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PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Welding Apparatus

5 We, TEXAS INSTRUMENTS INCORPORATED, a corporation organized according to the laws of the State of Delaware, United States of America, of 13500, North Central Expressway, Dallas, Texas, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

10 This invention relates to a control for welding apparatus adapted among other uses to weld the leads of microminiature electronic components such as semiconductor networks and the like to the conductive portions of printed circuit boards.

15 The present invention is a control for a welding apparatus; comprising a pair of weld electrodes adapted to interconnect with and cause a welding current to be conducted through a workpiece, said weld electrodes being moveable lateral to and engaging a common surface of said workpiece, a power supply for said electrodes, said power supply including regulating means for controlling the current applied to said electrodes, sensing means interconnected with said electrodes immediately adjacent said workpiece for sensing the voltage across said electrodes during a weld cycle of said apparatus, a feedback circuit interconnected with said sensing means and said regulating means for causing the latter to maintain the current to said workpiece below a pre-established level, and means included in said feedback circuit for selectively varying said pre-established level.

20 The present invention is also a control for a welding apparatus; comprising a pair of weld electrodes adapted to interconnect with a common surface and causing a welding current to be conducted through a workpiece, said weld electrodes having an adjustable space therebetween, a welding transformer having a secondary winding connected across

25 said electrodes, a primary winding, a capacitor, a source of charging for said capacitor, relay means adapted in a first position to interconnect said capacitor with said source for charging thereof and adapted in a second position to interconnect said capacitor to said primary winding for discharge therethrough, a variable impedance device connected across said primary winding, and means responsive to the voltage across said electrodes during a weld cycle for controlling the impedance of said variable impedance device thereby to maintain the current through said workpiece below a pre-established maximum level.

30 Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:—

35 FIG. 1 is a diagrammatic side elevation of certain mechanical elements of the invention, parts being broken away and shown in section;

40 FIG. 2 is a vertical section taken on line 2—2 of FIG. 1;

45 FIG. 3 is a horizontal section taken on line 3—3 of FIG. 1;

50 FIG. 4 is an enlarged view of certain parts of FIG. 2;

55 FIG. 5 is a cross section illustrating certain pedal-operating means;

60 FIG. 6 is an enlarged side elevation of an electrode and its support, parts being shown in section;

65 FIG. 7 is a section taken on line 7—7 of FIG. 6;

70 FIG. 8 is a front view of a pair of electrodes shown as being applied to coplanar welding areas;

75 FIG. 9 is a front view of a pair of electrodes shown as being applied to non-coplanar welding areas;

80 FIG. 10 is a block diagram illustrating a preferred electrical control system for the welding apparatus of FIGS. 1—9;

85 FIG. 11 is a circuit diagram illustrating

the electrical components of the FIG. 10 system and their interconnection; and

FIG. 12 is a block diagram illustrating a second control system for the welding apparatus of FIGS. 1-9, mechanical portions of the system being shown diagrammatically.

Corresponding reference characters indicate corresponding parts throughout the several views of the drawings.

Referring now more particularly to FIG. 1, there is shown at numeral 1 a base which carries a suitable worktable or insulated welding platform 3 for supporting work to be welded. On the base 1 is a housing 5, open at the front, as shown at 7. On the base 1 is a bracket 9 which supports a movable hydraulic cylinder 11. Support is effected by a sliding fit between a hole 10 in the bracket 9 and a downward cylindrical extension 12 of the cylinder 11.

In the cylinder 11 is a movable piston 13 which is sealed during movements by a flexible diaphragm 15 marginally held by the cylinder. Carried on the piston 13 is a piston rod 17. This passes through the lower extension of the cylinder 11. At its outer end rod 17 is attached at 19 to a vertically movable bracket 21. Bracket 21 forms part of a carrier member 23 which is vertically bored to receive a post 25 for vertical sliding movement thereon. The post 25 is affixed to the base 1, as indicated by the threaded attachment 27.

The sliding carrier member 23 has a forwardly extending central rib 29. At the upper and lower ends of carrier 23 are located transverse flanges 31. Affixed between the flanges 31 are guide means in the form of fixed vertical rods 33. Slidable for a limited distance on each rod 33 is a sleeve 35. Within each sleeve 35 is an electrically insulating bushing 37, flanged at its opposite ends, as shown at 39.

Extending forward from the rib portion 29 is a bracket 41 which supports a rotatable crosspin 43 (FIGS. 2 and 4). The pin 43 is held captive axially by set screw collars 45. It carries a calibrating knob 47. Under the knob is a calibration dial 48 which is attached to one of a pair of arms 59 (further to be described below).

The pin 43 carries threads 49 and 51 at its opposite ends. These are of opposite pitches and carry nuts 53. The arrangement is such that when the pin 43 is turned, the nuts 53 will recede or approach relative to one another, depending upon the direction in which the knob 47 is turned. Attached to and extending up and down from each nut 53 is a pair of collinear pins 55 which have slidable engagement with insulating bushings 57. The bushings 57 are located in arms 59, which extend forwardly from the vertically movable members 35 respectively. The purpose of this arrangement is to permit two

types of movement for the arms 59; first, opposite transverse swinging arm movements around the centres of the guide rods 33, so that welding rods (to be described) may have the space between them adjusted by turning knob 47; and second, opposite vertical movements of the arms 59 (with the sleeves 35 from which they extend) so that compensations can be effected in the contact planes of said welding rods.

The amount that the sleeves 35 of the arms 59 may move up and down on their pins 33 is determined by the clearances shown at 61 (FIGS. 1 and 2).

Extending up from the bracket 41 is a lug 63 forming a bearing for one end of a rocker pin 65. The other end of this pin is borne in a hole 67 in the rib 29 of carrier 23. Rotatable on pin 65 is a compensating beam or lever 69 which has a rounded head 71 at each end. Each head 71 is located in an opening 73 of one of the arms 59. Insulating bushings 75 in the openings 73 surround the heads 71. If desired, instead of employing insulating bushings 75, the beam 69 might be made of insulating material.

At numerals 77 are shown the welding rods or electrodes (above mentioned), each of which is located in an opening 79 of a downwardly-directed finger part 81 of an arm 59 (FIGS. 1, 3, 6 and 7). In FIG. 7 is shown one of the clamping means such as used for holding each welding rod 77. This consists of a ball 83 held loosely but captive in a suitable cage 85 located in finger 81. For assembly purposes, an opening 87 is provided extending across rod opening 79, for the introduction of the cage 85. Before the cage and ball are introduced, a wedging member 89 of hour-glass shape is threaded into an opening 91 extending crosswise of the finger part 81. This wedging member 89 contains a screw-driver slot 93, whereby it may be rotated so as to wedge the ball 83 into holding contact with a welding rod 77 in opening 79. It will be understood that other appropriate means may be used for clamping the electrodes in position in their respective arm portions 81.

The lower end of each electrode has a welding tip 95 (FIGS. 6, 8 and 9). The opposed faces or surfaces of electrodes 77 are parallel (see FIGS. 8 and 9) so that the tips 95 are parallel. This eliminates the necessity of realignment of the electrodes due to electrode wear. At its upper end each electrode carries an exteriorly threaded socket member 97 for the reception of a jack 99 forming the end of a lead wire 101. The jack 99 is held in place by a cap 103, threaded to the socket member 97. The purpose of wire 101 will be described below.

In FIG. 5 is shown pedal-operating means comprising a base 105 to which at 107 is pivoted a foot pedal 109. Foot pedal 109 carries a bracket 111 forming a guide for a

slider member 113. The position of the slider is controlled by an adjusting screw 115. Pivoted at 117 to the slider 113 is a piston rod 119. This is connected with a plunger 5 121 located in a flexible sealing bellows 123 in a hydraulic cylinder 125. The plunger 121 and bellows form a piston in the cylinder 125, operable by the piston rod 119 when the pedal 109 is rotated clockwise. By adjust- 10 ing the slider 113 on the bracket 111, the position of pivot 117 relative to the pedal 109 is changed and by this means the stroke of the plunger may be changed, as desired.

The cylinder 125 has a rigid extension 127 15 pivoted at 129 to a bell crank 131. The bell crank is pivoted at 133 to an appropriate support 135 on the base 105 and engages a plunger 137, backed by an overload spring 139. The purpose of the plunger 137 and 20 spring 139 is to provide a release of the bell crank 131 when hydraulic pressure in a cylinder 125 approaches that corresponding to a selected safe limit. The motion of the pedal 109 is also limited by adjustable stops 25 141 and 143.

A flexible hydraulic pressure line 145 leads from the cylinder 125 to the head 147 of cylinder 11 (FIGS. 1, 3 and 5). Thus when the pedal 109 is rotated crosswise (FIG. 5) 30 hydraulic pressure is introduced into the cylinder 11 so as to push down the piston rod 17, bracket 21 and carrier parts connected therewith. Return of fluid to cylinder 125 is provided for by return action on piston 35 13 of a spring 149 when foot pressure is taken from the pedal 109.

Referring again to FIGS. 1 and 3, the top of the housing 5 carries a motion transmission box 151 operative between a calibrated dial 153 and a gear train 157 for 40 turning a threaded vertical post 155. On the post is a nut 159 which is vertically movable when the post 155 is turned. An elongate bracket 160 (shown in FIG. 3) prevents the 45 nut from turning while permitting its axial movement (FIG. 3). The nut is coupled to a lever 161 through a tension spring 163, adapted to be hooked into various holes 165 of the lever 161. The lever is pivoted at 167 50 to the top of the housing 5 and is engaged on its underside at 169 by the head portion 147 of the cylinder 11. The lever also carries a lug 171, engageable with the operating button of a normally open firing switch 173. 55 This switch is carried from the top of the housing 5 by a bracket 174. By turning the calibrated knob 153 and thus adjusting the elevation of the nut 159, various clockwise moments of force may be obtained on the 60 lever 161 from spring 163.

At numerals 175 are shown welding-current leads which extend to bus bars 177 carried on an insulated plate 179 located on base 1. Flexible current leads 181 extend from the 65 bus bars 177 to the sleeves 35, whereby cur-

rent from a capacitor-discharge type power supply (described hereinafter) is conducted through arms 59 to the welding rods or electrodes 77.

As noted above, the welding apparatus of 70 this invention is adapted among other uses to weld the leads of micro-miniature electronic components such as semiconductor networks (hereinafter called SCN) or integrated modules 75 to the conductive portions or plating of printed circuit boards. In describing the operation of the mechanical portion of the apparatus, it will be assumed that this work- 80 piece, i.e., the printed circuit board, and the SCN are in proper position on table 3. These are shown in FIGS. 8 and 9, the SCN (or a portion thereof) at reference numeral 183 and its conductive lead at 185. The conduc- 85 tive portion or plating of a printed circuit board (indicated at 187) is shown at numeral 189, and the nonconducting substrate thereof is indicated at numeral 191.

Operation of the mechanical portion of the apparatus is as follows:—

The calibrating knob 47 is turned, thus 90 driving the nuts 53 on threaded crosspin 43 either together or apart. This swings the carriers 35 oppositely around the rods 33, whereby the desired distance is obtained between the welding tips 95. The calibration at the knob 47 indicates these distances which may be in the range of 0 to 40 mils.

Next, foot pressure on pedal 109 rotates it clockwise, which squeezes fluid under pressure out of the cylinder 125 through line 145 to 100 the head 147 of cylinder 11. Since at this time the electrodes do not contact their work, the piston 13 responds by moving downwardly more or less freely, although against return action of the spring 149. This moves the 105 bracket 21 down along with the assembly of parts 23, 31 and 41. These slide down on the post 25. This moves down the bracket 41 and its lug 63 which in turn carries down the pin 65. Pin 65 carries down with it the compensating lever or beam 69 which in turn carries down the sleeves 35, arms 59, fingers 81 and welding rods 77. Before any contact is made by electrodes 77 with the work, the two carriers 35 may or may not remain at 115 about the same level on their posts 33, as shown in FIG. 2. If the electrodes 77 make contact with the work in one plane, as shown in FIG. 8, they remain or seek a level. If they contact the work in different planes, then 120 the state of affairs shown in FIG. 9 occurs. In this case one (the right-hand) carrier 35 stops. Then as the parts descend further, the compensating beam 69 rocks, forcing down the other carrier 35 and taking with it the 125 left-hand electrode 77. It will be apparent that the sliding fits of the pins 55 of nuts 53 in the bushings 57 in arms 59 allow for compensating action between the arms 59 and the space-adjusting crosspin 43, as re- 130

quired. In any event, when the electrodes 77 make contact with the work, they exert equal pressures, either as shown in FIG. 8 or FIG. 9. Moreover, a reaction will be set up by them through the compensating beam 69 to the parts which slide on the post 25. These parts, as above noted, include the bracket 21. As a consequence the pressure in the cylinder 11 cannot push the piston 13 down any further. Pressure on the head 147 continues. Thereupon the cylinder 11 is pulled up, its part 12 sliding in the hole 10 of the bracket 9. At this time the parts connected with bracket 21 do not move, pressure on the work being maintained by the welding tips 95. Since the cylinder head 147 engages under the lever arm 161 at 169, this tends to rotate the arm anticlockwise against the adjusted tension of the spring 163.

Ultimately the lug 171 causes firing switch 173 to close. As explained hereinafter, this actuates a relay which in turn causes a capacitor to be discharged through the leads 175, the electrodes 77 and the work. A pulse of welding current passes from one of the welding electrodes 77 to the other through the parallel branches or conductive paths formed by the SCN lead 185 and the conductive portion or welding tab 189 of the printed circuit board. As explained hereinafter, the peak amplitude of the pulse voltage is accurately controlled during the weld cycle so as not to exceed a preestablished level. This is an important feature of this invention, as will be described in connection with FIGS. 10-12.

Because, with voltage control of the welding pulse, there is a constant and equal voltage across the two parallel paths, 185 and 189, the power dissipation in each path is an inverse function of its resistance. The most significant results of this relationship are that the power dissipated in a conductor to be welded is a direct function of its cross section, and any sudden increase in the resistance of parallel circuit 185 and 189 will not result in a catastrophic failure as would be the case were a constant current source being used. The weld joint thus formed does not extend over the full width of the gap due to the heatsink action of the electrodes. The high thermal conductivity of these electrodes (which are preferably made of copper) limits fusion to approximately 80% of the electrode gap. This heatsink effect is desirable because it eliminates fusion near the electrode tips which otherwise would result in the tips sticking to the welded surface.

Since switch 173 is actuated at a pre-selected pressure between the electrode tips and the workpiece, a high uniformity of welds may be attained. Acceptable welds joining SCN networks to printed circuitry have been made over a total pressure range from 1.5

to 3.5 pounds. By total pressure is meant the sum of the pressure exerted by the electrode tips. This wide range of acceptable pressures is possible because the weld is formed between the electrodes instead of beneath the electrodes. In any specific application, the only limits imposed on the electrode pressure are (1) the total pressure must be sufficient to break down surface oxidation between the network lead and the welding tab, and (2) this pressure must be less than a value which would tend to weaken the bond between the welding tab and the substrate.

The electrode gap (defined as the horizontal distance between the interfaces of the two electrodes tips) is a critical parameter in obtaining optimum weld joints. The electrode gap controls the mass of fusion nugget formed by the welding current pulse, large gaps resulting in the formation of large nuggets. The higher energies required to form large nuggets burn the board beneath the tab and weaken the organic bond between the substrate and the plating; while gaps which are too small result in a joint which is mechanically weak, due to incomplete fusion. Different applications will require different gap settings, and the accurate control of the gap by means of knob 47 and its associated components constitutes an important feature of this invention.

After firing, the pedal 109 is permitted to return anticlockwise to its initial position, as shown in FIG. 5. The spring 149 then expands, thereby returning cylinder 11 to its initial position and causing the piston rod 17 to lift bracket 21 and the parts including the electrodes to their elevated positions away from the work. In the process, fluid flows back through the line 145 to the cylinder 125. In view of the above, it will be apparent that the sealed piston 13 and cylinder 147 constitute expandable fluid chamber means having relatively movable parts, one of which (the piston) is connected to the electrode carrier means to move the electrodes to and against the work. The other part (head 147) is articulated to the lever or arm 161 which provides adjustable reaction (from spring 163) to determine the electrode contact pressure at the instant of welding.

A preferred embodiment of the electrical control portion of the welding apparatus which functions to provide selective energization of the weld electrodes and critical regulation of the current pulse through the workpiece during a welding cycle will now be considered in connection with FIGS. 10 and 11. Referring now to FIG. 10, weld electrodes 77 are shown in contact with lead 185 which is to be welded to the tab or surface 189. The flexible leads 181 are shown interconnected to the electrodes 77. These supply power from a capacitor-discharge type power supply

consisting of a welding transformer 201 having a primary winding 205 and a secondary winding 203, a regulating resistance 207, a welding relay 209 (which, as explained hereinafter, is under the control of firing switch 173), and a capacitor 211. The latter is selectively connected by relay 209 to a source of charging current, for example a 110 V d.c. power supply connected at point 212. A shunt 213, which, as explained hereinafter, consists of a variable and controlled impedance in the form of one or more transistors is connected in series with resistor 207, and in parallel with primary winding 205.

In the quiescent state, the movable contact of relay 209 is in the position illustrated wherein it interconnects the d.c. power supply with capacitor 211, charging the latter to the 110 v. level. Actuation of firing switch 173 causes energization of relay 209 which in turn connects capacitor 211 to resistor 207 thereby providing a discharge path for this capacitor through resistance 207, and through primary winding 205 and shunt 213. The pulse through winding 205 is coupled to secondary winding 203 and applied to electrodes 77. A typical pulse applied across the workpiece will have an amplitude of from .5 to .75 v., for example, and a duration of 2—3 milliseconds.

Because the impedance between electrodes 77 when they are not in contact with the workpiece is considerably higher than the resistance of the workpiece between electrodes 77, and since the latter is quite low, for example, 2 milliohms, the capacitor-discharge power supply is essentially a constant-current source for small changes in the resistance of the workpiece. Because of this, the heat generated during the welding cycle (which is equal or proportional to I^2R) varies with the resistance of the workpiece. And the thinner workpieces which are less able to stand increased heat have higher resistances resulting in higher I^2R heat generation. For example, if a lead having a thickness of 4 mils has a resistance of 3 milliohms, a 2-mil lead would have a resistance of 6 milliohms; and the lead having half the volume would in effect receive double the heat input. The present invention obviates or overcomes the burn-out problem by including a feedback circuit which provides a dynamic control during a welding cycle which maintains the voltage across the workpiece, and hence the current therethrough, at a value less than a preestablished safe level. In this controlled feedback system, the lead receives heat in proportion to its volume because this system sets the voltage level across the tips as the weld is taking place.

This feedback circuit includes a pulse weld amplifier 219, the input of which is connected by conductors 101 to the welding electrodes 77. As shown most clearly in FIG.

1, conductors 101 are connected directly to the weld electrodes immediately adjacent the workpiece. This is an important feature of the present invention which increases or enhances the signal-to-noise characteristics by reducing the total d.c. resistance between the sensing conductors 101. Pulse weld amplifier 219 is a d.c. coupled amplifier having a gain of approximately 6 to 10. This amplifier functions to bring the weld pulse up from an increment of .5 v. to from 3 to 5 v. The output of amplifier 219 is applied to one input of a voltage comparator of differential amplifier 221, the other input of which receives a reference voltage from a reference voltage generator 223. An output of comparator 221 occurs when the input from amplifier 219 exceeds the reference voltage supplied by generator 223, with the amplitude of the output being a function of the difference between the two inputs. The output of comparator 221 (when one occurs) is fed to an error amplifier 225 which in turn controls the value of the shunt impedance 213 to bring the weld pulse back to its proper value. It will be appreciated that regulating resistor 207 and shunt 213 constitute a voltage divider network, the output of which (applied to primary winding 205) is taken across shunt 213.

A sequence of operation of the FIG. 10 control is as follows: Initially relay 209 is deenergized, and the movable contact thereof interconnects capacitor 211 with point 212 causing this capacitor to be charged. Actuation of firing switch 173 energizes relay 209, thereby moving the contact thereof to interconnect capacitor 211 with resistor 207. This provides a discharge path for this capacitor through winding 205 and shunt 213. Transformer 201 couples the resulting pulse to electrodes 77 causing a short duration weld pulse to be conducted through the workpiece. Pulse weld amplifier 219 and voltage comparator 221 continuously monitor this pulse during a weld cycle, and if the pulse incipiently exceeds a preestablished level as determined by the setting of reference generator 223, these components provide a control signal to shunt 213 which varies the impedance characteristic thereof to bring the weld pulse below this preestablished value. Relay 209 is then deenergized by the lifting of the weld electrode assembly and concurrent opening of switch 173; the contact thereof again interconnects capacitor 211 with point 212; and the cycle is completed.

The system of FIG. 10 is shown schematically in FIG. 11 with like reference numerals representing corresponding parts. In addition to the shunt 213 which is shown as comprising a transistor 227 having a resistance 229 connected in its emitter circuit, the primary winding 205 has connected across it a transient-suppressing diode 231 and a Zener

diode 233. Pulse weld amplifier 219 is illustrated as comprising a pair of transistors 235 and 237 interconnected to the welding tips 77 by means of a coupling capacitor 239 and a resistance biasing network comprising resistors 241 and 243. The output of this amplifier is taken across an output resistance 244 interconnected between the collector of transistor 237 and the negative terminal of a 12 v. d.c. power supply indicated at 246. It will be appreciated that the second stage of this d.c. amplifier functions as an emitter follower to provide a low impedance output to the input of the voltage comparator.

The voltage comparator 221 consists of a pair of interconnected transistors 245 and 247 forming a differential amplifier circuit. The base of transistor 245 constitutes one input to the voltage comparator interconnected with the output of the d.c. amplifier, while the base of transistor 247 is connected to the rotor or tap of a potentiometer 249 which constitutes the reference voltage generator 223. The fixed resistance of potentiometer 249 is interconnected by means of a resistance 251 and a second resistance 253 across the terminals of power supply 246. The right side of the differential amplifier, i.e. transistor 247, is driven into conduction by the reference voltage, and the left side remains non-conducting as long as the output of the weld pulse amplifier does not exceed the pre-established value. When this output exceeds the reference voltage, transistor 245 conducts, causing an output or error signal to appear at the collector of transistor 245. The output is applied to the input of the error amplifier which comprises two transistors 255 and 257 with an emitter follower stage 259 in the output. The output of this error amplifier, taken at the emitter of transistor 259, is coupled to the base or control electrode of the shunt transistor 227 to control its conductivity and thereby control the level of the pulse applied from the capacitor 211 to the primary of the welding transformer 201.

It should be noted that while shunt 213 is illustrated as comprising a single transistor 227, a plurality of transistors having commonly connected bases could be employed to reduce individual collector currents.

In addition to the dynamic control of the weld pulse which takes place during a welding cycle, it is desirable in many instances to provide for a pre-resistance test, i.e., for a resistance measurement of the workpiece prior to the initiation of the welding cycle to determine whether the resistance of the workpiece is within a certain tolerance range preselected by the operator. It will be understood that if the resistance is outside of this range, no matter how accurate the dynamic control is, a satisfactory weld joint cannot be assured.

It is also desirable to conduct a post-resistance

test subsequent to the weld cycle to determine whether the resistance characteristics of the workpiece indicate a satisfactory weld joint.

The system of FIG. 12 includes components for performing both a pre-resistance test to determine whether the weld should be carried out upon impression of the proper pressure between the weld tips and the workpiece, and a post-resistance test to determine whether the resistance of the weld joint after a welding cycle is within a preselected range of values.

The system of FIG. 12 includes all of the components illustrated in FIG. 11, which components provide identical functions in this FIG. 12 system. In addition to these, the FIG. 12 system includes a test current generator 261 which operates at a relatively high frequency, for example, 25 kc. The output of this generator is connected across the weld tips 77, for example by connection to the bus bars 177 (see FIGS. 1 and 2). The leads 101, in addition to being interconnected to the input of the weld pulse amplifier 219, are connected with the input of an amplifier 263. This is a loosely tuned amplifier operative in the 25 kc. operating region. The output of amplifier 263 is applied to a detector 265, for example, a conventional full-wave bridge-type detector, which supplies a d.c. output voltage proportional to the amplitude level of the 25 kc. signal applied from amplifier 263. The output of detector 265 is in turn coupled to the respective inputs of two Schmitt trigger circuits 267 and 268. The former forms a part of the pre-resistance control; while the latter functions to carry out a post-resistance comparison. A d.c. reference voltage from a source 269 is applied to the second input of trigger circuit 267. Similarly, the second input of circuit 268 receives a d.c. reference voltage from a generator 270. The output of circuit 267 is applied to the coil of a relay 271. This relay has a first set of contacts 271a and a second set of contacts 271b, the latter being interconnected with a relay power supply 273 and the coil of relay 209. The weld firing switch 173 is shown as having its movable contact interconnected with power supply 273, one pole being connected to the coil of relay 209 and the other pole connected to a valve-holding relay 275. The movable contact of relay 275 is connected to a post-weld test relay 277, the coil of which is selectively energized by the output of trigger circuit 268. The movable arm of relay 277 and the arm of contacts 271a are connected to a 25 v.d.c. source connected at point 279.

When employed in the FIG. 12 system, pulse weld amplifier 219 includes a low-pass filter in its input stage to block the 25 kc. signal from generator 261. It will be appreciated that the primary winding

203 presents a high impedance, for all practical purposes, to this 25 kc. signal.

In the FIG. 12 system, a solenoid-actuated valve 281 is connected in hydraulic pressure line 145 between the hydraulic cylinder 125 and cylinder 11. This valve is controlled by solenoid 283 whereby when this solenoid is energized the valve closes thereby blocking all motion of the foot pedal 109 or the vertically movable bracket 21 which carries the weld electrodes 77.

Operation of the FIG. 12 system is as follows: Initially solenoid 283 is deenergized and a welding cycle is initiated by the depression of foot pedal 109 which brings weld electrodes into contact with the workpiece. Upon a predetermined pressure between the electrodes and the workpiece the weld firing switch 173 is actuated as explained above. A weld cycle is thereby initiated, and as explained above in connection with FIG. 10, the feedback circuit consisting of pulse weld amplifier 219, the voltage comparator 221 and error amplifier 225 function to flatten out or clip the pulse applied to the workpiece to maintain the voltage across the workpiece at a preestablished level. Before a weld is initiated, however, the pre-resistance welding test serves to prevent a weld cycle altogether if proper resistance characteristics are not exhibited by the workpiece. The test current generator 261 functions as a constant current source to supply a constant current at 25kc. to the workpiece. The voltage across this workpiece (which is a function of the resistance thereof) is applied to the input of amplifier 263 where it is amplified, and the resulting signal detected by detector 265. The output of the detector is coupled to the input of a Schmitt trigger circuit 267. This circuit functions to compare this input with the threshold level from generator 269, and if the input is too high (indicating an excessive resistance between the weld tips) the trigger circuit provides an output which energizes the coil of relay 271. This in turn actuates contacts 271b to open the weld fire circuit, thereby preventing energization of the coil of relay 209. As a result actuation of the contacts of relay 209 is prevented and a weld cycle cannot be initiated. This signals the operator that the resistance characteristics of the workpiece are such that a satisfactory weld joint cannot be assured. The operator can then take whatever corrective action may be necessary.

Actuation of weld firing switch 173, in addition to initiating a welding cycle, also causes deenergization of relay 275, thereby permitting the contact thereof to return to the position illustrated in FIG. 12. This completes a circuit from point 279 through the contacts 271a of relay 271 and through the now-closed contact of relay 275 to coil 283. This energizes the latter, closes valve

281 and thereby locks the weld electrodes 77 in their lower position.

The gap resistance, i.e. the resistance across the workpiece, increases appreciably upon welding, for example to a value which is double the pre-weld gap resistance. The post-weld resistance test provides a determination (1) whether this increase in resistance has occurred, and (2) whether the post-weld resistance is still below a preselected value, indicating a satisfactory weld. Unless both conditions (1) and (2) are satisfied, solenoid 283 remains energized, indicating an unsatisfactory weld.

To determine whether condition (1) is satisfied, trigger circuit 267 is again brought into play. If the resistance after the weld exceeds the level set in by reference voltage generator 269, trigger circuit 267 will, as before, energize relay 271 and actuate contacts 271a to open one of the conductive paths between point 279 and the movable contact of relay 275. (If the post-weld resistance is above a level established by the setting of generator 270, trigger circuit 268 will apply an output signal to relay 277. This indicates that condition (2) is not satisfied. Energization of relay 277 maintains coil 283 energized through the contacts of relay 275. However, if the post-weld resistance is less than the value established by generator 270 (i.e., if condition (2) is satisfied), relay 277 will not be energized and the second or remaining conductive path between point 279 and relay contacts 275 will be opened. This in turn deenergizes coil 283, opening valve 281 and thereby permitting bracket 21 to move upward, positioning electrodes 77 in their upper position. Concurrently, switch 173 is actuated to the position illustrated in FIG. 12. This reenergizes relay 275 drawing the movable arm out of circuit-closing relation with coil 283.

Summarizing, after initiation of a weld cycle, valve 281 is closed and is automatically reopened only if the post-weld resistance is (1) greater than the pre-resistance maximum level as established by the setting of generator 269, and (2) less than a level established by the adjustment of generator 270. Valve 281 is provided with a manual override to permit manual opening of the valve in the event the post-weld resistance does not satisfy conditions (1) and (2) above.

In the system of FIG. 12, a first voltmeter VI is shown interconnected at the output of the reference voltage generator 223. This meter provides a means of selecting a proper clipping level or top to the welding pulse, i.e., a preselected maximum voltage level for the welding pulse. A second meter V2 is selectively interconnected by means of a three-position switch either to the output of detector 265, or the output of the threshold level generators 269 or 270. In addition to pro-

viding a means of accurately selecting the respective threshold levels set in by generators 269 and 270, this meter provides a reading of the resistance exhibited by the workpiece between the weld tips 77, both during the pre-resistance and the post-resistance test.

Among the advantages of the invention described are that it provides a parallel-gap welder which facilitates the application and interconnection of microminiature electronic circuit components to printed circuit boards; welding apparatus having improved mechanical and electrical characteristics which make possible the welding of very fine conductive leads or wires to thin conductive portions on a nonconducting substrate of glass, ceramic, epoxy, or the like, without damaging the leads, said conducting surface portions, or the substrate; welding apparatus of the class described wherein the welding current through the workpiece being welded is accurately controlled during a welding cycle; welding apparatus wherein a pre-resistance test on the workpiece is employed to determine whether its electrical resistance falls within a pre-selected tolerance range, and wherein a weld cycle is prevented if the resistance of the workpiece is not within said range; welding apparatus of the class described wherein pre-resistance and post-resistance measurements are made to determine whether the electrical resistance of the workpiece is within a tolerable range both before and after a welding cycle; a conveniently operable welder mechanism adapted to apply replaceable electrodes to the work at selectively predetermined equal operating pressures; a mechanism of the class described which will effectively apply its electrodes to coplanar or non-coplanar surfaces; such mechanism in which arrangements are made for accurately and conveniently adjusting the electrode spacing over a substantial range; such a mechanism including means for preventing excess contact pressure of the electrodes; welding apparatus wherein the gap between the weld electrodes ensures that the welding area is clearly visible during a welding cycle, and wherein ease of access to the work beneath the electrodes is maintained during the cycle; apparatus of the class described wherein parallel electrode tips are employed, eliminating the necessity of realignment due to electrode wear; and welding apparatus wherein the quality of the weld joint is accurately controlled and wherein the weld process can be easily automated.

Reference is made to our co-pending patent application No. 2276/67 (Serial No. 1,074,793) which is divided from the present application.

WHAT WE CLAIM IS:—

1. A control for a welding apparatus; comprising a pair of weld electrodes adapted to interconnect with and cause a welding

current to be conducted through a workpiece, said weld electrodes being moveable lateral to and engaging a common surface of said workpiece, a power supply for said electrodes, said power supply including regulating means for controlling the current applied to said electrodes, sensing means interconnected with said electrodes immediately adjacent said workpiece for sensing the voltage across said electrodes during a weld cycle of said apparatus, a feedback circuit interconnected with said sensing means and said regulating means for causing the latter to maintain the current to said workpiece below a pre-established level, and means included in said feedback circuit for selectively varying said pre-established level.

2. A control according to claim 1, wherein said power supply comprises a welding transformer having a secondary winding connected across said electrodes, and a primary winding and wherein said regulating means comprises a controllable impedance connected across said primary winding.

3. A control according to claim 2, wherein said power supply is of the capacitor-discharge type including a capacitor, means for charging said capacitor, and means selectively interconnecting said capacitor across said primary winding for discharge therethrough.

4. A control according to claim 1, wherein said regulating means comprises an electronic device having a control electrode, and wherein said feedback circuit comprises a voltage comparator, the output of which is applied to said control electrode to control the conductivity of said electronic device.

5. A control according to any preceding claim, wherein said feedback circuit includes a differential amplifier having a pair of inputs and an output, and wherein said means for selectively varying said preestablished level includes a reference voltage generator interconnected with one of said inputs, the other input of said differential amplifier being connected to said sensing means, and the output thereof being connected to said regulating means.

6. A control according to claims 2 and 5 wherein, said controllable impedance is a transistor, the output of said differential amplifier being applied to the base of said transistor to control the conductivity thereof, thereby to control the current through said primary winding.

7. A control according to any preceding claim, further including means for initiating a weld cycle of said apparatus, and means for measuring the resistance of said workpiece prior to the initiation of a weld cycle to determine whether said resistance is within a predetermined tolerance range.

8. A control according to claim 7, further including means for preventing the initiation



viding a means of accurately selecting the respective threshold levels set in by generators 269 and 270, this meter provides a reading of the resistance exhibited by the workpiece between the weld tips 77, both during the

5 pre-resistance and the post-resistance test.

Among the advantages of the invention described are that it provides a parallel-gap welder which facilitates the application and

10 interconnection of microminiature electronic circuit components to printed circuit boards; welding apparatus having improved mechanical and electrical characteristics which make possible the welding of very fine conductive

15 leads or wires to thin conductive portions on a nonconducting substrate of glass, ceramic, epoxy, or the like, without damaging the leads, said conducting surface portions, or the substrate; welding apparatus of the class

20 described wherein the welding current through the workpiece being welded is accurately controlled during a welding cycle; welding apparatus wherein a pre-resistance test on the workpiece is employed to determine whether

25 its electrical resistance falls within a pre-selected tolerance range, and wherein a weld cycle is prevented if the resistance of the workpiece is not within said range; welding apparatus of the class described wherein pre-

30 resistance and post-resistance measurements are made to determine whether the electrical resistance of the workpiece is within a tolerable range both before and after a welding cycle; a conveniently operable welder mechanism adapted to apply replaceable electrodes

35 to the work at selectively predetermined equal operating pressures; a mechanism of the class described which will effectively apply its electrodes to coplanar or non-coplanar surfaces;

40 such mechanism in which arrangements are made for accurately and conveniently adjusting the electrode spacing over a substantial range; such a mechanism including means for preventing excess contact pressure of the electrodes; welding apparatus wherein the gap

45 between the weld electrodes ensures that the welding area is clearly visible during a welding cycle, and wherein ease of access to the work beneath the electrodes is maintained during the cycle; apparatus of the class described wherein parallel electrode tips are employed, eliminating the necessity of realignment due to electrode wear; and welding apparatus wherein the quality of the weld joint is

50 accurately controlled and wherein the weld process can be easily automated.

Reference is made to our co-pending patent application No. 2276/67 (Serial No. 1,074,793) which is divided from the present

60 application.

WHAT WE CLAIM IS:—

1. A control for a welding apparatus; comprising a pair of weld electrodes adapted to interconnect with and cause a welding

current to be conducted through a workpiece, said weld electrodes being moveable lateral to and engaging a common surface of said workpiece, a power supply for said electrodes, said power supply including regulating means for controlling the current applied to said electrodes, sensing means interconnected with said electrodes immediately adjacent said workpiece for sensing the voltage across said electrodes during a weld cycle of said apparatus, a feedback circuit interconnected with said sensing means and said regulating means for causing the latter to maintain the current to said workpiece below a pre-established level, and means included in said feedback circuit for selectively varying said pre-

2. A control according to claim 1, wherein said power supply comprises a welding transformer having a secondary winding connected across said electrodes, and a primary winding and wherein said regulating means comprises a controllable impedance connected across said primary winding.

3. A control according to claim 2, wherein said power supply is of the capacitor-discharge type including a capacitor, means for charging said capacitor, and means selectively interconnecting said capacitor across said primary winding for discharge therethrough.

4. A control according to claim 1, wherein said regulating means comprises an electronic device having a control electrode, and wherein said feedback circuit comprises a voltage comparator, the output of which is applied to said control electrode to control the conductivity of said electronic device.

5. A control according to any preceding claim, wherein said feedback circuit includes a differential amplifier having a pair of inputs and an output, and wherein said means for selectively varying said preestablished level includes a reference voltage generator interconnected with one of said inputs, the other input of said differential amplifier being connected to said sensing means, and the output thereof being connected to said regulating means.

6. A control according to claims 2 and 5 wherein, said controllable impedance is a transistor, the output of said differential amplifier being applied to the base of said transistor to control the conductivity thereof, thereby to control the current through said primary winding.

7. A control according to any preceding claim, further including means for initiating a weld cycle of said apparatus, and means for measuring the resistance of said workpiece prior to the initiation of a weld cycle to determine whether said resistance is within a predetermined tolerance range.

8. A control according to claim 7, further including means for preventing the initiation



of a weld cycle if said resistance is not within said tolerance range.

5 9. A control according to claim 7 or 8, wherein said means for measuring the resistance of said workpiece prior to the initiation of a weld cycle includes an a.c. generator for supplying an a.c. signal to said electrodes, and means for comparing the resulting a.c. voltage across said electrodes with a pre-
10 established reference level.

10 10. A control according to claim 9, wherein said comparing means comprises a trigger circuit having first and second inputs and an output, a detector interconnected with said
15 electrodes for providing a d.c. output proportional to said resistance, said d.c. output being applied to said first input, a reference voltage generator for providing said preestablished
20 reference level, said reference level being applied to said second input, said trigger circuit providing an output whenever said d.c. output exceeds said reference level, and means
25 responsive to the output of said trigger circuit for preventing the initiation of a weld cycle if said d.c. output exceeds said reference level.

30 11. A control for a welding apparatus according to any preceding claim, further including means for measuring the resistance of said workpiece subsequent to a weld cycle for determining whether said weld cycle
35 resulted in a suitable weld joint.

40 12. A control according to claim 11, wherein said means for measuring the resistance of said workpiece subsequent to a weld cycle includes an a.c. generator for supplying an a.c. signal to said electrodes, and means for
45 comparing the resulting a.c. voltage across said electrodes with a preestablished reference level.

50 13. A control according to any preceding claim, wherein said welding apparatus includes means for bringing said electrodes into contact with said workpiece, and wherein said
55 control further includes means for preventing said electrodes to be withdrawn from said workpiece if said resistance measurement subsequent to a weld cycle indicates an unsatisfactory weld joint.

60 14. A control according to claim 1, wherein said welding apparatus comprises means for bringing said electrodes into pressure contact with said workpiece, and means responsive to the pressure between said electrodes
65 and said workpiece for initiating a weld cycle when said pressure reaches a preestablished level.

15. A control according to claim 14, wherein said means for bringing said electrodes into pressure contact with said workpiece includes a first guide, a carrier movable on said guide, a pair of guide means on said carrier, arms oppositely movable on said guide means, each of said arms carrying one of said electrodes,
a compensating device on said carrier having

means articulated with said arms respectively to effect opposite relative movement thereof when the carrier is advanced on said first guide and one of the electrodes contacts a portion of the workpiece in one plane, whereby the other electrode is adapted to advance to contact a portion of the workpiece in another plane.

16. A control according to claim 14 or 15, wherein there is a gap of predetermined dimension between said electrodes, and wherein said apparatus includes means for accurately varying said gap, thereby to control the characteristics of a weld joint obtained during a weld cycle.

17. A control for a welding apparatus; comprising a pair of weld electrodes adapted to interconnect with a common surface and causing a welding current to be conducted through a workpiece, said weld electrodes having an adjustable space therebetween a welding transformer having a secondary winding connected across said electrodes, a primary winding, a capacitor, a source of charging for said capacitor, relay means adapted in a first position to interconnect said capacitor with said source for charging thereof and adapted in a second position to interconnect said capacitor to said primary winding for discharge therethrough, a variable impedance device connected across said primary winding, and means responsive to the voltage across said electrodes during a weld cycle for controlling the impedance of said variable impedance device thereby to maintain the current through said workpiece below a preestablished maximum level.

18. A control according to claim 17, wherein said variable impedance device comprises a transistor, and wherein said means for controlling the impedance of said transistor is a feedback circuit including a differential amplifier for applying an error signal to the base of said transistor proportional to the amount that said voltage across said electrodes exceeds said preestablished level.

19. A control according to claim 17 or 18, further including means for actuating said relay means from its first to its second position thereby to initiate a weld cycle, means for measuring the resistance of said workpiece between said electrodes prior to initiation of a weld cycle, and means for preventing initiation of a weld cycle if said resistance is not within a preselected tolerance range.

20. A control according to claim 19, wherein said means for measuring the resistance of said workpiece prior to the initiation of a weld cycle includes an a.c. generator for supplying an a.c. signal to said electrodes, and means for comparing the resulting a.c. voltage across said electrodes with a preestablished reference level.

21. A control according to claim 20, wherein said comparing means comprises a trigger

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- circuit having first and second inputs and an output, a detector interconnected with said electrodes for providing a d.c. output proportional to said resistance, said d.c. output being
- 5 applied to said first input, a reference voltage generator for providing said preestablished reference level, said reference level being applied to said second input, said trigger circuit providing an output whenever said
- 10 d.c. output exceeds said reference level, and means responsive to the output of said trigger circuit for preventing the initiation of a weld cycle if said d.c. output exceeds said reference level.
- 15 22. A control according to any of claims 17 to 21, further including means for measuring the resistance of said workpiece subsequent to a weld cycle, and means for indicating whether said resistance is within a preselected tolerance range between preselected upper and lower levels.
- 20 23. A control according to claim 22, wherein said welder includes hydraulic means for bringing said electrodes into pressure contact with said workpiece, and wherein said
- 25 control includes electrically actuated valve means for holding said electrodes in contact with said workpiece after a weld cycle if said workpiece resistance subsequent to a weld
- 30 cycle is not within said tolerance range.
24. A control according to claim 23 and any of claims 17 to 22, including switch means responsive to the pressure between said electrodes and said workpiece for actuating said
- 35 relay means to its second position thereby to initiate a weld cycle when said pressure reaches a preselected level.
25. A control as set forth in claim 24, wherein said means for bringing said electrodes into pressure contact with said workpiece
- 40 comprises a first guide, a carrier slidable on the first guide, a pair of guide means on the carrier parallel to the first guide, arms oppositely slidable on said guide means and
- 45 rotatable thereon, each arm adapted to carry an electrode, a compensating lever pivoted to said carrier between said arms, the ends of said lever being pivoted to the arms respectively to effect opposite relative movements
- 50 therebetween on the carrier, an adjusting screw connected transversely to the carrier for rotary but non-axial movements therewith, said screw having threads of opposite pitches, nuts on said threads, said nuts having connections with said arms adapted to prevent
- 55 rotation of the nuts relative to the arms but permitting opposite sliding motions of the arms with respect to the screw, and means for turning the screw to move the arms through the nuts.
26. A control for welding apparatus having a pair of weld electrodes adapted to interconnect with and cause a welding current to be conducted through a workpiece, said
- 60 control being substantially as hereinbefore described with reference to the accompanying drawings.
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