Automatic Contact Welding in Wire Spring Relay Manufacture

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Welding of precious metal contacts to the new wire spring relay has presented some unusual manufacturing problems. As the name implies, the springs of these relays are wires. The contacts through which electrical circuits are established consist of small blocks of palladium accurately and securely welded to one end of these wires. The wires, arranged in a parallel array, are imbedded for part of their length in molded phenol plastic to form parts which will be designated as "combs" in this paper. There are two kinds of combs, those with the wires arranged in pairs called twin wire combs, and single wire combs. Different welding techniques are required, each of which will be described separately.

INTRODUCTION

The wire spring relay, Fig. 1, was designed with such advantages over U and Y type relays as higher operating speed, longer life, lower power consumption and lower cost, as described in a recent article in this Journal.* The lower cost will be achieved largely by reduction of assembly labor time, by reduction of adjustment effort after assembly due to greater precision in the manufacture of component parts and by extensive use of automatic manufacturing processes. To attain these goals the closest cooperation has been necessary, particularly during the design stage, between Bell Telephone Laboratories relay engineers and Western Electric development engineers. Small lots of wire spring relays of several of the early designs were manufactured by the Western to furnish the Laboratories with relays for testing. These operations provided Western development engineers with valuable manufacturing experience.

The present design of relay has been in production on a pilot plant basis. The contact welders have operated as individual units during

* A. C. Keller, A New General Purpose Relay for Telephone Switching Systems, B.S.T.J., Nov., 1952.

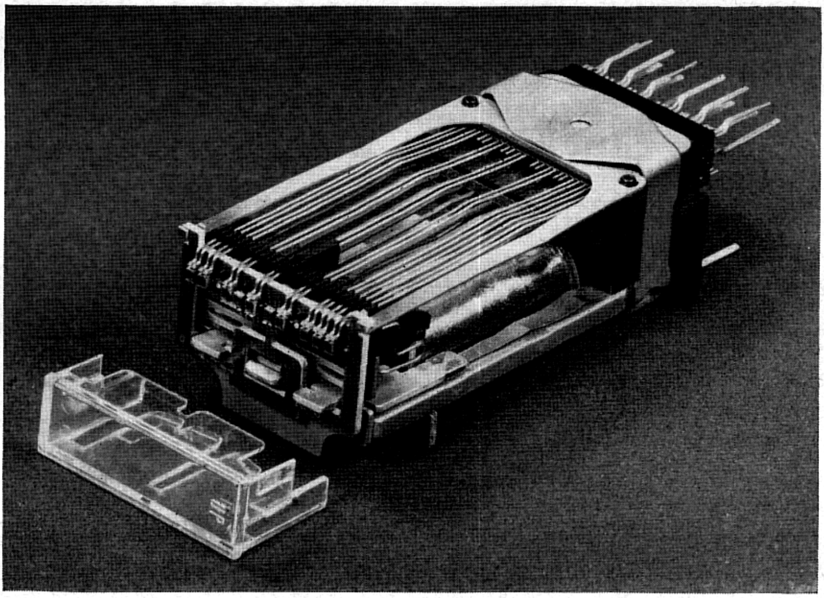


Fig. 1 — Wire spring relay.

that period as contrasted to their inclusion as components in automatic welding and wire forming lines now being placed in operation. The performance reported herein is based on individual operation.

Part I — Automatic Multiple Resistance Welding of Twin Wire Combs

The problem to be solved by Western Electric development engineers was that of welding small blocks of palladium, a precious metal, to flattened ends of 0.0226-inch diameter nickel silver wires molded in twin wire combs, Fig. 2. In addition to a secure weld, close limits had to be

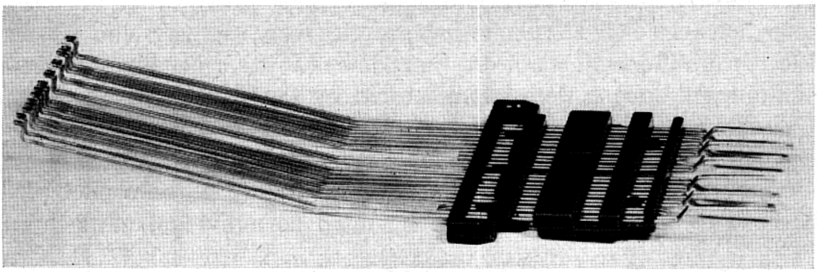


Fig. 2 — Twin wire comb.

met on the location of the precious metal. For example, Fig. 5, the upper contact surfaces had to be located with a precision of 0.004 inch. The contact itself had to be centered laterally with respect to the straight portion of the wire within 0.004 inch. Variables in the wire materials, such as elasticity, make such limits difficult to meet. The wires in the twin combs are oriented in pairs to provide bifurcated contacts, i.e., the contacts on both wires of any pair mate with one stationary contact of the single wire comb to furnish two current paths. Any number of pairs up to a maximum of twelve may be required by a code of relays. To conserve precious metal, contacts are welded only to those wires needed for a particular comb. The wires not required are clipped from the comb by a hydraulic press operated die in the automatic welding and wire forming line.

The 24-circuit capacitor discharge resistance welders, one of which is shown in Fig. 3, were designed and constructed for welding twin wire contacts. As stated before, this welder is one of the units in a welding and wire forming line. Combs from the molding operation are delivered to the beginning of the line in magazines. By fully automatic means they are removed from the magazine, carried by a reciprocating conveyor through each machine unit in the line and, when fully processed, placed in another magazine. The line of machine units, Fig. 4, forms the contact end of the wires, degreases the wires, welds the contacts to the wires, coins the contacts to the specified dimensions, forms the terminals, clips the ends to length, tension bends the wires, removes unnecessary wires and tins the terminal ends.

REASONS FOR SELECTION OF PROJECTION TYPE RESISTANCE WELDING

A capacitor discharge resistance projection welder was chosen for this job for the following reasons:

1. It is capable of welding automatically in a line of other machines.

2. It can provide the fast rate of temperature build-up required to prevent excessive heating of the small nickel silver wire ends.

3. A capacitor, charged to a fixed voltage, offers a good means of controlling weld energy within narrow limits.

4. Resistance projection welding can concentrate heat at the point required. The use of a projection at the welding interface lowers the electrical current needed to a value which can be handled by electrodes without excessive heating. By placing a projection on the metal with the lower electrical resistance, in this instance the palladium, the temperature of the palladium can be increased in the weld zone as compared to that of the nickel silver wire, thus securing a better heat balance at the joint

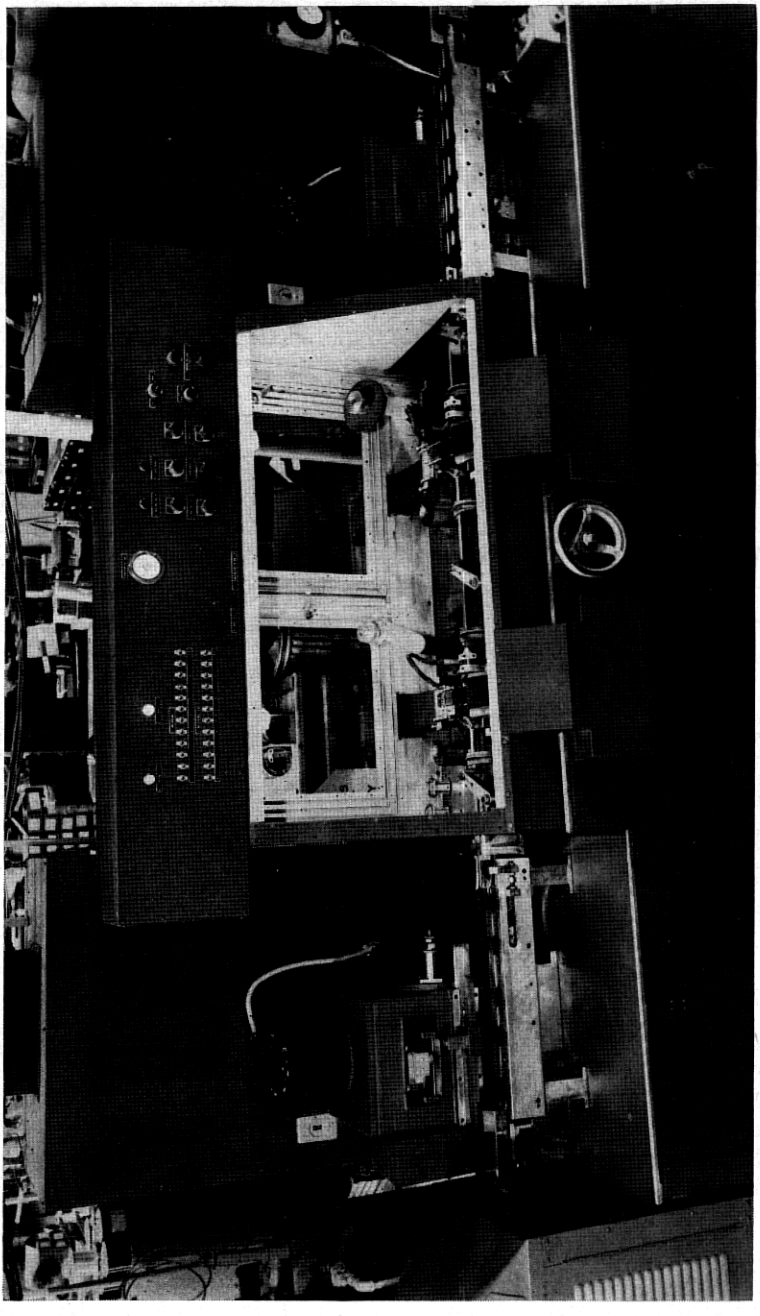


Fig. 3 — General purpose apparatus twin comb welders.

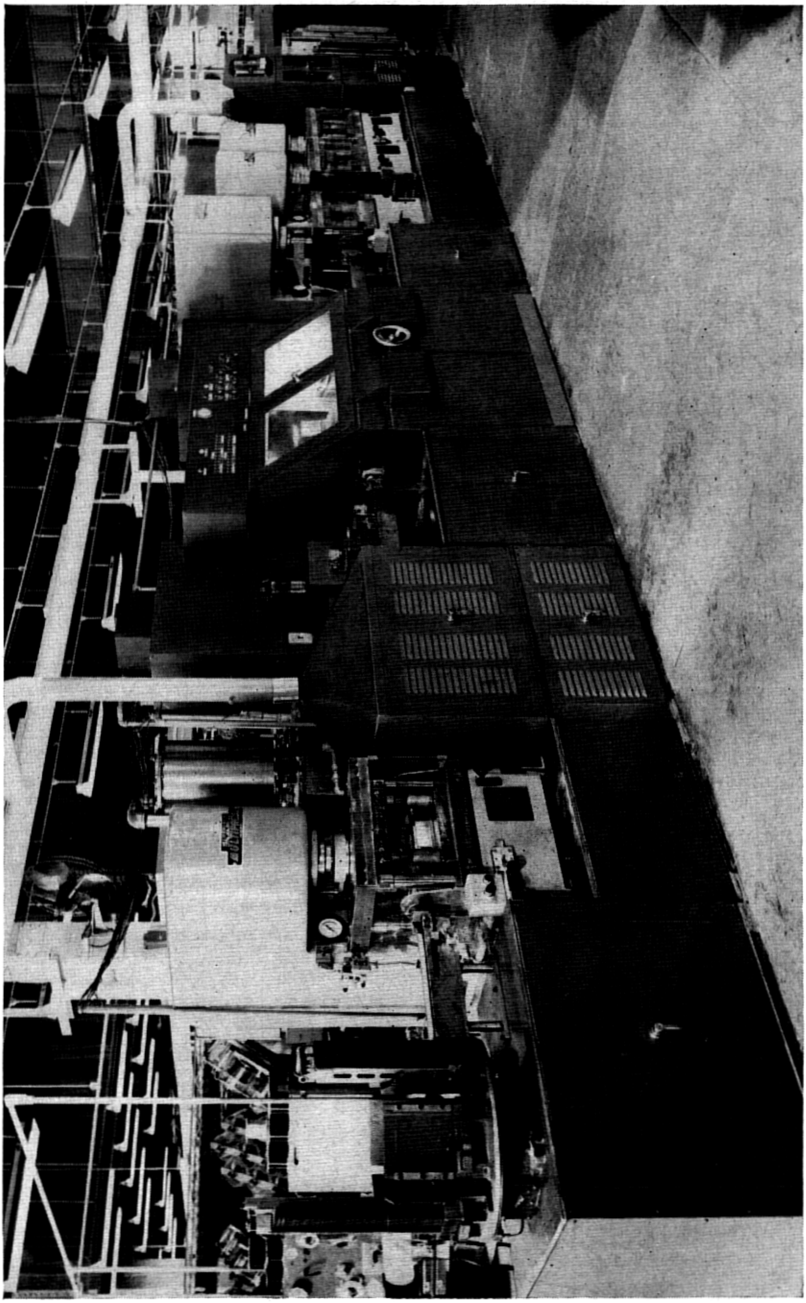


Fig. 4 — Line of machine units.

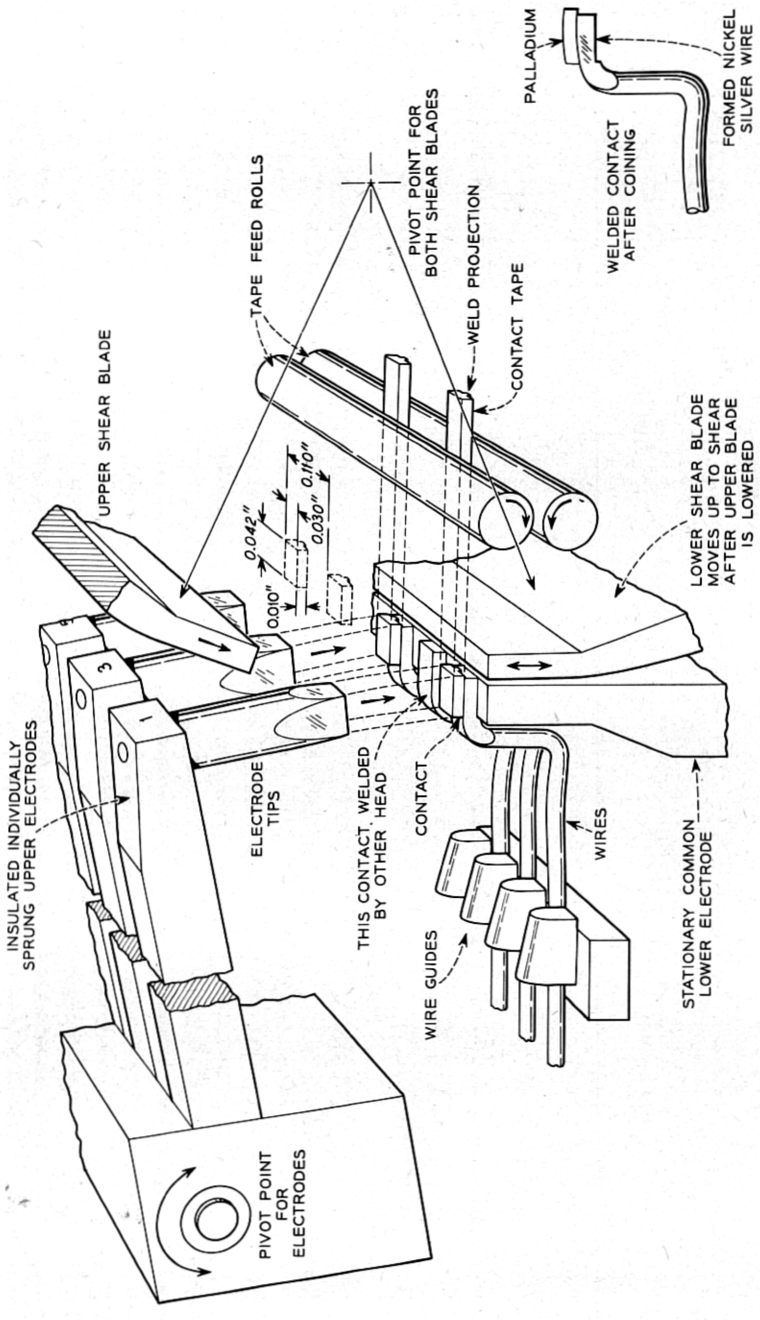


Fig. 5 — Sketch of a welding head.

The projection also confines the location of the weld to a central area of the wire end. When the weld nugget is confined to a central area, cold surrounding metal helps prevent flashing out of hot metal and results in stronger welds. To further centralize the weld nugget and to limit the projection area in contact with the nickel silver wire, the wire surface is preformed to a large radius at right angles to the weld bead.

WELDER HEAD OPERATION

Welding is done in two stages. Head No. 1 welds the odd numbered wires of each pair, after which the comb is advanced and head No. 2 welds the even number wires. This is necessary because of the small distance between the wire centers. The electrodes in each head are spaced to match the interval between odd or even numbered wire centers. Fig. 5 shows an isometric sketch of a welding head. The sequence of operations for either head is as follows:

1. The twin wire comb is advanced to a locating nest and lowered into position with the reference holes in the plastic engaged on pilot pins.
2. As the comb is lowered, the contact wires enter guide slots of a rake at a point adjacent to the plastic.
3. This rake is moved toward the ends of the wires, thereby spacing and positioning them as shown in Fig. 5. A plastic spacing member is incorporated in the relay for aligning the contacts in the relay assembly.
4. The palladium contact metal, in tape form, is advanced the proper distance to provide a contact of the specified length. These tapes, parallel with the wires, extend from guide slots for a distance slightly greater than a contact length and project over the wire ends. The tape guide slots, incorporated in a split holder, consist of steel inserts embedded in phenol fibre so designed that when the upper section is shifted laterally with respect to the lower section, the steel inserts clamp or release the tapes. Since the rake is located with reference to the tape guide, accurate spacing of contacts in the relay assembly is secured regardless of minor deviations of position of the wire ends at the welding machine. The phenol fibre mounting electrically insulates the tapes from one another to prevent part of the weld current from passing through adjacent tapes.
5. The upper electrodes, on the end of cantilever arms, are brought down on the palladium-nickel silver wire assembly.
6. The capacitors are discharged and the welds are made.
7. The upper electrodes are pivoted upward out of the way.
8. The wire guide rake is returned to a position near the plastic.
9. The upper shear blade is lowered onto the contact ends clamping them against the lower electrode.

10. The lower shear blade is moved upward, shearing off the tapes.
11. The upper shear blade is raised and the welded comb is transferred either to the second similar welder head or to the next operation.

The upper electrode tips are pins of special electrode material fixed in the ends of the supporting cantilever spring members by tapered joints, Fig. 5. Each electrode member is insulated electrically from the others and from ground by a coating of Teflon and a slotted phenol fibre guide block (not shown in Fig. 5) at the end adjacent to the electrode tips. Teflon furnishes the necessary insulation in a minimum of space and is slippery enough to allow free movement of any member. The cantilever construction makes a very light electrode assembly with the quick follow through necessary to maintain pressure on the weld area as the projection on the palladium tape is melted during the short weld cycle. A deflection of one-sixteenth inch at the tips will produce a force of about ten pounds, which is ample for this welding job. The working surfaces of the electrode tips are dressed approximately every 20,000 parts by an abrasive wheel mounted on an arbor and rotated back and forth by hand with the electrode tips pressed against the flat side of the wheel. In this manner all electrodes are dressed to a uniform length and angle simultaneously. After repeated dressings have reduced the tip length by approximately one-eighth inch, new tips are inserted.

MECHANICS OF THE WELDER

The welder is driven by an electric motor connected to the main cam shaft through a suitable reduction gear. This cam shaft is located just under the table top and extends the length of the machine. A mechanical overload clutch is provided on the output shaft of the reduction gear. All cams for the head movements are located on the main shaft. A solenoid operated clutch stops the main cam shaft when necessary. When no comb is in the weld position the weld control circuit is held open and solenoids shift either of the tape feed cams axially out of line with their followers to prevent the feeding of tape. This prevents burning the electrodes, saves precious metal and avoids loose contact pieces which might interfere with succeeding welds. A reciprocating conveyor, extending through the machine about four inches above the table top, carries the combs through the two weld positions. Excessive load, as when a part jams, will trip a microswitch and stop the machine.

TAPE SUPPLY

The contact tapes are advanced the amount required to provide the exact contact lengths by means of opposing rubber-faced feed rolls in

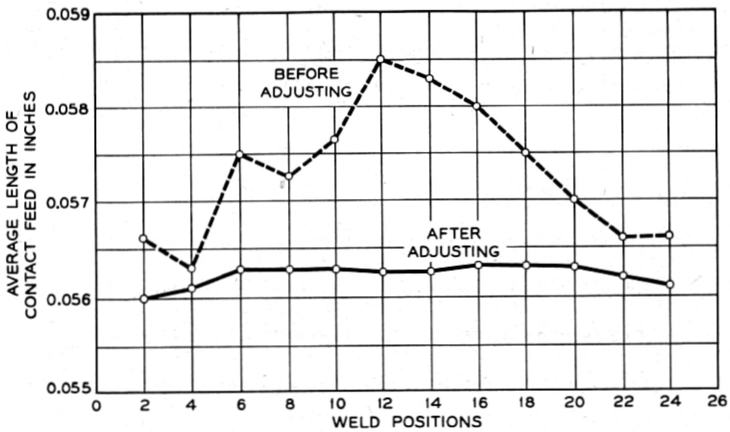


Fig. 6 — Contact length before and after adjusting hardness of rubber feed rolls and omitting gears between them.

each head. Fig. 6 shows the results of an early test on feed accuracy. Improved accuracy was obtained by providing free running tape reels. All portions of the tapes and reels are insulated from each other to prevent loss of weld energy.

ELECTRICAL FUNCTIONS

Electrically the welder has 24 separate weld circuits. Each circuit, shown schematically in Fig. 7, includes a capacitor which is charged through its own thyratron to a predetermined high voltage maintained by a voltage regulating transformer. The capacitor discharges through a thyratron and a transformer to produce the customary low voltage-high current weld energy. The transformers are located under the table near the welding heads.

The electronic equipment is mounted in cabinets to the right and left of the welder proper, as shown in Fig. 3. The capacitors are located in low cabinets, on either side, together with their solenoid controlled safety short-circuiting system. The cabinet above the welding heads contains control switches and relays. Toggle switches are provided for cutting off the weld energy for each of the 24 circuits.

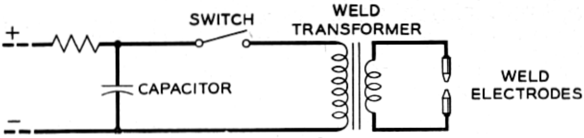


Fig. 7 — Schematic of weld circuit.

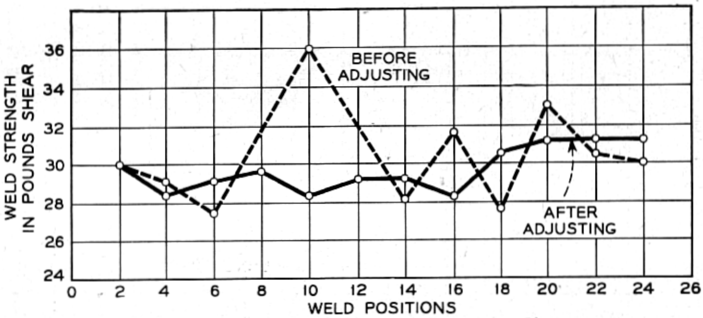


Fig. 8 — Weld strength versus resistance adjustment.

The welds occur in rapid succession in each head thereby preventing electrical interference between the many circuits involved. When combs which require less than a full complement of contacts are to be welded, the tapes in the not wanted positions are removed from the feed rolls and the toggle switches on the control cabinet are set to direct the weld energy in the sequence desired. To aid in obtaining uniform weld strength from the 24 circuits, all secondary leads from the transformers to the upper welding electrodes are of the same length. To further aid in effecting uniform weld strength, rheostats are provided in the high voltage side of the discharge circuit. Fig. 8 shows the result of adjusting these rheostats to balance the weld strengths produced by all circuits. A longer pulse would give the heat produced more time to be conducted away from the weld zone and would tend to heat more of the wire end, to the point, perhaps, of melting it completely. The three millisecond welding time has proven to be satisfactory for this job. However, the shorter the duration of the weld the higher will be the current peak required to obtain the necessary heat; the higher the current peak, the greater will be the likelihood of burning the electrodes and shortening electrode life. Adjustment of the pressure on the electrodes can be employed as a compensating factor. As the pressure is increased the tendency to burn the contacting surfaces is decreased, but the weld projection on the palladium is flattened correspondingly and the temperature of the weld, for a given current, is lowered accordingly. These variables can be adjusted to maintain optimum balance between uniformity of weld strength and electrode life.

CONCLUSIONS

More than ten million welds from this automatic machine have offered convincing proof of its capabilities. Fig. 9 indicates that good weld strengths are being obtained. These values are shear strengths obtained on a dial indicator type of gage, reading directly in pounds, when the contact is sheared from the wire along the wire axis. A minimum test requirement of ten pounds has been established.

Part II — Automatic Percussion Welding of Single Wire Combs

Percussion welding is not new. Early work goes back beyond the beginning of the century, but little application has been made of it and only a meager amount of literature is available. However, this method has a real field of usefulness as the application described in this paper will show. The original Vang process, wherein a capacitor charged to a high potential, often several thousand volts, is discharged across the gap between parts as they approach each other under a propelling force, is a good general description of the method used. The arc so produced heats the abutting surfaces before they collide so that a very thin layer of metal is brought to welding temperature. The propelling force, continuing to act, brings the parts together percussively and the weld is made. Little metal is heated and little heat penetrates the adjoining metal; therefore, the heat balance problem is greatly minimized and different metals weld together with little trouble. There is, however, the problem of protecting personnel from high voltage. Also, the two surfaces being welded must be insulated electrically from each other. This excludes the use of this process for joining the ends of the same piece of metal as in making a ring.

The project undertaken by Western Electric development engineers in the case of the single wire combs was the development of a machine for

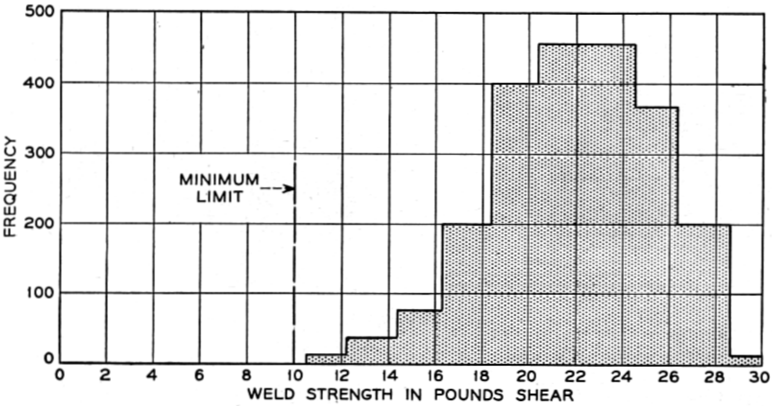


Fig. 9 — Weld strength distribution.

the automatic multiple percussion welding of contact blocks to the ends of an array of small wires extending less than a quarter of an inch from molded phenolic plastic. This array, fixed in plastic, forms a comb which is illustrated in Fig. 10. When completed this comb becomes the stationary contact member of the wire spring relay. The small blocks of metal on the ends of the wires are cut from a composite tape of which a small portion near the top and/or the bottom surface is palladium. There is a family of combs to be welded, depending on the number and type of contacts required by the code of relays into which each comb is assembled. Unlike the twin wire combs, wires which do not require contacts are left in the single wire combs, primarily to facilitate reading terminal locations during wiring into equipment. All top palladium contact surfaces must be located in the same plane across the 12 wire positions of the comb within a tolerance of ± 0.002 inch to meet design requirements. In addition, other dimensions for locating the precious metal must be held to close limits for reasons of precious metal economy.

The contact blocks for the wire comb are welded to the wire ends by the automatic percussion welder, Fig. 11, which is a unit in an automatic welding and forming line, Fig. 12, similar to but not identical with the

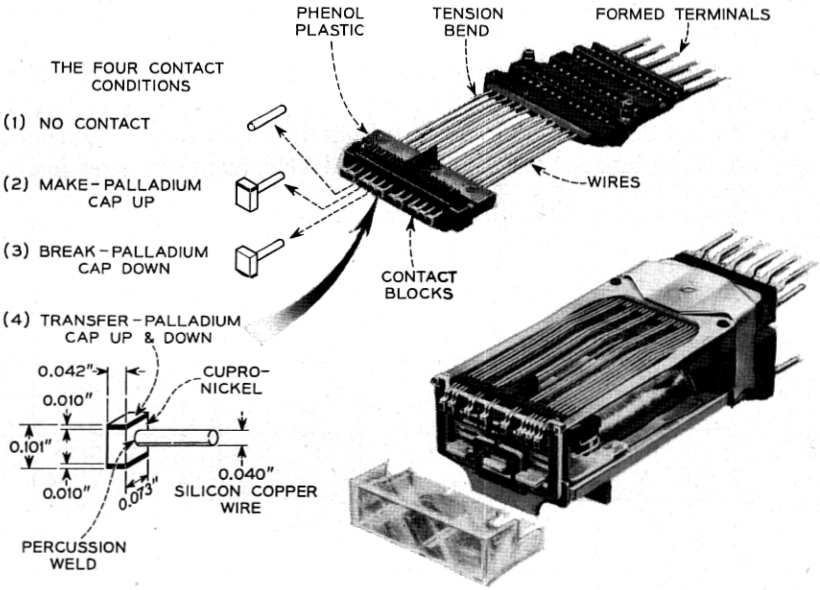


Fig. 10 — Single-wire comb with percussion welded contacts. Also view of wire spring relay.

line used for twin wire comb manufacture. These lines, by being fully automatic in operation, are interesting examples of automation.

REASONS FOR SELECTION OF PERCUSSION WELDING

Percussion welding was selected for this process for the following reasons:

1. The electrodes may be placed well away from the weld zone. The lesser current required for arc welding as compared to resistance welding makes it possible to conduct this current through the wires without heating them appreciably. The electrodes must be placed away from the wire ends so the clamping force will not deflect the wires from their normal position, thus causing a misalignment of contact surfaces.

2. A suitable heat balance in the weld zone can be obtained readily. If the slower butt welding method were used this would be more difficult because of the unequal size and differing electrical and heat conductivities of the abutting parts.

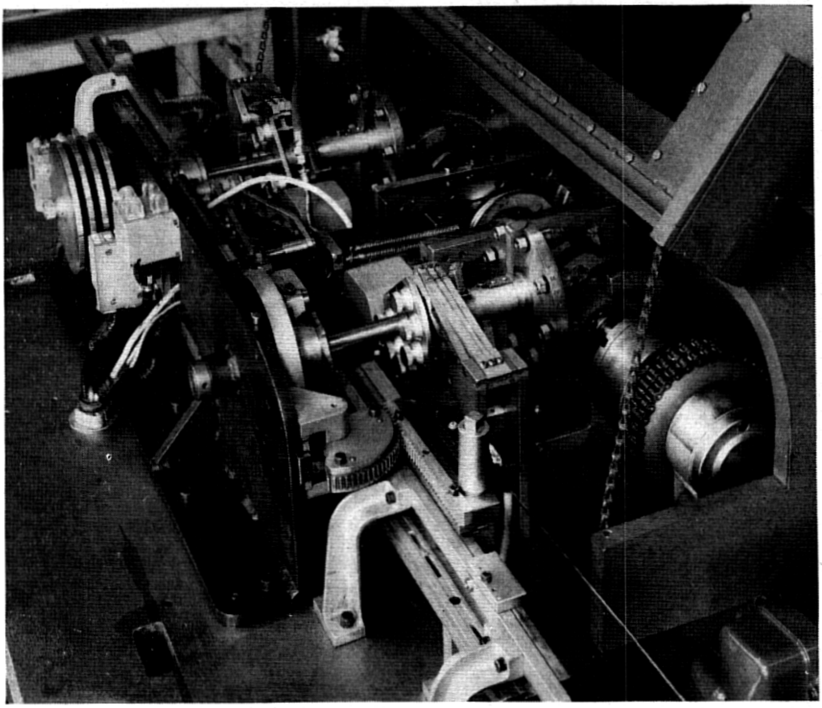


Fig. 11 — Percussion welder for contacts on single-wire combs.

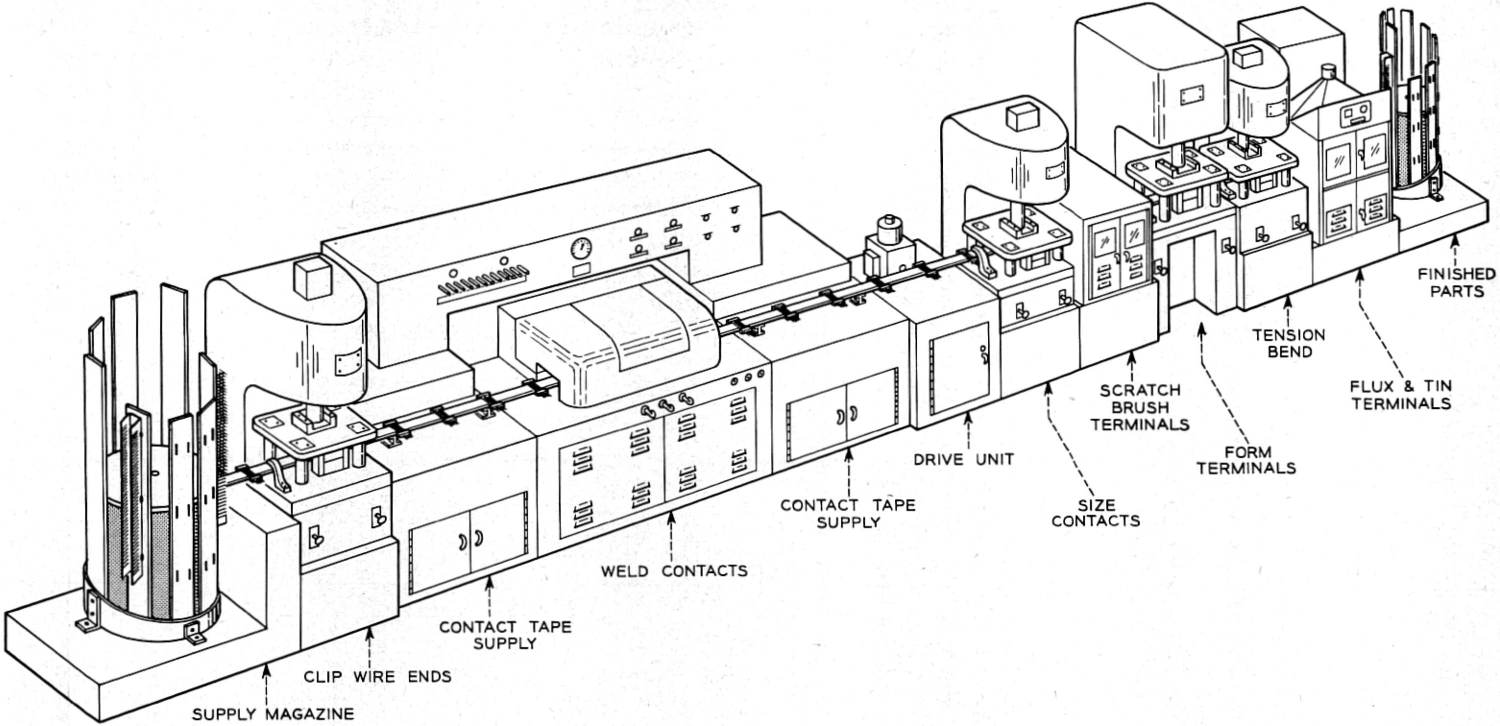


Fig. 12 — Single-wire comb line.

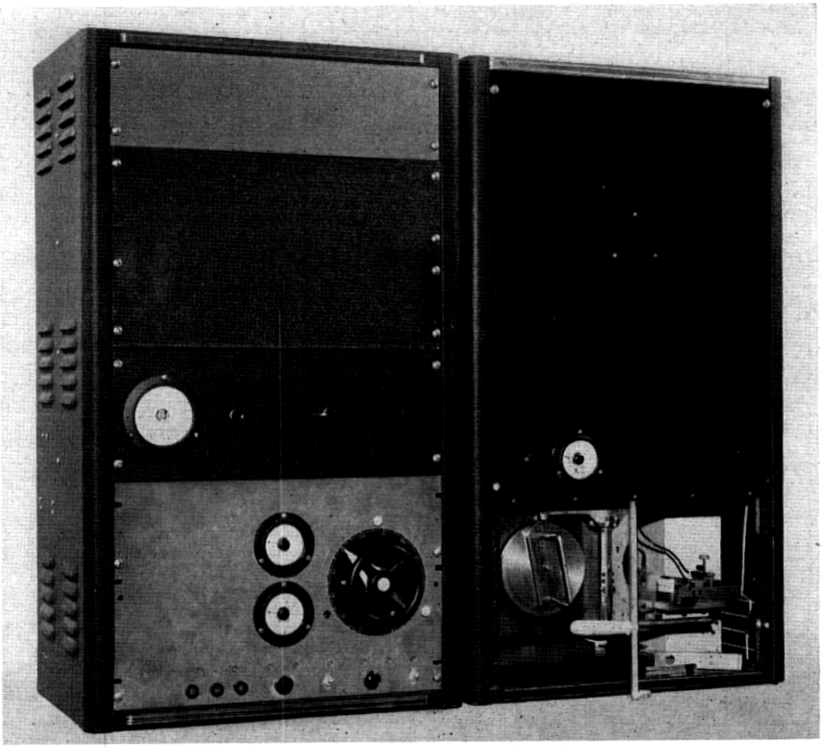
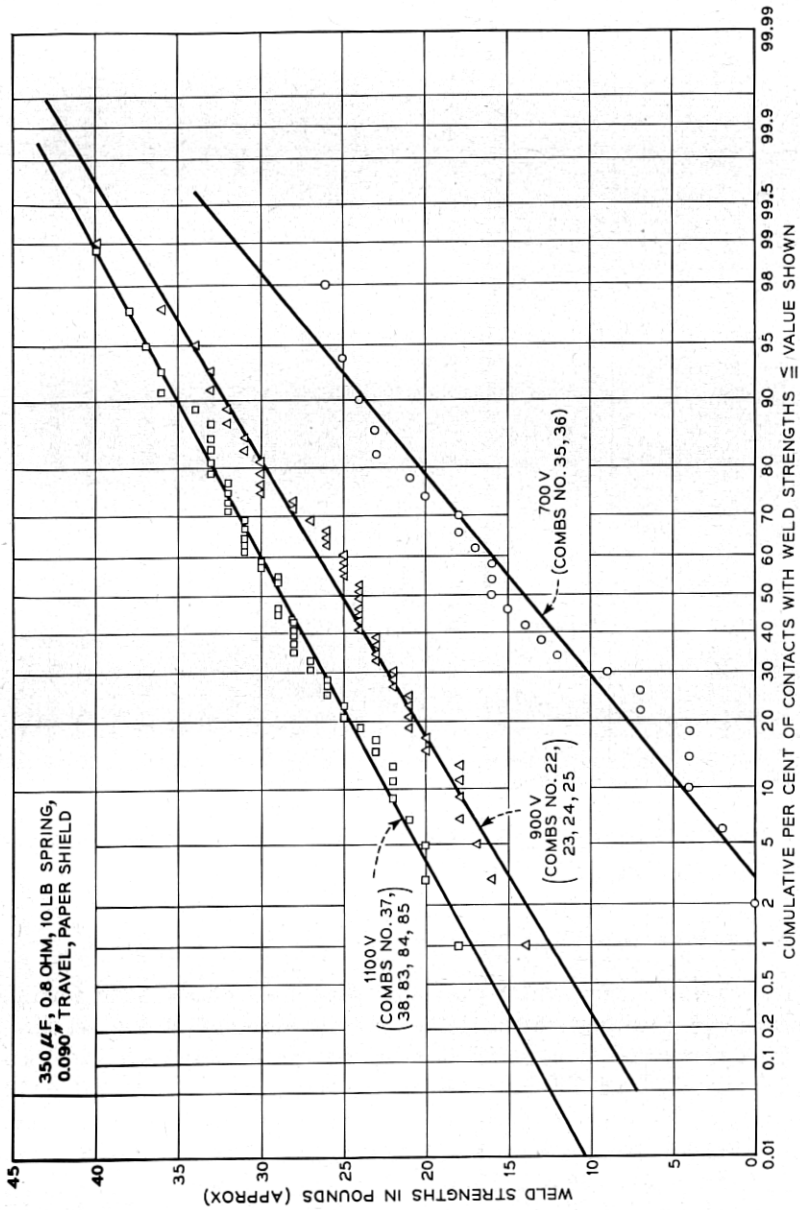


Fig. 13 — Experimental percussive welder for welding contacts to a molded comb on a "one at a time" basis.

3. The fast welding time recommends its use in high speed automatic welding machines.

EXPERIMENTAL WORK

The earliest experimental work was performed on a simple welding fixture with a spring loaded sliding jaw for retaining a contact sized piece of metal and a clamp for holding the wire. Some welds were produced but they varied widely in strength. The next fixture built, Fig. 13, was designed to weld contacts to a molded comb on a one at a time basis. A lightweight spring jawed slider held the contact and guided its travel along a fixed path. This slider was propelled by a lever actuated by a spring and controlled by a cam. The cam was powered by a variable speed drive. An extended study failed to show good weld results except at high speeds when the lever was unable to follow the cam surface and moved



Figs. 14 — Effect of voltage variation on weld strength. (Typical establishing data.)

freely, controlled only by its mass and the applied spring force. From this study the presently used spring actuated welding gun has evolved.

To determine the operating conditions that would be required, an investigation was made in which a group of 48 contacts was welded under carefully controlled conditions following which one condition was varied and the tests repeated. Many curves were established in this way for such variable factors as voltage, capacitance, resistance, spring force, and distance traveled; all related to weld strength. Weld strength was measured by a hook-pull gage developed at Bell Telephone Laboratories. The "burn-off" i.e., reduction in length of the wire and contact as a result of the arc heat, was determined in many of these tests because it usually provided a measure of weld strength uniformity. Many other conditions were investigated such as the weldability of different metals; the effect of cleanliness and of contamination on the joining metals; the influence of the physical form of the joining metals, such as pointed, rounded, or flat surfaces on wire ends; the effect of atmospheric conditions, of the presence of various gases, or a stream of compressed air, and of shields in or near the weld zone. The nature of the weld flash deposit was studied. Neither streamers of base metal which might extend over the edges of the palladium caps nor loosely adhering and easily dislodged metallic particles could be tolerated. Charted data from some of these tests are shown in Figs. 14, 15, and 16.

Another phase of the investigation was concerned with obtaining such

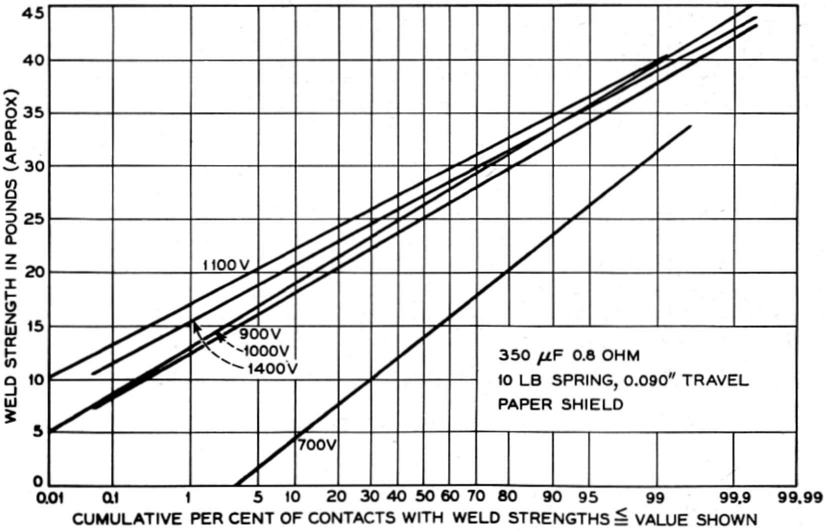


Fig. 15 — Effect of voltage variation on weld strength.

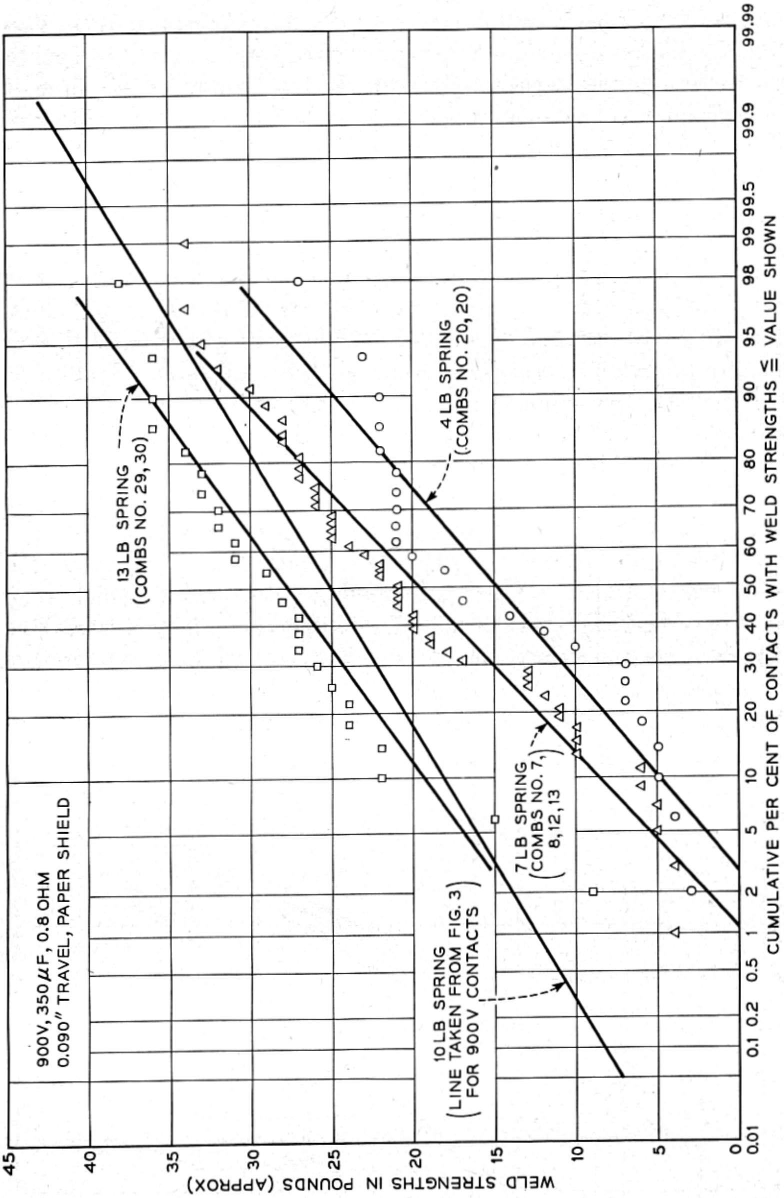


Fig. 16 — Effect of spring pressure on weld strength.

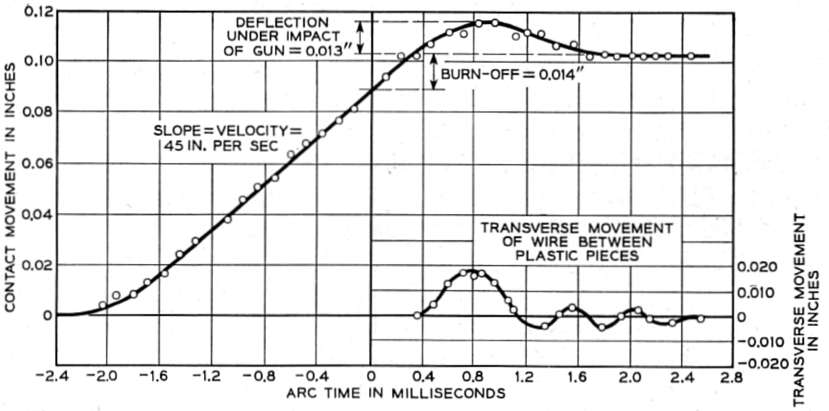


Fig. 17 — Motion of contact during percussion welding plotted from measurements on film.

evidence of what occurred during the welding operation as could be revealed by high speed motion pictures. Fig. 17 shows the kind of information obtained from these films; notably the speed of approach, the amount of burn-off, and the deflection of the comb wires back of the front plastic block upon impact by the welding gun.

In connection with a study directed toward a better understanding of the mechanism of percussion welding undertaken by E. E. Sumner of Bell Telephone Laboratories tests were made with an electro-capacitive transducer, oscilloscope, and polaroid camera arrangement for the purpose of recording variations in the velocity of the welding gun. The characteristics of the current discharge during welding was recorded by another oscilloscope-camera setup. Burn-off was measured and broken weld surfaces on the contacts were examined and photographed. These tests pointed to the value of a parallel capacitor discharge circuit as a solution to the arc duration variability problem. A commercial trial of parallel capacitor circuits at Western Electric demonstrated the merit of this type of circuit, which will be described in more detail later. Calculations from the transducer traces indicated that the striking force of the contact and contact holder upon impact with the comb wire is less than seventy-five pounds. The welding gun was operated on a reed mounting during Mr. Sumner's study.

Early experimental work on percussion welding showed that small gas pockets in the weld zone were causing weak welds. Nickel silver was used at that time. Its component of easily volatilized zinc was suspected of causing the trouble. Then various metals and alloys were tested and silicon-copper was chosen for the wires in the comb. This alloy, however, was not suited for use as the base metal of the contact block because it was difficult to weld in the roll welding process used for fabrication of the contact tape. A 70-30 per cent cupro-nickel was selected for this base metal because it approximated the resistance of the palladium, a necessary condition for roll welding, and it did not have an easily volatile component to weaken the percussion welds.

Another subject investigated was the speed of approach of the parts during the percussion welding operation. The comb and its array of

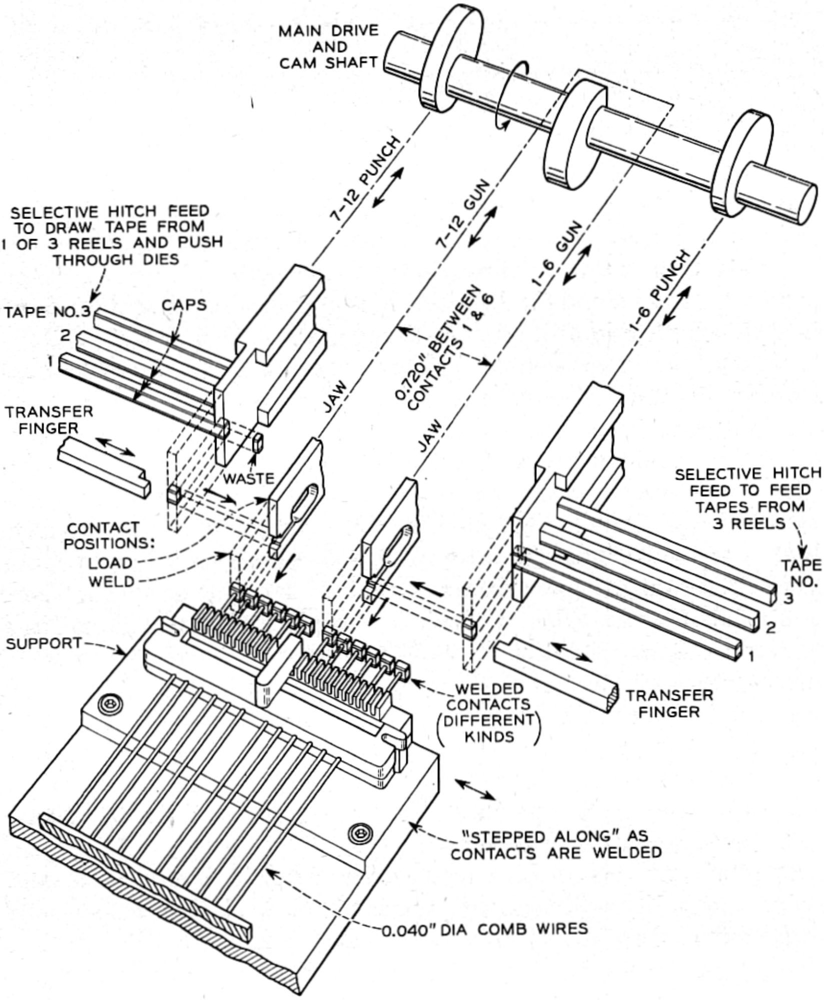


Fig. 18 — Schematic of the percussion welder.

wires is held stationary and the contact block is moved to the wires to make the weld. The speed of approach is an important factor in controlling the arc duration and the impact force. Various speeds of the contact block carriage from approximately 1 to 80 inches per second were tried. The best welds were obtained by a spring actuated gun which attained a velocity at impact of approximately 40 inches per second.

AUTOMATIC WELDER OPERATION

The automatic percussion welder contains duplicate welder heads which are mirror images of each other. Two contacts are welded at a time, one on each half of the comb, Fig. 18. After each welding operation or one cycle, the comb is indexed to the next pair of wire centers. Six cycles complete the welding of twelve contacts, or a lesser number if required. The guns do not weld at exactly the same time. There is an interval of one degree of revolution of the main shaft between the firing points to prevent electrical or mechanical interference. The welder was designed to select the type of contact, cut it from the tape and weld it in one cycle, to avoid the handling problems associated with precutting and magazining contact blocks.

TAPE SUPPLY AND SELECTOR

One of four contact conditions will apply for each wire; (1) no contact, (2) contact with palladium cap up, (3) palladium cap down, or (4) palladium cap both up and down. This requires three reels of tape on the right for one head and three on the left for the other. Adjustable knobs on both right and left tape feed cams are set for one of the four tape feed conditions for each wire position of the comb. Thus, any combination of contact conditions can be set up to make parts for any code of relay.

CONTACT SHEAR AND TRANSFER

The three tapes enter the shearing die through individual openings. However, only that tape selected by the tape selector is fed into the die and subsequently sheared by one punch stroke, Fig. 18. The tape is punched from such a direction that the base metal is not dragged over the boundary line into the palladium zone. This avoids contamination of the palladium. As the contact is blanked out, the walls of a notch in the punch confine it on the precious metal sides to prevent distortion. The punch delivers the contact to a transfer position at the end of the shearing stroke. There a transfer finger pushes the contact out of the punch notch, through a guide channel and into the waiting gun jaws.

WELDING GUNS

The welding gun is a light reciprocating member that carries two opposing steel fingers or jaws to receive the contact block from the transfer finger mentioned above. The jaw opening is a few thousandths of an inch less than the nominal height of the contact, however, the edges are beveled so that when a contact is pressed against them they spring open, the contact enters and is held securely in place. After welding the jaws are pulled off the contact. At the extreme return travel of the gun any contact which might remain in the jaws because it was not properly welded is removed by an ejector blade. When in the loading position, a portion of the blade stops the travel of the contact through the jaw opening so it is held in a uniform position and will be located on the wire with precision.

GUN MASS CONSIDERATION

During welding the comb must be supported accurately to meet the close contact location requirements. It must be supported securely to withstand the impact of the guns, or weak welds may result. The mass of the gun is important. Evidence indicates that more uniform and higher weld strengths are obtained with lightweight guns. A magnesium gun weighing about 60 grams produced better welds than did the original steel gun weighing about 130 grams. A newly installed steel gun weighing about 30 grams appears to be even more satisfactory. Other guns are being designed and tested to further check various features. A striking force of approximately 75 pounds tends to loosen the wires in the plastic and to produce weak welds. The 60 and 30 gram guns propelled at about 40 inches per second at impact produce less than half this force. The velocity during the arcing period is important to control the amount of heating. One-half cycle of vibration of jaw and wire after impact is the time available for the weld to freeze before a tension strain is placed on it. This time has been measured in the laboratory by the use of a transducer. Weak welds resulted when the time was less than 1 millisecond.

ELECTRICAL FUNCTIONS

Fundamentally, each weld circuit includes a capacitor which is charged during a small portion of each cycle and subsequently discharged through a resistance in series with the weld. During the charging period, which is controlled by a cam and microswitch, the contact and the wire end of the comb are separated electrically at the weld point. A multiple leaf brush under considerable pressure connects the one side of the circuit to the terminal end of the individual wire being welded. The gun, and through it the contact block, is connected to the other side of the circuit. After a cam frees the gun, the spring propells it toward the wire end and an electrical arc is established by the high potential (900 to

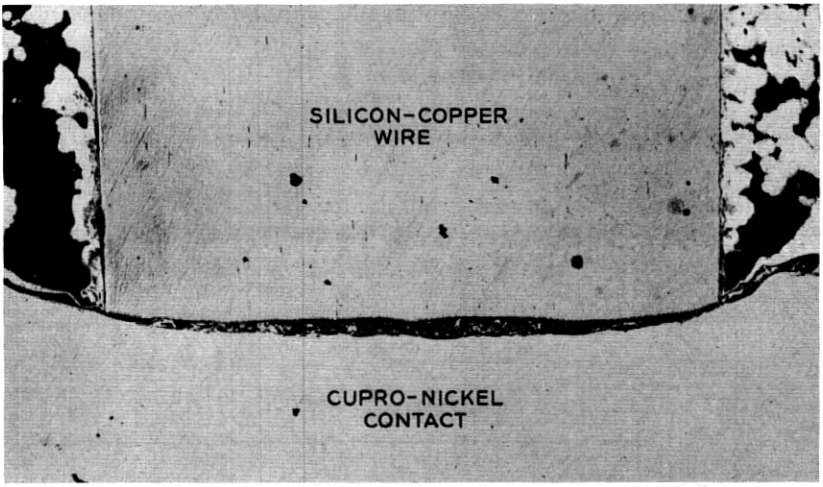


Fig. 19 — Section of a percussion weld. Original amplification 100 ×.

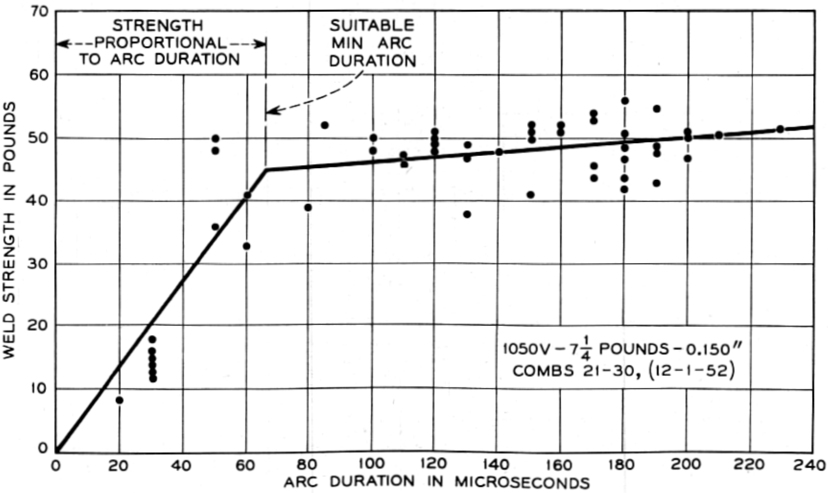


Fig. 20 — Weld strength versus arc duration.

shear test data. In a limited number of samples which were tension tested failure occurred more frequently in the wire than in the weld.

JAW LIFE

Jaw life is dependent upon many factors, but one of importance is the prevention of accidental conditions which establish an arc directly to the jaws. The jaws are adjusted so they will not touch the wire end and thereby discharge the capacitors if no contact is in the jaws. However, if only a very short length of contact metal is cut off and put in the jaws it may start the arc but there may not be sufficient material or the material may not be held securely enough to keep the arc from burning the jaw surfaces. Another possible trouble condition occurs when the end of the wire is misplaced so it touches a jaw. A safety circuit is provided with microswitches which trigger thyratrons to discharge the capacitors when either of these conditions occur. Signal lamps are provided to indicate at which microswitch the trouble is occurring. A reset microswitch is used in the test for shorted contacts so the indication can be held to a later time in the cycle. At the end of the stroke this switch is reset. After the part is nested approximately a quarter of a second is available to test for safe welding conditions. A cam-actuated microswitch controls the time of test and, if conditions are at fault, the weld energy is discharged through a thyratron before the parts are brought together for welding.

SAFETY

Safety for personnel from high voltage is provided by door switches, solenoid released shorting bars and bleeder resistors on the capacitors. Safety from mechanical jams is provided by a slip clutch on the main drive gear and by a pull out clutch and automatic stop switch located in the comb transfer drive mechanism.

CONCLUSIONS

After making millions of welds by automatic percussive welding methods, it is found to be a method well suited to this job. Accuracy of location and good weld strength are obtained. This welding method is especially useful where speed and precision are desired, and where joints must be made between dissimilar metals. Metals of high heat conductivity and high electrical conductivity join readily by this method.

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