing current and losses are included in the primary current reading, it provides accurate data for power supply calculations, because the actual line demand may be determined by multiplying secondary amperes by open circuit secondary volts. Both of these values appear on the nameplate of the welder. The minimum turn ratio, which gives maximum secondary voltage, can be determined in the usual way by taking open circuit voltage readings. Then if:

$E_1$ = primary volts
$I_1$ = primary amperes
$N$ = turn ratio of transformer
$E_2$ = secondary volts $= E_1/N$
$I_2$ = secondary amperes $= I_1 \times N$
$E_1 \times I_1 = E_2 \times I_2$

$$\text{kva demand} = \frac{E_2 \times I_2}{1{,}000} = \frac{E_1 \times I_1}{1{,}000}$$

In the same manner secondary voltage, primary and secondary current, and kva demand can be determined with the welder adjusted for any number of transformer primary turns, when the transformer turn ratio or the secondary voltage on any two taps $A$ and $B$ are known.

$$E_{2B} = E_{2A}\left(\frac{N_A}{N_B}\right)$$

$$I_{2B} = I_{2A}\left(\frac{N_A}{N_B}\right) = I_{2A}\left(\frac{E_{2B}}{E_{2A}}\right)$$

$$I_{1B} = I_{1A}\left(\frac{N_A}{N_B}\right)^2 = I_{1A}\left(\frac{E_{2B}}{E_{2A}}\right)^2$$

$$\text{kva}_B = E_{2B} \times I_{2B} = \text{kva}_A\left(\frac{N_A}{N_B}\right)^2 = \text{kva}_A\left(\frac{E_{2B}}{E_{2A}}\right)^2$$

A resistance welder may be manufactured for operation at any voltage or frequency of power supply. The open circuit secondary voltage of any transformer equals the primary voltage divided by the turn ratio of the transformer. Therefore, the only difference in transformers for different supply voltages is in the turn ratio. Since most resistance welder transformers, except for portable gun transformers which will be discussed later, have one turn secondaries, the number of turns in the primary winding is the same as the turn ratio. Table I gives the turn ratio and maximum and minimum turns for 220-, 440-, and 550-volt transformers to produce the 3.75 minimum and 6.25 maximum secondary volts in the example used above.

Frequency however, has a considerable effect both upon the design of the welder transformer and upon the demand which the welder will, to perform a given welding operation, create upon the power supply. For purposes of comparison, the characteristics of a 25-cycle spot welder to produce 25,000 amperes, the same value of current used in the 60-cycle example shown in Table I, will be computed.

The resistance of the secondary circuit in a 25-cycle welder is, for practical purposes, the same as that of a 60-cycle welder. Inductive reactance is however a function of frequency. $X = (2\pi f l)$, in which 2, $\pi$, and inductance $l$ remain constant. Inductive reactance $X$ is proportional to frequency. Thus if 60-cycle reactance is 0.000236 ohm, as in the 60-cycle example, the 25-cycle reactance will be:

$$X_{25\ \text{cycle}} = 0.000236 \times \frac{25}{60} = 0.0000995 \text{ ohm}$$

If resistance is constant at 0.000075 ohm

$$Z_{25\ \text{cycle}} = \sqrt{R^2 + X^2}$$
$$= \sqrt{(0.000075)^2 + (0.0000995)^2}$$
$$= 0.000125 \text{ ohm}$$

The secondary voltage required to produce 25,000 amperes is:

$$E_2 = I_2 Z_2 = 25{,}000 \text{ amperes} \times 0.000125 \text{ ohm} = 3.125 \text{ volts}$$

The maximum kva demand which the welder will create is:

$$\text{kva} = \frac{E_2 \times I_2}{1{,}000} = \frac{3.125 \times 25{,}000}{1{,}000} = 78 \text{ kva}$$

The power factor of the 25-cycle welder will be:

$$PF = \frac{R}{Z} = \frac{0.000075}{0.000125} = 0.60$$

Comparison of these values with the example developed for the 60-cycle welder shows that when a welder has an $X/R$ ratio of approximately 3/1, the kva demand to produce a given secondary current will be approximately one-half the magnitude at 25 cycles as at 60 cycles, and the 25-cycle power factor will be about twice the 60-cycle power factor.

As 60-cycle power factor increases, the difference between 25- and 60-cycle demands and power factors decrease. For example, the difference for a gun welder, which has a 60-cycle power factor of approximately 90 per cent is less than 10 per cent in both kva demand and power factor. This is discussed further under the subject of gun welders, and a comparison is given in Table II.

**Table II. Relative Characteristics of 60- and 25-Cycle Welders Producing Equal Values of Short-Circuit Secondary Amperes**

| Type of Welder | Power Supply Frequency, Cycles | Secondary Amperes I | Secondary Ohms Resistance | Secondary Ohms Reactance $=2\pi fl$ | Secondary Ohms Impedance $R+jX$ | Volts IZ | Kva Demand $\frac{E \times I}{1000}$ | Power Factor $\frac{R}{Z}$ |
|---|---|---|---|---|---|---|---|---|
| Size 1 projection, 18 inch throat, 8 inch platen spacing | 60 | 23,000 | 0.000075 | 0.000236 | 0.000250 | 6.1 | 140 | 0.30 |
| | 25 | 23,000 | 0.000075 | 0.0000984 | 0.0001238 | 3.1 | 71 | 0.606 |
| Standard gun with 6 inch × 8 inch throat, 8 foot light duty (267,000 cm) low reactance cable | 60 | 23,000 | 0.000730 | 0.000320 | 0.000800 | 18.4 | 424 | 0.913 |
| | 25 | 23,000 | 0.000730 | 0.000130 | 0.000740 | 17.0 | 392 | 0.988 |
| Standard gun with 6 inch × 8 inch throat, 8 foot heavy duty (450,000 cm) low reactance cable | 60 | 23,000 | 0.000526 | 0.000290 | 0.000600 | 13.8 | 317 | 0.877 |
| | 25 | 23,000 | 0.000526 | 0.000121 | 0.000538 | 12.4 | 285 | 0.974 |

**Table III. Frame Sizes and Kva Rating* R.W.M.A. Standard 60-Cycle Rocker Arm, Press, Seam, Butt and Portable Gun Welders**

| Type of Weld | Type Welder | Standard | |
|---|---|---|---|
| | | Frame Size | Kva Rating |
| Spot | Rocker arm | 000 | 5.0 |
| | | 00 | 7.5 |
| | | 0 | 10.0 |
| | | 1 | 15.0 |
| | | 2 | 30.0 |
| | | 3 | 50.0 |
| Spot | Press | 000 | 5 |
| | | 00 | 20 |
| | | 0 | 30 & 50 |
| | | 1 | 30, 50 & 75 |
| | | 2 | 100 & 150 |
| | | 3 | 150 & 250 |
| | | 4 | 300, 400, & 500 |
| Projection | Press | Same as spot welder | |
| Seam | Seam | 1 | 50 & 75 |
| | | 2 | 100, 150, & 200 |
| | | 3 | 250 & 400 |
| Upset butt | Butt | 000 | 2 |
| | | 00 | 5 |
| | | 0 | 10 |
| Flash butt | Butt | 1 | 20 |
| | | 2 | 50 |
| | | 3 | 100 |
| | | 4 | 150 |
| | | 5 | 250 |
| Spot | Portable | Welder size | |
| | | 1 | 30 |
| | | 2 | 50 |
| | | 3 | 75 |
| | | 4 | 100 |
| | | 5 | 150 |
| | | 6 | 200 |

* Kva rating on 50 per cent duty cycle basis.

## Electrical Rating of Resistance Welders

The name-plate rating of most electric apparatus is based upon ability to operate under given conditions without exceeding a specified temperature rise. When designed for such operation, it may carry a short time or intermittent duty rating instead of a continuous duty rating.

Because most welding operations require "off" periods during which work is changed or repositioned, and during which no welding current flows, resistance welding machines are rated upon an intermittent duty basis in which the ratio of weld time to total time is called duty cycle.

The R.W.M.A. defines name-plate rating as "the periodic rating based upon a 50 per cent duty cycle and a 1-minute integrating time." In other words, resistance welders are rated upon a basis of being able to carry a load equal to name-plate rating for 30 seconds out of every minute without exceeding the specified temperature rise.

The maximum demand which a given welder can create is a function of the impedance of its electrical circuit and the secondary volts built into its transformer, and the demand which it will create for a given welding operation is determined by the adjustment of the machine for the material and thickness of stock being welded. It is therefore possible, and often desirable, to operate a welder at a demand higher than name-plate rating and a duty cycle lower than the 50 per cent upon which name-plate rating is based. The relationship between kva rating, kva load, and duty cycle for any welding setup is:

$$\text{kva rating} = \text{kva load} \times \sqrt{2 \times \text{duty cycle}}$$

For example, if the 60-cycle spot welder described above is being designed for operation on 5 per cent duty cycle:

$$\text{kva rating} = 156 \text{ kva demand} \sqrt{2 \times 0.05} = 50 \text{ kva}$$

If it were being designed for operation at 50 per cent duty cycle the rating would be:

$$\text{Kva rating} = 156 \text{ kva demand} \sqrt{2 \times 0.50} = 156 \text{ kva}$$

The same equation can be used to determine the permissible duty cycle at which a given welder may be operated if the kva demand is known:

$$\text{Duty cycle} = \left(\frac{\text{kva rating}}{\text{kva load}}\right)^2 \times 0.5$$

Thus if the 50-kva welder were to be operated at 100-kva load, the maximum permissible duty cycle would be:

$$\text{Duty cycle} = \left(\frac{50}{100}\right)^2 \times 0.5 = 0.125 \text{ or } 12.5 \text{ per cent}$$

The capacity of those parts of the power supply system in which voltage drop can be neglected, such as fuses, switches, and very short cables, can be based upon the continuous duty rating of the welder. Substituting 100 per cent duty cycle in the above equation, we find that:

$$\text{Kva demand} = \frac{\text{kva rating}}{\sqrt{2 \times 1.00}} = \text{kva rating} \times \frac{1}{\sqrt{2}} = \text{kva rating} \times 0.707$$

Thus the continuous rating is 70.7 per cent of name-plate rating.

The R.W.M.A. have specified that the following minimum data appear upon resistance welder transformer nameplates:

1. Manufacturer's name and principal address.
2. Serial number of transformer.
3. Kva rating at 50 per cent duty cycle.
4. Primary voltage.
5. Primary frequency.
6. Maximum and minimum secondary voltage.
7. Maximum temperature rise upon which name-plate rating is based.

Upon resistance welding machine nameplate; items 1 through 7 and,

8. Temperature of input cooling water.
9. Water pressure required.
10. Short-circuit secondary amperes at maximum secondary volts and specified throat dimensions.

The maximum demand which the welder will create may be determined by multiplying the maximum secondary volts of item 6 by the short-circuit secondary amperes of item 10.

Table III is a summary of standard frame sizes and kva ratings for R.W.M.A. spot, projection, seam, butt, flash and gun welders.

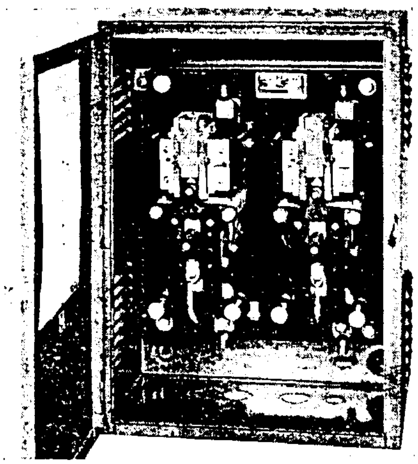
As previously discussed, 25-cycle spot and projection welders because of their lower inductive reactance, require a lower secondary voltage than 60-cycle welders to produce the same value of secondary amperes. Thus the kva demand is lower at 25 than at 60 cycles and since rating is a function of demand and duty cycle, a 25-cycle welder, to produce the same welding amperes at the same duty cycle as its 60-cycle counterpart, will carry a lower name-plate rating. Table IV gives the rating of 25-cycle spot and projection welders which produce the same welding amperes at the same duty cycle as the 60-cycle ratings listed.

## Controls

In most resistance welding processes, the weld is formed by applying pressure to the point to be welded and heating the metals to fusing temperature by passing a high electric current through the pressure area, then maintaining pres-

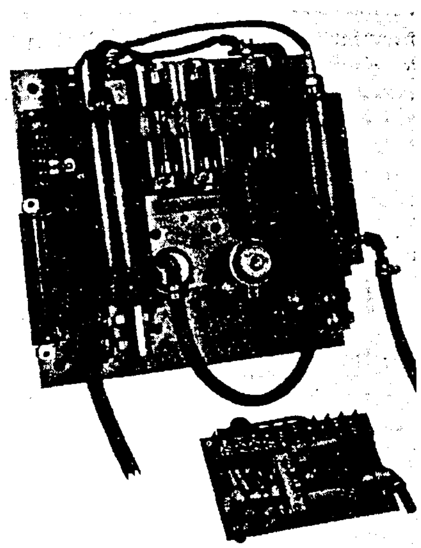
**Table IV. 60-25 Cycle Equivalent Ratings R.W.M.A. Standard Rocker Arm and Press Welders**

| Kva Rating on 60 Cycles | Equivalent Rating on 25 Cycles |
|---|---|
| 5 | 2.5 |
| 7.5 | 4.0 |
| 10 | 5.0 |
| 15 | 7.5 |
| 20 | 10 |
| 30 | 15 |
| 40 | 20 |
| 50 | 25 |
| 75 | 40 |
| 100 | 50 |
| 150 | 75 |
| 200 | 100 |
| 250 | 125 |
| 300 | 150 |
| 400 | 200 |
| 500 | 250 |



Courtesy Square D Company

**Figure 3(A). Magnetic contactor**



Courtesy Waltronic Company

**Figure 3(B). Ignitron tube contactor**

sure until the fused metals have solidified. In the earliest welders, pressure was applied by the operator through a foot treadle or hand-operated lever and welding current was turned on-and-off by a manually operated switch. In modern welders this elementary method has largely been replaced by mechanical, air, or hydraulic pressure systems and by mechanical or electronic timing devices which are broadly known as controls.

One control component used with every welder is a current contactor which, when closed, permits the welding current to flow. The current in the primary circuit of the welding transformer is always smaller than the current in the secondary circuit. It is therefore customary to connect the contactor into the primary circuit and control the flow of high welding current by starting and interrupting the lower primary current. The location of the contactor in the electrical circuit of a welder is shown in Figure 2(B). Contactors are usually either mechanical (magnetic), or electronic, employing ignitron tubes, or thyraton tubes.

Figure 3 shows a mechanical (magnetic) and an ignitron tube contactor.

Welders which use a mechanical pressure system are usually motor driven and the duration of current flow and timing with respect to pressure are controlled either directly with an adjustable cam which is turned by the driving mechanism, or by a weld timer which is initiated by this cam.

When an air or hydraulic pressure system is used in a spot or projection welder, the timing of both pressure and current flow are controlled by auxiliary timing devices.

Welding current flows as long as the welding electrodes are in contact with the work and the welding contactor is closed. This time interval is known as weld time and its duration is controlled by a weld timer. The spot, projection or seam welding of light metals up to approximately 0.125 inch in thickness requires extremely short weld times, usually less than 1 second. Weld timers therefore, usually have a maximum limit of between 30 and 120 cycles, 0.5 to 2 seconds. For the welding of heavy gauges or for special applications weld timers having a longer maximum time can be obtained.

Mechanical or ignitron tube contactors will begin to conduct at any point of the voltage wave at which they close the circuit. Timers which permit conduction to start indiscriminately at any point on the wave are known as nonsynchronous timers. Such closure may result in transient current conditions during the first several cycles of conduction, the most harmful effect of which is to produce inconsistent welds in materials, the welding of which is critical. With a thyratron or ignitron contactor, it is possible, by the use of especially designed control circuits in the weld timer, to start conduction at any selected point, within certain limits, on the voltage wave, and also to obtain a higher degree of repetitive accuracy when the timer functions. Such timers are designated as

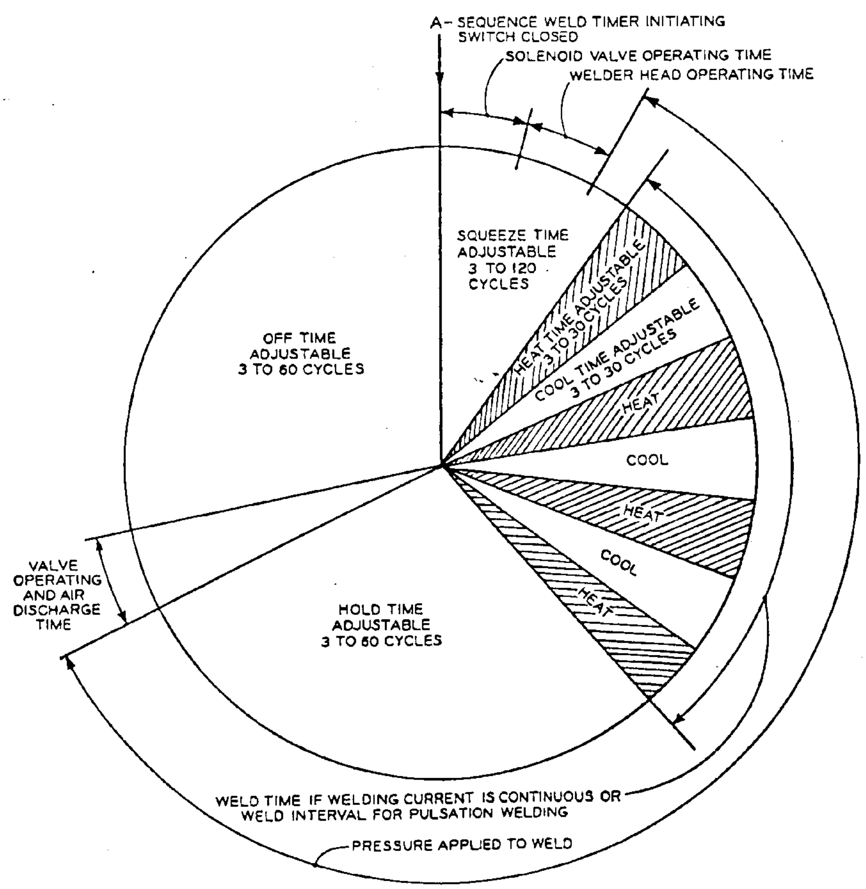



**Figure 4. Pie chart of NEMA type sequence-weld timer**

**Table V. NEMA Standard Combination Timer Contactor Units**

| NEMA Type | Primary Current Contactor | Weld Timer: Spot & Projection: Non-synchronous | Weld Timer: Spot & Projection: Synchronous | Weld Timer: Seam | Phase Shift Heat Control | Squeeze | Cool | Weld Interval | Hold | Off | Voltage Regulator | Current Regulator |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N1H | x | x | | | x | | | | | | | |
| N1C | x | x | | | x | | | | | | | x |
| N1V | x | x | | | x | | | | | | x | |
| N2 | x | x | | | | x | | | x | x | | |
| N2H | x | x | | | x | x | | | x | x | | |
| N3 | x | x | | | | x | x | x | x | x | | |
| N3H | x | x | | | x | x | x | x | x | x | | |
| S1H | x | | x | | x | | | | | | | |
| S2H | x | | x | | x | x | | | x | x | | |
| S2C | x | | x | | x | x | | | x | x | | x |
| S2V | x | | x | | x | x | | | x | x | x | |
| S3H | x | | x | | x | x | x | x | x | x | | |
| S3C | x | | x | | x | x | x | x | x | x | | x |
| S3V | x | | x | | x | x | x | x | x | x | x | |
| S4H | x | | | † | x | x | | | x | x | | |
| S4C | x | | | † | x | x | | | x | x | | x |
| S4V | x | | | † | x | x | | | x | x | x | |
| S5H | x | | | x | x | | | | | | | |
| S5C | x | | | x | x | | | | | | | x |
| S5V | x | | | x | x | | | | | | x | |
| HS3H* | x | | x | | x | x | x | x | x | x | | |
| HS4H* | x | | | † | x | x | | | x | x | | |
| HS6H* | x | | | † | x | | | | | | | |
| HS6C* | x | | | † | x | | | | | | | x |

* 2300 volt.
† Includes selector switch to change from seam to multi-impulse welding.

synchronous-precision weld timers. Synchronous-precision weld timers are more expensive than nonsynchronous timers and are ordinarily used on applications where extremely short weld time is required or transient current conditions cannot be tolerated.

For the spot or projection welding of heavy gauge material two techniques are available. In the first, welding current is applied in a single impulse of long duration and requires controls similar to those previously described. In the second, the welding current is applied to each weld in a series of pulses. This requires a timer which switches the power on-and-off during each weld. The control device which performs this function is known as a pulsation timer and consists of three interval timers, a heat timer, which controls the time during which current flows; a cool timer, which controls the off time between successive heat times; and a weld interval timer, which controls the number of pulses. The magnitude of demand in pulsation welding is usually lower than for a similar single impulse, but the on-and-off characteristic may prove to be less desirable from a power supply standpoint than the higher magnitude of single impulse welding.

In the interest of high production, it is essential to keep the total time that pressure is applied to a minimum, and to co-ordinate the weld time with respect to the application and removal of pressure. With air or hydraulically actuated spot or projection welders this is accomplished by a sequence-weld timer. The pie chart of Figure 4 illustrates the relationship of pressure and the flow of welding current in a sequence weld timer.

After the work is in position, the welding cycle is started by closing the sequence-weld timer initiating switch, point "A" of Figure 4. This immediately closes a valve-actuating relay in the sequence-weld timer which in turn, energizes a solenoid valve and causes the pressure system to function. Simultaneously, it starts the first timing device of the sequence-weld timer to timing out. This first time interval is known as squeeze time and the timing device as the squeeze timer. Its purpose is to delay the start of current conduction until the pressure system of the welder has built up pressure on the work. Timing out of the squeeze time initiates the weld timer or, in case of a pulsation timer, the heat and weld interval timers. Current conduction starts with the initiation of the weld or heat timer and continues until that timer has timed out, when it is stopped. In pulsation welding, heat and cool times repeat to give the desired number of pulsations.

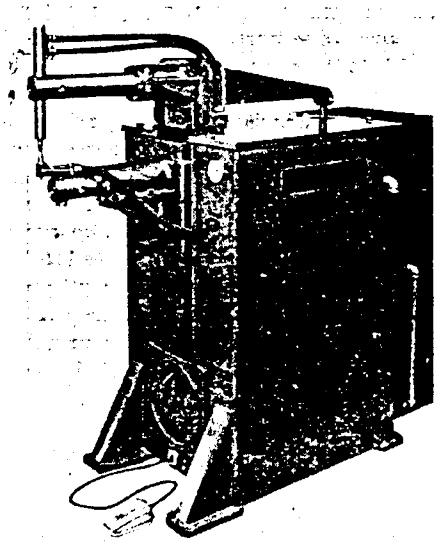
It is usually necessary for pressure to be maintained after current flow has stopped to permit formation of the weld nugget. The duration of this interval is known as hold time and the timing unit which controls it as the hold timer.

Thus the sequence of time intervals for a single weld is: squeeze, weld, hold; or for pulsation welding: squeeze, heat, cool repeated for the duration of weld interval, and hold.

At the end of hold time, pressure is released, the welder head retracts, and the work may be moved. If but one weld is being made in the work piece the operator removes the work, inserts the next piece, again closes the initiating switch and repeats the operation for each spot. If, however, a series of welds are being made in the same piece so that it is necessary for the operator only to reposition the work pie ce, and the time between welds can always be the same, an off time can be introduced between the end of one hold and the start of the next squeeze time, so that the operator can hold the initiating switch closed and thereby increase the productivity of the welder. This timing unit is known as an off timer.

Most sequence-weld timers contain an off timer and a toggle switch which, when set on nonrepeat causes the timer to stop functioning at the end of each hold time or, when on repeat, permits the control to repeat the squeeze, weld, hold, off sequence as long as the initiating switch is held closed.

Different values of pressure and current are required to weld different metals or even different thicknesses of the same metal. Refer to welding schedules in Section VI of this report. The proper pressure can be obtained by adjusting the pressure medium. Current can be adjusted in steps by taps on the primary winding of the welder transformer with



Precision Welder & Machine Company

**Figure 5. Rocker arm welder**

**Table VI. Electrical Characteristics of R.W.M.A. Standard Rocker Arm Type Spot Welders**

| RWMA Standards | | | | | | Approximate Short-Circuit Characteristics | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 60 Cycles | | 25 Cycles | |
| Welder Frame Size | Transformer Kva Rating* 60 Cycles | Transformer Kva Rating* 25 Cycles | Throat Depth Inches | Arm Spacing Inches | Secondary Amperes (±10%) | Kva Demand | Power Factor | Kva Demand | Power Factor |
| 000 | 5 | 2.5 | 8 | 6 | 7,000 | 13 | 0.32 | 6.7 | 0.62 |
| 000 | 5 | 2.5 | 12 | 6 | 6,000 | 11.5 | 0.28 | 5.7 | 0.57 |
| 000 | 5 | 2.5 | 16 | 6 | 5,000 | 9.5 | 0.25 | 4.7 | 0.52 |
| 00 | 7.5 | 4 | 8 | 6 | 8,500 | 20 | 0.32 | 10 | 0.62 |
| 00 | 7.5 | 4 | 12 | 6 | 7,500 | 17 | 0.28 | 8.5 | 0.57 |
| 00 | 7.5 | 4 | 16 | 6 | 6,000 | 14 | 0.25 | 7.0 | 0.52 |
| 0 | 10 | 5 | 8 | 6 | 10,000 | 27 | 0.32 | 13.5 | 0.62 |
| 0 | 10 | 5 | 12 | 6 | 8,500 | 23 | 0.28 | 11.5 | 0.57 |
| 0 | 10 | 5 | 16 | 6 | 7,000 | 19 | 0.25 | 9.5 | 0.52 |
| 1 | 15 | 7.5 | 12 | 8 | 10,000 | 40 | 0.25 | 19 | 0.52 |
| 1 | 15 | 7.5 | 18 | 8 | 9,000 | 36 | 0.23 | 17 | 0.48 |
| 1 | 15 | 7.5 | 24 | 8 | 8,000 | 30 | 0.20 | 15 | 0.43 |
| 2 | 30 | 15 | 12 | 8 | 19,000 | 100 | 0.30 | 49 | 0.60 |
| 2 | 30 | 15 | 24 | 8 | 15,000 | 85 | 0.25 | 39 | 0.52 |
| 2 | 30 | 15 | 30 | 8 | 13,000 | 73 | 0.23 | 34 | 0.48 |
| 3 | 50 | 25 | 12 | 8 | 25,000 | 170 | 0.30 | 83 | 0.60 |
| 3 | 50 | 25 | 24 | 8 | 20,000 | 150 | 0.25 | 74 | 0.52 |
| 3 | 50 | 25 | 36 | 8 | 18,000 | 135 | 0.20 | 66 | 0.43 |

* 50% duty cycle.

which the transformer turn ratio can be changed. Another method of current adjustment, which can be used with a thyratron or an ignitron contactor and either tapped or untapped transformers, is by the use of a phase shift heat control, a device which controls the point on each half cycle of voltage at which ignitron tubes begin to conduct. At full or 100 per cent heat setting the heat control permits the ignitrons to carry current for essentially entire half cycles. At less than 100-per-cent setting the heat control permits the ignitrons to carry current for less than entire half-cycles. In general, heat control units may be adjusted to a minimum of 40 per cent on 220-volt power supplies and 20 per cent on 440-volt power supplies. Since heat is proportional to current squared, these ranges of settings produce heat ranges of 100 to 16 per cent at 220 volts, and 100 to 4 per cent at 440 volts.

Also falling within the category of controls are various auxiliary devices such as voltage compensators, current regulators, slope control, and forge timers which, while often of extreme importance from a welding standpoint have little or no direct effect upon power supply problems and hence will not be discussed.

Standard control units are manufactured by various electrical and electronic equipment manufacturers. Early in the history of welder controls, the various components such as sequence-weld timer, ignitron contactor and phase shift heat control were manufactured as separate units and to obtain a complete control it was necessary to mount and interwire the individual units. Such individual units are still available, but most manufacturers now feature combination units in which various components are housed in one cabinet and interconnected. The National Electrical Manufacturers Association have assigned NEMA designations to various combinations as shown in Table V. Various other separate units and combinations are available for special applications. On strictly special welders which require special control functions, welder manufacturers ordinarily build special control panels which incorporated the desired functions.

## Load Characteristics of Single-Phase Direct Energy Welders

### Rocker Arm Welders

Rocker arm welders, Figure 5, so named because of the rocker action of the upper conductor, are one of the most common type of single-phase a-c direct energy welders. Standard machines are used primarily for making spot welds, one at a time, in metals up to about 0.125 inch thickness. The maximum demand of the largest standard rocker arm welder will not exceed about 170 kva. Weld times range from 1 to 30 cycles and pulsation welding is not usually required on rocker arm welders. The 60-cycle power factor is usually between about 0.25 and 0.40. Since the standard rocker arm welder is a direct energy machine, the frequency of occurrence of its demand depends upon production. In production lines, rocker arm welders usually make from as low as about 10 welds per minute, if the work is large or hard to handle, to as many as 150 or 175 welds per minute under the most favorable circumstances.

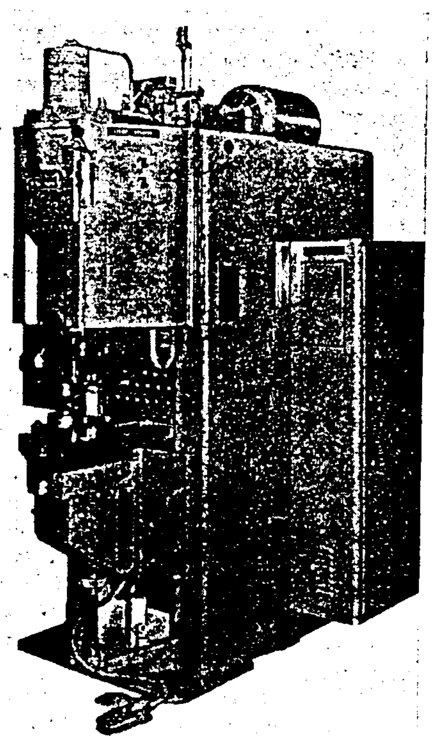
The rocker arm principle also is used in heavy duty spot welders up to about 54-inch throat depth in single-phase ratings up to about 300 kva, and for frequency converters, dry disk rectifiers, and energy storage types of welders. These are relatively few in number and may be considered as special machines.

Table VI gives the electrical characteristics of R.W.M.A. standard 60-cycle and 25-cycle rocker arm welders.

### Press-Type Welders

Press-type welders, Figure 2(A), are used for spot welding, Figure 1(A), and projection welding, Figure 1(B), any kind or thickness of material which can be resistance welded. Their design is such that the upper electrode travels in a straight line instead of an arc, as does the upper electrode of a rocker arm welder. Press welders are therefore used for welding light gauges of metal or small parts if straight line action of the upper electrode is required. For such operations pressure and current requirements, kva demand and kva rating are usually low. Welds per minute usually range from about 50 to 200 per minute. Power factors on small press welders are often as high as 50 to 60 per cent.

Press-type design permits extremely rigid machine construction so that high



Courtesy Taylor-Winfield Corporation

**Figure 6. Heavy-duty press welder**

pressures can be used without causing objectionable frame distortion or deflection of welding electrodes. Press welders are therefore used for practically all spot or projection welding applications which are beyond the pressure range of rocker arm welders. When used for spot welding, the press welder is equipped with horns, electrode holders and electrodes similar or identical to those used in rocker arm welders. When used for projection welding, it is equipped with platens which hold the dies into which the work pieces are placed for welding. A heavy duty press type welder is shown in Figure 6.

Welding current, as well as pressure requirements, increase as material thickness or number of projections increase. Press welders for heavy applications are designed to produce extremely high values of welding current, standard projection welders going as high as 110,000 amperes. This requires a relatively high secondary voltage, about 20 volts for 110,000 amperes. Thus the welding demand of these large welders may be in the order of 2,000 or 2,500 kva. The power factor is usually between about 25 and 40 per cent. Weld times vary from one cycle to as high as 10 seconds. Pulsation welding and special timing sequences such as preheat, weld, post heat, and anneal are often used for heavy materials to improve weld quality. The frequency of operation for the lighter welding operations is much the same as for rocker arm welders, as high as 150 or 175 welds per minute. Frequency usually decreases as thickness of material increases because of the relative difficulty of handling larger parts. Kva demand increases as stock thickness increases. Tables VII and VIII respectively give the electrical characteristics of standard 60-cycle and 25-cycle press-type spot and projection welders.

Press-type welders also are used for resistance brazing, in which case carbon blocks are used instead of projection welding dies. Brazing currents are usually relatively low but relatively high voltage is required to force the current through the carbon blocks. The impedance of the carbon blocks is almost entirely resistance. Therefore, the load power factor is relatively high, often between 70 and 85 per cent. Time of current flow is usually longer than for welding operations.

**Table VII. Electrical Characteristics of R.W.M.A. Standard Press Type Spot Welders**

| R.W.M.A. Standards | | | | | | Approximate Short-Circuit Characteristics | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 60 Cycles | | 25 Cycles | |
| Welder Frame Size | Transformer Kva Rating* 60 Cycles | Transformer Kva Rating* 25 Cycles | Throat Depth Inches | Arm Spacing Inches | Secondary Amperes† | Kva Demand† | Power Factor‡ | Kva Demand† | Power Factor‡ |
| 000 | 5 | 2.5 | 8 | 3 | 6,500 | 8 | 0.60 | 5.4 | 0.88 |
| 00 | 20 | 10 | 8 | 3 | 14,000 | 26 | 0.55 | 17 | 0.85 |
| 0 | 30 | 15 | 8 | 3 | 21,000 | 60 | 0.55 | 33 | 0.85 |
| 0 | 50 | 25 | 8 | 3 | 28,000 | 104 | 0.50 | 57 | 0.81 |
| 1 | 30 | 15 | 18 | 8 | 17,000 | 82 | 0.30 | 45 | 0.60 |
| 1 | 30 | 15 | 24 | 8 | 15,000 | 72 | 0.28 | 33 | 0.57 |
| 1 | 30 | 15 | 36 | 8 | 15,000 | 92 | 0.25 | 46 | 0.52 |
| 1 | 50 | 25 | 18 | 8 | 22,000 | 134 | 0.30 | 72 | 0.60 |
| 1 | 50 | 25 | 24 | 8 | 19,000 | 116 | 0.28 | 58 | 0.57 |
| 1 | 50 | 25 | 36 | 8 | 19,000 | 140 | 0.25 | 70 | 0.52 |
| 1 | 75 | 40 | 18 | 8 | 27,000 | 203 | 0.30 | 100 | 0.60 |
| 1 | 75 | 40 | 24 | 8 | 23,000 | 173 | 0.28 | 86 | 0.57 |
| 1 | 75 | 40 | 36 | 8 | 23,000 | 194 | 0.25 | 105 | 0.52 |
| 2 | 100 | 50 | 18 | 8 | 31,000 | 260 | 0.32 | 130 | 0.62 |
| 2 | 100 | 50 | 24 | 8 | 27,000 | 226 | 0.30 | 113 | 0.60 |
| 2 | 100 | 50 | 36 | 8 | 27,000 | 297 | 0.28 | 150 | 0.57 |
| 2 | 150 | 75 | 18 | 8 | 38,000 | 418 | 0.32 | 210 | 0.62 |
| 2 | 150 | 75 | 24 | 8 | 34,000 | 375 | 0.30 | 190 | 0.60 |
| 2 | 150 | 75 | 36 | 8 | 34,000 | 415 | 0.28 | 205 | 0.57 |
| 3 | 150 | 75 | 18 | 8 | 38,000 | 418 | 0.35 | 210 | 0.67 |
| 3 | 150 | 75 | 24 | 8 | 34,000 | 375 | 0.33 | 190 | 0.65 |
| 3 | 150 | 75 | 36 | 8 | 34,000 | 418 | 0.30 | 205 | 0.60 |
| 3 | 250 | 125 | 18 | 8 | 50,000 | 690 | 0.35 | 345 | 0.67 |
| 3 | 250 | 125 | 24 | 8 | 45,000 | 620 | 0.33 | 310 | 0.65 |
| 3 | 250 | 125 | 36 | 8 | 45,000 | 675 | 0.30 | 340 | 0.60 |

* 50 per cent duty cycle.
† ±10 per cent.
‡ ±5 per cent.

**Table VIII. Electrical Characteristics of R.W.M.A. Standard Press Type Projection Welders**

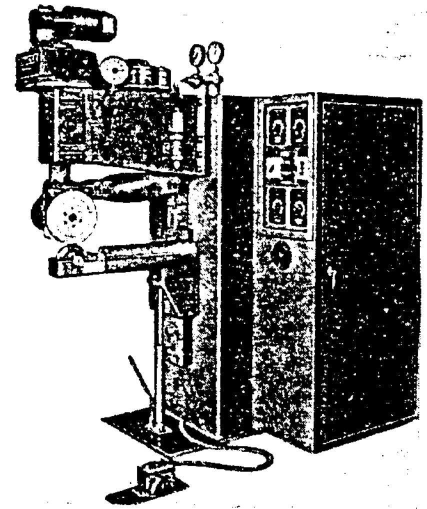
| R.W.M.A. Standards | | | | | | Approximate Short-Circuit Characteristics | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 60 Cycles | | 25 Cycles | |
| Welder Frame Size | Transformer Kva Rating* 60 Cycles | Transformer Kva Rating* 25 Cycles | Throat Depth Inches | Platen Spacing Inches | Secondary Amperes ±10% | Kva Demand | Power Factor | Kva Demand | Power Factor |
| 000 | 5 | 2.5 | 6 | 3 | 7,000 | 7.0 | 0.50 | 4 | 0.81 |
| 00 | 20 | 10 | 6 | 3 | 15,000 | 25 | 0.55 | 14 | 0.84 |
| 0 | 30 | 15 | 6 | 3 | 22,000 | 55 | 0.55 | 31 | 0.84 |
| 0 | 50 | 25 | 6 | 3 | 29,000 | 96 | 0.55 | 52 | 0.84 |
| 1 | 30 | 15 | 12 | 8 | 22,000 | 105 | 0.33 | 52 | 0.62 |
| 1 | 30 | 15 | 18 | 8 | 20,000 | 95 | 0.30 | 48 | 0.60 |
| 1 | 30 | 15 | 30 | 8 | 18,000 | 110 | 0.28 | 54 | 0.57 |
| 1 | 50 | 25 | 12 | 8 | 28,000 | 171 | 0.33 | 80 | 0.62 |
| 1 | 50 | 25 | 18 | 8 | 24,000 | 140 | 0.30 | 71 | 0.60 |
| 1 | 50 | 25 | 30 | 8 | 23,000 | 170 | 0.28 | 85 | 0.57 |
| 1 | 75 | 40 | 12 | 8 | 37,000 | 270 | 0.33 | 135 | 0.62 |
| 1 | 75 | 40 | 18 | 8 | 30,000 | 220 | 0.30 | 110 | 0.60 |
| 1 | 75 | 40 | 30 | 8 | 29,000 | 243 | 0.28 | 120 | 0.57 |
| 2 | 100 | 50 | 12 | 8 | 46,000 | 385 | 0.30 | 190 | 0.60 |
| 2 | 100 | 50 | 18 | 8 | 37,000 | 310 | 0.26 | 155 | 0.54 |
| 2 | 100 | 50 | 30 | 8 | 37,000 | 405 | 0.23 | 200 | 0.48 |
| 2 | 150 | 75 | 12 | 8 | 60,000 | 660 | 0.30 | 330 | 0.60 |
| 2 | 150 | 75 | 18 | 8 | 49,000 | 540 | 0.26 | 270 | 0.54 |
| 2 | 150 | 75 | 30 | 8 | 49,000 | 600 | 0.23 | 300 | 0.48 |
| 3 | 150 | 75 | 12 | 8 | 60,000 | 660 | 0.30 | 330 | 0.60 |
| 3 | 150 | 75 | 18 | 8 | 49,000 | 540 | 0.26 | 270 | 0.54 |
| 3 | 150 | 75 | 30 | 8 | 49,000 | 600 | 0.23 | 300 | 0.48 |
| 3 | 250 | 125 | 12 | 8 | 80,000 | 1,175 | 0.30 | 585 | 0.60 |
| 3 | 250 | 125 | 18 | 8 | 65,000 | 950 | 0.26 | 475 | 0.54 |
| 3 | 250 | 125 | 30 | 8 | 65,000 | 1,040 | 0.23 | 520 | 0.48 |
| 4 | 300 | 150 | 12 | 8 | 88,000 | 1,400 | 0.30 | 700 | 0.60 |
| 4 | 300 | 150 | 18 | 8 | 73,000 | 1,175 | 0.26 | 585 | 0.54 |
| 4 | 300 | 150 | 30 | 8 | 73,000 | 1,500 | 0.23 | 750 | 0.48 |
| 4 | 400 | 200 | 12 | 8 | 100,000 | 1,800 | 0.30 | 900 | 0.60 |
| 4 | 400 | 200 | 18 | 8 | 84,000 | 1,500 | 0.26 | 750 | 0.54 |
| 4 | 400 | 200 | 30 | 8 | 84,000 | 1,925 | 0.23 | 960 | 0.48 |
| 4 | 500 | 250 | 12 | 8 | 110,000 | 2,200 | 0.30 | 1,100 | 0.60 |
| 4 | 500 | 250 | 18 | 8 | 94,000 | 1,900 | 0.26 | 950 | 0.54 |
| 4 | 500 | 250 | 30 | 8 | 94,000 | 2,500 | 0.23 | 1,250 | 0.48 |

* 50 per cent duty cycle.

## Seam Welders

A seam weld is a line of spot welds as illustrated in Figure 1(C). The spots may be spaced according to the requirements of the job from perhaps an inch separation when it is desired only to hold the work piece together mechanically, to close overlapping to provide a liquid or gas-tight weld. When the spots are far apart, the operation is sometimes called roll spot or stitch welding.

Seam welding is performed on seam welders which are similar in construction to press-type welders except that the electrodes are disks which are caused to



Courtesy Sciaky Brothers

**Figure 7. Longitudinal seam welder**

rotate by a driving mechanism. If the wheels are positioned so that their rotation moves the work into or out of the throat of the welder, the machine is called a longitudinal seam welder. If positioned so that the work moves across the throat, the machine is a circular seam welder. Figure 7 shows a longitudinal machine.

A seam weld may be made by causing the current to flow continuously during the welding operation, or by a series of on-and-off periods. The latter method is favored in present-day practice. Recommended timing schedules for mild steel range from 1-cycle-on and 1-cycle-off when welding two pieces of 22 gauge at 144 inches per minute, to 6-cycles-on and 6-cycles-off to weld two pieces of 0.125 inch stock at 24 inches per minute. Other materials and other welding speeds require other timing schedules.

Because of the close proximity of individual spots, part of the secondary current will be shunted through spots which have already been made. For this reason higher current is ordinarily required for seam welding than for spot welding equal thicknesses of the same material. A higher kva demand is required to produce the higher current. Power factor is usually between about 25 and 40 per cent. Table IX gives the electrical characteristics of R.W.M.A. standard seam welders.

Because pressure is applied continuously during an entire seam weld and because the number of on-and-off periods of current depend upon the length of the weld, the sequence-weld timer controls used with spot and projection welders are not adaptable for seam welding and special seam welder control panels are used.

Because it is not practical to seam weld thick materials which can be readily spot and projection welded, the kva demands in seam welding do not reach the magnitude of demands encountered in spot and projection welding. However the frequency of on-and-off periods, from four or five to as high as 30 per second create a condition in which a given kva demand in seam welding may cause a much more objectionable voltage fluctuation than an even higher kva demand for spot or projection welding at a lower frequency of application.

## Portable Gun Welders

In fabricating an assembly such as an automobile frame, a refrigerator shell or a kitchen cabinet, the fact that the assembly is large or odd shaped makes it difficult, if not impossible, to move to a welder. A more practical solution is to fasten the parts to be welded into a fixture and then position the welder to make the desired welds. For this purpose portable gun welders are used.

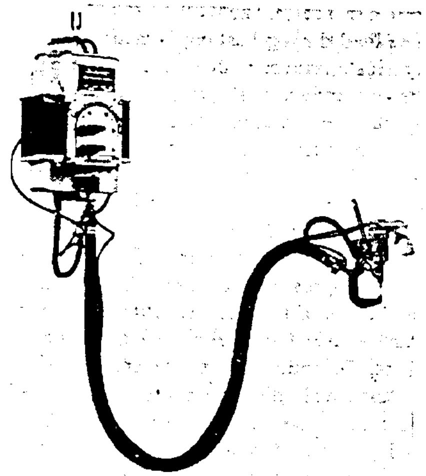
In most portable gun welders the transformer, instead of being mounted in or on the frame of the machine as in a stationary welder, is mounted separately and connected to the gun, which contains the pressure system by cables which carry the welding current from the transformer to the welding electrodes. The transformer is usually hung overhead, and the cables, which must be long enough for the gun to be positioned for the weld, are usually between 4 to 20 feet in length. These cables are a part of the secondary circuit of the welder and their resistance and reactance combined with that of the transformer and gun forms the secondary impedance of the welder. The combined resistance and reactance of the transformer, secondary cables and gun is greater than the resistance and reactance of a stationary welder. Consequently a higher secondary voltage is required to produce a given welding current, and since kva demand equals welding current times the secondary volts required to produce it, the kva demand created by a gun welder is higher than that created by a stationary welder to produce the same welding current. For a given transformer, gun, cable size and welding current, the secondary volts and kva demand increase as cable length increases.

There are two general classifications of portable gun welders. The "push" or "poke" gun is a type in which one cable is grounded to the work with a suitable clamp and the other cable goes to the gun which is held by the operator at any point on the assembly at which it is desired to make a weld. The only pressure is that supplied by the operator. In using a push gun the welder transformer is usually left on the same tap for different welds on the same work piece and thus the secondary voltage is essentially constant. Since the impedance of the secondary circuit will change from spot to spot as the cables are moved around, the welding current and kva demand will also change. Push guns are usually used only for welding light gauge metals and in applications where high quality welds are not required. The magnitude and power factor of their demand are impossible to predict because of the continual changes in impedance of the secondary circuit. Usually their weld frequency does not exceed 60

**Table IX. Electrical Characteristics of R.W.M.A. Standard Seam Welders**

| R.W.M.A. Standards | | | | | Approximate Short-Circuit Characteristics 60 Cycles | |
|---|---|---|---|---|---|---|
| Welder Frame Size | 60 Cycles Kva Rating* | Throat Depth, Inches | Welding Wheel Diameter | Secondary Amperes ±20% | Kva Demand | Power Factor |
| 1 | 50 | 18 | 7 | 22,000 | 90 | 0.40 |
| 1 | 50 | 24 | 7 | 19,000 | 75 | 0.36 |
| 1 | 50 | 30 | 7 | 22,000 | 115 | 0.33 |
| 1 | 75 | 18 | 7 | 27,000 | 135 | 0.40 |
| 1 | 75 | 24 | 7 | 23,000 | 115 | 0.36 |
| 1 | 75 | 30 | 7 | 27,000 | 175 | 0.33 |
| 2 | 100 | 18 | 8 | 31,000 | 165 | 0.37 |
| 2 | 100 | 30 | 8 | 31,000 | 210 | 0.32 |
| 2 | 100 | 42 | 8 | 26,000 | 180 | 0.29 |
| 2 | 150 | 18 | 8 | 38,000 | 270 | 0.37 |
| 2 | 150 | 30 | 8 | 38,000 | 350 | 0.32 |
| 2 | 150 | 42 | 8 | 32,000 | 295 | 0.29 |
| 2 | 200 | 18 | 8 | 43,000 | 350 | 0.37 |
| 2 | 200 | 30 | 8 | 43,000 | 450 | 0.32 |
| 2 | 200 | 42 | 8 | 36,000 | 380 | 0.29 |
| 3 | 250 | 24 | 10 | 43,000 | 450 | 0.34 |
| 3 | 250 | 36 | 10 | 41,000 | 515 | 0.29 |
| 3 | 250 | 48 | 10 | 35,000 | 425 | 0.24 |
| 3 | 400 | 24 | 10 | 54,000 | 700 | 0.34 |
| 3 | 400 | 36 | 10 | 52,000 | 825 | 0.29 |
| 3 | 400 | 48 | 10 | 45,000 | 775 | 0.24 |

* 50 per cent duty cycle.



Courtesy Federal Machine & Welder Company

Figure 8. Portable gun welder

Table X. Electrical Characteristics of R.W.M.A. Standard Portable Gun Welders*

| R.W.M.A. Standards: Welder Size Number | 60 Cycle† Kva Rating | Type Cable | Cable Length Feet | Secondary Amperes ±15% | Approximate Short-Circuit Characteristics 60 Cycles: Kva Demand | Power Factor |
|---|---|---|---|---|---|---|
| 1 | 30 | Low reactance 267mcm | 6 | 10,000 | 100 | 0.80 |
| 2 | 50 | Low reactance 267mcm | 6 | 12,000 | 145 | 0.80 |
| 3 | 75 | Low reactance 267mcm | 6 | 14,000 | 200 | 0.80 |
| 4 | 100 | Low reactance 267mcm | 6 | 16,000 | 250 | 0.80 |
| 5 | 150 | Low reactance 450mcm | 6 | 19,000 | 280 | 0.75 |
| 6 | 200 | Low reactance 450mcm | 6 | 22,000 | 500 | 0.75 |

* Gun throat area not over 8 inches × 12 inches.

† 50% duty cycle.

to 100 spots a minute, with relatively long off times while work is changed.

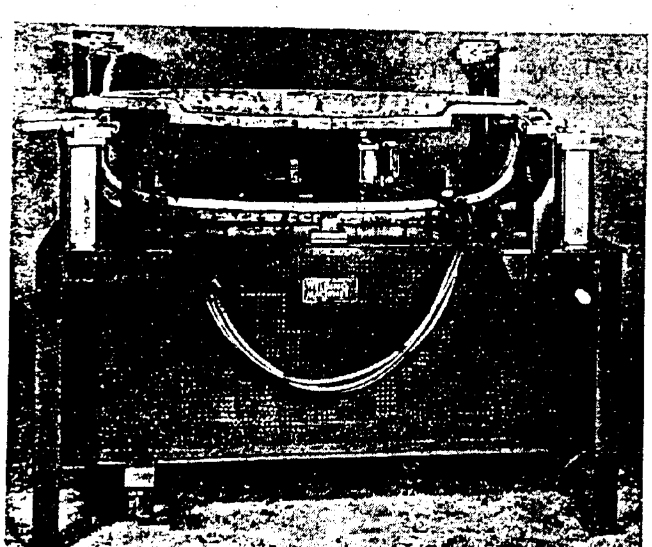
The more conventional type of gun welder uses the same type of portable transformer as the push gun, but the yoke is arranged to hold electrodes in much the same manner as a stationary welder, with one on each side of the weld. The yoke also includes an air or hydraulic cylinder which furnishes the welding pressure. The same controls are used with a gun as with a rocker arm or press welder. A yoke type gun welder may utilize separate going-and-return secondary cables, in the same manner as a push gun. In that case, the condition regarding welding current, kva demand and power factor are the same as for a push gun; they vary and hence are unpredictable. Because higher pressure can be obtained with a yoke type gun, higher welding currents can be utilized. If the cables are close together, the mechanical forces which result from their reactance when current flows, cause them to attempt to move apart. This "kicking" tends to wear the cables and to tire the operator.

These undesirable features of kick and variation in weld current brought about the development of a special cable in which the going-and-return cables are designed to keep reactance to a minimum and which are water-cooled to permit maximum loading. They are known as low reactance, or kickless, cables, and can be obtained in several different sizes and any desired length. A portable gun-type welder with low reactance cable is shown in Figure 8. Because the reactance of a given cable is fixed, welding current does not vary from spot to spot and consistent welds of high quality can be obtained, and the kva and power factor of the demand can be predicted. Because the inherent power factor of the cable is high, the load power factor of yoke-type guns using kickless cables, is relatively high. However, due to the higher total impedance caused by the resistance of the cable, the secondary volts required and the kva demand created for a given welding current are higher than in a stationary-type welder. In order to permit obtaining the higher secondary voltage required without increasing the area of the core, and thus the size, weight, and cost of the transformer, gun welder transformers are usually arranged so that the maximum secondary voltage can be doubled by connecting the individual secondary sections in series.

Table X gives the electrical characteristics of R.W.M.A. standard 60-cycle gun welders with 6-foot low reactance cables.

Gun welders are sometimes operated at as high as 450 spots per minute. They are commonly operated at between about 50 and 150 spots per minute.

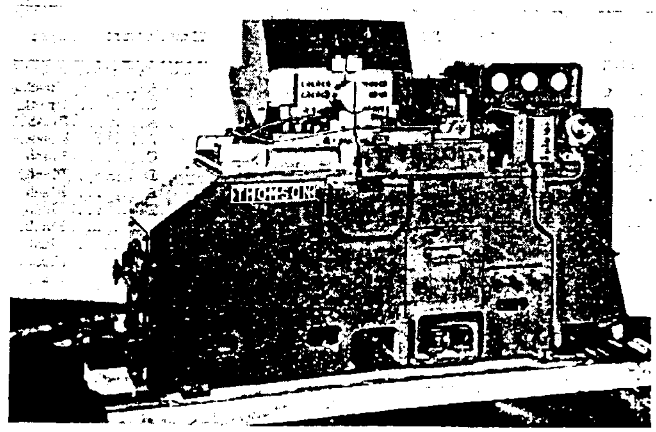
As was discussed previously, reactance is proportional to line frequency with the result that the secondary volts required to produce a given welding current, and the kva demand decrease as supply fre-



Courtesy Welding Machines Manufacturing Company

Figure 9 (left). Fixture type gun welder

Figure 10 (below). Butt welder



Courtesy Thomson Electric Welder Company quency decreases. In the example previously given for a 60-cycle welder, the secondary volts required to produce 25,000 amperes in a stationary welder at 25 cycles was 3.12 compared to 6.25 volts at 60 cycles. The relative kva demands and power factors were 78 kva and 60 per cent for 25 cycles against 156 kva and 30 per cent for 60 cycles.

In gun welders the difference is not so pronounced because of their high 60-cycle power factor. Table II gives a comparison of the electrical characteristics at 60 cycles and at 25 cycles of a size 1 press-type projection welder, a gun with an 8-foot light-duty low-reactance cable and the same gun with an 8-foot heavy-duty cable. This table highlights the difference between stationary and gun welders and between 60-cycle and 25-cycle units. Because of the comparatively small difference in the 60-cycle and 25-cycle secondary impedance of gun welders, approximately the same secondary voltage and kva demand are required to produce a given welding current at either frequency. Therefore 25-cycle gun welder transformers, which are designed to carry the same current as 60-cycle transformers, carry the same kva rating but can be operated at a somewhat higher duty cycle.

### Fixture-Type Gun Welders

A fixture-type gun welder is shown in Figure 9. This type of equipment is strictly special and the arrangement of the secondary circuits vary so that no typical values of secondary volts and amperes, kva demand or power factor can be given. However, if the open circuit secondary volts and secondary amperes are stamped in the welder nameplate, the short circuit kva demand can be determined. Otherwise it will be necessary to make a short circuit test to determine these facts.

### Butt Welders

Butt welding is a process for resistance welding two pieces of metal end-to-end or edge-to-edge, in which the entire abutting surfaces are welded. An end-to-end butt weld is shown in Figure 1(D). A butt welder is shown in Figure 10. There are two distinct methods of butt welding; upset butt and flash butt. In both methods the work pieces are held in clamps, which are the terminals of opposite polarity of the secondary circuit of the welder.

In upset butt welding the two areas to be joined are brought into solid contact with each other while current is passed through them. The heat results from the flow of current through the resistance of the work pieces and the contact resistance at the point of weld. When the surfaces have reached a plastic state of weldability machine pressure forges them together. Although the resistance of the work pieces rise as they heat up, the change in the total impedance of the secondary circuit is usually not great and butt welding is characterized by a relatively constant load. The actual welding current and kva demand depends upon the material being welded, the cross section of the work pieces and the distance from the abutting surfaces to the clamps which hold the work. The weld time for upset butt welding depends upon the material and the cross-sectional area of the work pieces and contact areas. The power factor for butt welding operations is usually relatively high, from 50 to 75 per cent—because of the resistance of the work pieces between the clamps and the surfaces being welded. For the same reason, the maximum welding kva of an upset butt welder is usually smaller and its power factor higher in relation to the short-circuit kva, than in a rocker arm, press or seam welder.

Flash butt welding differs from upset butt welding in that the work pieces are held in very light contact during the heating interval with the result that, as particles of the surfaces become molten they are expelled from the weld area in a flashing action. This is known as the flashing period. During this interval, the current is often actually conducted through ionized air between the two surfaces. When the surfaces have reached the desired state of plasticity, a high pressure is suddenly applied to forge the weld. This is known as the upset period. The load during flashing is characterized by instantaneous demands of widely varying kva and power factor. During upset, unless welding technique requires that the current be cut off, the kva demand is much higher and the power factor much lower than during flashing. If the work is clamped close to the weld, the load and power factor during upset often approach the short-circuit characteristics of the welder. Flashing times vary widely for different welding operations, depending upon the cross section of the work piece and the mass to be heated. Upset time is usually short.

There are two general types of butt welders, manual and automatic. In manual units, the pressure is applied by the operator through a hand lever. The operator determines the amount of pressure and the length of both flashing and upset time. He also controls the time that current is turned on. Current cut-off may be controlled by the operator or may be automatically controlled with a limit switch. Automatic butt welders incorporate a pressure medium such as springs or an air or hydraulic system. The pressure cycle and time of current flow are automatically controlled.

Although R.W.M.A. has not as yet established standards of secondary current for butt welders such as those which have been established for other types of welders, Table XI gives the open circuit secondary volts, short-circuit secondary amperes, kva and power factor of several manufacturers' butt welders. This table illustrates the difference in these characteristics between machines of various manufacturers.

Because the work impedance in a butt weld often comprises a large part of the

**Table XI. Typical Characteristics of Butt Welders**

| | Welder | | | Maximum | | | |
|---|---|---|---|---|---|---|---|
| | | | | | Approximate Short Circuit | | |
| Manufacturer | Type | Frame Size | Kva Rating, 60 Cycle | Open Circuit Secondary Volts | Secondary Amperes | Kva | Power Factor |
| A | Upset | 0 | 10 | 3.0 | 13,000 | 39 | 0.35 |
| C | Upset | 0 | 20 | 4.5 | 20,000 | 90 | 0.25 |
| A | Flash | 1 | 20 | 4.4 | 18,700 | 82 | 0.37 |
| B | Flash | 1 | 20 | 3.4 | 28,000 | 95 | 0.40 |
| C | Flash | 1 | 20 | 5.0 | 23,000 | 115 | 0.48 |
| D | Flash | 1 | 20 | 4.4 | 25,000 | 110 | 0.25 |
| A | Flash | 2 | 50 | 7.85 | 38,500 | 302 | 0.37 |
| B | Flash | 2 | 50 | 5.5 | 40,000 | 220 | 0.40 |
| C | Flash | 2 | 50 | 6.28 | 30,000 | 188 | 0.45 |
| D | Flash | 2 | 50 | 6.0 | 26,000 | 155 | 0.50 |
| A | Flash | 3 | 100 | 8.15 | 53,500 | 436 | 0.43 |
| B | Flash | 3 | 100 | 7.5 | 49,000 | 370 | 0.40 |
| C | Flash | 3 | 100 | 8.46 | 49,000 | 415 | 0.37 |
| D | Flash | 3 | 100 | 7.3 | 40,000 | 290 | 0.50 |
| A | Flash | 4 | 150 | 9.6 | 52,500 | 500 | 0.37 |
| B | Flash | 4 | 150 | 10.5 | 72,000 | 760 | 0.40 |
| C | Flash | 4 | 150 | 8.8 | 51,000 | 450 | 0.37 |
| D | Flash | 4 | 150 | 8.4 | 46,000 | 385 | 0.50 |
| A | Flash | 5 | 250 | 11.0 | 70,000 | 770 | 0.38 |
| B | Flash | 5 | 250 | 11.0 | 82,000 | 900 | 0.40 |
| C | Flash | 5 | 250 | 10.0 | 57,000 | 570 | 0.37 |

total secondary impedance, the kva demand and power factor for butt welding at 25 cycles may not be appreciably different than at 60 cycles. Many welder manufacturers use transformers having the same secondary volts and same kva ratings for either frequency.

## Series Capacitors

Series capacitors applied to a single-phase direct energy welder provide a means for raising the power factor to near unity by counteracting the inductive reactance of the secondary circuit. They often make possible the use of a welder which could not be operated at its inherent power factor from existing facilities, or may prove to be less expensive than installing additional system capacity to serve the load. They are generally adaptable to welders which have a fixed throat and which perform a single welding operation as, for example, a seam welder or a heavy spot or projection welder used on one job. They are not generally adaptable to portable gun welders with low reactance cables, to welders which have a low inductance secondary circuit, or to 25-cycle welders, because these types have inherently high power factor. Care must be used in applying series capacitors to critical welding operations where variations in work resistance will cause variations in welding current and thus in weld quality. Their greatest disadvantage on applications for which they are technically adaptable is that generally a separate capacitor installation and special controls are required for each welder that is installed. If many welders are involved it may be found more economical to strengthen the power supply to serve the load than to apply series capacitors to each welder.

Series capacitors are installed in the primary circuit of a resistance welder in such a manner that the primary current contactor turns the current to the welder transformer and to the capacitors on-and-off simultaneously. The voltage across the capacitors during weld bears the same relationship to supply voltage as the rkva component of the load bears to the kw component. The voltage across the welder transformer bears the same relationship to supply voltage as the kva component of the load bears to the kw component. Consequently either a specially wound high-voltage welder transformer, or an autotransformer to be used in conjunction with a standard welder transformer is usually required. Although under certain conditions standard control units may be used, special controls are ordinarily required. Variation in welding current is obtained with taps in the autotransformer, which permit adjusting the voltage applied to the welder transformer, or by phase shift heat control.

Series capacitors are applied for the welding condition. If the welder is fired with the electrodes together under short-circuit conditions its power factor is lower than during welding, and since the voltage of the capacitor is a function of power factor, capacitor units of high enough voltage rating to stand the voltage under short-circuit conditions, or an overvoltage protective device, must be furnished. The capacitor units retain their charge during the off-time between welds and, as a safety precaution, provision is made to automatically connect a discharge resistor across them when the main power switch is opened.

The application of series capacitors requires an accurate knowledge of short circuit and welding kva demands and power factors, and of the maximum duty cycles at which the welder will be operated. It requires also close co-ordination of the welder transformer, the capacitor units and the welder controls. Capacitors and controls are essentially standard equipment while the welder and welding characteristics vary between applications. Consequently the welder manufacturer is ordinarily the only one in a position to supply the technical information and assume the responsibility for the successful operation of the installation. Series capacitor installations are therefore usually handled through the welder manufacturer.

For purposes of illustration, the voltage drop, *VD*, in a single-phase power system serving a single-phase welder without series capacitors may be calculated from the formula:

$$VD = I\,(R \cos\theta + X \sin\theta)$$

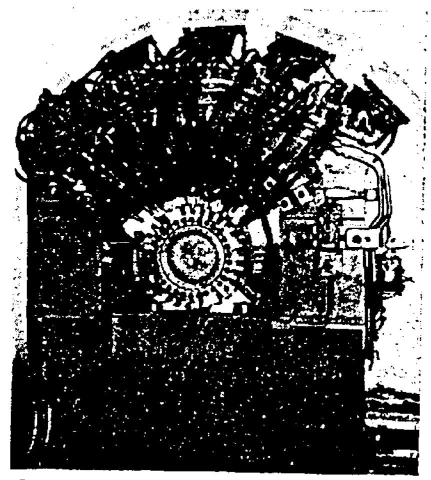
in which

$I$ = load amperes
$R$ = resistance of the power supply system
$X$ = reactance of the power supply system
$\cos\theta$ = load power factor
$\sin\theta$ = sine of the power factor angle

In most power supply systems having sufficient capacity to serve welder load the ratio of resistance to reactance does not exceed about 0.3/1.0

If we assume a 230-volt system having a resistance of 0.003 ohm and a reactance of 0.010 ohm, and a welder having a demand of 230 kva at 0.30 power factor:

$I = 1{,}000$ amperes
$R = 0.003$ ohm
$X = 0.010$ ohm



Courtesy National Electric Welding Machines Company

**Figure 11. Hydromatic welder**

$\cos\theta = 0.3$
$\sin\theta = 0.954$

The voltage drop which this load will cause is:

$$\begin{aligned} VD &= I\,(R \cos\theta + \sin\theta) \\ &= 1{,}000\,(0.003 \times 0.3 + 0.010 \times 0.954) \\ &= 1{,}000\,(0.0009 + 0.00954) \\ &= (0.9 + 9.45) \\ &= \frac{10.44}{230} \times 100 = 4.54 \text{ per cent drop} \end{aligned}$$

It will be seen that 0.9 volt, or approximate 10 per cent of the total drop, is the product of the resistance of the circuit and the cosine of the power factor angle, and 9.54 volts, or approximately 90 per cent of the total drop is due to the reactance of the circuit and the sine of the power factor angle.

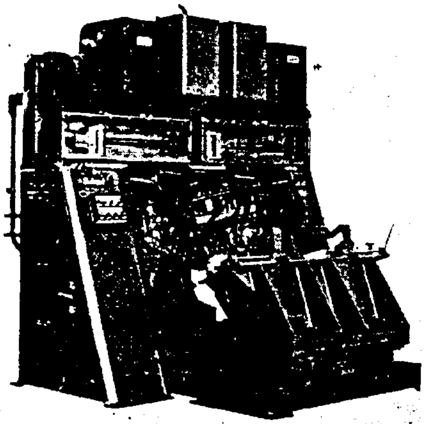
By adding series capacitors to this welder and raising its power factor to unity, the line current is reduced to $1{,}000 \times 0.30 = 300$ amperes; the cosine of the power factor angle becomes 1.0 and the sine zero. The voltage drop which the welder would cause would then be:

$$\begin{aligned} VD &= 300\,(0.003 \times 1.0 + 0.010 \times 0) \\ &= 300\,(0.003 + 0) \\ &= 0.90 \text{ volts} \\ &\frac{0.90}{230} \times 100 = 0.39 \text{ per cent drop} \end{aligned}$$

A 0.39 per cent drop might be entirely permissible while 4.54 per cent drop would be intolerable.

## Load Characteristics of Load-Distributing Type Welders

The fabrication of a large assembly such as a metal desk drawer, a refrigerator shell, or an automobile body requires a relatively large number of spot or projec-



Courtesy Federal Machine & Welder Company

Figure 12. Ultraspeed welder

tion welds. Welding time can be radically reduced, and production increased correspondingly, if all welds can be made without having to reposition the work pieces between a single pair of electrodes for each individual weld. For this purpose multielectrode welding machines are used, in which as many as 200 individual welds can be made without repositioning the work. This is accomplished by providing a separate electrode for each weld. These welders can be arranged to take power from a single phase and make welds simultaneously, but they also offer the possibility of various electrical arrangements by which the welds can be distributed over more than one phase, or made in sequence rather than simultaneously, on one, two or three phases. If arranged to make all welds simultaneously on one phase, the total single-phase demand upon the power system would be the product of the demand for each weld times the number of welds, and for a large number of welds could reach a rather staggering value.

There are three general classes of multielectrode welders which have exploited these various possibilities for distributing the load: the hydromatic welder, the ultraspeed welder, and the multitransformer welding press. In some of these it is usually possible to design the circuit of each electrode to keep the secondary leads relatively short, and the throat area small, and so keep the kva demand per electrode to a lower value than in conventional single spot welders.

### Hydromatic Welders

In the hydromatic welder shown in Figure 11, the individual electrodes are connected to either a single transformer or one of several transformers, and are operated by a special control which causes one or more electrodes at a time to contact the work, and energizes the transformer each time an electrode or group of electrodes is in welding position. All electrodes are "hot" each time the transformer is energized, but welds are made only by those making contact with the work. The instantaneous demand depends upon the number of welds being made simultaneously, and is repeated in rapid succession until all welds on the assembly have been made.

### Ultraspeed Welders

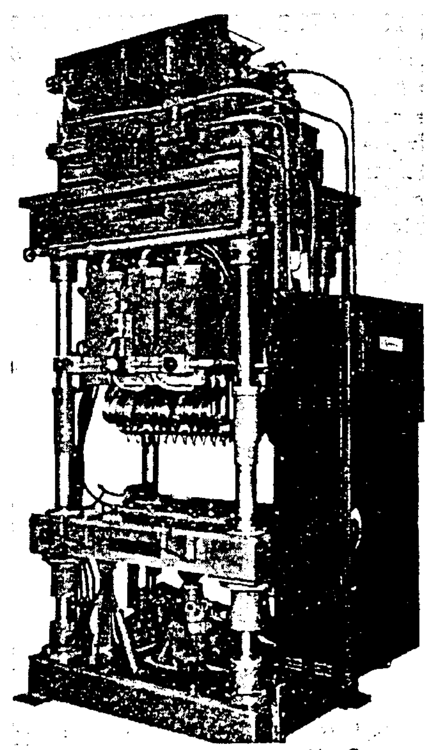
In the ultraspeed welder, Figure 12, the secondary circuit resembles a commutator and brush arrangement with each electrode being connected to a terminal which corresponds to a commutator segment. A rolling, wiping, or pressure contact corresponds to the brush. All electrodes are brought in contact with the work simultaneously, but each is energized and makes a weld only when its circuit to the transformer is completed through the brush and commutator. The load characteristics of an ultraspeed are similar to those of a hydromatic. Each reduces the magnitude of demand, which is repeated for each weld or group of welds. Since both are welders of strictly special design, no typical values of demand can be given for them. Load characteristics must be obtained from the welder manufacturer for each machine.

### Multitransformer Welding Press

The welding press may, in general concept, be likened to a stamping press except that instead of punching, forming or trimming, the welding press makes a multiplicity of welds on a single assembly. A welding press is shown in Figure 13. The electrical power unit consists either of large transformers having many secondary sections, or of a number of small transformers, each of which usually has two secondary sections. In either case an electrode is connected to each terminal of each secondary section. Thus each secondary section and its associated electrodes comprise, from an electrical standpoint, a complete welding system. Each system is usually arranged so that a separate weld is made under each electrode, whereas in a standard spot welder a single weld is made between a pair of electrodes. This is known as series welding and is illustrated in Figure 14.

The significant feature in series welding is that both electrodes contact the same side of the work pieces and a backup bar is used to carry the welding current from one weld to the other. In Figure 14, the weld current flows from transformer secondary terminal $A$ through electrode $A$, and weld area $A$, through the backup bar to weld area $B$, through weld $B$ and electrode $B$, back to terminal $B$ of the transformer secondary. Some current will, of course, flow from one weld to the other through the work, but by following the proper welding technique as to material thickness and distance between welds this shunting effect can be kept to a minimum. In series welding the kva demand created to make two welds is greater than the kva required to make a single weld only by the amount which the impedance of the second weld area increases the impedance of the entire secondary circuit, plus the amount by which shunting increases the total current required. The total increase in kva is usually about 25 per cent. In other words, two welds can be obtained with about 25 per cent higher kva than required for a single direct weld.

From a power supply standpoint the advantage of series welding is that, because the electrodes both contact the same side of the work piece, the transformers can be located very close to the electrodes, the secondary conductors made very short and the throat area made only as large as is required to provide the necessary spot spacing and separation of going and returning conductors. This



Courtesy Precision Welder & Machine Company

Figure 13. Multitransformer welder press

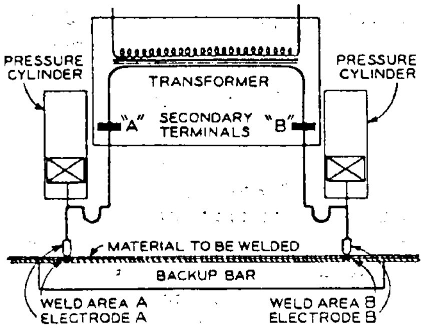



**Figure 14. Diagram illustrating series welding**

keeps the impedance of the secondary circuit low, which in turn means that fewer volts and thus a lower kva demand are required to produce a given welding current.

Design factors require different secondary circuit configurations and different backup bar arrangements even in the same welder, so that the impedance of a welding press is not as nearly fixed as that of R.W.M.A. standard welders previously described. Therefore a table similar to those given for the other welders cannot be presented. However, one of the largest users of welding presses states that the kva demands shown in Table XII are sufficiently accurate for powe supply calculations.

**Table XII**

| | Kva Demand per Pair of Series Welds |
|---|---|
| For two pieces of 20-gauge SAE 1010 mild steel | 44 |
| For two pieces of 18-gauge SAE 1010 mild steel | 60 |
| For two pieces of 16-gauge SAE 1010 mild steel | 80 |

The trend is to improve the electrical design of welding presses, so that it is probable that these values will decrease somewhat in the future.

Because of the closeness of going and return conductors in the welding circuits the secondary reactance is usually relatively low and power factor relatively high, between about 50 and 70 per cent on 60 cycles.

Each welding press usually has but one pressure system, so that all electrodes are in contact with the work at the same time. However, the transformers can be energized in any desired sequence, that is, all at one time or in groups, with any number of transformers in a group, and can be connected all to the same phase or divided between two or among all three phases. From a production standpoint it is desirable to energize all transformers and make all welds simultaneously. However, if the power system is not adequate for the demand which simultaneous operation would create, various groups may be energized in sequence. With modern controls it is possible to energize individual groups with as little as about 1.5 cycles time between groups which, from a light flicker standpoint, is often not objectionable.

**Table XIII. Kva Demand for Different Groupings of Transformers**

| Simultaneous Transformers Energized | Series Welds | Number of Groups of Welds | Total Welds | Kva Demand Per Group Material Thickness 20 gauge | 18 gauge | 16 gauge |
|---|---|---|---|---|---|---|
| 1 | 2 | 8 | 32 | 88 | 120 | 160 |
| 2 | 4 | 4 | 32 | 176 | 240 | 320 |
| 4 | 8 | 2 | 32 | 352 | 480 | 640 |
| 8 | 16 | 1 | 32 | 704 | 960 | 1280 |

For a welding press, with all transformers connected to the same phase, making a total of 32 welds, the kva demand for different groupings of transformers is shown Table XIII.

Hydromatic and ultraspeed welders and multitransformer welding presses are essentially special equipment. To use either a hydromatic or an ultraspeed welder for different work pieces, except perhaps for assemblies of the same general shape but of different sizes which can be compensated for by machine adjustments, requires completely rebuilding the welder. Some types of welding presses can however be converted with relative ease by changing the electrode mounting brackets to reposition the electrodes, and the backup dies.

## Frequency Converter Welders

In the description of single-phase a-c welders it was shown that, for a given secondary circuit and secondary current, the secondary volts, line current, and kva demands were lower, and the load power factor higher, for 25-cycle than for 60-cycle welders. This is because these factors are all a function of secondary circuit reactance, which is in turn a function of frequency. It follows then that with frequencies of less than 25 cycles in the secondary circuit, the same secondary current could be obtained with still lower secondary voltages, line currents, and kva demands, and higher power factors than at 25 cycles. These characteristics are desirable from a power supply standpoint. Frequency converter controls are designed to take advantage of this phenomenon and are manufactured for use with special spot, projection, and seam welders.

Frequency converters may be designed for operation from either a single-phase or a 3-phase power supply. Because of the advantages of spreading the load over three phases, most units are 3-phase, which gives rise to the name "3-phase welders" that is often applied to them. However, since there are other types of welders, dry disk rectifier, multitransformer, and storage of energy, which also use a 3-phase input, the term frequence converter welder is more descriptive of the device, and is the preferred name.

Frequency converter welders incorporate an especially designed transformer and especially designed controls which take power at line frequency and, by rectification and transformer action, produce a series of unidirectional pulses of current in the secondary circuit. When these pulses are of alternating polarity, the result is a nonsinusoidal alternating current.

Figure 15 shows in simplified form the power circuit of a frequency converter welder designed for 3-phase input. *C1*, *C2*, and *C3* represent primary coils wound on the common core of the welder transformer. *C4* is the welder secondary circuit. *A1*, *A2*, and *A3*, *B1*, *B2*, and *B3*

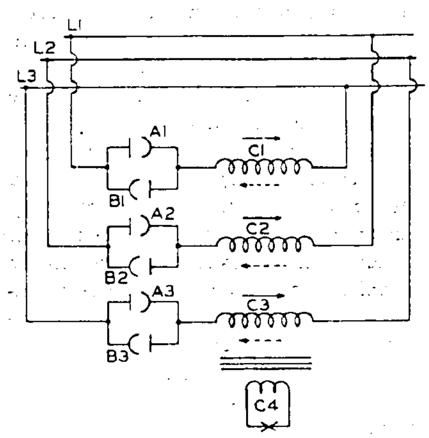
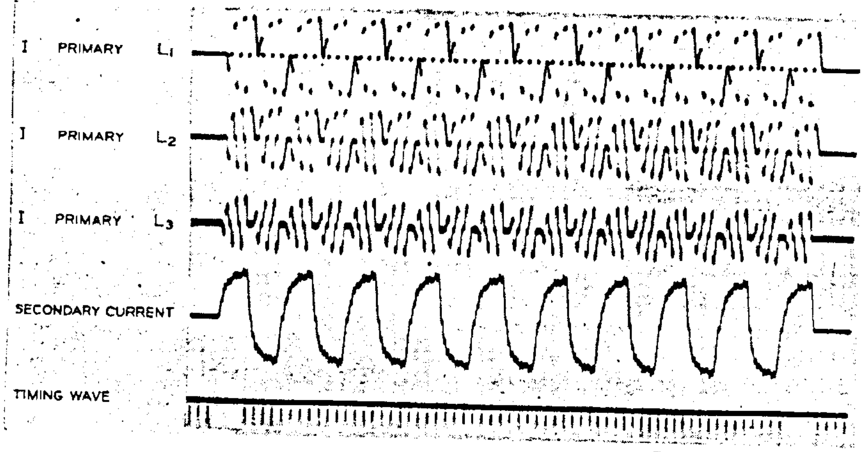



**Figure 15. Power circuit of a frequency converter welder**




Courtesy Sciaky Brothers

**Figure 16. Typical primary and secondary currents of a frequency converter welder**

are gaseous conduction, ignitron tubes in which current can flow only in one direction. *L1*, *L2*, and *L3* represent the 3-phase line.

In operation, tube *A1* is made conductive during the half-cycle, 60-cycle base, that its anode is positive. This causes current to flow from line *L1*, through coil *C1*, to line *L3*. When the anode voltage of tube *A2* rises above the anode voltage of tube *A1*, *A2* will begin to conduct and current will flow from line *L2*, through coil *C2* to line *L1*. At essentially the same time that tube *A2* begins to conduct, tube *A1* stops conducting. When the anode voltage of tube *A3* rises above the anode voltage of tube *A2*, *A3* will begin to conduct and current will flow from line *L3*, through coil *C3* to line *L2*. At essentially the same time that tube *A3* begins to conduct, tube *A2* stops conducting. Primary coils *C1*, *C2* and *C3* are arranged so that their respective currents induce a flux in the same direction in the transformer core which, in turn, induces a unidirectional voltage in the secondary coil. When the secondary circuit is closed, as during a weld, this unidirectional voltage causes unidirectional current to flow in the circuit and thus through the weld.

When tubes *A1*, *A2*, *A3* are caused to stop conducting, the flow of secondary current in effect stops also. The number of times that tubes *A1*, *A2*, and *A3* are permitted to conduct determines the duration of the flow of a single pulse of unidirectional secondary current. This interval is known as pulse time. At any time after the secondary current has stopped flowing, tubes *B1*, *B2*, and *B3* may be caused to conduct in the same manner as described for tubes *A1*, *A2*, and *A3*. Since the *B* tubes are connected to pass current through the transformer coils in the opposite direction from the *A* tubes, the flux in the transformer core, and the voltage induced in the secondary coil are also in the opposite direction, and the secondary current is opposite in polarity.

The time between the conduction of opposite sets of tubes is known as interpulse time. The duration of one pulse of each polarity plus two interpulse times constitutes one low frequency cycle. The number of cycles per second is the low frequency setting of the welder. Among the more commonly used frequencies are $5^5/_{11}$, $6^2/_3$, $8^4/_7$, 12, and 20 cycles. Frequencies as low as 3 cycles are in use. The number of low frequency cycles which the control permits weld current to flow for each spot is called weld time. It is adjustable.

Some frequency converter controls also are arranged to permit the firing of only one group of ignitron tubes, *A* or *B* provide unidirectional current for each individual weld. Successive welds are ordinarily made with pulses of alternate polarity to keep the welder transformer from saturating.

In a given welder the longest pulse time permissible is determined by the amount of core iron and the number of primary turns in the transformer; it must not be long enough to cause the core to saturate.

Figure 16 shows the primary and secondary currents of a frequency converter welder set for a secondary circuit frequency of $8^4/_7$ cycles per second.

The secondary voltage and secondary phase and line currents of a frequency converter are not sinusoidal in shape and consequently cannot be metered accurately with ordinary meters. The secondary current pulse has a relatively slowly rising wave front which results in the instantaneous values of primary current and kva demand being greater at the end than at the beginning of each pulse.

Primary current, which is used in

**Table XIV**

| | Single-Phase A-C Welder | Frequency Converter Welder Set for 12-Cycle Low Frequency |
|---|---|---|
| $I_2$ = rms secondary amperes | 34,000 | 34,000 |
| $E_{2-60}$ = secondary volts @ 60 cycles | 12.2 | |
| P.F.$_{60}$ = 60-cycle power factor = cos $\theta$ | 0.28 | |
| Sin $\theta$ | 0.96 | |
| $Z_{60}$ = 60-cycle secondary impedance = $E_{2-60}/I_2$ | $\frac{12.2}{34,000} = 0.000360$ | |
| $R_{60}$ = 60-cycle secondary resistance = $Z_{60}$ cos $\theta$ | $0.000360 \times 0.28 = 0.000100$ | |
| $X_{60}$ = 60-cycle secondary reactance = $Z_{60}$ sin $\theta$ | $0.000360 \times 0.96 = 0.000343$ | |
| $X_{12}$ = 12-cycle secondary reactance = $X_{60} \times 12/60$ | | $0.000343 \times \frac{12}{60} = 0.000068$ |
| Tan $\theta_{12} = \frac{X_{12}}{R_{60}}$ | | $\frac{0.000068}{0.000100} = 0.68$ |
| Cos $\theta_{12}$ = 12-cycle power factor | | 0.83 |
| $Z_{12}$ = 12-cycle secondary impedance = $R_{60}$/cos $\theta_{12}$ | | $\frac{0.000100}{0.83} = 0.000120$ |
| $E_{dO}$ = open circuit secondary volts = $I_2 \times Z_{12}/0.91$* | | $\frac{34,000 \times 0.000120}{0.91} = 4.47$ |
| N = transformer turns per coil = $1.17E_1/E_{dO}$* | | $\frac{1.17 \times 440}{4.47} = 115$ |
| $I_L$ = rms line current = $I_2 \times E_{2-60}/E_{1-60}$ | $34,000 \times \frac{12.2}{440} = 945$ | |
| $I_{LV}$ = rms equivalent of line frequency component of primary current = $0.647I^2/N$* | | $\frac{0.647 \times 34,000}{115} = 191$ |
| kva$_L$ = $E_1 \times I_L/1,000$ | $\frac{440 \times 945}{1,000} = 415$ | |
| kva$_{LV}$ = $E_1 \times I_{LV}\sqrt{3}/1,000$ | | $\frac{440 \times 191 \times 1.73}{1,000} = 145$ |

* 0.91 and 1.17 are factors to compensate for the shape of the secondary wave. 0.674 is a factor introduced by the manner in which the circuit converts from 3-phase primary to single-phase secondary current.

voltage drop calculations, consists of a line frequency component plus harmonics. The effect of the harmonics on voltage drop is negligible when the total drop is only a few per cent of no load voltage and harmonics may therefore be neglected. The remaining line frequency component may be considered as sine wave in shape and the currents for the three phases as being of equal magnitude and displaced from each other by 120 electrical degrees.

The power factor of the demand of a frequency converter welder upon a power supply system is not the same as the power factor of the secondary circuit. It is affected by the design of the welder transformer. The power factor may, for voltage drop calculations, be assumed to be 85 per cent.

Although the currents and voltages of a frequency converter welder are non-sinusoidal, include harmonics, and cannot be measured with ordinary instruments, it is possible to calculate the electrical characteristics required for either design or power supply purposes with acceptable accuracy from the known secondary voltage, current and power factor of a 60-cycle welder, the secondary circuit of which is the same as that of the frequency converter.

The calculations given in Table XIV show the method of determining these values for a frequency converter which is to produce 34,000 amperes with the secondary short-circuited and which has the same secondary circuit as a single-phase welder the characteristics of which are:

| | |
|---|---|
| Short-circuit secondary amperes | 34,000 |
| Open-circuit secondary volts | 12.2 |
| 60-cycle power factor | 0.28 |

Both are served from 60-cycle power supplies. The frequency converter controls are adjusted to produce a 12-cycle frequency in the secondary circuit of the welder.

The same procedure may be used to calculate these values for any other secondary frequency by using the numerical value of that frequency instead of the 12 cycles used in Table XIV.

For high conductivity material such as aluminum the impedance of the work does not usually add over 10 per cent to the impedance of a frequency converter secondary circuit. Therefore the maximum welding current will be approximately 90 per cent of the short-circuit current. The load power factor during welding may be considered to be the same as the short-circuit power factor of the welder.

For mild steel however, especially in the heavier gauges, the impedance of the work will add appreciably to the impedance of the welder proper. Thus to obtain the same welding current the welder transformer must be designed with a higher secondary voltage. This in turn will increase the welding kva and the short-circuit secondary current and kva.

The following calculations show the secondary volts, primary amperes, and kva demand to produce 34,000 amperes in the above frequency converter welder when welding two pieces of steel having an impedance of 0.000060 ohm at the same power factor as the welder proper.

$$(Z_{12}+Z \text{ work}) = (0.000120+0.000060) = 0.000180 \text{ ohm}$$

$$E_{do} = \frac{34{,}000 \text{ amperes} \times 0.000180 \text{ ohm}}{0.91} = 6.7 \text{ volts}$$

$$N = \frac{1.17 \times 440}{6.7} = 77 \text{ turns}$$

$$I_{LV} = \frac{0.647 \times 34{,}000}{77} = 285 \text{ amperes}$$

$$\text{kva}_{LV} = \frac{440 \times 285 \times 1.73}{1{,}000} = 218 \text{ kva}$$

If this welder is operated without work between the electrodes, the impedance of the secondary circuit will be the short-circuit impedance of the welding machine which was shown to be 0.000120 ohms. Under this condition:

$$I_2 = \frac{E_{do} \times 0.91}{Z_{12}} = \frac{617 \times 0.91}{0.000120} = 51{,}000 \text{ amperes}$$

$$I_{LV} = \frac{0.647 \times 51{,}000}{89} = 370 \text{ amperes}$$

$$\text{kva}_{LV} = \frac{440 \times 370 \times 1.73}{1{,}000} = 282 \text{ kva}$$

Repeated operation under short-circuit conditions of a frequency converter welder with sufficient secondary voltage to weld steel might damage the ignitron tubes. Provisions are usually made to permit firing of the welder only when work pieces are in place. It is therefore customary to base power supply requirements upon the voltage drop which is created by the welding, rather than by the short-circuit demand.

Line current and power factor, the characteristics of a load which determine magnitude of voltage drop in a power supply system, are functions of the frequency of the secondary circuit of a frequency converter. Line current decreases and power factor increases as this frequency is decreased. Although most present-day frequency converter controls can, by making internal adjustments, be arranged to operate at more

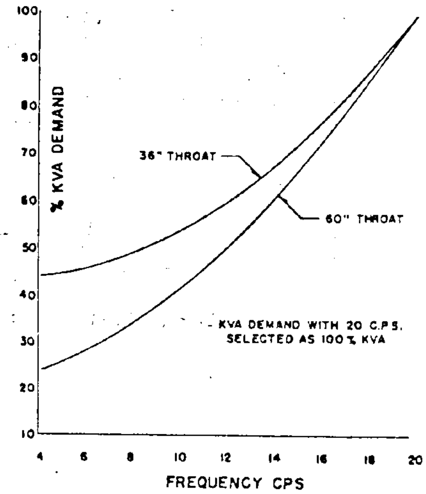
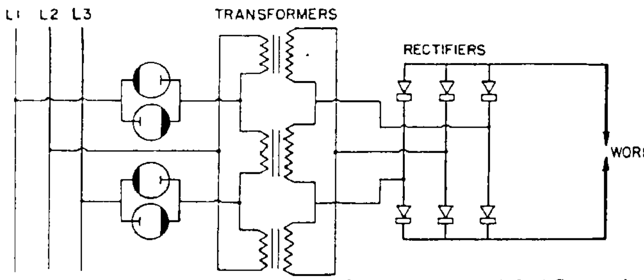



**Figure 17. Effect of frequency on kva demand, frequency converter welders**

than one output frequency, the minimum frequency at which a given welder may be operated is determined by the amount of core iron in the transformer. Also the range of frequencies at which a given welder may be operated may be limited by the welding operation. Figure 17 shows the relative kva demands for secondary frequencies of between 3 and 20 cycles per second.

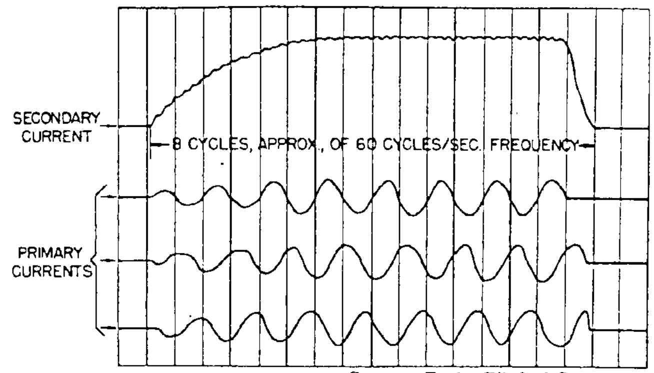
As previously stated, some frequency converter controls are arranged to permit firing only one group of ignitron tubes (*A* or *B* as previously described) to provide unidirectional current for each individual weld. This unipolarity method can be used only when the total energy required to weld is not greater than that which the welder can deliver in a single pulse. It is used ordinarily for welding aluminum or magnesium. The length of the pulse time, which is the duration of the weld, increases as the thickness of stock increases, and is in the order of one cycle, 60-cycle base, to weld two pieces of 0.020 aluminum, to 5 cycles to weld two pieces of 0.125 aluminum. When the energy required for a single weld exceeds the amount which can be supplied in a single pulse, full cycle welding must be used.

The magnitude of voltage dip which can occur on a power company system without causing objectionable light flicker depends upon the duration of the dip and the frequency with which it occurs, as well as upon its magnitude. Dips which occur at regularly spaced intervals of about once a second or oftener, are said to have cyclic frequency of occurrence. Dips which occur at random and not oftener than about once a second




Courtesy Taylor Winfield Corporation

**Figure 18. Electric circuit, dry-disc rectifier welder**

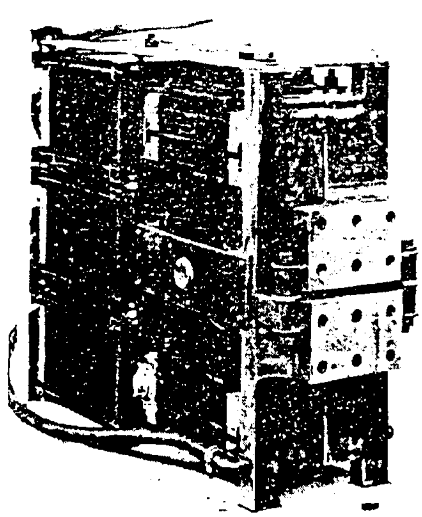



Courtesy Taylor Winfield Corporation

**Figure 20. Typical primary and secondary currents, dry-disc rectifier welder**

are said to be noncyclic. Greater magnitudes of dip can usually be permitted at noncyclic than at cyclic frequencies.

Frequency converter load is characterized by an inherent cyclic frequency which occurs as one set of ignitron tubes is turned off and tubes of the opposite polarity, *A* and *B* tubes as previously described, are turned on. The frequency of dips per second is twice the output frequency of the welder. For example, a welder being operated at 12-cycle output frequency would cause voltage dips at a rate of 24 per second. An output frequency of $6^2/_3$ cycles per second would cause voltage dips at a rate or frequency of $13^1/_3$ per second. Under some circumstances this cyclic frequency of occurence, rather than the magnitude of voltage dip, may determine whether a power system could serve a given frequency converter welder. When the controls are adjusted to fire only one set of ignitron tubes, and thus supply unidirectional current for each weld, frequency converter load does not have this cyclic frequency. Thus a higher kva of demand can often be accepted where each weld is made with a single impulse than where full cycle, low frequency current is used.



Courtesy Taylor Winfield Corporation

**Figure 19. Power pack, dry-disc rectifier welder**

Frequency converter welders have not been standardized to the extent that single-phase a-c welders have been standardized. Consequently tables similar to those for single-phase machines cannot be given. The welder manufacturer should be consulted to obtain the load characteristics of a frequency converter welder.

## Dry-Disc Rectifier Welders

Dry-disc rectifier welders are direct energy welders which take 3-phase alternating current at line frequency and convert it to direct welding current by means of a full-wave dry-disc rectifier. The welder may be of the spot, projection or seam types.

Reference is made to a schematic diagram, Figure 18, which shows a 3-phase transformer which feeds a low-voltage high current output into a rectifier power pack, which in turn acts like an electrical check valve to furnish direct welding current to the work.

The transformer primaries are connected to and disconnected from the power supply by contactors, usually electronic, which turn the welding current on-and-off as required by the weld. The welding transformers are of conventional construction with primary windings to operate on various power supply voltages and frequencies. The rectifiers consist of a group of heavy copper plates, like bus bars, between which are assembled the rectifying disc assemblies. These disc assemblies are of the magnesium-copper-sulphide type, which have the desirable characteristics for welder service of operating at high currents, withstanding heavy overloads, and being self-healing if the rectifying surface is accidentally punctured.

Figure 19 shows a typical transformer and rectifier power pack assembly which replaces the transformer in a conventional single-phase a-c welder. Figure 20 shows typical a-c primary and d-c secondary traces of a 3-phase full-wave rectifier welder. All traces are of a continuous nature. The shape, length, and amplitude of the d-c wave may be varied according to the requirements of the welding application.

In considering the effect of line frequency upon the load characteristics of a single-phase a-c welder it was shown that, because the inductive reactance of the welder secondary circuit is proportional to frequency, the secondary voltage required, and the kva demand created to produce a given welding current are lower at 25 cycles that at 60 cycles. In d-c rectifier welders, because of the zero frequency in the secondary circuit, the secondary volts required and the kva demand created to produce a given welding current are much lower than for single-phase 60-cycle welders.

The power load of a rectifier welder is equally distributed over three phases, as shown in Figure 20. Balanced loading permits equal heating of the 3-phase power supply lines, switches and fuses, as well as equal loading of electronic contactor power tubes. It permits measuring the current in only one phase instead of all three phases, and determination of welding current, with acceptable accuracy over the normal working range, by a ratio to the measured primary current. This ratio (output direct current with which the weld is made, to input alternating current) depends upon rectifier characteristics and the number of rectifiers used. Within the usual welding range of 8,000 to 120,000 amperes it is fairly constant. For currents outside of that range it varies appreciably. The welder manufacturer must be consulted to ascertain this ratio for a given welder.

The welding current of a d-c rectifier welder is turned on and flows continuously for the length of time required by the weld. This time is known as weld time and is adjustable in steps of one cycle from a minimum of essentially one cycle to the desired maximum number of cycles required by the weld; cycles are in terms of the power supply frequency. The power demand is continuous and of the same duration as weld time. Pulsation welding is not often used with dry-disc rectifier welders.

The power factor of the full-wave d-c rectifier welder can be measured, with acceptable accuracy with an ammeter, a voltmeter, and a single-phase watt meter with the voltage element connected phase to neutral. In the oscillogram of Figure 21, the watt trace is a double frequency trace so that the peak deflection above zero represents true watts and the peak deflection below zero represents reactive volt amperes. It shows that, because there is very little deflection below the line, the welder is operating at a very high power factor, above 90 per cent. Power factor is independent of welding load and so does not vary as the load varies.

Because primary current is not directly proportional to welding current but depends in part upon the rectifier characteristics, and because rectifier welders have not been standardized to the extent that single-phase a-c welders have been standardized, tables of characteristics similar to those presented for single-phase machines cannot be given. The welder manufacturer will have to be consulted to obtain the load characteristics of rectifier welders.

Table XV is presented as an example only, to show the relative load characteristics of a single-phase a-c welder, a frequency converter, and a dry-disc rectifier welder having the same throat depth and arm spacing to produce 34,000 secondary amperes (a) under short circuit conditions, (b) when welding aluminum having a resistance of 0.000015 ohm and (c) when welding steel having a resistance of 0.000060 ohm. The values given for the frequency converter, rms value of the line frequency component, are those used in voltage drop calculations. It will be noted that the line current and kva demand of the frequency converter and of the rectifier welder are appreciably greater when welding than under short-circuit conditions, while these characteristics for the single-phase machine are only slightly

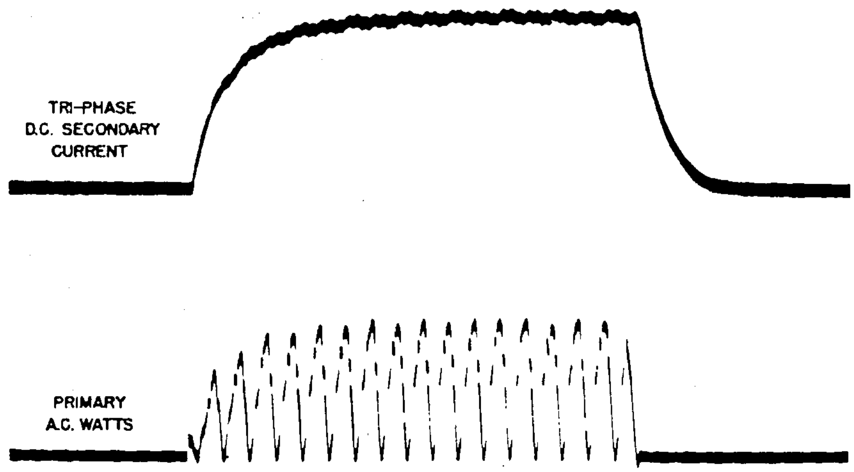



**Figure 21. Typical secondary amperes and primary watts, dry-disc rectifier welder**

greater. This is because the impedance of the work increases the impedance of the secondary circuit to a greater extent in frequency converters and dry-disc rectifier welders, than in single-phase a-c machines.

It should be noted that in this example the same current, 34,000 amperes, is assumed for both short-circuit and welding conditions. This in turn assumes a higher secondary voltage to compensate for the increase in welding impedance over short-circuit impedance. In actual practice, as has been pointed out previously, the maximum welding demand which a given welder can create is always less than its maximum short-circuit demand. This is because the secondary voltage, which is determined by the turn ratios of the welder transformer, is fixed, and maximum welding current is less than maximum short-circuit current because the insertion of work between the electrodes increases the impedance of the secondary circuit.

## Storage-of-Energy Type Welders

The mechanism of a welding machine which operates on the storage of energy principle is similar to that of a conventional single-phase a-c welder in that it incorporates a pressure system and an electrical circuit for transmitting the welding current through the electrodes and into the material being welded. In addition to the welding machine proper the complete equipment includes the device in which the energy is stored and necessary associated controls. The advantage, from a power supply standpoint, of this type equipment is that the energy can be taken at low level over a relatively long time between welds and discharged at the high rate and in the short time required by welding technique. Thus the high demands incident to a-c resistance welding are not present. Also the storage device can be designed for connection to a 3-phase power supply and thus can spread the load over all three phases rather than impose it upon one phase, and with most equipment the power factor of the load is relatively high. However, the amount of energy which can be stored is limited to the capacity of the storage unit and thus the use of energy storage welders are limited to welding applications which do not use more energy than the capacity of the device. Also, the maximum weld time obtainable is relatively short, especially as compared to a frequency converter or dry-disc rectifier welder, so that the use of stored energy machines is limited to applications which fall within the obtainable weld time.

### Capacitor Discharge Welders

Capacitor discharge welders are particularly suitable for the welding of

**Table XV. Relative Load Characteristics**

| | Type of Welder | | |
|---|---|---|---|
| | Single-Phase A-C | Frequency Converter | Dry-Disc Rectifier |
| Short circuit | | | |
| Line amperes | 945 | 191 | 170 |
| Kva | 415 | 145 | 130 |
| Power factor | 0.28 | * | ** |
| Welding aluminum (work resistance 0.000015 ohm) | | | |
| Line amperes | 965 | 216 | 197 |
| Kva | 425 | 165 | 150 |
| Power factor | 0.32 | * | ** |
| Welding steel (work resistance 0.000060 ohm) | | | |
| Line amperes | 1040 | 285 | 270 |
| Kva | 455 | 218 | 205 |
| Power factor | 0.43 | * | ** |

* Power factor, for voltage drop calculations may be assumed to be 0.85.

** Power factor is 0.90 or above and is independent of welding load.

**Table XVI. KVA Demand for a Capacitor Discharge Welder**

| Single Sheet Thickness | Kva Demand | Maximum Spots Per Minute |
|---|---|---|
| 0.020 | 50 | 100 |
| 0.040 | 50 | 100 |
| 0.060 | 50 | 70 |
| 0.080 | 75 | 50 |
| 0.125 | 75 | 25 |

aluminum, which requires precise quantities of energy and accurate adjustment of the rate of energy input with respect to time. Stainless and light gauges of mild steel can be welded satisfactorily, but since they can be welded equally well on less expensive and faster single-phase a-c machines, the latter are ordinarily used. Consequently capacitor discharge welders are used mostly for welding aluminum.

In capacitor discharge welding energy is taken from the a-c power supply at utilization voltage and, by means of a grid-controlled rectifier, is converted to direct current which charges a bank of capacitor units in which the energy is stored. The rectifier unit may be either single- or 3-phase but design practice is to make only the smallest units single-phase, while all large units are 3-phase. Load power factor approaches unity. The amount of energy stored in a given capacitor bank is a function of the voltage to which the capacitors are charged so that by accurately controlling the charging voltage, precise amounts of energy may be stored during each charging interval.

After the capacitor bank is charged, the welding electrodes are brought together against the work and the energy is discharged into the primary winding of a specially designed transformer by means of an ignitron tube. As soon as the energy has been discharged into the welder transformer the first ignitron tube stops conducting and a second ignitron tube, connected across the primary winding, begins to conduct and so locks the energy into the transformer until it is delivered through the secondary circuit to the weld, when the shunt tube also stops conducting. The weld begins simultaneously with the start of conduction of the first ignitron tube and continues until the second or shunt tube stops conducting. The peak current and total amount of energy are controlled by adjusting the voltage to which the capacitor bank is charged; and the position of the current peak with respect to the beginning of the weld, and the general shape of the discharge wave, are controlled by the turn ratio of the transformer.

Since the energy is delivered from the capacitor bank into the transformer as unidirectional current, the core of the transformer must contain sufficient iron not to saturate during a single weld. After each welding impulse, a certain amount of residual magnetism remains in the transformer. If the welding impulses are repeated the residual accumulates and the iron will saturate unless provision is made to restore the equilibrium. In present-day practice this is done in one of two ways: by reversing the direction of discharge into the core for each weld, or by the flux reset method in which a small amount of magnetizing current is caused to flow through the transformer winding in the opposite direction to the energy discharge during the charging interval.

Because of its low compressive strength projection welding of aluminum is extremely difficult and impractical if not impossible. Consequently capacitor discharge welders are used primarily for spot welding. The majority of machines are of the rocker arm, press, or roll spot type. The roll spot welder utilizes circular wheel-like electrodes between which the work is clamped continuously. Between welds the electrodes rotate an amount equal to the distance between spots and the work moves ahead. During welds the electrodes stop and remain stationary. Aluminum may also be seam and flash welded, but these types of welds are made on single-phase a-c or frequency-converter welders.

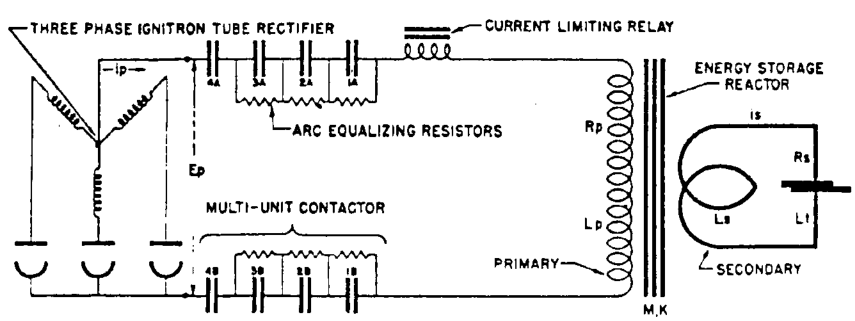
The rectifier units on large welders are 3-phase and load power factor approaches unity. Because the energy is being stored at a low rate over a charging time which is long with respect to welding time the kva demand is relatively low. Table XVI gives the kva demand for a capacitor discharge welder having a 30-inch throat and 6-inch arm spacing for different thicknesses of aluminum.

## Electromagnetic Storage-of-Energy Welders

The electromagnetic storage-of-energy welder, Figure 22, utilizes a 3-phase half-wave rectifier which is operated from the 3-phase a-c supply line and delivers 80 to 155 volts direct current to a welding reactor through a mechanical contactor. Upon closing the contactor, with the electrodes closed upon the work, direct current passes through the primary windings on the welding reactor, producing a preheat current in the secondary load circuit. The current rises exponentially in the primary and at a preset maximum current a maximum current relay trips and causes the contactors to drop in sequence. The opening of the contactors causes the energy of the stationary field at that point to be transformed by the rapidly decaying field into a strong pulse of current in the secondary which performs the welding operation. Current is taken from the supply line for a relatively long period of time for storage in the reactor and surrounding space, and the energy is suddenly delivered to the work circuit to perform the welding operation. In this way the energy is taken from the lines at a low rate, that is, low current or kva demand, and is given up as a high current. These machines are characterized by low power demand, balanced 3-phase load and high power factor.

## Storage Battery Welders

Storage battery welders are similar in design to conventional single-phase a-c machines. Electrically they differ in that a bank of storage batteries rather than a transformer provides the high welding current. The batteries are charged by 3-phase, full wave, dry-disc type rectifiers which take the power from the plant distribution system and which are usually arranged to provide a high-and-low range of charging rates. The low charging rate supplies sufficient




Courtesy Sciaky Brothers

**Figure 22. Schematic diagram of magnetic storage-of-energy welder**

energy to the cells for usual welding speeds. When the welder is operated at high duty cycles the high rate is automatically selected. A tapped autotransformer and selector switches provide a wide range of current adjustments for high-and-low charging rates. One battery welder which supplied 35,000 amperes created a demand of less than 20 kva, 3-phase at 85 per cent power factor.

The welding current is of course direct rather than alternating, and current to make each weld is caused to flow by making and breaking the actual high welding current rather than the higher voltage, lower primary current as in the case of an a-c welder. This is accomplished by a specially constructed carbon pile rheostat which is operated by air pressure. Typical designs are said by the manufacturer to be capable of making and breaking current up to 40,000 amperes continuously at 200 times per minute.

Each battery cell is charged to approximately 2.15 volts. Rough adjustments of maximum current can be made by the series-parallel arrangement of the individual cells. Finer adjustment of welding current is accomplished by inserting an adjustable series resistor in the circuit which carries the welding current. The current can be decreased by increasing the value of this resistance. The $I^2R$ constitutes a power loss.

In addition to the desirable power characteristics of the battery welder, it is said to have desirable welding characteristics especially in the welding of aluminum.

### Homopolar Generator Welders

The homopolar generator welder is another type of welder which operates on the storage-of-energy principle. This device consists essentially of a specially designed homopolar generator which supplies direct current to the welding circuit, a flywheel, a carbon pile contactor, a 3-phase induction motor, and a welder. The homopolar generator developed particularly for this application is said to perform satisfactorily under the conditions of high instantaneous demand, short weld time and intermittent application which are characteristic of resistance welding. The flywheel absorbs energy between welds and releases it during the weld, thus practically eliminating the high magnitude of demand upon the power supply system. The carbon pile contactor is in the welding circuit. It functions by closing two parallel sets of thin carbon plates under high pressure exerted by an air cylinder and bell crank mechanism. As it opens, the resistance of the carbon contacts increases very greatly before they finally open, so that at the actual break the ratio of resistance to inductance of the circuit is quite high and little or no sparking results. An early model which produced somewhat more than 50,000 amperes at a terminal voltage of about 5.5 volts was powered by a 15-horsepower motor.

In this equipment the current available for welding is determined by the generator characteristics and excitation, while motor size is determined by the load factor of the welding operation. The load upon the power supply is similar in characteristics to those of a machine tool driven by a motor of the same horsepower rating.

The homopolar generator welder must not be operated at such long weld times that the rotating parts give up all of their stored energy, or with such short off time between welds that the energy cannot be replenished or the generator will slow down and the motor may "stall."

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