

June 2, 1953

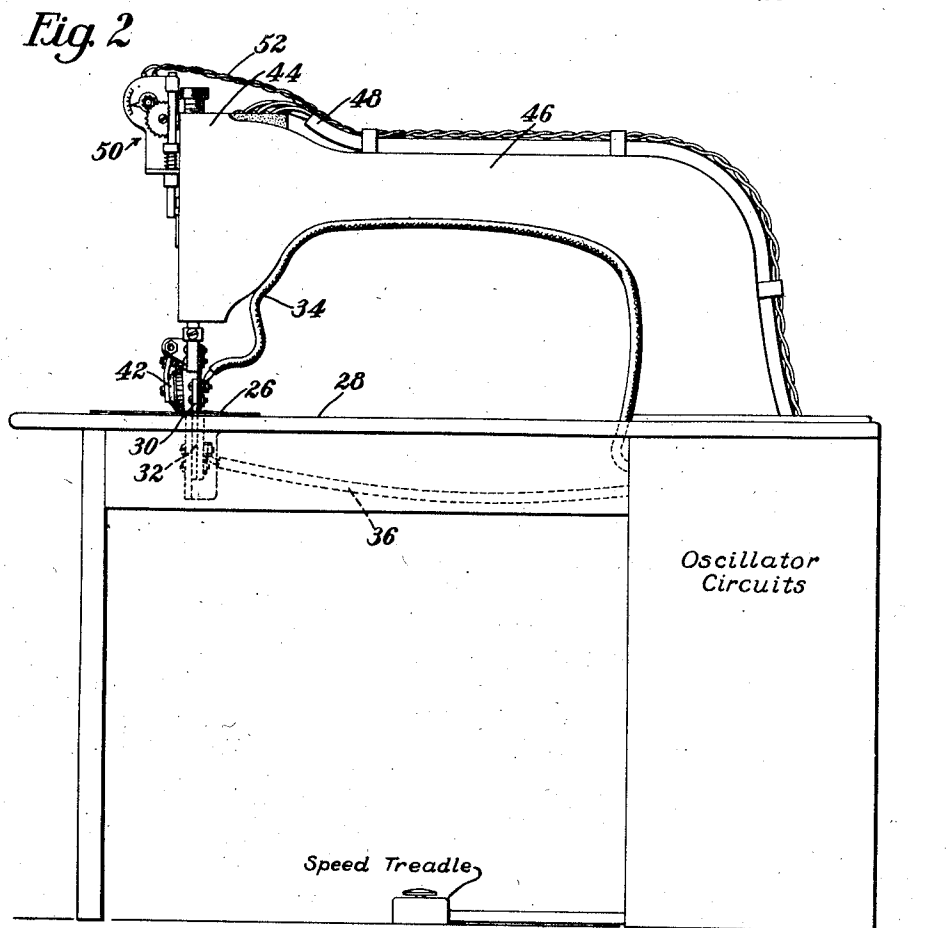
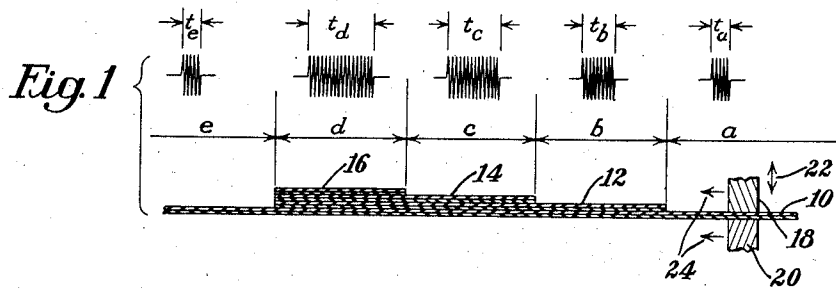
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2,640,908

MACHINE FOR PROGRESSIVELY BONDING SHEET MATERIAL

Filed Nov. 7, 1947

8 Sheets-Sheet 1



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MACHINE FOR PROGRESSIVELY BONDING SHEET MATERIAL

Filed Nov. 7, 1947

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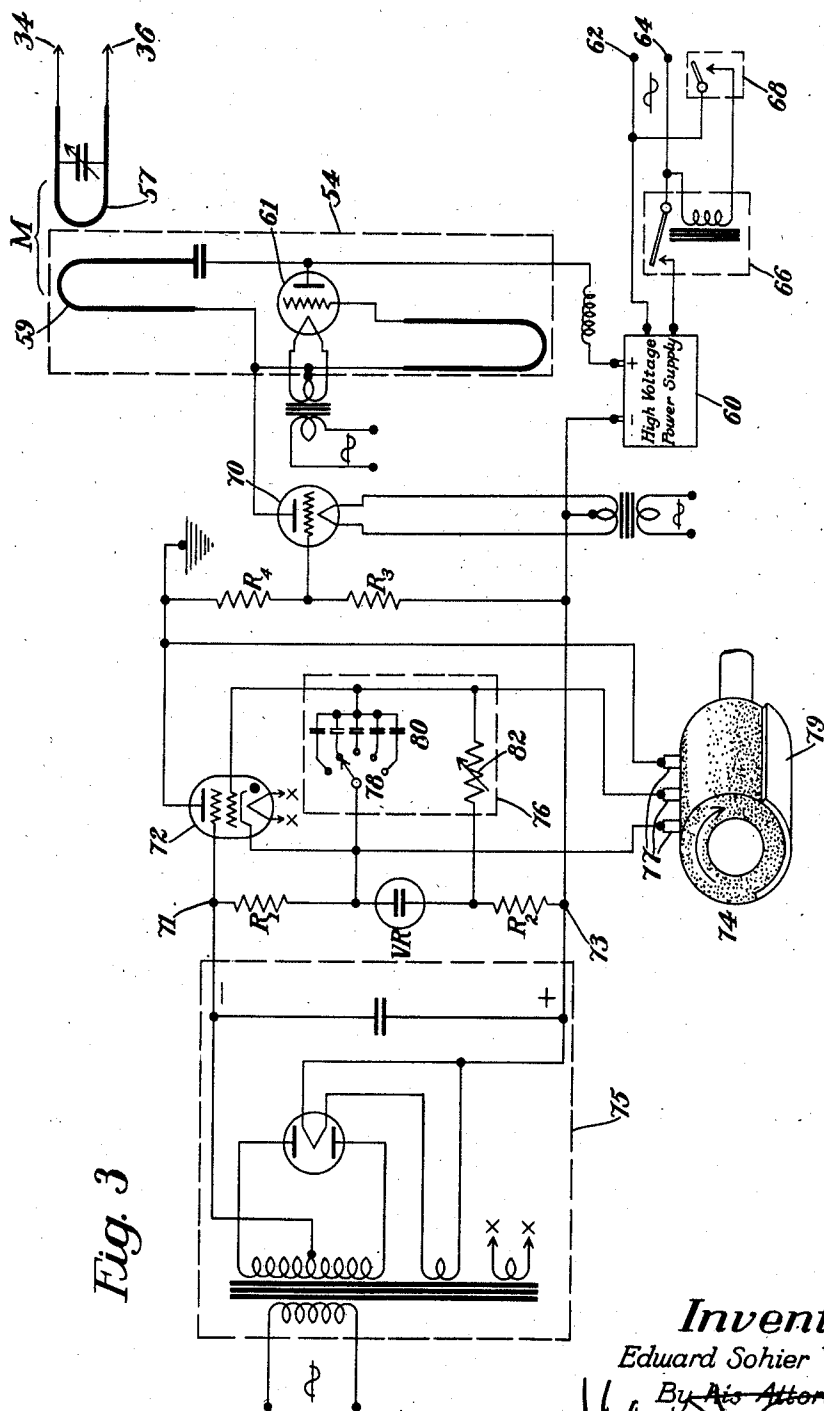


Fig. 3

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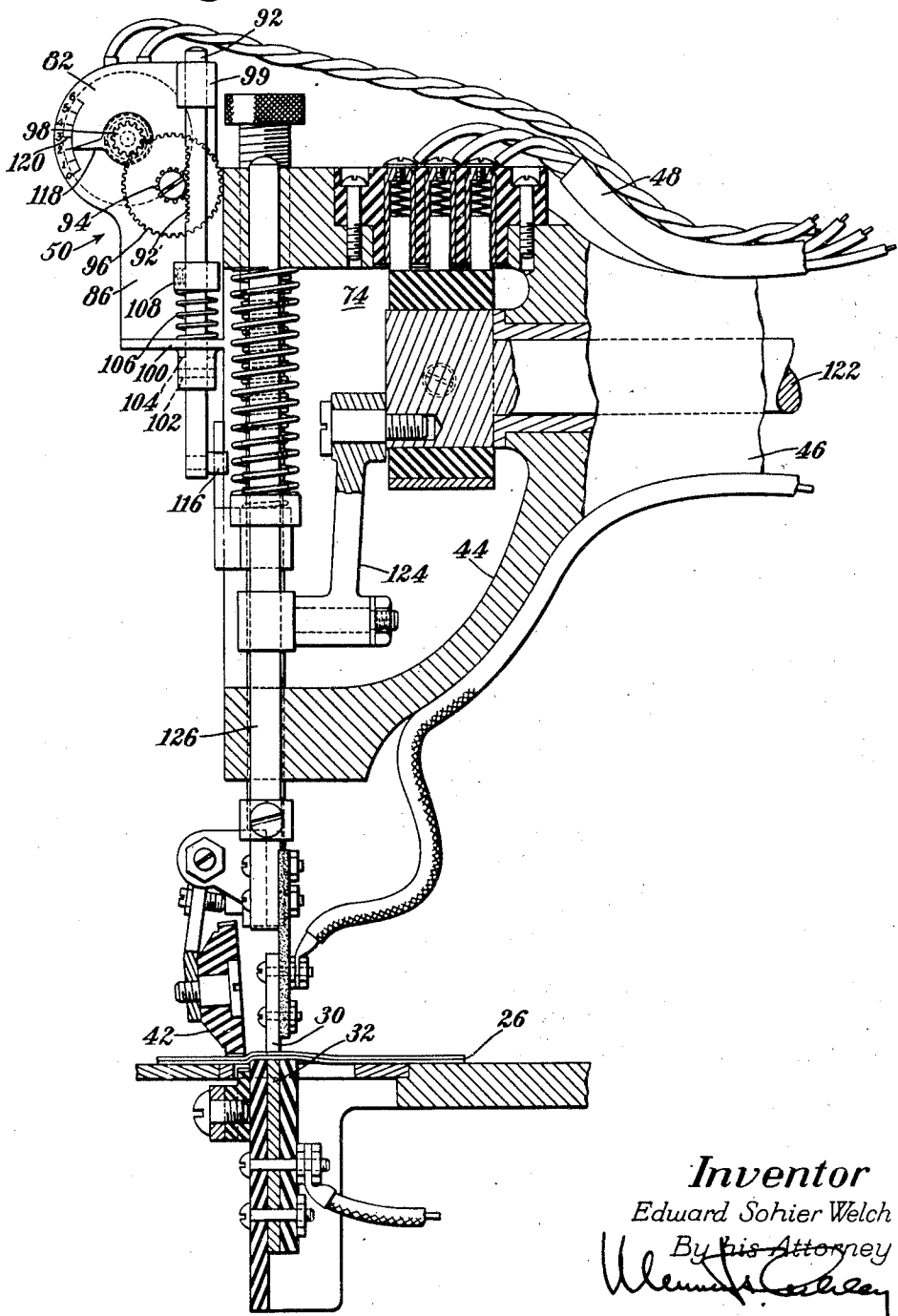
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MACHINE FOR PROGRESSIVELY BONDING SHEET MATERIAL

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8 Sheets-Sheet 3

Fig. 4



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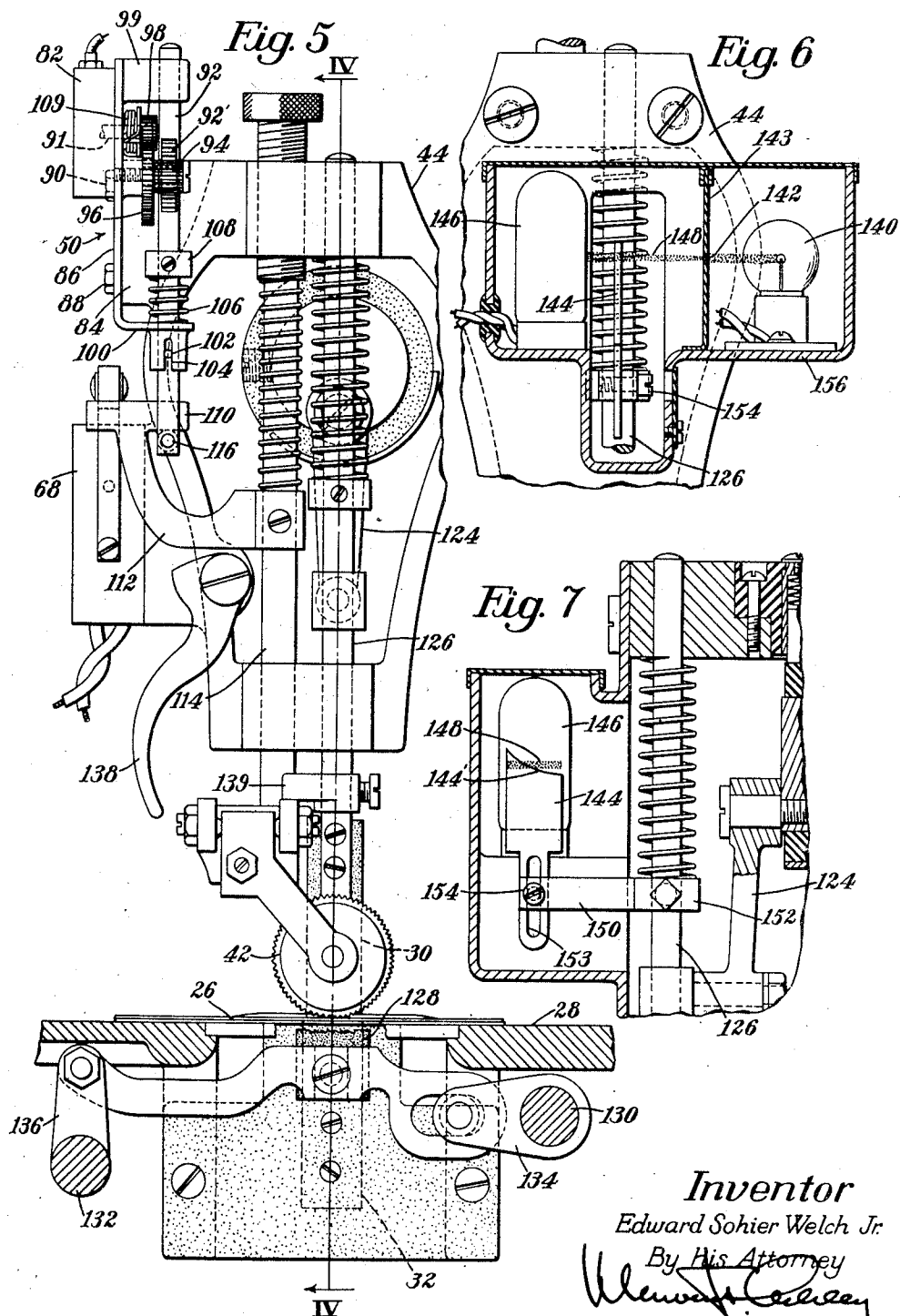
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MACHINE FOR PROGRESSIVELY BONDING SHEET MATERIAL

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Fig. 8

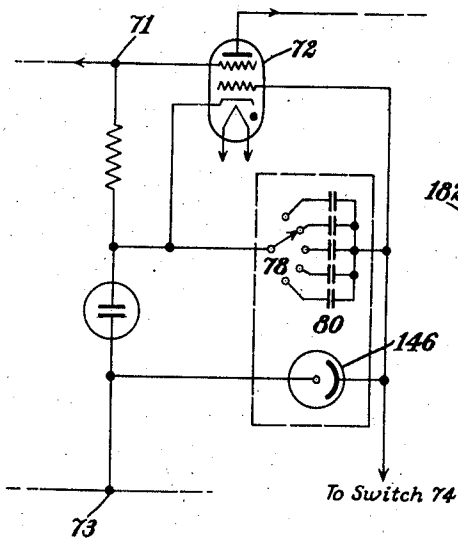


Fig. 9

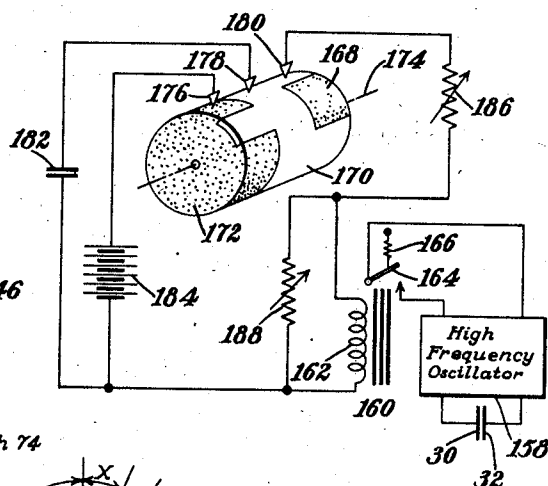


Fig. 10

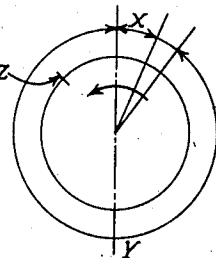


Fig. 11

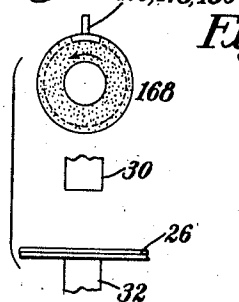


Fig. 12

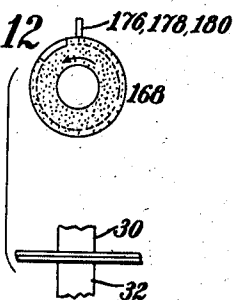
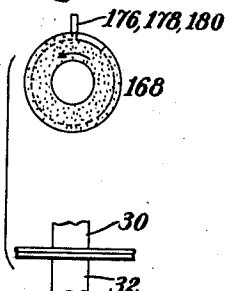


Fig. 13



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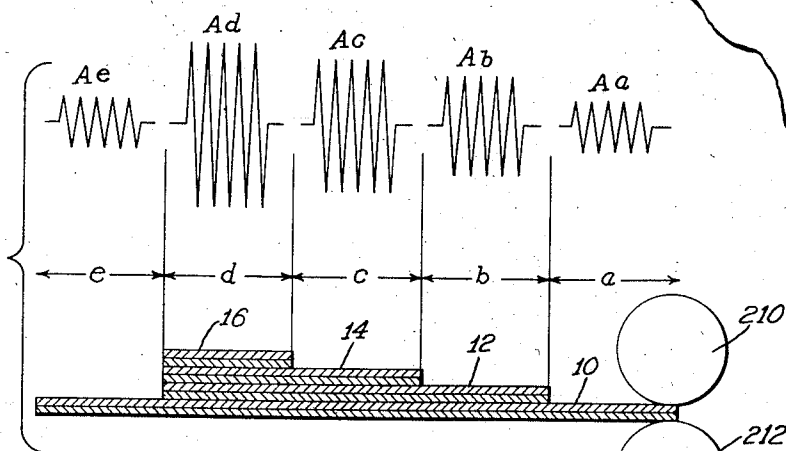
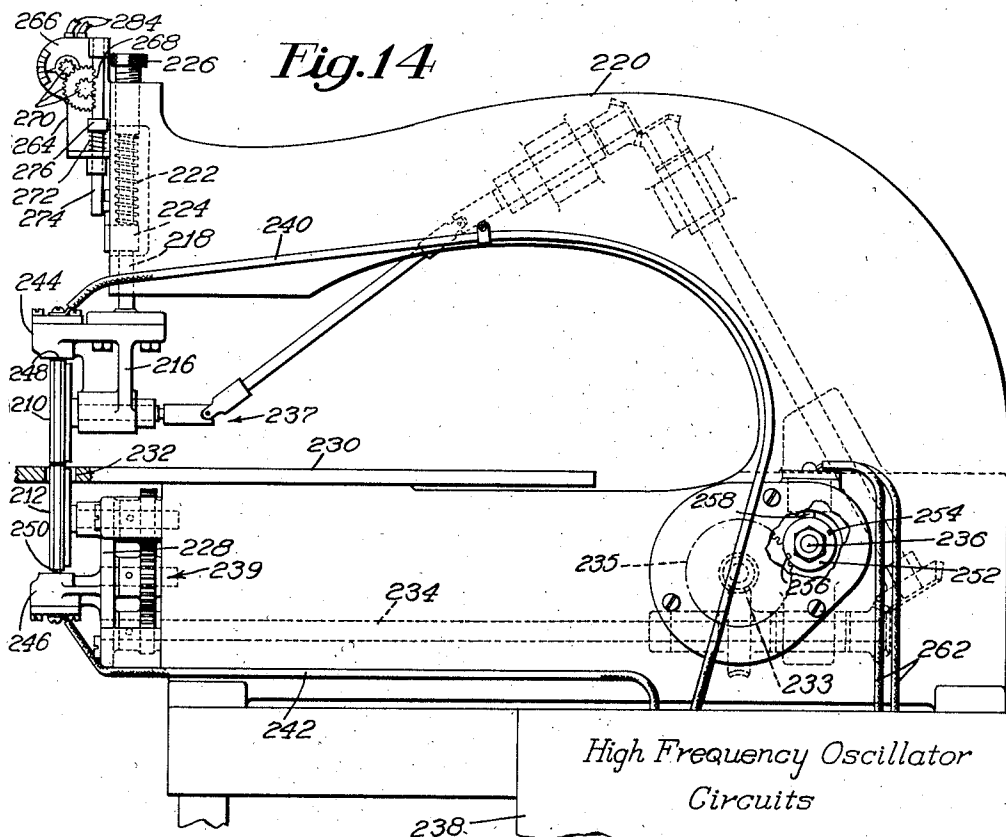
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2,640,908

MACHINE FOR PROGRESSIVELY BONDING SHEET MATERIAL

Filed Nov. 7, 1947

8 Sheets-Sheet 6



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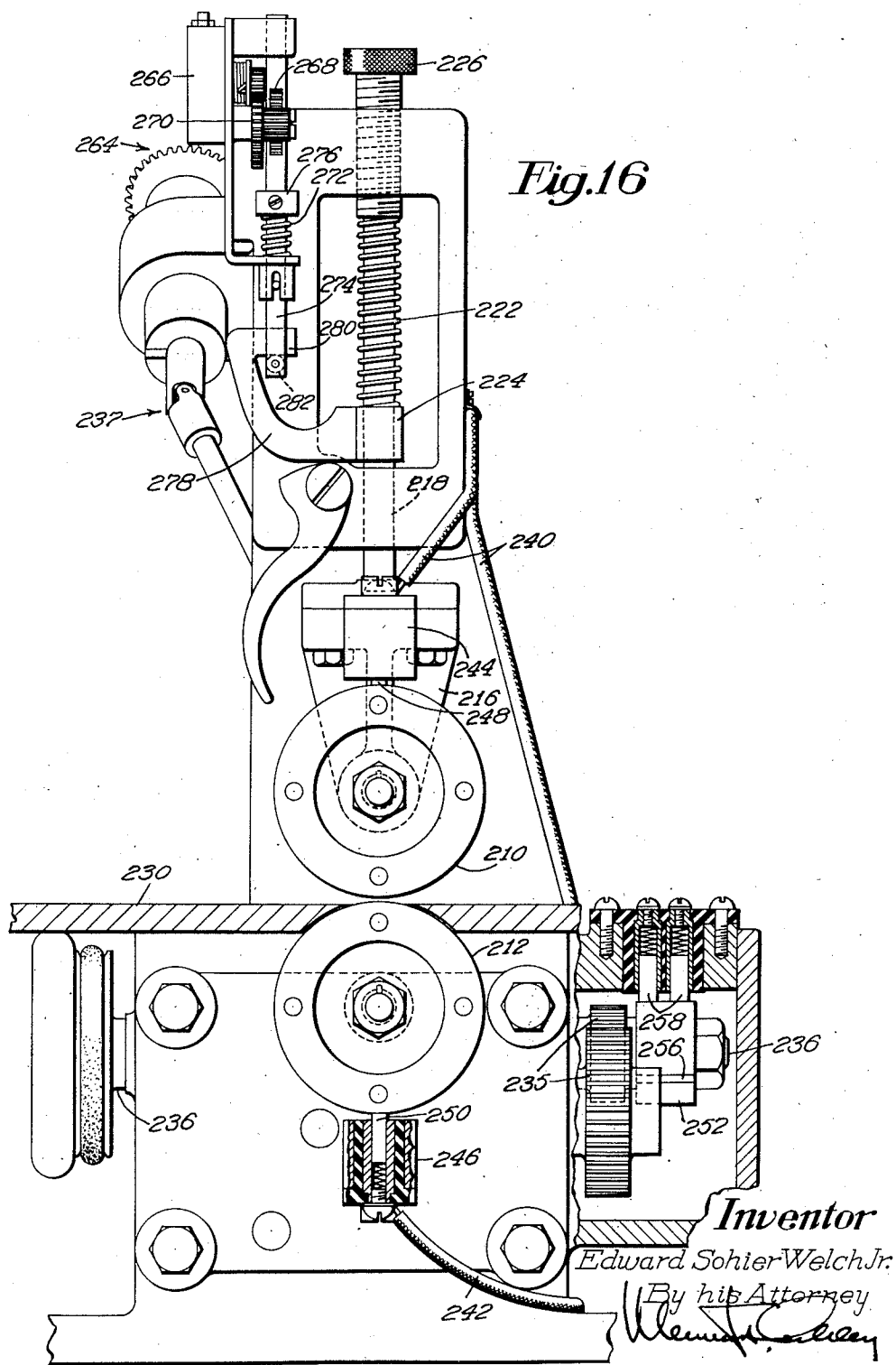
E. S. WELCH, JR

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MACHINE FOR PROGRESSIVELY BONDING SHEET MATERIAL

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**June 2, 1953**

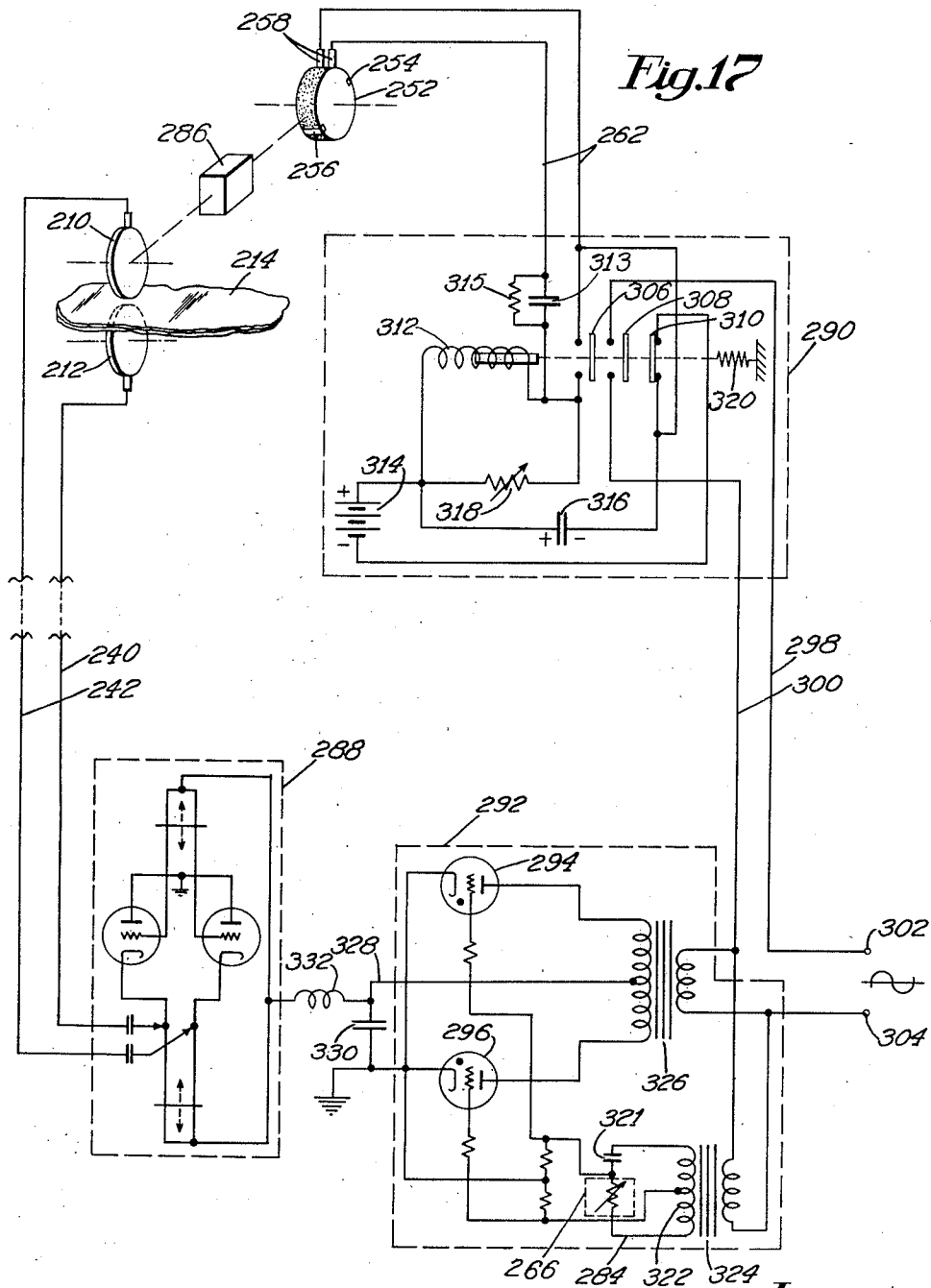
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**2,640,908**

# MACHINE FOR PROGRESSIVELY BONDING SHEET MATERIAL

Filed Nov. 7, 1947

8 Sheets-Sheet 8



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## UNITED STATES PATENT OFFICE

2,640,908

MACHINE FOR PROGRESSIVELY BONDING  
SHEET MATERIAL

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Application November 7, 1947, Serial No. 784,738

5 Claims. (Cl. 219—47)

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This invention relates to apparatus for progressively heating work parts by subjection to a high-frequency electric field between electrodes. More specifically it relates to the provision, in such apparatus, of means for adjusting the supply of electric energy to accommodate changes in the thickness of such parts and the speed with which the parts are moved past the electrodes. The invention is herein described by reference to its embodiment in dielectric progressive bonding apparatus suitable for bonding plies of thermoactive dielectric materials or dielectric materials coated with thermoactive adhesives.

The present invention is concerned primarily with solving certain problems arising in the general field of "electronic heating," so called because of the use of vacuum tube circuits in generating high-frequency energy as a means of producing heat in the work. One such problem relates to maintaining uniformity of the heating despite changes in certain working conditions, and is reflected in the need for apparatus for progressively bonding dielectric work pieces, frequently made up of overlapped layers, in uniform manner along a seam although the thickness of the composite work or the work-feed speed or both may change at various times during the progress of the operation. Fulfilling this requirement is important because of the steadily growing supply of new and improved vinyl and other plastics for water-proof wearing apparel and other articles and in view of the unique adaptability of the high-frequency bonding process generally in manufacturing such articles. The problem to be solved is well illustrated in the manufacture of waterproof garments or raincoats of plastic sheet materials where it has been found highly advantageous, because of the length and curvature of the seams required, to bond overlapping pieces of material progressively by means of high-frequency dielectric heating. There is, furthermore, in any such garment a wide variation in the number of layers to be bonded because of the overlapping of adjacent layers in making cuffs, pockets, collars and the like. This variation may run from two to ten or more thicknesses of sheet material so that satisfactory bonding requires the ability to produce seams of uniform bonding quality regardless of such variations. In producing a uniform seam under such circumstances it has been found necessary, in order to effect a uniform rise of temperature at all points, to so modify the amount of heat delivered to the work at any given fractional area that it will be proportional to the thickness of

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the work and hence to the instantaneous volume of the work in that area.

In the illustrative case of bonding together homogeneous plastic sheet materials in contacting relation, it is well known that the effective voltage gradient of a high-frequency electric field passed through the sheets normally between external electrodes, will be uniform, as will the resulting heating effect, throughout the material within this field. By voltage gradient is meant the rate of change of potential through the work from one electrode to the other, and such a gradient is often expressed as volts per centimeter. Since the rate of heating depends upon the effective magnitude of the voltage gradient, it follows that an increase, for example, in work thickness will result in a lowered heating rate with the same applied voltage at the electrodes. Thus, in a system where the amplitude of the applied voltage is not modified, or where some other suitable compensating effect, such as lengthening the time of application of the energy to each work portion is not introduced, as the work thickness changes during bonding, the bonding temperatures and thus the uniformity of the resulting bond will be affected. More important perhaps, because of the great convenience of a variable work-feed speed to the operator, the apparatus should maintain the uniformity of the bond or other treatment throughout a wide range of work-feed speeds. Thus the amount of heating (or the number of watts consumed by the work) per unit length of the path treated must be completely independent of the work-feed speed, and variations in this amount must be provided when appropriate, other than by varying the work-feed speed.

It is, accordingly, an important object of this invention to provide an improved progressive dielectric heating apparatus in which the treatment of the work, such as the formation of a bond, is maintained uniform in successive work portions throughout a wide range of work-feed speeds despite variations in energy requirements due, for example, to variations in the thickness of such portions.

The amount of heating of a given portion of material depends upon the product of the rate of heating and the time of heating. Where successive equally thick portions of a piece of work are each treated by a pulse of electric energy of a given frequency and duration, the amount of heating of any such portion will be substantially proportional to the product of the square of the voltage amplitude of the pulse, and the length

of the pulse, which product is hereinafter referred to as the energy content of the pulse. Where, however, there occurs, for example, a two-fold increase in the thickness of the work portions, such portions will require a four-fold increase in the pulse energy content to preserve uniformity of heat generated per unit of volume, since the work thickness affects the voltage gradient. That is to say, the energy content of the pulse should vary substantially in proportion to the square of the thickness. By "substantially" it is meant that considerations of heat transfer, such as the relatively lower proportional heat loss from thicker portions, may render desirable a slight departure from an exact proportionality to the square of the thickness. Such a quadruple energy content may be provided, for example, by doubling the amplitude or by quadrupling the length of the pulsing.

In accordance with the foregoing object of the invention, apparatus is provided wherein electrical energy is delivered to the work progressively along a treatment path in pulses at a pulse frequency or repetition rate which is varied with variations in feed speed so that each unit length of the treatment path receives the same number of pulses and in which the energy content of the pulses is adjusted during the process of treatment independently of work feed speed, in accordance with variations in thickness, or other energy requirement, of the work. The control of the energy content of each pulse may be effected, for example, by varying its length or its amplitude.

In the operation of this apparatus, the operator's attention may be directed solely to the manipulation of the work and to the regulation of bonding speed, as by means of a treadle, to suit his convenience.

A feature of the invention resides in a machine comprising bonding electrodes, means for advancing the work through the field thereof, a high-frequency electrical pulse generator triggerable to provide a predetermined-duration pulse of energy for supplying the electrodes, and means for triggering the generator at a rate proportional to the work feed speed, combined with means responsive to work thickness for adjusting the energy content of the pulses so that the heat produced thereby is substantially proportional to the volume of the work which then is in the field of the electrodes.

Another feature of the invention resides in a modified pulse-generating circuit especially adapted for utilization in high-frequency bonding apparatus of the type described, in which the initiation of the pulse is caused by the operation of a switch and the termination of the pulse is determined by the falling off to a predetermined value of a condenser discharge current flowing through the field coil of a switching relay. The switching relay may thus be used with a variable resistor adjusted in response to the work thickness to control the operation of a high-frequency oscillator to adjust the duration of a pulse of electric energy in accordance with this feature of the invention.

In another illustrated embodiment means is provided for determining the amplitude of the pulses delivered, in accordance with the thickness of the work which then is in the field region of the electrodes, and in accordance with another feature of the invention a high-frequency oscillator employed for supplying energy to the electrodes is arranged to deliver energy in pulses

by a circuit set in operation by a triggering means comprising a switch mechanism. The latter is actuated intermittently with the rotation of work feed rolls which serve also as electrodes, and the amplitude of the pulses of energy delivered to the electrodes is adjustable by means of a variable resistor having a rotary contact arm which is arranged to be moved in response to movement of a work-engaging member into a position determined by the separation distance between the opposing peripheral surfaces of the electrode rolls, i. e. the work thickness.

In accordance with another feature of the invention the oscillator plate voltage is regulated in response to variations in work thickness as a means of effecting a constant bonding temperature in successive fractional bonding areas.

These and other aspects, features and advantages of the invention will be more fully described in the following description with reference to the drawings, in which:

Fig. 1 is a diagram illustrating the method of bonding which involves varying the length of high-frequency energy pulses supplied to progressive bonding electrodes in accordance with changes in work thickness during the bonding operation;

Fig. 2 is a front elevation of one form of a progressive bonding machine of the invention;

Fig. 3 is a schematic circuit diagram of a circuit for generating high-frequency energy pulses of predetermined duration in accordance with the practice of the invention;

Fig. 4 is an enlarged front elevation, partly sectional on a line IV—IV of Fig. 5, showing the operating head of the machine of Fig. 2;

Fig. 5 is an end elevation of the same operating portion;

Fig. 6 is an end elevation of apparatus for accomplishing the same result as the machine in Fig. 4, illustrating a photoelectric, automatic-pulse-length control arrangement;

Fig. 7 is a front elevation of the same photoelectric control arrangement;

Fig. 8 is a schematic circuit diagram showing the photocell of Figs. 6 and 7 embodied in the pulse-generating circuit of Fig. 3 for controlling pulse length;

Fig. 9 is another form of pulse-generating circuit employing a rotary switch and control relay;

Fig. 10 illustrates a rotary switch having conductive segments employed in connection with Fig. 9;

Figs. 11, 12, and 13 illustrate the operation of the circuit of Fig. 9 as applied to a progressive bonding machine, showing three typical positions of the switch and electrodes during a cycle of operation of the machine;

Fig. 14 is a partial front elevation of another form of progressive high-frequency bonding machine embodying the invention;

Fig. 15 is another diagram showing how this latter form compensates for changes in thickness;

Fig. 16 is a partial side elevation of the same machine, showing certain details of the switch mechanism of the electrode apparatus and of the pulse amplitude controlling mechanism; and

Fig. 17 is a schematic circuit diagram of the principal electrical components of such a machine.

The diagram of Fig. 1 is useful in understanding the operation of that embodiment for progressively bonding plastic work material of variable thickness in which the pulse-energy content,

which is determined by the duration (length) and voltage amplitude of the pulse, is adjusted by adjustment of pulse length. The work material shown comprises double plastic sheets 10, 12, 14, and 16 which are successively stacked in the manner shown to provide a work assemblage having thicknesses of 2, 4, 6 and 8 and 2 layers respectively in the sections *a*, *b*, *c*, *d* and *e* along a bonding path to be followed by electrodes 18 and 20. The lower electrode 20 is held continuously against the bottom surface of the work while the upper electrode 18 is reciprocated vertically, as indicated by the double arrow 22, to bring the work under pressure intermittently between the electrodes, and relative traversing movement is effected between the electrodes and the work to be bonded in the direction of the arrows 24. This traversing movement is preferably a step-by-step movement executed in timed relation with the reciprocation of the upper electrode 18, there being such movement between the work and the electrodes only when the electrode 18 is away from the work. High-frequency energy is delivered to the electrodes in pulses, a pulse occurring each time the electrode 18 descends upon the work and the length, i. e. the duration, of the pulses is continuously determined in accordance with the thickness of the work immediately between the electrodes. That is, the electrode dwell interval will be determined by the mechanical operation of the machine, i. e. speed, while the pulse interval will be shorter, occurring preferably during the early portion of the dwell interval. In the drawing, these pulses are indicated graphically directly above the sections of the work to which they apply. The time duration of each pulse is indicated qualitatively by the letter *t* bearing the subscript of the corresponding work section *a*, *b*, etc.

The work parts are seamed together by forming a succession of individual bonds which may overlap by any predetermined amount depending both upon the length of the electrodes in contact with the work and the length of the relative traversing movement during each step. In practice this distance will be fixed so that the bonding rate may be varied at will without affecting the quality of the bond, as in the method of copending application filed July 16, 1946, Serial No. 684,957, in the name of Glenn L. Mellen, as long as the duration of the pulse of high-frequency energy is less than the dwell period of the electrode 18 against the work. By additionally varying the energy content as by changing the pulse length as the work thickness changes, however, in accordance with the present method, which to a first approximation, assuming constant voltage across the electrodes, calls for a pulse length proportion to the square of the instantaneous thickness of the work, the quality of the seam may be made uniform throughout, irrespective of changes in either bonding speed or in work thickness.

In practice, the above said proportional relationship between pulse length and work thickness may require modification because when the work thickness changes the voltage between the electrodes, unless separately regulated, will usually not remain constant because of the change in electrical impedance presented by the electrodes to the high-frequency oscillator circuit. Other factors such as the effect of the electrodes in conducting heat away from the material in different proportional amounts with work of different thickness and heat conductivity may also affect this relationship. The manner of making

adjustments providing for factors of this character will later be described herein.

The bonding machine of Fig. 2 is of the sewing machine type, in the sense of its general appearance and mode of handling the work physically, although, of course, thread is not employed in creating a seam between work parts and the work is not pierced by needle holes. Details of the machine necessary to a fuller understanding of its operation are later herein described in connection with Figs. 4 and 5. However, it will be well to state at this point that in the use of the machine work parts 26 to be seamed together are placed upon an operating table or base 28 adjacent to electrodes 30 and 32 and the latter are supplied with high-frequency energy respectively through leads 34 and 36 connected to a high-frequency oscillator housed within the unit designated as "Oscillator Circuits" and herein later described in more detail. The work is fed past the electrodes by the action of a presser wheel 42 and a feed dog 128 (Fig. 5) in timed relation with the rise and fall of the upper electrode 30 against the work and a pulse of high-frequency energy is delivered to the electrodes each time they are brought to bear mutually upon the work. A rotary switch 74 (Fig. 4), housed within a recessed head 44 carried by a goose neck 46, controls the timing of the oscillator in delivering pulses of high-frequency energy to the electrodes.

The manner of controlling the length of the pulses as a function of work thickness will now be set forth, first with particular reference to the oscillator circuits illustrated in Fig. 3 and later with reference to the control unit 50 associated with said circuits as such unit is embodied in the machine. In Fig. 3, a high-frequency oscillator 54 is shown which is arranged for producing high-frequency energy to be coupled to the output leads 34 and 36 by means of the mutual coupling effect *M* between an output circuit 59 of the oscillator and an inductive loop 57 of a resonant circuit connected to the leads 34 and 36 for delivery of said energy to the bonding electrodes of the machine. Plate voltage is supplied to an oscillator tube 61 by means of the high-voltage power supply 60 which is connected to alternating current power terminals 62 and 64 through a relay switch 66 controlled by a microswitch 68 in turn arranged to be operated when the operator lowers the presser wheel 42 (Fig. 5). When the power supply 60 is appropriately energized from the power terminals 62 and 64, the oscillator 54 is ready to deliver power to the electrodes through the leads 34 and 36.

Pulsing of the oscillator is effected by means of a switch tube 70 connected in series with the anode-cathode circuit of the oscillator tube 61 and the tube 70 is controlled by a timing circuit comprising a thyatron tube 72, a rotary switch 74 and associated circuit components. In thus controlling the oscillator 54, the switch tube 70 is normally biased negatively, preferably beyond cut-off, and the oscillator is thereby rendered inoperative because of the high series impedance of the tube 70, but when the bias voltage is removed, as it is by the timing circuit during a pulse, the oscillator becomes operative to deliver a pulse of energy to the bonding electrodes. In this connection certain aspects of the timing circuit of Fig. 3 and certain features of the herein described machine and of the method of delivering pulses of high-frequency energy to the bonding electrodes are

also described in copending application Serial No. 684,057 above referred to. That application also relates to the progressive heating of plastic materials but it chiefly concerns the problem of speed variations alone and does not contemplate a solution to the problems herein dealt with.

In the operation of the timing circuit a constant direct voltage of the indicated polarity is applied between circuit points 71 and 73 by means of a power supply 75. This voltage causes current to flow through the network comprising resistor R<sub>1</sub>, constant-voltage gaseous discharge tube VR and resistor R<sub>2</sub>, the combined voltage of the tube VR and the resistor R<sub>2</sub> being applied to a series circuit including the resistors R<sub>3</sub> and R<sub>4</sub>, and either the tube 72 or the two outer of three brushes 77 and a conductive segment 79 of the switch 74, depending upon the position of the latter. The voltage drop resulting in resistor R<sub>3</sub> provides the negative bias to maintain switch tube 70 nonconductive.

A pulse is initiated when this bias is removed by the action of the switch 74 when the conductive segment 79 passes from under the brushes 77 and the latter fall onto the main insulating surface of the switch which is caused to occur in the machine at a time just after the electrode 30 (Fig. 4) descends upon the work. Simultaneously, in the action of the circuit in removing the bias from the tube 70, tube 72 is open circuited by the switch 74 and one of the condensers 80 of a bank, selected by means of a switch 78, begins to charge through a variable resistor 82 from the voltage across tube VR. During the initial charging period of this condenser 80, tube 72 is held nonconductive by virtue of the biasing effect at its second grid caused by the constant voltage developed in resistor R<sub>1</sub>, and since no current then flows through switch 74 or tube 72 there will be no bias voltage in resistor R<sub>3</sub> and a pulse will have been initiated. The pulse is terminated later at a controlled time when the voltage of condenser 80, which voltage produces a positive biasing effect at the first grid of tube 72, becomes sufficient to overcome the biasing effect at the second grid of the tube 72 and cause conduction therein.

The time of termination of the pulse, i. e. the pulse length, is controlled by the setting of resistor 82 which in turn is governed during a bonding operation in accordance with variations in work thickness in a manner to be described. The range of pulse length variations, that is the average or basic pulse length to be varied by resistor 82, may be shifted to different values to suit different work materials. This is done with the selector switch 78 in selecting a condenser of an appropriate size from the bank 80. It will then be apparent, for purposes of definition, that the dotted line 76 encloses a circuit portion which may be appropriately referred to as "time-constant" circuit since the elements therein determine pulse duration time. Continued rotation of the switch 74 causes repetition of the foregoing cycle of operation in the circuit. Accordingly, there is thus provided an electric pulse generator triggerable by the switch 74 to provide pulses of a duration predetermined by the setting of the time-constant circuit.

In Figs. 4 and 5 a pulse-length-control unit 50 embodying the variable resistor 82 is shown

as mounted on the end of the recessed head 44 which, for this purpose, has been provided with a projecting shoulder portion 84 to which a bracket member 86 of the control unit 50 is attached by means of bolts 88 and 90. The bracket member 86 comprises the body portion of the control unit to which member are mounted the variable resistor 82 with a rotatable contact arm mounted on a shaft 91, and a rack and gear assembly for rotating the resistor arm to vary the pulse length in said timing circuit. This assembly comprises a rack bar 92, embodying a gear rack 92', and a pinion 94, meshing therewith and integral with a larger gear 96 engaging a driven gear 98 connected to the arm shaft of the variable resistor 82. The resistance value of variable resistor 82 is thus determined by the vertical position of the rack bar 92 and the latter in a way to be described is positioned in accordance with the thickness of the work being bonded between the electrodes. In this regard the rack bar 92 is slidably retained by arms 99 and 100 extending laterally from the bracket 86. Rotational slip of the bar 92 is prevented by means of a pin 102 projecting from the side of the bar and engaging a vertical slot 104 in a downwardly extending sleeve on the arm 100. The bar 92 is urged upwardly by means of a spring 106 bearing against a collar 108 fixed to the arm, which, in company with a coil spring 109 tending to turn the contact arm shaft 91 of resistor 82, prevents backlash in the gears from interfering with the accurate control of the position of said resistor arm in the process of moving the bar 92.

In order to effect a change in the position of the bar 92, a lateral extension or finger 110 has been provided on an arm 112 carried by a vertical rod 114 which supports the presser wheel 42. A pin 116 extending through the lower end of the rack bar 92 is arranged for engagement with the lower surface of the finger 110 and is held in close contact therewith principally by the spring 106. Variations in the vertical position of the presser wheel 42 caused by changes in work thickness will, therefore, be reflected in corresponding adjustments of the variable resistor 82 to control the length of pulses of high-frequency energy supplied to the electrodes.

In the control unit 50, a pointer 118 (Fig. 4) has been provided on the arm shaft 91 of variable resistor 82, which registers with a graduated scale 120 marked around the edge of the resistor casing so as to indicate the thickness of the work between the electrodes in any instant. This indicator provides a useful means of checking the proper adjustment of the various parts of the apparatus associated with the control unit 50 before commencing to operate the machine.

In the operation of the machine of Figs. 4 and 5, driving power for reciprocating the upper electrode 30 is provided through a shaft 122 turning a link 124 which is connected at its upper end to a crank embodied in the disk portion of switch 74 and at its lower end to a rod 126 carrying the electrode 30, and the movement of the electrode 30 is carried out in timed relation with the movement of a feed dog 128 driven by oscillating shafts 130 and 132 through crank members 134 and 136. To place the work between the electrodes, a cam lever 138 is lifted which raises the rod 114 carry-

ing the wheel 42 and hence, by means of a flange 139 fixed to the electrode-carrying rod 126, also raises such rod, the work is inserted, and the wheel 42 lowered for operation of the machine, whereupon the work is fed between the electrodes in step-by-step manner by the action of the feed dog 128 assisted from above by the presser wheel 42. The upper electrode 30 is brought to bear against the work on the return motion of the feed dog, and at the beginning of this period the switch 74 initiates the operation of the timing circuit which pulses the oscillator, as aforesaid. The maximum length of the pulse is predetermined in the design of the oscillator circuits, and it will be less than the shortest period of dwell of the upper electrode 30 against the work, which period will occur at the highest anticipated speed of the machine.

In Figs. 6 and 7, an alternative pulse length control unit is illustrated. In this arrangement the length of the pulse is determined by the amount of light falling upon a photoelectric cell 146 connected to act as a variable resistance, effectively replacing the resistor 82 in the time-constant circuit of Fig. 3, to function in a manner to be described. While the variable resistance control unit 82 of Figs. 4 and 5 was particularly suited to applications wherein the heightwise positioning of the presser wheel 42 could be utilized as a measure of work thickness, there are instances where it is desirable to use the actual distance between the electrodes therefor, especially in bonding along a marginal edge where the work thickness between the electrodes may differ from that under the presser wheel 42. This alternative control unit presently to be described is particularly suited to this problem since it involves no sliding contacts which would wear with extended use, as in a variable resistor. Such a unit comprises a light source 140 (Fig. 6), a rectangular aperture 142 formed in a partition 143 and arranged for producing a narrow rectangular beam of light 148, a reciprocative shutter 144, and a photocell 146 adapted to receive the light passing by the shutter 144. The shutter 144 comprises a light-intercepting blade having a diagonal edge 144' traversing the rectangular beam of light 148 and reciprocates vertically with the upper electrode 30 of the machine of Figs. 4 and 5. For this purpose, the shutter is carried by an arm 150 integral with a spring-engaging collar 152 fixed on the rod 126 which carries the upper electrode 30. The initial vertical position of the shutter 144 relative to the light beam 148 may be adjusted by means of a slotted extension 153 thereof engaged by a clamp screw 154 passing through the arm 150. The entire unit is housed within a light-tight box 155 which is mounted on the end of the recessed head 44 of the said machine.

Fig. 8 shows the location of the photocell 146 in the timing circuit of Fig. 3 and it will be seen that the only essential alteration of that circuit is in the substitution of the photocell 146 for the variable resistor 82.

In the operation of the photoelectric control unit of Figs. 6 and 7 and of the circuit of Fig. 3 embodying the substitute arrangement of Fig. 8, the amount of light falling upon the photocell 146 during the delivery of power to the electrodes will determine the effective resistance of the photocell and will thereby determine the pulse length in the timing circuit. During the periods

between pulses, the resistance of the photocell will vary as the shutter follows the movement of the electrode 30 but this will not affect the essential operation of the circuit because the electrode is stationary during the charging of the timing condenser through the photocell.

It has been stated herein that, to a first approximation, assuming constant electrode voltage, there should be a proportional relationship between pulse length and the square of the work thickness, but that this relationship preferably should be modified in practice to meet the effect of such factors, for example, as changes in electrode voltage occasioned by variations in electrode spacing attending variations in work thickness and the cooling effect of the electrodes on the work arising from their heat conduction properties. In seeking the optimum relationship in apparatus of the invention, with reference to either the variable resistor or the photoelectric type pulse length control units, a series of calibration trials may be executed involving the bonding of work material of different thicknesses at different pulse lengths and experimentally selecting the pulse length best suited to each thickness. On the basis of the results of these trials the desired variation in resistance of either the variable resistor 82 (Fig. 3) or of the photocell 146 (Fig. 8) as a function of work thickness is readily determined.

By well-known methods, the resistor 82 may thus be of a nonlinear type, varying in accordance with the relationship thus determined, or, where it is desirable to employ a linear resistor, the rack bar 92, while not so shown, may be raised and lowered by the presser wheel assembly operating through a special cam designed to convert, in accordance with said relationship, variations in work thickness into appropriate changes in resistance of the member 82. In the case of the photoelectric control unit, the diagonal edge 144' of the shutter 144 may be appropriately shaped to meet the requirements of the work in terms of pulse length. The indicated shape of the edge 144' was selected arbitrarily for purposes of illustration herein.

In accordance with another feature of the invention, in Fig. 9 there is shown a modified timing circuit particularly adapted for controlling the operation of an oscillator in the same manner as the timing circuit of Fig. 3, for the generation of pulses. In this circuit the pulses are initiated intermittently by means of a switch 168 coordinated with the operation of the feed mechanism and the electrodes, and are of a controlled time duration. In Fig. 9, a high-frequency oscillator 158, which may replace the oscillator of Fig. 2 serving electrodes 30 and 32, is controlled by a relay 160, having a field coil 162 and a switch 164 normally held open by a spring 166. When a sufficient current flows in the coil 162, switch 164 closes and the oscillator 158 will be turned on, marking the beginning of a pulse, which may occur simultaneously, for example, with the lowering of the upper electrode 30 against the work in the apparatus of Fig. 5. The pulse is terminated by cutting off the current in coil 162 or by reducing it to a value insufficient to hold the switch 164 closed against the force of the spring 166.

The control of current in the coil 162 effectively to "pulse" the oscillator on and off intermittently depends upon a rotary switch 168, employed in place of the switch 74, Fig. 3, and comprising a conductive sleeve 170 shaped as shown, embedded

in and surrounding a cylindrical insulator 172 rotative about an axis 174, and three aligned contacts 176, 178, 180 engaging the continuous peripheral surface formed by members 170 and 172. When the switch unit, comprising members 170 and 172, rotates from the position shown (Fig. 9) in the direction of an arrow (Fig. 10), the contacts 176 and 178, which are open-circuited in their shown positions, are connected, thereby allowing condenser 182 to charge to the voltage of a direct voltage source 184. Subsequently these contacts are open-circuited and the contacts 178 and 180 connected, thereby permitting condenser 182 to discharge current through the series circuit comprising a variable resistor 186 and the parallel combination of the coil 162 and a variable resistor 188, whereupon the relay switch 164 is closed and an oscillator pulse initiated. The pulse lasts until the current through the coil 162 becomes insufficient to overcome the pull of the spring 166 because of the drop in voltage of the condenser 182, whereupon the switch 164 again opens. The cycle repeats itself with continued rotation of the switch 168. The resistor 186 may be varied to control the pulse length, i. e. the time duration of closure of the relay switch 164, as a function of work thickness by embodying such resistor in a control unit 50, and resistor 188 may be adjusted to produce different basic pulse lengths suited respectively to different work materials, thus serving the same purpose as the bank of condensers 80 of Fig. 3.

In one practical system of thus controlling the oscillator operation, the oscillator tube normally would be grid-biased negatively beyond cut-off and the bias would be removed with the closing of the relay switch 164. In this connection, it has been found desirable to shield the relay 160 from the intense fields of the oscillator 158 to prevent damage to the contacts of the relay switch 164.

Fig. 10 illustrates a suitable timing sequence governing the design of the switch 168, indicating the shape of the several segments of the conductive sleeve 170. The arc length X represents the period allowed for charging condenser 182 while the length Y represents the period of discharge thereof. The pulse will terminate at some point Z variable with changes in work thickness, but the point Z, in a practical application, will always come within the Y period at all bonding speeds and for all work thickness variations. In Figs. 11, 12, and 13 there are shown three typical positions of the switch 168 relative to the positions of the upper electrode 30 during an operating cycle with the arrangement of Fig. 9 embodied in apparatus as in Fig. 5. In Fig. 11, the electrode 30 is above the work and about to descend and the condenser 182 is in process of becoming charged. In Fig. 12, the electrode 30 has just descended on the work and the condenser 182 has commenced to discharge through the relay coil 162, initiating a pulse of energy from the high-frequency oscillator, while in Fig. 13, the electrode 30 is about to leave the work and the pulse has ended. In this figure the switch is almost in position for recharging the condenser 182 and repeating the foregoing cycle.

The form of the invention which is illustrated in Figs. 14 to 17, inclusive, utilizes a pair of opposing roll electrodes 210 and 212 between which work material 214 is fed under pressure and subjected to the heating effect of a high-frequency field extending between those portions of the peripheral surfaces of the rolls which are next to

the work. Preferably the rolls 210 and 212 are both power driven in order that they may also serve in feeding the work therebetween. These roll electrodes comprise a middle disk of conductive material sandwiched between a pair of dielectric disks. The dielectric disks facilitate the feeding of the work and prevent displacement of the softened work material up around the edges of the electrodes. The invention is, however, also applicable to machines having other electrode arrangements.

The upper electrode 210 is journaled in a bracket 216 carried at the lower end of a spring-loaded rod 218 which is slidably retained in the end of a gooseneck 220 forming a part of the frame of the machine. The electrode 210 is thus urged against the work under the pressure of a spring 222 engaging a collar 224 secured to the rod 218, and the pressure of the spring may be adjusted by means of a knurled cap screw 226. The lower electrode 212 is suitably mounted for rotation on a bracket 228 beneath a work-supporting table 230 of the machine, with the upper peripheral edge of this electrode protruding just slightly above the surface of the table 230 through an aperture 232.

Driving power for the lower electrode roll is derived from a horizontal shaft 234 connected by worm and gear 233 and pinions 235 (Fig. 16) to a main drive shaft 236 and is transmitted to the upper electrode through a series of shafts, gears, and universal joints, including joint 237, in the manner indicated. The connection of the lower electrode to the shaft 234 is through a shaft and gear transmission system 239. In the illustrated machine the main drive shaft 236 and the electrode transmission systems are conveniently geared together in such a ratio that the electrodes turn at approximately  $\frac{1}{50}$  of the speed of the shaft 236.

Forming a part of the base of the machine is a cabinet 238 housing the high-frequency oscillator circuits employed in supplying high-frequency electric energy to the electrodes. Suitable leads 240 and 242 are provided extending between the high-frequency oscillator within the cabinet 238 and brush holders 244 and 246, respectively carrying electrode-contacting brushes 248 and 250. The details of construction of a suitable brush holder are shown at 246 in Fig. 16.

In accordance with the illustrated practice of the invention, high-frequency energy is delivered to the electrodes 210 and 212 in controlled pulses wherein the pulse repetition rate is determined by means of a rotary switch 252 and an associated pulsing circuit to be described. The switch 252, employing two inlaid conductive segments 254 and 256 (Fig. 14) which periodically pass beneath and connect the switch contacts in the form of brushes 258 (Fig. 16), is mounted on the drive shaft 236 and thus rotates approximately fifty times as fast as the electrodes 210 and 212 and, as will be further described later herein, a pulse of high-frequency energy is delivered to the electrodes each time one of the conductive segments 254 or 256 engages the switch contact brushes 258. Suitable leads 262 (Fig. 14) extend from the respective contact brushes to the high-frequency oscillator cabinet and therein to an oscillator pulsing circuit in a manner to be described.

In accordance with the foregoing, approximately 100 pulses of energy are supplied to the electrodes for every revolution thereof and it will be appreciated, therefore, that successive fractional

bonding areas of the work coming between the electrodes will each receive a pulse of energy in forming a continuous bond between the work parts. It will be appreciated further that the amount of heat generated in the work in each of these areas and, therefore, the quality of the resulting bond, may be made substantially independent of bonding speed. The pulse repetition rate may readily be varied, by modifying the driving apparatus so as to vary the amount of spacing or overlap between these successive fractional bonding areas so that a segmented or a continuous seam may be produced in the work, as desired.

Further in accordance with an arrangement to be described, the energy content and here the amplitude of a pulse delivered in a fractional bonding area is predetermined in accordance with the thickness of the work in such area. By this means the desired substantially proportional relation between heat energy produced and volume of work to be heated may be maintained in a most expeditious manner, and fully automatic compensation may be achieved in respect to both changes in bonding speed and in work thickness, during a bonding operation. Thus the operator by means of a suitable control, such as a treadle (not shown), may freely vary the speed of the machine without attention to the bonding effect and may thus devote his entire attention to manipulating the work about the electrodes.

Fig. 15 shows diagrammatically the manner in which the amplitude of the pulses is varied in proportion to changes in the thickness of the work and its arrangement is similar to the diagram of Fig. 1. Thus sheets of plastic material 10, 12, 14 and 16 passing between electrodes 210 and 212 will be seen to have, in sections a, b, c, d and e, thicknesses of 2, 4, 6, 8 and 2 layers, respectively. As these sections are treated, pulses of an amplitude corresponding to the thickness under treatment are represented by Aa, Ab etc.; it being understood that the number of pulses depends on the length of the sections as before.

In controlling the amplitude of the pulses as a function of work thickness in accordance with the present invention, a control unit 264 is provided, comprising a variable resistor 266, a gear rack 268, resistor-driving gears 270 connected to the rotary contact arm of the variable resistor, and a suitable spring 272 encircling a rack bar 274 and maintaining an upward pressure against a collar 276 secured to the rack bar 274, substantially as disclosed in Fig. 4. The position of the rotary contact arm of the variable resistor is determined in accordance with the vertical position of the upper electrode 210 and, hence, in accordance with work thickness. For this purpose, an arm 278 is provided which is integral with the collar 224 fixed to the vertical rod 218, and this arm has a horizontally projecting finger 280 overlying a pin 282 carried at the bottom of the rack bar 274, the pin 282 being forced continuously into contact with the finger 280 by the action of the spring 272. Thus the position of the gear rack 268 and thereby of the contact arm of the variable resistor 266 is determined continuously in accordance with the thickness of the work. As has been described in connection with Fig. 4, in further detail, the resistance value of the variable resistor will determine the amplitude of the pulses of energy delivered to the electrodes in accordance with work thickness, the resistance element being connected in the electrical circuit through leads 284.

Referring now to Fig. 17, the drive mechanism is indicated symbolically at 236 while the electrodes 240, 212 and the rotary switch 252 are shown as mechanically connected thereto as previously described. The pulse generator circuits are shown divided into three sections: a high-frequency oscillator 288, a pulsing circuit 290, and an oscillator voltage-supply circuit 292. The oscillator 288 comprises a conventional tuned-grid, tuned-cathode circuit while the voltage-supply circuit 292 comprises a controlled full-wave type rectifier utilizing gas-filled, grid-controlled rectifier tubes 294 and 296. The pulsing circuit 290 acts effectively as a switch turning on and off the supply-line voltage to the oscillator voltage-supply circuit 292 to pulse the oscillator 288, the switching leads being shown at 298 and 300, and supply-line voltage being applied at terminals 302 and 304.

The pulsing circuit 290 comprises essentially a relay having switches 306, 308, 310 and a field coil 312, a source 314 of constant voltage, a storage condenser 316 and a variable resistor 318. The switching leads 298 and 300 are effectively connected by the relay switch 308, thereby transmitting voltage to the voltage-supply circuit 292 each time one of the conductive segments 254 or 256 of the rotary switch 252 passes beneath the contact brushes 258. The length of time during which the leads 298 and 300 are thus effectively connected, or the corresponding length of the pulses of energy from the oscillator, is determined by means within the pulsing circuit 290 and may be adjusted by means of variable resistor 318 which determines the flow of current through the relay coil 312 from the storage condenser 316. While the contact brushes 258 of the switch 252 rest against an insulating portion of the switch, the relay switches 306, 308 and 310 are held in the position shown by a tension spring 320 within the relay and no current will flow through the relay coil 312. The storage condenser 316 will then be charged to the voltage of the direct current source 314 through a circuit including relay switch 310. At the instant the contact brushes 258 are connected, a direct current will flow through the relay field coil 312, through the brushes 258 from both the direct current source 314 and the storage condenser 316. At this instant, the relay switch 310 will be opened and the switches 306 and 308 closed, whereby the direct current source 314 will be removed from the circuit, the brushes 258 bypassed by the circuit connection formed through relay switch 306, the leads 298 and 300 will be connected through the relay switch 308 and the storage condenser 316 will commence to discharge through a circuit including relay field coil 312 and the variable resistor 318 in parallel. The length of the ensuing pulse will be determined by the time of discharge of the storage condenser 316, or the time required for this discharge current, flowing through the relay field coil 312, to drop to a value at which the spring 320 overcomes the pull of the relay and again brings the relay switches into their normal position, as shown. The time of discharge of the storage condenser 316 may be regulated manually by means of the variable resistor 318, thereby regulating the pulse length.

If, by chance, the machine should be stopped at a point mechanically where one of the conductive segments 254 or 256 rests beneath the contact brushes 258 of the switch 252, it may be possible for the oscillator to be set in continuous operation. This is undesirable and may be

avoided in various ways, for instance, by the insertion of a blocking condenser 313 in one of the leads 262, whereby a pulse of current sufficient to actuate the relay may be transmitted through such condenser and through the leads 262 and the brushes 258 of the switch 252, but a continuous flow of current through this path will be blocked because of the rapid accumulation of an opposing charge on the plates of the condenser 313. A bypass resistor 315 may be connected in parallel with the condenser 313 to remove this charge normally during periods between pulses. However, this resistor should have sufficient resistance to suppress the direct current, which it will permit to flow in the leads 262, to a value insufficient to actuate the relay during the time the machine is stopped at the above-said point.

In the operation of the voltage supply circuit 292, and in connection with the manner of controlling the pulse amplitude of the high-frequency energy produced by the oscillator 288, the oscillator plate voltage is controlled effectively by regulating the amount of rectification in the rectifier tubes 294 and 296. This is accomplished by means of a grid-voltage-phasing circuit comprising the variable resistor 266 (adjusted in value as previously described as a function of work thickness), a condenser 321, and a secondary winding 322 of a grid voltage transformer 324. This phase-shifting circuit may be of a conventional type, as shown, and acts to shift the phase of the alternating voltage applied to the grids of the rectifier tubes 294 and 296, with respect to the alternating voltage applied to the anodes of these tubes through a main power transformer 326. Thus, in accordance with the accepted understanding of the resulting operation of the rectifiers 294 and 296, the point during the anode voltage cycle at which the respective tubes conduct, during each cycle, is determined by the amount of phase shift between the anode voltage and the corresponding grid voltage. As a result, the rectified output voltage appearing on the lead 328 and thereafter filtered by means of a condenser 330 and an inductance 332 will depend upon the amount of this phase shift and, therefore, upon the value of the resistance of the variable resistor 266. Thus, the delivered plate voltage and hence the power output of the oscillator 288 will be varied with changes in work thickness as desired.

In accordance with preference, it may be desirable to effectively calibrate the apparatus in order to take into account any nonlinear effects in the circuits or in the conversion of high-frequency energy into useful heat in the work, thereby to provide the exact desired relationship between the pulse amplitude and the work thickness. This may readily be done by carrying out a plan of calibration in which different typical work thicknesses will be bonded between the electrodes while using a variable calibrating resistor in the circuit, in place of the resistor 266, to determine the exact desired value of resistance for a particular work thickness, the value selected preferably being such that the bonding voltage will be somewhat below the maximum permissible value. A series of such determinations will permit the determination of the desired resistance variation with work thickness and, consequently, will permit the design and construction of a variable resistor 266 having such a resistance variation. Such resistors are readily constructed and the resistance element

may be wound or drawn in accordance with any predetermined resistance variation, for the present purpose. Alternatively other forms of control, such as photoelectric control, may be employed in securing a circuit effect related to work thickness, as in the arrangement shown in Figs. 6 and 7.

The invention thus illustrated in connection with high-frequency progressive bonding by means set forth is not limited in these respects, as will be appreciated by those skilled in the art. It is broadly applicable to any progressive treating application, using an electric discharge or field wherein there is relative progressive movement between the work and an applicator and wherein the power delivered may be controlled in the described manner, i. e. by the control of energy content, as a function of variations in treating requirements of the work, or also by the control of pulse repetition rate as a function of rate of progression of said applicator relative to the work. Moreover other types of electrodes and feed motion may be employed than those herein described, when progressively bonding thermoactive work parts.

This application is a continuation in part of an application for United States Letters Patent Serial No. 716,939 filed December 18, 1946, in my name, now abandoned.

Having thus described my invention, what I claim as new and desire to secure by Letters Patent of the United States is:

1. In progressive bonding apparatus adapted for seaming together articles of thermoactive sheet material or materials coated with thermoactive adhesives during the process of which are encountered varying numbers of sheets in stacked relation, electrode means adapted for relative movement toward and away from each other and between which the work may be advanced, means for relatively separating and bringing together said electrode means to bear mutually against the work intermittently, means cooperative with said latter means for advancing the work during periods when one of said electrode means is apart from the work, high-frequency voltage supply means connected to said electrode means, means for rendering said supply means operative when said electrode means are brought together, and means for rendering said supply means inoperative before said electrode means are separated and after a time interval determined automatically by means responsive to the distance between said electrode means.

2. In progressive high-frequency bonding apparatus having electrode means between which the work may be passed, means for advancing the work past said electrode means, high-frequency oscillator means connected with said electrode means, control-circuit means comprising relay means for controlling said oscillator, a storage condenser, a source of direct voltage, switching means cooperative with said work-advancing means intermittently to charge said condenser from said direct voltage source and to discharge said condenser through the field coil of said relay, said relay turning on said oscillator only during the initial discharge period of said condenser, said period ending when the discharge current of said condenser falls to a predetermined value, and means comprising a variable resistor together with means for adjusting said resistor in accordance with the thickness of the work between said electrode means, for determining the

rate of discharge of said condenser thereby to determine the length of said period.

3. Electrical heating apparatus of the class described, comprising electrodes arranged to engage opposite surfaces of a workpiece for setting up a field in the work, means for feeding the workpiece progressively past said electrodes, high-frequency oscillator means triggerable for supplying pulses of electrical energy to said electrodes, trigger means operatively connected to said feeding means for triggering said oscillator means at a repetition frequency substantially proportional to the speed of operation of the feeding means, a control for said oscillator means to adjust the length of the pulse of high-frequency energy supplied by the oscillator means to the electrodes, and a sensing device connected to said control and responsive to the thickness of the work in an area adjacent to the electrodes to operate said control to increase or decrease the length of said pulses in response respectively to an increase or decrease in said thickness.

4. In progressive bonding apparatus adapted for seaming together thermoactive sheet materials, electrode means for producing a field in the work, work feed means for advancing the work progressively through the field region of said electrode means, a predetermined-pulse-length high-frequency electrical pulse generator for supplying pulses of electrical energy to said electrode means, trigger means operatively connected with said feeding means for triggering said generator to cause said generator to supply pulses of electrical energy to said electrodes at a repetition frequency substantially proportional to the speed of operation of the feeding means, a control for said generator operable to adjust the voltage amplitude of the pulses of electrical energy supplied to the electrodes, and a sensing device responsive to variations in the thickness in the workpiece adjacent to the electrodes and connected to said control to operate the control to increase or decrease the voltage amplitude of the pulses of electrical energy supplied to said electrodes in response respectively to increase or decrease in the work thickness.

5. In dielectric heating apparatus, the combination of electrodes arranged to engage opposite surfaces of a workpiece, means for feeding

a workpiece past the electrodes, a high-frequency electrical pulse generator, means for connecting the output of the generator to the electrodes, said generator including an oscillator and a control operatively connected to the oscillator, said control being triggerable to cause said generator to supply pulses of electrical energy to said electrodes, means operatively connected with said feeding means for triggering said control means at a repetition frequency substantially proportional to the speed of operation of the feeding means, a second control for said pulse generator operable to adjust the energy content of the pulse of high-frequency energy supplied by the oscillator to the electrodes, and sensing means responsive to variations in the thickness of the workpiece adjacent to said electrodes and connected to said second control to operate said second control to increase or decrease the energy content of the pulses in response respectively to increase or decrease in the work thickness.

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