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Buck Converter Topology for Superior Performance Application in Spot Welding

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Abstract: In the automobile industry, Resistance Spot Welding (RSW) is widely used for its low cost, high speed, simple mechanism and applicability for automation. RSW has become the predominant means of auto body assembly, resulting in two to six thousands spot welds performed on each manufactured car. In the North American automobile industry there are approximately 100 billion spot welds, which are done every year. RSW is the joining of two or more metal parts together in a localized area by resistive heating and pressure. Small Scale RSW (SSRSW) is commonly used for medical devices and electronic components, because the welded parts are thinner and smaller compared to common RSW applications, such as automotive applications. This project study will focus on studying and improving weld power supplies, weld schedules and control modes. One of the goals for this project is to improve the consistency of weld nugget size and strength by using different control parameters, which will be weighted geometric averages of voltage and current. These control parameters are fed back to a Proportional Integral Derivative (PID) controller that is designed to control the Direct Current (DC) power supply for the RSW to come up with the best control parameters that will improve the consistency of the RSW spot welds.

Keywords: Resistance Spot Welding (RSW), Small Scale RSW, Large Scale RSW, DC power Supply, Timer IC and Buck Converter.

I. INTRODUCTION

Resistance spot welding (RSW) is one of the key metal joining techniques for high volume production in the automotive, biomedical and electronics industry. RSW is a process in which faying surfaces are joined in one or more spots by the heat generated by resistance to the flow of electric current through work pieces that are held together under force by electrodes. A short time pulse of high-amperage current heats the contacting surfaces in the region of current concentration. When the flow of current ceases, the electrode force is maintained while the weld metal rapidly cools and solidifies. The electrodes are retracted after each weld, which usually is completed in a fraction of a second. Large-Scale Resistance Spot Welding (LSRSW) has become the predominant means of auto body assembly, with an average of two to six thousands spot welds performed on each manufactured car leading to 100 billion spot welds per year in the North America automobile industry. On the other hand, for increasing application of very thin metal sheets in manufacturing electronic components and devices, Small-Scale Resistance Spot Welding (SSRSW) is attracting more and more researchers' attention.

Weld quality and weld power supplies are the centre of all aspects of welding in general and more specifically in the automobile industry. Hence, a material, before it is used in production, needs to be qualified as weldable; namely, that using standard welding equipment and schedules would yield welds of sufficient size and strength. RSW differs from some other forms of welding in that no extra material is used, such as filler rod in arc welding; hence it is not complicated by the addition of extra material. However, the melting process is entirely contained within the work pieces, thus observation and measurement are severely constrained and there are no universally accepted standards of weld quality. Therefore, for the sole purpose of assuring the quality of the spot weld, the primary objective of spot welding research has been tomonitor and control the process.

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II. PRINCIPLE

Resistance welding is accomplished when current is caused to flow through electrode tips and the separate pieces of metal to be joined. The resistance of the base metal to electrical current flow causes localized heating in the joint, and the weld is made. The resistance spot weld is unique because the actual weld nugget is formed internally in relation to the surface of the base metal. Figure shows a resistance spot weld nugget compared to a gas tungsten-arc (TIG) spot weld.

The gas tungsten-arc spot is made from one side only. The resistance spot weld is normally made with electrodes on each side of the work piece. Resistance spot welds may be made with the work piece in any position. The resistance spot weld nugget is formed when the interface of the weld joint is heated due to the resistance of the joint surfaces to electrical current flow. In all cases, of course, the current must flow or the weld cannot be made. The pressure of the electrode tips on the work piece holds the part in close and intimate contact during the making of the weld. Remember, however, that resistance spot welding machines are NOT designed as force clamps to pull the work pieces together for welding.

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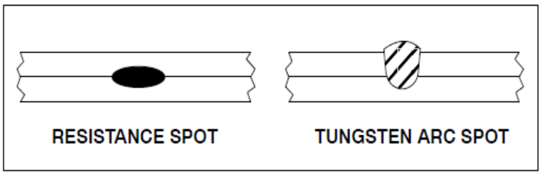

Fig. 1 Resistance and TIG Spot Weld

The resistance spot weld nugget is formed when the interface of the weld joint is heated due to the resistance of the joint surfaces to electrical current flow. In all cases, of course, the current must flow or the weld cannot be made. The pressure of the electrode tips on the work piece holds the part in close and intimate contact during the making of the weld. Remember, however, that resistance spot welding machines are NOT designed as force clamps to pull the Work pieces together for welding.

- **HEAT GENERATION**

A modification of Ohm's Law may be made when watts and heat are considered synonymous. When current is passed through a conductor the electrical resistance of the conductor to current flow will cause heat to be generated. The basic formula for heat generation may be stated:

$H = I^2R$

H = Heat

I^2 = Welding Current Squared

R = Resistance

The secondary portion of a resistance spot welding circuit, including the parts to be welded, is actually a series of resistances. The total additive value of this electrical resistance affects the current output of the resistance spot welding machine and the heat generation of the circuit. The key fact is, although current value is the same in all parts of the electrical circuit, the resistance values may vary considerably at different points in the circuit. The heat generated is directly proportional to the resistance at any point in the circuit.

Squeeze Time

Time between pressure application and weld.

Heat Or Weld Time

Weld time in cycles.

Hold Time

Time that pressure is maintained after weld is made.

Off Time

Electrodes separated to permit moving of material for next spot.

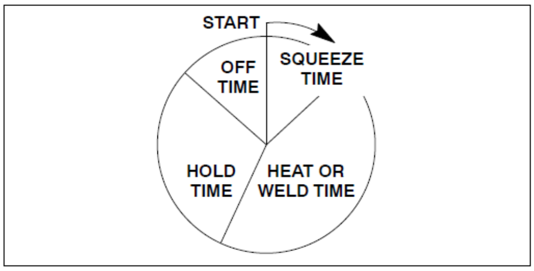

Fig 2. Spot Welding Time Cycle

Resistance spot welding machines are constructed so minimum resistance will be apparent in the transformer, flexible cables, tongs, and electrode tips. The resistance spot welding machines are designed to bring the welding current to the weldment in the most efficient manner. It is at the weldment that the greatest relative resistance is required. The term "relative" means with relation to the rest of the actual welding circuit.

There are six major points of resistance in the work area. They are as follows:

1) The contact point between the electrode and top work piece.
2) The top work piece.
3) The interface of the top and bottom work pieces.
4) The bottom work piece.
5) The contact point between the bottom work piece and the electrode.
6) Resistance of electrode tips.

The resistances are in series, and each point of resistance will retard current flow. The amount of resistance at point 3, the interface of the work pieces, depends on the heat−transfer capabilities of the material, the material's electrical resistance, and the combined thickness of the materials at the weld joint. It is at this part of the circuit that the nugget of the weld is formed.

- **THE TIME FACTOR**

Resistance spot welding depends on the resistance of the base metaland the amount of current flowing to produce the heat necessary to make the spot weld. Another important factor is time. In most cases several thousand amperes are used in making the spot weld. Such amperage values, flowing through a relatively high resistance, will createa lot of heat in a short time. To make good resistance spot welds, it is necessary to have close control of the time the current is flowing. Actually, time is the only controllable variable in most single impulse resistance spot welding applications. Current is very often economically impractical to control. It is also unpredictable in many cases. Most resistance spot welds are made in very short time periods. Since alternating current is normally used for the welding process, procedures may be based on a 60 cycle time (sixty cycles = 1 second). Figure 2 shows the resistance spot welding time cycle.

Previously, the formula for heat generation was used. With the addition of the time element, the formula is completed as follows:

$H = I^2RTK$

H = Heat

I^2 = Current Squared

R = Resistance

T = Time

K = Heat Losses

Control of time is important. If the time element is too long, the base metal in the joint may exceed the melting (and possibly the boiling)point of the material. This could cause faulty welds due to gas porosity. There is also the

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possibility of expulsion of molten metal from the weld joint, which could decrease the cross section of the joint and weaken the weld. Shorter weld times also decrease the possibility of excessive heat transfer in the base metal. Distortion of the welded parts is minimized, and the heat affected zone around the weld nugget is substantially smaller.

- **PRESSURE**

The effect of pressure on the resistance spot weld should be carefully considered. The primary purpose of pressure is to hold the parts to be welded in intimate contact at the joint interface. This action assures consistent electrical resistance and conductivity at the point of weld. The tongs and electrode tips should not be used to pull the work pieces together. The resistance spot welding machine is not designed as an electrical “C” clamp! The parts to be welded should be in intimate contact before pressure is applied.

Investigations have shown that high pressures exerted on the weld joint decrease the resistance at the point of contact between the electrode tip and the work piece surface. The greater the pressure the lower the resistance factor. Proper pressures, with intimate contact of the electrode tip and the base metal, tend to conduct heat away from the weld. Higher currents are necessary with greater pressures and, conversely, lower pressures require less amperage from the resistance spot welding machine. This fact should be carefully noted, particularly when using a heat control with the various resistance spot welding machines.

- **ELECTRODE TIPS**

Copper is the base metal normally used for resistance spot welding tongs and tips. The purpose of the electrode tips is to conduct the welding current to the work piece, to be the focal point of the pressure applied to the weld joint, and to conduct heat from the work surface. The tips must to maintain their integrity of shape and characteristics of thermal and electrical conductivity under working conditions. Electrode tips are made of copper alloys and other materials. The Resistance Welders Manufacturing Association (RWMA) has classified electrode tips into two groups: Group A − Copper based alloys Group B − Refractory metal tips the groups are further classified by number. Group A, Class I, II, III, IV, and V are made of copper alloys. Group B, Class 10, 11, 12, 13, and 14 are the refractory alloys. Group A, Class I electrode tips are the closest in composition to pure copper. As the Class Number goes higher, the hardness and annealing temperature values increase, while the thermal and electrical conductivity decreases. Group B compositions are sintered mixtures of copper and tungsten, etc., designed for wear resistance and compressive strength at high temperatures. Group B, Class 10 alloys have about 40 percent the conductivity of copper with conductivity decreasing as the number value increases. Group B electrode tips are not normally used for applications in which resistance spot welding machines would be employed.

As current density is increased, the weld time is decreased proportionately. If, however, the current density becomes too high, there is the possibility of expelling molten metal from the interface of the joint thereby weakening the weld. The ideal time and current density condition is somewhere just below the level of causing metal to be expelled.

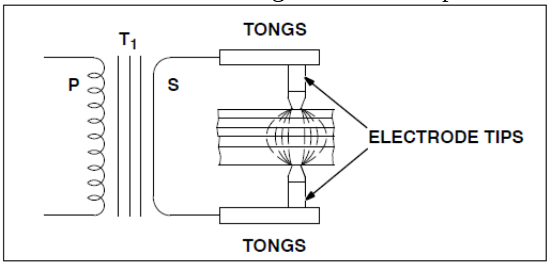

Fig. 3 Resistance Spot Weld Heat Zones

It is apparent that the heat input cannot be greater than the total dissipation rate of the work piece and the electrode without having metal expelled from the joint. Thoughts have changed concerning the flow of current through the work piece. Previously, current was considered to flow in a straight line through the weld joint. This is not necessarily true when multiple thicknesses of material are being welded. The characteristic is for the current to “fan out”, thereby decreasing the current density at the point of weld the greatest distance from the electrode tips. The illustration (Figure 3) shows the resistance spot weld heat zones for several thicknesses of metal. Note that the uncontrollable variables (such as interface contamination) are multiplied when resistance spot welding several thicknesses of material. Quality levels will be much lower for “stack” resistance spot welding, which explains why such welding practices are avoided whenever possible.

- **PRESSURE OR WELDING FORCE**

The pressure exerted by the tongs and the electrode tips on the work piece has a great effect on the amount of weld current that flows through the joint. The greater the pressure, the higher the welding current value will be, within the capacity of the resistance spot welding machine. Setting pressure is relatively easy. Normally, samples of material to be welded are placed between the electrode tips and checked for adequate pressure to make the weld. If more or less pressure is required, the operating manual for the resistance spot welding machine will give explicit directions for making the correct setting. As part of the equipment set-up, the tong and electrode tip travel should be adjusted to the minimum required amount to prevent “hammering” the electrode tips and tip holders.

- **HEAT BALANCE**

There is no particular problem of heat balance when the materials to be welded are of equal type and thickness. The heat balance, in such cases, is automatically correct if the electrode tips are of equal diameter, type, etc. Heat balance may be defined as the conditions of welding in which the fusion zone of the pieces to be joined are subjected to equal heat and pressure. When the weldment has parts of unequal thermal characteristics, such as copper and steel, a poor weld may result for several reasons. The metals may not alloy properly at the interface of the joint. There may be a greater amount of localized heating in the steel than in the copper. The reason would be because copper has low electrical resistance and high thermal transfer characteristics, while steel has high electrical resistance and low thermal transfer characteristics.

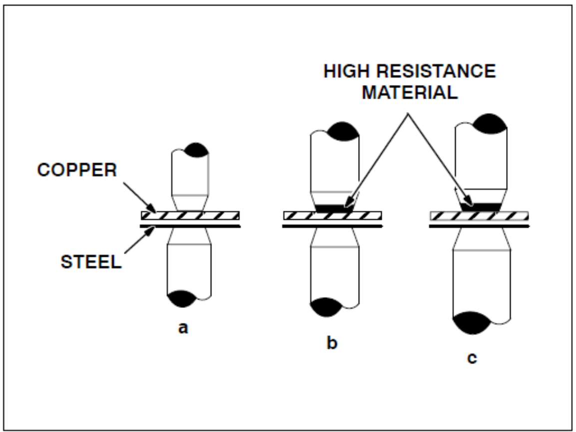

Fig. 4 Techniques For Obtaining Heat Balance

Correct heat balance may be obtained in a weldment of this type by one of several methods. Figure 4 illustrates three possible solutions to the problem. Figure 4(a) shows the use of a smaller electrode tip area for the copper side of the joint to equalize the fusion characteristics by varying the current density in the dissimilar materials. Figure 4(b) shows the use of an electrode tip with high electrical resistance material, such as tungsten or molybdenum, at the contact point. The result is to create approximately the same fusion zone in the copper as in the steel. A combination of the two methods is shown in Figure 4(c).

- **SURFACE CONDITIONS**

All metals develop oxides which can be detrimental to resistance spot welding. Some oxides, particularly those of a refractory nature, are more troublesome than others. In addition, the mill scale found on hot-rolled steels will act as an insulator and prevent good-quality resistance spot welding. Surfaces to be joined by this process should be clean, free of oxides and chemical compounds, and have a smooth surface

III. MATERIALS DATA FOR RESISTANCE SPOT WELDING

This section of the text will consider methods used for resistance spot welding some of the common metals that are used in fabrication work. It is not intended that all the possible problems that could arise will be answered. The purpose of this part of the text is to provide general operational data for use with resistance spot welding machines. Where applicable, the data provided will be related to specific models and size (KVA) of units. The units listed in this section are not recommended for aluminium or copper alloys.

A. MILD STEEL

Mild or low-carbon steel comprises the largest percentage of material welded with the resistance spot welding process. All low-carbon steels are readily weldable with the process if proper equipment and procedures are used. The carbon steels have a tendency to develop hard, brittle welds as the carbon content increases if proper post-heating procedures are not used. Quick quenching of the weld, where the nuggets cools rapidly, increases the probability of hard, brittle micro-structure in the weld. Hot rolled steel will normally have mill scale on the surface of the metal. This type of material is usually not resistance spot welded with resistance welding machines of the kVA ratings of Miller-built units. Cold rolled steel (CRS) and hot rolled steel, pickled and oiled (HRSP & O), may be resistance spot welded with very little trouble. If the oil concentration is excessive on the sheet metal, it could cause the formation of carbon at the electrode tips thereby decreasing their useful life. De−greasing or wiping is recommended for heavily oiled sheet stock.

B. LOW ALLOY AND MEDIUM CARBON STEELS

There are some pertinent differences in resistance spot welding low alloy and medium carbon steels as compared to mild or low carbon steels. The resistance factor for the low alloy and medium carbon steels is higher; therefore, the current requirements are slightly lower. Time and temperature are more critical since metallurgical changes will be greater with these alloys. There is certainly more possibility of weld embrittlement than there is with mild steel. Resistance spot welding pressures are normally higher with these materials because of the additional compressive strength inherent in the low alloy and medium carbon steels. It is always a good idea to use longer welding times when welding these alloys to retard the cooling rate and permit more ductile welds.

C. STAINLESS STEELS

The chrome-nickel steel alloys (austenitic) have very high electrical resistance and are readily joined by resistance spot welding. The consideration of great importance with these materials is rapid cooling through the critical range, 800°F to 1400°F. The rapid quench associated with resistance spot welding is ideal for reducing the possibility of chromium carbide precipitation at the grain boundaries. Of course, the longer the weldment is held at the critical temperatures, the greater the possibility of carbide precipitation.

D. STEELS, DIP COATED OR PLATED

The overwhelming majority of material in this category is galvanized or zinc-coated steel. Although some galvanized steel is electroplated, the dip-coated steel costs less and is predominantly used. The zinc coating is uneven in thickness on dip-coated steel. The resistance factor will vary from weld to weld, and it is very difficult to set conditions in chart form for the material. It is impossible to maintain the integrity of the galvanized coating when resistance spot welding. The low melting point of the zinc coating, compared to the fusion temperature of the steel sheet, causes the zinc to vaporize. Of course, there must be adequate pressure to force the zinc aside at the weld interface to permit steel-to-steel fusion. Otherwise, the strength of the resistance spot weld is open to question.

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Materials are available to repair the external damage to the coating that may be incurred because of the welding heat. There is no remedy for the loss of coating material at the interfaces of the weld, unfortunately. In fact, the vaporization of the zinc can cause porosity in the weld and a general weakening of the expected shear strength.

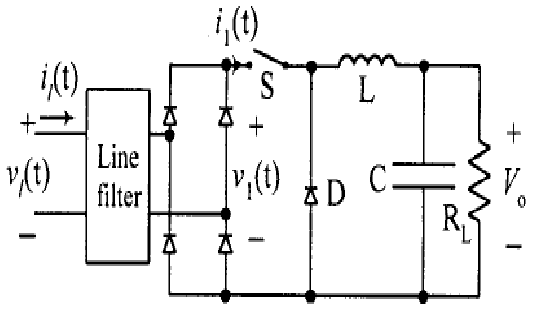
E. ALUMINUM AND ALUMINUM ALLOYS

Resistance spot welding machines with kVA ratings much greater than 20 kVA are necessary to make sound welds on most aluminium materials and any other high−conductivity type of base metal. The electrical conductivity of aluminium is high, and welding machines must provide high currents and exact pressures in order to provide the heat necessary to melt the aluminium and produce a sound weld.

IV. PROPOSED SYSTEM DISCRIPTION

1. BUCK CONVERTER

It is a converter in which the output voltage is less than the input voltage. It is like a step-down converter. In figure Fig a, Va< Vs**.** The circuit diagram of Buck Converter is drawn below.



(a) Buck converter

The operation of Buck Converter can be described in two modes.

1.1 MODES OF OPERATION OF BUCK CONVERTER

MODE-1: It begins when transistor Q1 is switched ON at t=0. The input current rises, flows through filter inductor L, filter capacitor C and load resistor R. The circuit diagram showing operation of Buck Converter in Mode1 is shown below.

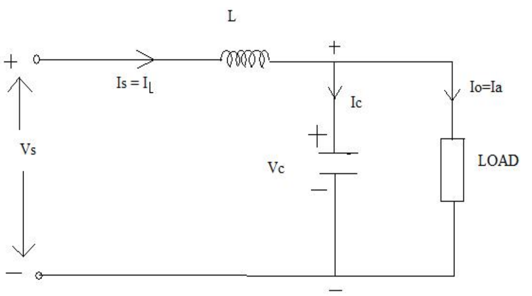


Fig. 5(a) Mode 1 operation of Buck Converter

MODE-2: It begins when transistor Q1 is switched OFF at $t=t_1$. The freewheeling diode Dm conducts because of the energy stored in the inductor and the current flows through L, C, load and diode Dm. The circuit diagram showing operation of Buck Converter in Mode 2 is shown below.

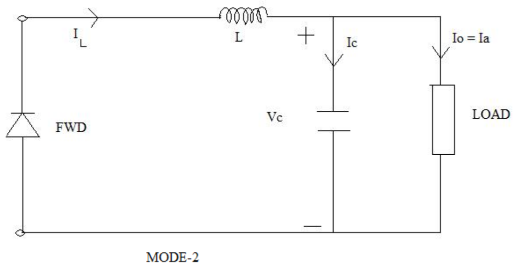


Fig. 5(b) Mode 2 operation of Buck Converter

1.2 WAVEFORMS

The waveforms of switching state, current and voltage during continuous conduction mode (CCM) operation of Buck Converter are given below. In figure Fig 3.4, shown below,

T_{ON}= On period of transistor,
T_{OFF}= Off period of transistor,
V_i= Input Voltage,
V_o= Output Voltage,
V_L= Voltage across inductor L,
V_D= Voltage across diode Dm,
I_L= Current flowing through the inductor,
I_{max}= Maximum value of I_L ,
I_{min}= Minimum value of I_L ,
D = Duty cycle= V_i/V_o
During

T_{ON},V_L=V_i – V_o. The diode Dm becomes reverse biased and current through inductor rises in linear manner.
During T_{OFF}, V_L= -V_o. The diode Dm becomes forward biased and current through inductor decreases.

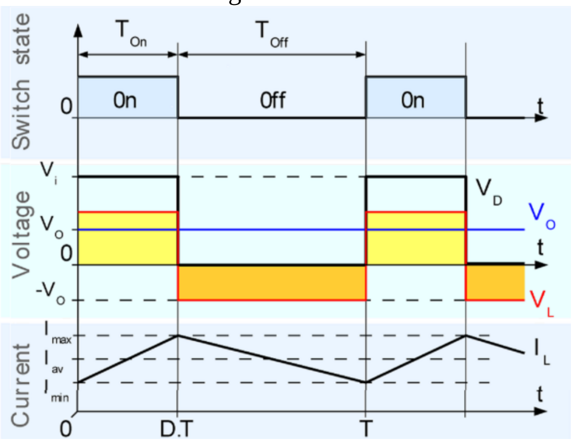


Fig. 5(c) Waveforms obtained in Continuous Conduction Mode of Buck Converter

2. SPOT WELDING

In the case of resistance pressure welding, the heating occurs at the welding point as a consequence of Joule resistance heating caused by current flow through an electrical conductor, Figure 8.2.In spot and projection welding, the plates to be welded in overlap. Current supply is carried out through spherical or flat electrodes, respectively. In roller seam welding, two driven roller electrodes are applied. The plates to be welded are mainly overlapped. The heat input rate Q_{input} is generated by resistance heating in a current carrying conductor, However, only the effective heat quantity Q_{eff} is

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instrumental in the formation of the weld nugget. Q_{eff} is composed of the input heat minus the dissipation heat. The heat loss arises from the heat dissipation into the electrodes and the plates and also from thermal radiation.
In the spot welding process, two overlapped or stacked stamped components are welded together as a result of the resistance heating caused by the passage of electric current. This resistance heating is provided by the work pieces as they are held together under pressure between two electrodes as shown in Figure 6.

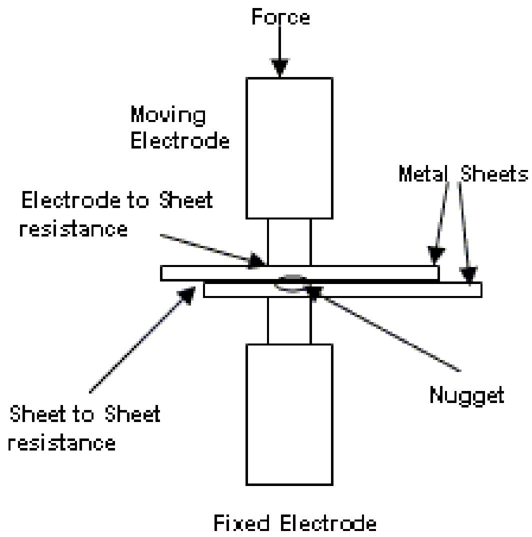

Fig. 6 The occurrence of resistances in electrical RSW

The copper alloy electrodes are used to apply pressure and convey the electrical current through the work piece during the formation of nugget. In the spot welding process, a weld nugget will start to form after sufficient energy has been put into the weld zone to raise the material to the solidus-liquid us temperature of the materials to be bonded and hence to begin the formation of a melted weld pool. The magnitude and duration of the current and the resistance of the work pieces determine the size of the formed nugget.

The heat needed to create the coherence is generated by applying an electric current through the stack-up of sheets between the electrodes. Therefore, the formation of a welded joint strongly depends on the electrical and thermal properties of the sheet and coating materials. As a weld's formation can be linked to the electrical and thermal processes of welding, controlling the electrical and thermal parameters is a common practice. The general expression of heat generated in an electric circuit can be expressed as

$$Q = \int I^2 R dt = \int V_t^2 / R dt = \int V_t I dt$$

Where, Q is the heat generated in the work pieces, I is the welding current, Vt is the voltage at the weld tips and R is the electrical resistance seen at the weld head. Since it is well know that the resistance, and possibly the current and voltage, vary with time, the above expression is expressed as an integral over time.

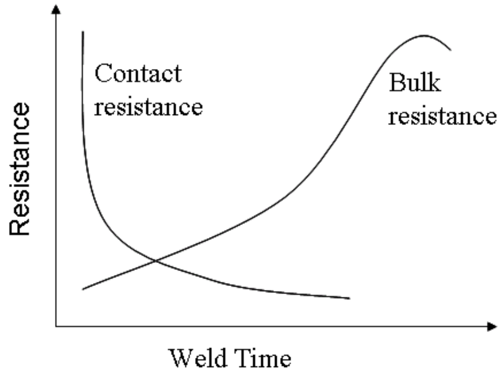

Fig. 7 Schematic showing the change in resistance during RSW

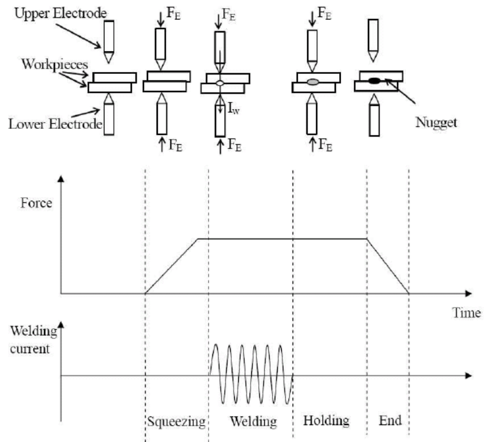

Fig. 8 The procedure of RSW

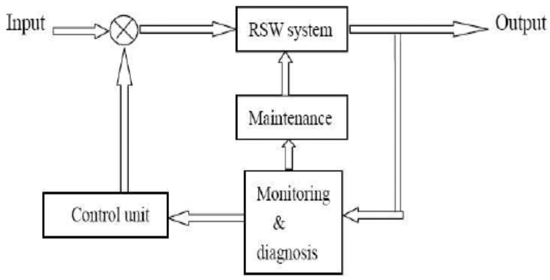

Fig. 9 Schematic of a typical RSW monitoring and control system

BLOCK DIAGRAM

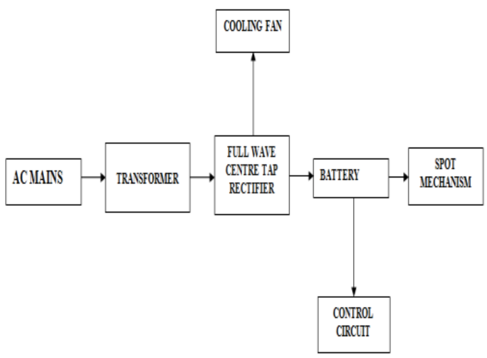

Fig.10 Spot Welding By Using Buck Converter Topology

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Fig. 11 Hardware System of Spot Welding Using Buck Topology

TABLE I: COMPONENT SPECIFICATION

Sr. No.	Components	Rating	Qty
1	Control circuit		
	a. Resistance	12 MΩ	13
	b. capacitor	10,4700,100µF	3
	c. voltage regulator IC		1
	d. Relay	3-32V DC,1ph.	1
2	Transformer	220/12 V, 5 Amp	1
3	Metal cap transistor		1
4	Fan	12V DC	1
5	Battery	12V DC	1

V. ADVANTAGES

1) Resistance spot welding is a welding technique that is used for almost all known metals.
2) It is possible that shunt currents flowing through a previously made spot weld will take welding current away from the second second spot weld to be made.
3) Spot welding is quick and easy.
4) There is no use of filler metals or any fluxes to create a join by spot welding and there is no open dangerous flame.
5) Spot welding can performed without any special skill.
6) Automated machines can spot weld in factories in speed up production.
7) The machine is use in car factories produce as many as 200 spot welds in six seconds.
8) Spot welding can be used to join many different metals, and can join different types to each other.
9) Sheets as thin as ¼ inch can be spot welded and multiple sheets are join together at the same time.

VI. DISADVANTAGE

1) The electrodes have to be able to reach both sides of the pieces of metal that are being joined together.
2) A particular spot welder machine will be able to hold only a certain thickness of metal usually 5 to 50 inches and although the position of the electrodes can be adjusted, there will be only a limited amount movement in most electrode holders.
3) The size and shape of the electrode will decide that size and strength of the weld.
4) The metal may also become less resistant to corrosion.

VII. RESULT AND CONCLUSION

In literature lots of work has been done in improving the control scheme and the power supply for RSW since the 1940s till now, and there is still more to do to improve it. This project work was done to help in the improving process for RSW, and still more to be added to it, as shown in the future work section. More than half of our project work was practical than theory, which was a great chance for me to learn hands on experience in the electrical engineering control field, than just applying theory and math without seeing the practical side of it, that in some cases doesn't fully agree with the theory and math. As a result of this project work, a simple designed, fully independent, portable, and inexpensive RSW power supply was built. Constant tip voltage feedback was implemented with the PID controller designed to control our RSW power supply, which gave a smaller nugget diameter variance compared to Open loop voltage control and constant current control modes.

Finally, this project resulted in a good starting operating point in improving the consistency for RSW that with more research work could give more improvement. That concludes that the RSW research will keep going on for the perfect RSW control and power supply that once a button is pushed, a perfect spot weld is made.

Our project is useful for spot welding of two same or different kinds of metals to join together. The heat transfer model developed in this study includes in its formulation the independent process parameters such as current, electrode force and time, the material's thermally dependent physical properties and the weld efficiency factor. The analytical results predicted by the model are compared with those obtained experimentally.

In our project we can done resistance spot welding technique that is used for almost all known metals. The actual weld is made at the interface of the parts to be joined. The electrical resistance of the material to be welded causes a localized heating at the interfaces of the metals to be joined. Welding procedures for each type of material must be developed for the most satisfactory results.

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A finite difference thermal model was developed for resistance spot welding, capable of predicting the temperature as a function of time and location for any position in the work piece, and for any low-carbon sheet steel. This model could also be applied to any other metal provided the physical properties of given material are included in the model.

Acceptable correlations between the theoretical and experimental temperatures have been made. The temperatures in the spot welds were measured using fine thermocouples imbedded in the sheet-steel coupons near the faying interface.

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