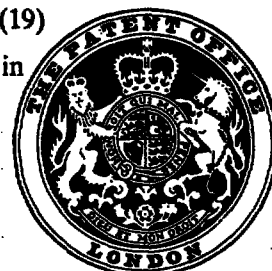


PATENT SPECIFICATION

(11) 1 594 009

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- (21) Application No. 45690/77 (22) Filed 3 Nov. 1977 (19)
 (31) Convention Application No's 14143/76 (32) Filed 10 Nov. 1976 in
 14145/76
 (33) Switzerland (CH)
 (44) Complete Specification Published 30 Jul. 1981
 (51) INT.CL.³ B23K 11/06
 G05F 1/44
 (52) Index at Acceptance
 G3N 284 E2X
 H2H 23G WR



SCIENCE REFERENCE LIBRARY

(54) IMPROVEMENTS IN OR RELATING TO RESISTANCE SEAM WELDING

(71) We, FAEL S.A., a Swiss Body Corporate, of Rue de la Musinière 17 CH-2072 Saint-Blaise, Switzerland, 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:-

The present invention relates to the control of the welding energy during electrical resistance seam welding.

When forming a welding seam between two roller electrodes the welding energy delivered to each location of the welding seam is proportional to the square of the effective (root-mean-square) value of the current intensity of the current which flows between the electrodes through the work-piece parts which are to be welded to one another and proportional to the length of time during which a given location of the welding seam is disposed between the electrodes and exposed to the current flow. In order to produce a qualitatively high-grade welding seam the welding energy supplied to each location of the welding seam must be maintained with relatively narrow limits as closely as possible to a predetermined reference or set value. If the supplied welding energy is too small, then there is produced an inadequate welding of the workpiece parts. Conversely, if the supplied welding energy is too great, then there occurs an impermissible great heating of the material or, in fact, a partial scorching thereof, resulting in damage to the work-piece material.

With the aid of electronic control devices it is possible to maintain the effective value of the welding current intensity, during the welding operation, sufficiently constant, so that the welding energy also remains practically constant. If also the welding speed, i.e., the feed of the workpiece parts between the electrodes and which are to be

welded to one another, remains constant, then each point along the formed welding seam has delivered thereto a uniform welding energy.

It has been proposed during resistance welding by means of alternating-current to influence the operating or welding capacity by phase control of the half-waves of the alternating-current voltage in that the ignition or firing point is shifted within the voltage wave, resulting in a change in the effective value of the welding current intensity. For this purpose there are available both ignitron as well as also thyristor circuit arrangements which can be connected at the primary current circuit of the welding transformer.

The inductance of the welding transformer and the welding current circuit, as is known, brings about a phase difference ϕ between the voltage and the current, with the current trailing the voltage. The magnitude of the phase difference is different for different welding machines. During the phase control the current flow always begins at the firing or ignition point i.e. with the surge-like appearance of the voltage, whereafter the current flows until the following null throughpass of the current half-wave. Due to the inductance of the current circuit there occurs an overshoot of the voltage past the null point at the end of the cut voltage half-wave, resulting in a corresponding prolongation of the current flow. Hence, the currentless intervals between the successive current half-waves are shorter than would be expected from the displacement angle of the firing or ignition point. Consequently, there is limited the output control range in contrast to the case of an ohmic load. The greater the phase difference ϕ that much smaller becomes the control range, i.e., that much greater must be the displacement angle of the ignition point in order to be able to even bring about a

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reduction of the welding energy. On the other hand, it has been found that independent of the phase difference ϕ the welding capacity can be reduced to null already with an ignition point-displacement angle of 155° and with an ignition point-displacement angle of 120° only amounts to about 10%. Hence, the control range with phase control is limited both towards the bottom as well as also towards the top, so that for welding energy control between 100% and 10% there is only available a range of about 30° to 120° and 70° to 120° of the ignition point-displacement angle respectively, depending upon whether the phase difference ϕ between the voltage and current amounts to 30° or 70°.

The described phenomena during the welding energy control of a welding machine by phase control is disadvantageous for the following reasons:

Due to the relatively narrow adjustment range of the ignition point-displacement angle the adjustment becomes critical since even slight changes of the ignition or firing point cause relatively large changes of the welding capacity. In the case of electrode roll-resistance seam welding larger ignition point-displacement angles result in correspondingly greater spacing between the individual weld spots or points of the seam, which can lead to leakiness and mechanical weakness of the welding seam. It is for this reason that in practice there is not exceeded an ignition point-displacement angle of about 90°, which, however, still further narrows the adjustment range. In order to nonetheless be able to cover a sufficiently large welding energy range, there is required the use of a welding transformer with tapping at the primary side.

According to the invention, there is provided a method of controlling the welding energy during electrical resistance welding of workpieces by means of an electrode roll-resistance seam welding machine, in which the effective value of the welding current is controlled in response of an electrical control signal, at least a component of which is a welding current-correction signal substantially analogous to the welding speed in order to provide a substantially constant welding energy supplied to the workpieces at each section, along the formed welding seam at any welding speed, the said welding current-correction signal being produced by means of a programmed control device which simultaneously delivers an electrical rotational speed-reference value signal to a rotational speed regulator for controlling and regulating the welding speed.

Further according to the invention, there is provided apparatus for controlling the welding energy during electrical resistance

welding of workpieces by means of an electrode roll-resistance seam welding machine having a pair of roller electrodes, drive means for feeding the workpieces to be welded between said roller electrodes during welding, a welding transformer having a primary winding and a secondary winding which is electrically connected to said welding rolls, and means for supplying to the primary winding of said welding transformer an alternating current for welding, said apparatus comprising: means for controlling the effective value of the current intensity of the welding alternating current in response of an electrical control signal; an adjustable electrical reference value transmitter for generating an electrical welding current-reference value signal; a rotational speed regulator associated with said drive means, for automatically controlling the welding speed as a function of an electrical rotational speed-reference value signal; means for producing the rotational speed-reference value signal as a function of infed data, said producing means including means for generating an electrical signal analogous to the welding speed; and means for superimposing the welding current-correction signal and the welding current-reference value signal for producing the electrical control signal in such a manner that the work-pieces have delivered thereto at each section along the formed welding seam a substantially constant welding energy at any welding speed.

In a preferred embodiment, the effective value or root-mean-square value of the current intensity of the welding alternating-current is controlled by changing the amplitude of the substantially sinusoidal alternating-current voltage applied to the primary winding of the welding transformer during each complete half-wave.

It is possible to rectify the current supplied by an alternating-current power distribution network and to control its voltage, for instance by a phase controlled rectifier, and then to transform the rectified current into an alternating-current by means of a preferably static inverter. The alternating-current is then used to supply the primary winding of the welding transformer.

The primary winding of the welding transformer can be supplied with an alternating-current produced by a separately excited generator and the amplitude of the voltage of the alternating-current produced by the generator is controlled by altering the excitation of the generator. In this regard it is advantageous to supply the excitation winding of the generator by means of a controllable rectifier from an alternating-current distribution network and to drive the generator by means of an electric motor which is powered from the alternating-current dis-

tribution network.

In both instances it is possible and advantageous, to impart to the welding alternating-current produced by means of the static inverter and the generator, respectively, a greater frequency than that of the alternating-current distribution network.

An embodiment of the invention will now be described, by way of example only, with reference to the accompanying diagrammatic drawings, in which:

Figure 1 is a diagram showing the previously proposed phase control illustrating the course as a function of time of the voltage curve and current curve of the welding transformer;

Figure 2 is a diagram to an enlarged scale of an analogous illustration of the voltage curve and current curve with greater phase differences between the voltage and current;

Figure 3 is a diagram showing the functional correlation between the ignition point-displacement angle α and the resultant welding capacity for different phase differences between the voltage and current;

Figure 4 is a block circuit diagram of a first circuit arrangement for use in the preferred embodiment of the invention as illustrated in Figure 7;

Figure 5 shows graphs portraying the course as a function of time of the voltage curves and current curves of the welding alternating-current at the primary side of the welding transformer for different welding energies controlled by means of the circuit arrangement in Figure 4;

Figure 6 is a block circuit diagram of a second circuit arrangement for use in the preferred embodiment as illustrated in Figure 7; and

Figure 7 is a block circuit diagram of the preferred embodiment of the invention, wherein the welding speed is controlled as a function of a program control device or a computer and the welding energy is thereby maintained constant.

Turning now to the drawings, based upon the showing of Figures 1 to 3 there initially will again be considered the reasons why the previously conventional phase control was relatively unsuitable for controlling the welding energy. At the upper portion of the diagram of Figure 1 there is shown a curve portraying the course as a function of time of the alternating-current voltage U which prevails across the primary winding of a welding transformer at an ignition point-displacement angle α of about 70° . There will be recognized that always at the ignition or firing point there increases in a surge-like or sudden manner the instantaneous voltage and that during the next null throughpass of the voltage curve the voltage overshoots to

the opposite polarity. This is a consequence of the inductance of the primary winding of the transformer. In the lower part of the diagram of Figure 1 there is shown a curve of the corresponding course as a function of time of the current I flowing in the primary winding of the transformer. It will be seen that the current gradually appears (due to the inductance) always at the firing or ignition point and lasts through the null throughpass of the voltage curve until the null throughpass of the current curve. The current intervals between the successive current half-waves of opposite polarity are thus smaller than the ignition point displacement.

The operations have been shown even more clearly in Figure 2 relating to a transformer winding with large inductance, wherein, however, the ignition point-delay angle α , like in Figure 1, amounts to about 70° . At the time a_1 there suddenly appears the instantaneous voltage U . It overshoots the next null throughpass of the voltage curve until reaching the point b_1 , and then rapidly breaks down to null. The corresponding half-wave of the current I begins at the firing or ignition point a_1 and first ends at the point b_1 relatively shortly prior to ignition of the next voltage half-wave at the ignition point a_2 . At the firing or ignition point a_2 there however already begins the next current half-wave of the opposite polarity, so that only relatively short current pauses or intervals are present between the successive half-waves. Thus, the resultant effective or foot-mean-square value of the welding current I_s is only relatively slightly less than that which would be present without phase control. Consequently, also the resultant welding energy $P_{ws} = I_s^2 R$, wherein R designates the resistance of the current circuit, is not located below, to the desired degree, the complete welding energy without phase control.

The actual correlation between the attainable or welding energy P_{ws} and the ignition point-displacement angle α has been graphically illustrated in Figure 3 for different phase angles φ between the voltage and current in the primary current circuit of the welding transformer. From the graphs of Figure 3 there will be apparent, for instance, that with a phase angle φ of 60° and an ignition point-displacement angle α of 70° there only results a reduction in the welding energy P_{ws} to 82%. Since in consideration of the quality of the welding seam which is to be formed it is not practically possible to exceed an ignition point-displacement angle of 90° , there is available for the control of the welding energy P_{ws} only a relatively small region within which there can be adjusted the ignition point-displacement angle α , and the welding energy only can be

altered within a range of 100% down to about 40% (at $\phi = 50^\circ$) and 55% (at $\phi = 70^\circ$) respectively. This narrow control range for the welding energy is oftentimes inadequate in practice. What is also disadvantageous is that the adjustment of the ignition point-displacement angle α is relatively critical, because a relatively small change in the ignition point setting or adjustment has an appreciable effect upon the resultant welding energy.

In order to overcome the discussed drawbacks it is proposed to change the effective or root-mean-square value of the welding current by amplitude change at the complete voltage half-waves, instead of by phase control. This can be accomplished, for instance, by means of the control circuits shown by way of example in Figures 4 and 6. These control circuits are intended for use with the preferred embodiment of the invention which will be more fully described in connection with Figure 7.

In Figure 4, reference numeral 20 designates a welding transformer having a primary winding 21 carrying, for instance, a voltage of 380 volts and a secondary winding 22 for a low voltage of a few volts, but a high current intensity of several 1000 amperes. The low voltage-secondary winding 22 of the welding transformer 20 is electrically connected in conventional manner with a lower roller or electrode 23 and an upper roller electrode 24. Passing between these electrodes 23 and 24 are the workpiece parts 26 and 27 which are to be welded to one another. In order to accomplish the feed of the workpiece parts 26 and 27 between the electrodes 23 and 24 during the welding operation, the electrodes are driven in a manner which will be described in greater detail with reference to the preferred embodiment of figure 7. There is conventionally arranged in the primary current circuit of the transformer 20 an electronic switch 25, for instance a thyristor or ignitron switch or circuit arrangement, which merely serves the purpose of closing the current circuit when a welding operation is to be started and to interrupt such current circuit when the welding operation is terminated. The switching-in and switching-off of the current circuit is advantageously synchronized in each instance with a null through-pass of the supply alternating-current voltage.

The control circuit 30 provided for controlling the welding energy of the welder possesses a controllable rectifier or rectifier arrangement 32, powered by means of the connection terminals 31 from an alternating-current distribution network, generally indicated by reference character 31a. The rectifier 32 may be, for instance, a three-phase-semi-controlled bridge circuit arrangement

of conventional construction employing thyristors and diodes. The rectifier 32 delivers a direct-current voltage to two conductors or lines 33 and 34, this direct-current voltage being smoothed by a choke or reactance coil 35. The amplitude of the produced direct-current voltage between the conductors or lines 33 and 34 can be controlled with the aid of a circuit arrangement 36 functioning as a voltage regulator, which delivers to the rectifier 32 ignition or firing pulses synchronized with the power supply network and rendering it possible to change the firing or ignition point of the thyristors within each power network alternating-current voltage half-wave as a function of a controlling direct-current. The aforementioned controlling direct-current is composed of two control components. The one control current component serves as a reference of set value signal and is supplied by an adjustable reference value transmitter 37, which, for instance, comprises a potentiometer connected with a constant direct-current voltage source. The other component of the control current serves as an actual value signal and is produced with the aid of a voltage divider formed by two resistors 38 and 39 connected across the conductors or lines 33 and 34. The reference value signal is delivered by means of a line or conductor 41 and the actual value signal by means of a return or feedback line 42 to inputs 43a and 43b respectively, of a summation amplifier 43, where both of the control current components are algebraically added and then conjointly delivered by means of an output or connection 44 to the voltage regulator 36. The one input 43a of the summation amplifier 43 additionally is connected by a conductor or line 100 with a connection terminal 101, the significance of which will be described more fully hereinafter in conjunction with Figure 7.

The two lines or conductors 33 and 34 are connected with the inputs 45a of a static direct-current/alternating-current inverter 45 of known construction, the outputs 45b of which supply by means of the lines 46 and 47 and the switch 25 the primary winding 21 of the welding transformer 20 with an at least approximately sinusoidal alternating-current voltage and deliver the necessary welding alternating-current. The amplitude of the alternating-current voltage produced by the inverter 45 is proportional to the amplitude of the direct-current voltage between the lines 33 and 34. The frequency of the welding alternating-current produced by means of the inverter 45 can advantageously be higher than the frequency of the alternating-current distribution network 31a at which there are connected the connection terminals 31.

The use and mode of operation of the

described circuit arrangement and the method for controlling the welding energy which can be carried out thereby are as follows:

5 With the aid of the reference or set value transmitter 37 there is produced a reference or set value signal which, in the form of a first control current component, is delivered via the summation amplifier 43 to the voltage regulator 36. In accordance with this reference value signal there is set the ignition of firing point of the thyristors in the rectifier or rectifier arrangement 32 within each voltage half-wave of the network alternating-current delivered to such rectifier 32, so that the rectified voltage appearing at the lines 33 and 34 assumes a value which is analogous to the reference value signal. The inverter 45 delivers to the lines or conductors 46 and 47 and thus to the primary winding 21 of the welding transformer 20 an at least approximately sinusoidal alternating-current voltage, the amplitude of which is proportional to the amplitude of the rectified voltage at the lines 33 and 34. Hence, the amplitude of the alternating-current voltage at the primary winding 21 of the welding transformer 20 corresponds to the reference value signal which has been set by means of the reference value transmitter 37. By changing this reference value signal it is possible to continuously alter the amplitude of the aforementioned alternating-current voltage, also resulting in a corresponding change in the effective value of the practically sinusoidal welding alternating-current and thus also in a continuous change of the or welding energy.

10 With the aid of the voltage divider 38, 39 there is also produced an actual value signal which is proportional to the amplitude of the rectified voltage, this actual value signal being supplied by means of the return or feedback line 42 to the summation amplifier 43. In the summation amplifier 43 there are combined the reference value signal delivered by the reference value transmitter 37 and the actual value signal in a manner such that each deviation of the actual value of the rectified voltage from the reference value results in such a change in the control direct-current appearing at the line or conductor 44 that by means of the voltage regulator 36 there occurs a corresponding change in the ignition point of the thyristors in the rectifier circuit or arrangement 32, with the result that the occurring deviation of the rectified voltage from the desired reference value can be at least approximately compensated. In this way there is automatically maintained constant the rectified voltage at the set reference value. This has the result that also the amplitude of the alternating-current voltage which is produced by the inverter 45 and the effective

value of the welding alternating-current as well as also the resultant welding energy remain practically constant. The reference value set at the reference value transmitter 37 is thus automatically maintained if, for instance, the voltage of the alternating-current network or the load at the output side of the inverter 45 fluctuates.

Now in Figure 5 there is illustrated the course as a function of time of the voltage at the primary winding 21 of the welding transformer 20 as well as the current flowing through the primary winding for different welding capacities or outputs. It will be apparent from this graphic illustration that the alternating-current voltage for full sinusoidal half-waves is variable in amplitude so that for instance there are formed the voltage curves u_1, u_2, u_3 , which, in turn, result in the corresponding current curves i_1, i_2, i_3 with full half-waves at a phase angle α .

In the arrangement shown in Figure 6 the primary winding 21 of the welding transformer 20 is supplied by a synchronous generator 50 by means of the lines or conductors 46 and 47, at one of which lines there is connected the electronic switch 25. The rotor of the synchronous generator 50 is connected by means of a shaft 51 with the rotor of an electric motor 52, which, by means of the connection terminals 53, is powered from an alternating-current distribution network, generally indicated by reference character 53a. Generator 50 comprises an excitation winding 55 which is supplied by a control circuit 60 which will be described more fully hereinafter.

The control circuit 60 contains a controllable rectifier 62, the input side or inputs 62a of which are connected via the lines 61 with the alternating-current distribution network 53a and the output side or output 62b of which are connected via the lines 63 and 64 directly with the excitation winding 55 of the generator 50. The rectifier 62 preferably contains thyristors, the firing of which can be controlled within each half-wave of the alternating-current voltage. In order to control the firing or ignition point there are provided two integration circuit arrangements 65 and 66 which are connected in series. The input or input means 65a of the first integration circuit arrangement 65 is connected by a line or conductor 68 with a reference value transmitter 37 which serves to produce an adjustable reference value signal in the form of a direct-current. Further, the input side 65a of the same integration circuit arrangement 65 is connected by a conductor or line 100 with a connection terminal 101, the significance of which will be shown in connection with Figure 7. The input side 66a of the second integration circuit arrangement 66 is supplied by means of the line or conductor 70

with an actual value signal in the form of a direct-current which is derived from the actual value of the alternating-current voltage between the conductors 46 and 47. For this purpose the primary winding 71a of a measuring transformer 71 is connected with the lines or conductors 46 and 47, and the secondary winding 71b of such measuring transformer 71 is connected by means of a rectifier 75 with the aforesaid line or conductor 70. Furthermore, a measuring current converter 80 is connected with the line or conductor 47, whose measuring winding, generally designated by reference character 80a delivers by means of a rectifier 82 a further actual value signal in the form of a direct-current which is supplied by the line 83 to the input side or input means 66a of the second integration circuit arrangement 66.

The use and mode of operation of the arrangement shown in Figure 6 and the method for controlling the welding energy which is rendered possible with the use thereof, are as follows:

By means of the reference value transmitter 37 there is adjusted or set a reference value signal. In accordance with this reference value signal there is controlled within each alternating-current voltage half-wave and by means of the integration circuit arrangement 65 and 66 the firing points of the thyristors of the rectifier 62, so that the direct-current flowing through the excitation winding 55 of the generator 50 assumes a predetermined current intensity, resulting in a predestined amplitude of the alternating-current voltage between the lines 46 and 47 and which is produced by the generator 50. When the reference value signal is changed, then there is also changed the excitation of the generator 50 and the amplitude of the alternating-current voltage produced by such generator, and the alternating-current voltage half-waves always remain intact, as such has been illustrated in Figure 5. With the amplitude change of the alternating-current voltage between the lines or conductors 46 and 47 and accomplished in the afore-described manner, there is also changed the effective or root-mean-square value of the alternating-current flowing through the primary winding 21 of the welding transformer 20, and as likewise shown in Figure 5. The change in the current intensity results in a corresponding change of the resultant welding energy. Accordingly, it is possible to select and set the current intensity of the welding alternating-current and the welding energy, respectively, by means of the reference value transmitter 37.

The first actual value signal which is produced by means of the measuring transformer 71 and the rectifier circuit 75, is

proportional to the amplitude of the alternating-current voltage produced by the generator 50, whereas the second actual value signal which is produced by means of the current converter 80 and the rectifier 82, is proportional to the intensity of the welding current flowing in the primary current circuit of the welding transformer 20. If the amplitude of the alternating-current voltage between the lines 46 and 47 deviates from the reference value set by means of the reference value transmitter 37, then the first actual value signal automatically ensures for such a shift of the firing or ignition point of the thyristors in the rectifier circuit 62 that the voltage deviation is compensated. If the current intensity in the primary current circuit of the welding transformer 20 changes, for instance due to load fluctuations at the secondary side of the welding transformer, then the second actual value signal automatically ensures for a shift or displacement of the firing point of the thyristors in such a manner that the excitation of the generator 50 correspondingly changes, in order to again compensate for the current intensity changes which have arisen. Changes in the current intensity at the primary current circuit of the welding transformer 20 of course also result in corresponding changes in the voltage amplitude, and for which reason the regulation accomplished with the aid of the first actual value signal proportional to the voltage amplitude would be sufficient for achieving the desired constancy. The additional regulation by means of the second actual value signal proportional to the current intensity, however, produces an acceleration of the correction by a leading regulation of the excitation of the generator 50. The frequency of the welding alternating-current produced by means of the generator 50 can be chosen to be greater than the network frequency if such appears advantageous as concerns the quality of the welds or the welding speed during electrode roll-resistance seam welding. It should be clear that by changing the rotational speed of the drive motor 52 it is easily possible to change the frequency of the welding alternating-current.

Both of the described arrangements of Figures 4 and 6 enable a continuous regulation or control of the welding energy between a maximum value and practically null and each time at complete half-waves of the welding alternating-current voltage and the welding alternating-current. Therefore, it is not necessary to use a welding transformer having taps. Since in the practice of electrode roll-resistance seam welding it is oftentimes necessary anyway to work with a higher frequency of the welding current than that of the alternating-current distribu-

tion network, it was necessary in these situations to already previously use a static inverter or a rotating inverter for frequency increase. The described arrangements for controlling the welding energy by amplitude change of the welding alternating-current voltage, instead of phase control, therefore does not require practically any increased costly equipment expenditure, rather can be realized with relatively modest additional means, which moreover are commercially available.

Apparatus in accordance with a preferred embodiment of the invention will now be described in connection with Figure 7. The control circuit 30 serving for controlling the welding energy has been shown in Figure 7 only in the form of a block, since the components thereof are as described with reference to Figure 4.

In order to bring about the feed of the workpiece parts 26 and 27 between the roller electrodes 23 and 24 during the welding operation, the preferred embodiment of Figure 7 has the upper electrode 24 secured to a shaft 28 which can be driven by an electric motor 29 at the desired rotational speed. Advantageously, a conventional reduction gearing or transmission (not shown) is provided between the rotor of the motor 29 and the shaft 28. The rotor of the motor 29 is coupled by a shaft 140 with a tachometer generator 141, at the output 142 of which there appears a direct-current voltage proportional to the actual value of the rotational speed of the motor 29.

Instead of the tachometer generator 41 it is equally possible to use in place thereof a tachopulse transmitter which, during each revolution of the shafts 28 and 140 produces a given number of electrical pulses, and the pulse repetition frequency serves as the actual value signal for the welding speed.

A program control device or computer 150 is provided for controlling the rotational speed of the motor 29 as a function of certain criteria which are not here of further interest. The device 150 has two outputs 151 and 152, there appearing at the one output 151 a digital or analogue rotational speed-reference value signal for the control of the motor 29. With the aforementioned output 151 there is connected an input 153 of an electronic rotational speed regulator 154 of known construction, the output 155 of which is connected with the motor 29. The rotational speed regulator 154 has a second input 156 which is connected with the output 142 of the tachometer generator or tachopulse transmitter 141. Thus, the rotational speed regulator 154 has delivered thereto by means of its one input 153 a rotational speed-reference value signal and by means of its other input 156 a rotational speed-actual value signal. The rotational speed

regulator 154 automatically ensures that the rotational speed of the motor 29 corresponds to the infed reference value signal and that possible arising deviations of the actual value of the rotational speed from the reference or set value will be automatically corrected.

It will be recalled that it was mentioned the device 150 has a second output 152. At this second output 152 there appears a direct-current voltage corresponding to the reference value signal for the rotational speed, this direct-current voltage being supplied to a potentiometer 143. Connected with a tap of the potentiometer 143 is the input 144 of an amplifier 145, the output 146 of which is connected with the connection terminal 101 of the control arrangement or control means 30 (see also Figure 4). Hence, the output 146 of amplifier 145 delivers to the summation amplifier 43 of the control circuit 30 (Figure 4) a welding current-correction signal in the form of a direct-current of variable intensity, this welding current-correction signal being analogous to the rotational speed of the motor 29 and thus the welding speed.

In the summation amplifier 43 there are combined with one another the reference value signal set by means of the reference value transmitter 37 and the correction value signal for the welding current intensity delivered by the amplifier 145, so that by means of the circuit arrangement 36 and the controlled rectifier 32 the effective value of the welding alternating-current does not depend solely upon the setting or adjustment of the reference value transmitter 37, rather additionally also upon the momentary actual value of the rotational speed of the motor 29 and thus the welding speed. If the rotational speed of the motor 29 increases, then there correspondingly also increases the welding current-correction signal at the input 436 of the summation amplifier 43, causing a corresponding increase of the effective value of the welding current intensity. Conversely, a reduction in the rotational speed of the motor 29 brings about a corresponding reduction of the welding current intensity. By means of the potentiometer 143 it is possible to adjust the influence of the changes in the rotational speed upon the intensity of the welding current such that the workpiece parts 26, 27 which are to be welded to one another have delivered thereto at each point along the formed welding seam the same welding energy, independent of the momentary welding speed.

If the control device 150 delivers an altered rotational speed-reference value signal to the input 153 of the rotational speed regulator 154 in the form of a command that the rotational speed of the motor 29 must be

correspondingly changed, then the control device 150 simultaneously also causes a corresponding change in the welding current intensity so that notwithstanding the change of the welding speed the same welding energy is delivered to each point along the formed welding seam.

As mentioned, the control device 150 can be a computer, and specifically as employed in an apparatus for controlling the start of welding and the termination of welding during continuous resistance welding as e.g. disclosed in British Patent Specification No. 1,509,416 (Swiss Patent No. 572,375).

The means for generating a welding current-correction signal, described in accordance with the preferred embodiment of Figure 7 and which welding current-correction signal is dependent upon the feed speed of the workpiece parts 26 and 27 to be welded to one another, can of course also be combined with the control circuit shown in Figure 6, by connecting the output 146 of amplifier 145 with the connecting terminal 101 of the control circuit 60 (Figure 6).

The apparatus particularly described controls the welding energy during resistance welding in an extremely efficient and reliable manner. The apparatus is relatively simple in construction and design, economical to manufacture, extremely reliable in performance, not readily subject to breakdown or malfunction, and requires a minimum of servicing and maintenance.

With the apparatus described it is possible to change throughout a relatively large range the welding energy of an electrical resistance welding machine by a continuous voltage change of the welding alternating-current, so that there can be avoided the drawbacks of the previously proposed phase control. Moreover, it is also possible to automatically maintain constant the effective value of the welding current intensity and thus the welding energy, so that with constant feed speed of the workpiece parts between the welding rolls, and which workpiece parts are to be welded together, there is delivered to all of the welding points or spots of the welding seam produced by a respective alternating-current half-wave of the welding current, the same thermal energy. However, there are situations where the welding speed unintentionally experiences temporary changes. Also, as described in British Patent Specification No. 1,509,416 the feed speed of the workpiece parts to be welded to one another can be controlled during welding such that the last weld spot of the seam which is produced by an alternating-current half-wave of the welding current is dispositioned at a predetermined distance from the trailing end of the parts which are to be welded to one another. This of course required a control of the welding

speed and results in a speed-change in the operation of the welding machine.

The apparatus described prevents the formation of poor welding seams due to too low or excessively supplied welding energy, if during the welding operation the feed speed of the workpiece parts to be welded to one another changes unintentionally or intentionally.

WHAT WE CLAIM IS:

1. A method of controlling the welding energy during electrical resistance welding of workpieces by means of an electrode roll-resistance seam welding machine, in which the effective value of the welding current is controlled in response of an electrical control signal, at least a component of which is a welding current-correction signal substantially analogous to the welding speed in order to provide a substantially constant welding energy supplied to the workpieces at each section along the formed welding seam at any welding speed, the said welding current-correction signal being produced by means of a programmed control device which simultaneously delivers an electrical rotational speed-reference value signal to a rotational speed regulator for controlling and regulating the welding speed.
2. A method as claimed in claim 1, comprising superimposing the welding current-correction signal and an electrical welding current-reference value signal delivered by a reference value transmitter, in order to form said electrical control signal.
3. A method as claimed in claim 1 or claim 2, wherein the welding current-correction signal is derived from the electrical rotational speed-reference value signal.
4. Apparatus for controlling the welding energy during electrical resistance welding of workpieces by means of an electrode roll resistance seam welding machine having a pair of roller electrodes, drive means for feeding the workpieces to be welded between said roller electrodes during welding, a welding transformer having a primary winding and a secondary winding which is electrically connected to said welding rolls, and means for supplying to the primary winding of said welding transformer an alternating current for welding, said apparatus comprising: means for controlling the effective value of the current intensity of the welding alternating current in response of an electrical control signal; an adjustable electrical reference value transmitter for generating an electrical welding current-reference value signal; a rotational speed regulator associated with said drive means, for automatically controlling the welding speed as a function of an electrical rotational speed-reference value



correspondingly changed, then the control device 150 simultaneously also causes a corresponding change in the welding current intensity so that notwithstanding the change of the welding speed the same welding energy is delivered to each point along the formed welding seam.

As mentioned, the control device 150 can be a computer, and specifically as employed in an apparatus for controlling the start of welding and the termination of welding during continuous resistance welding as e.g. disclosed in British Patent Specification No. 1,509,416 (Swiss Patent No. 572,375).

The means for generating a welding current-correction signal, described in accordance with the preferred embodiment of Figure 7 and which welding current-correction signal is dependent upon the feed speed of the workpiece parts 26 and 27 to be welded to one another, can of course also be combined with the control circuit shown in Figure 6, by connecting the output 146 of amplifier 145 with the connecting terminal 101 of the control circuit 60 (Figure 6).

The apparatus particularly described controls the welding energy during resistance welding in an extremely efficient and reliable manner. The apparatus is relatively simple in construction and design, economical to manufacture, extremely reliable in performance, not readily subject to breakdown or malfunction, and requires a minimum of servicing and maintenance.

With the apparatus described it is possible to change throughout a relatively large range the welding energy of an electrical resistance welding machine by a continuous voltage change of the welding alternating-current, so that there can be avoided the drawbacks of the previously proposed phase control. Moreover, it is also possible to automatically maintain constant the effective value of the welding current intensity and thus the welding energy, so that with constant feed speed of the workpiece parts between the welding rolls, and which workpiece parts are to be welded together, there is delivered to all of the welding points or spots of the welding seam produced by a respective alternating-current half-wave of the welding current, the same thermal energy. However, there are situations where the welding speed unintentionally experiences temporary changes. Also, as described in British Patent Specification No. 1,509,416 the feed speed of the workpiece parts to be welded to one another can be controlled during welding such that the last weld spot of the seam which is produced by an alternating-current half-wave of the welding current is disposed at a predetermined distance from the trailing end of the parts which are to be welded to one another. This of course required a control of the welding

speed and results in a speed-change in the operation of the welding machine.

The apparatus described prevents the formation of poor welding seams due to too low or excessively supplied welding energy, if during the welding operation the feed speed of the workpiece parts to be welded to one another changes unintentionally or intentionally.

WHAT WE CLAIM IS:

1. A method of controlling the welding energy during electrical resistance welding of workpieces by means of an electrode roll-resistance seam welding machine, in which the effective value of the welding current is controlled in response of an electrical control signal, at least a component of which is a welding current-correction signal substantially analogous to the welding speed in order to provide a substantially constant welding energy supplied to the workpieces at each section along the formed welding seam at any welding speed, the said welding current-correction signal being produced by means of a programmed control device which simultaneously delivers an electrical rotational speed-reference value signal to a rotational speed regulator for controlling and regulating the welding speed.
2. A method as claimed in claim 1, comprising superimposing the welding current-correction signal and an electrical welding current-reference value signal delivered by a reference value transmitter, in order to form said electrical control signal.
3. A method as claimed in claim 1 or claim 2, wherein the welding current-correction signal is derived from the electrical rotational speed-reference value signal.
4. Apparatus for controlling the welding energy during electrical resistance welding of workpieces by means of an electrode roll resistance seam welding machine having a pair of roller electrodes, drive means for feeding the workpieces to be welded between said roller electrodes during welding, a welding transformer having a primary winding and a secondary winding which is electrically connected to said welding rolls, and means for supplying to the primary winding of said welding transformer an alternating current for welding, said apparatus comprising: means for controlling the effective value of the current intensity of the welding alternating current in response of an electrical control signal; an adjustable electrical reference value transmitter for generating an electrical welding current-reference value signal; a rotational speed regulator associated with said drive means, for automatically controlling the welding speed as a function of an electrical rotational speed-reference value



(18)

signal;
means for producing the rotational speed-reference value signal as a function of infed data, said producing means including means for generating an electrical signal analogous to the welding speed; and means for superimposing the welding current-correction signal and the welding current-reference value signal for producing the electrical control signal in such a manner that the work-pieces have delivered thereto at each section along the formed welding seam a substantially constant welding energy at any welding speed.

5. Apparatus as claimed in claim 4, wherein said means for producing the rotational speed-reference value signal comprises a programmed control device.

6. Apparatus as claimed in claim 4 or claim 5, further including adjustment means for changing the welding current-correction signal in relation to the welding current-reference value signal.

7. A method substantially as hereinbefore described with reference to Figures 4 and 7, or 6 and 7 of the accompanying drawings.

8. Apparatus substantially as hereinbefore described with reference to Figures 4 and 7, or 6 and 7 of the accompanying drawings.

9. A resistance welding machine in combination with control apparatus as claimed in any one of claims 4 to 6, or 8.

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Printed for Her Majesty's Stationery Office,
by Croydon Printing Company Limited, Croydon, Surrey, 1981.
Published by The Patent Office, 25 Southampton Buildings,
London, WC2A 1AY, from which copies may be obtained.