United States Patent

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[54] **ELECTRON BEAM HEATING APPARATUS AND CONTROL SYSTEM THEREIN**
8 Claims, 7 Drawing Figs.

[52] U.S. Cl. 13/31
[51] Int. Cl. H05b 7/00
[50] Field of Search ..... 13/31, 12; 219/121 EB

[56] **References Cited**
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ABSTRACT: Electron beam heating apparatus is described in which the electron beam is deflected to a series of impact positions on a target surface. Signals for operating deflecting fields are produced by signal-generating means having provision for adjusting the duration at which the signal is at any given level. The energy applied to the target surface by the beam at any of the plurality of impact positions is thereby controllable by controlling the length of the time during which the beam is directed at each position.

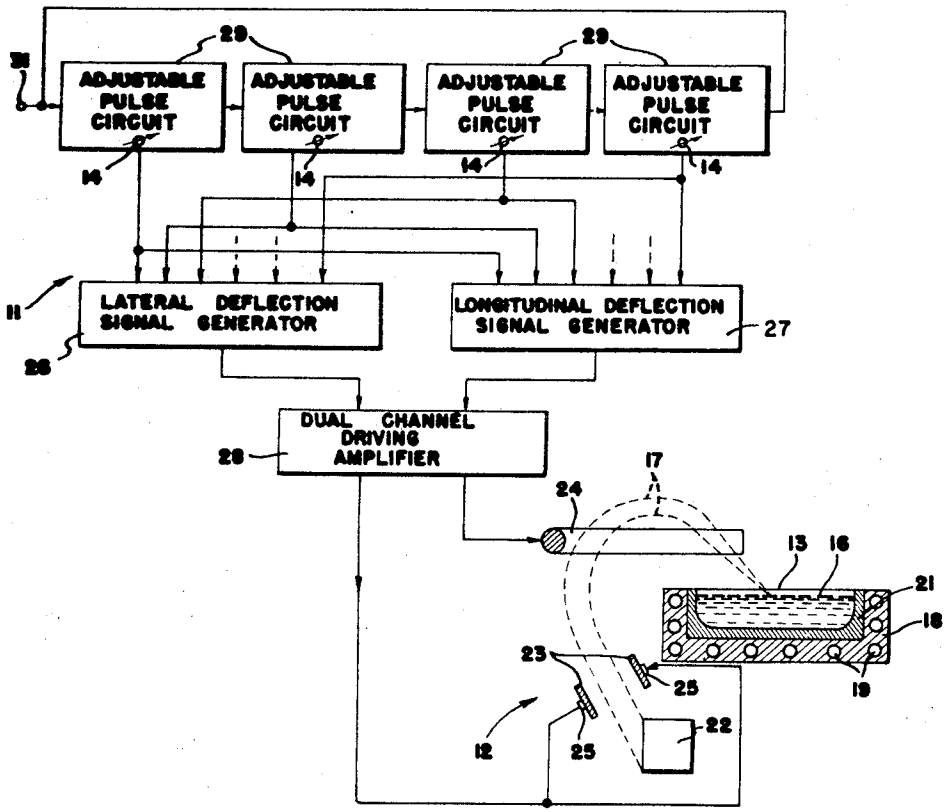


FIG.2

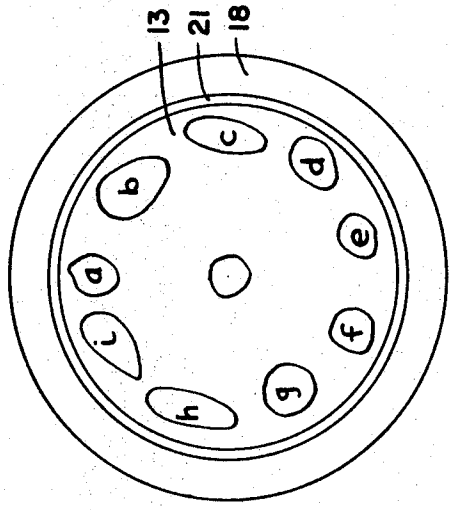
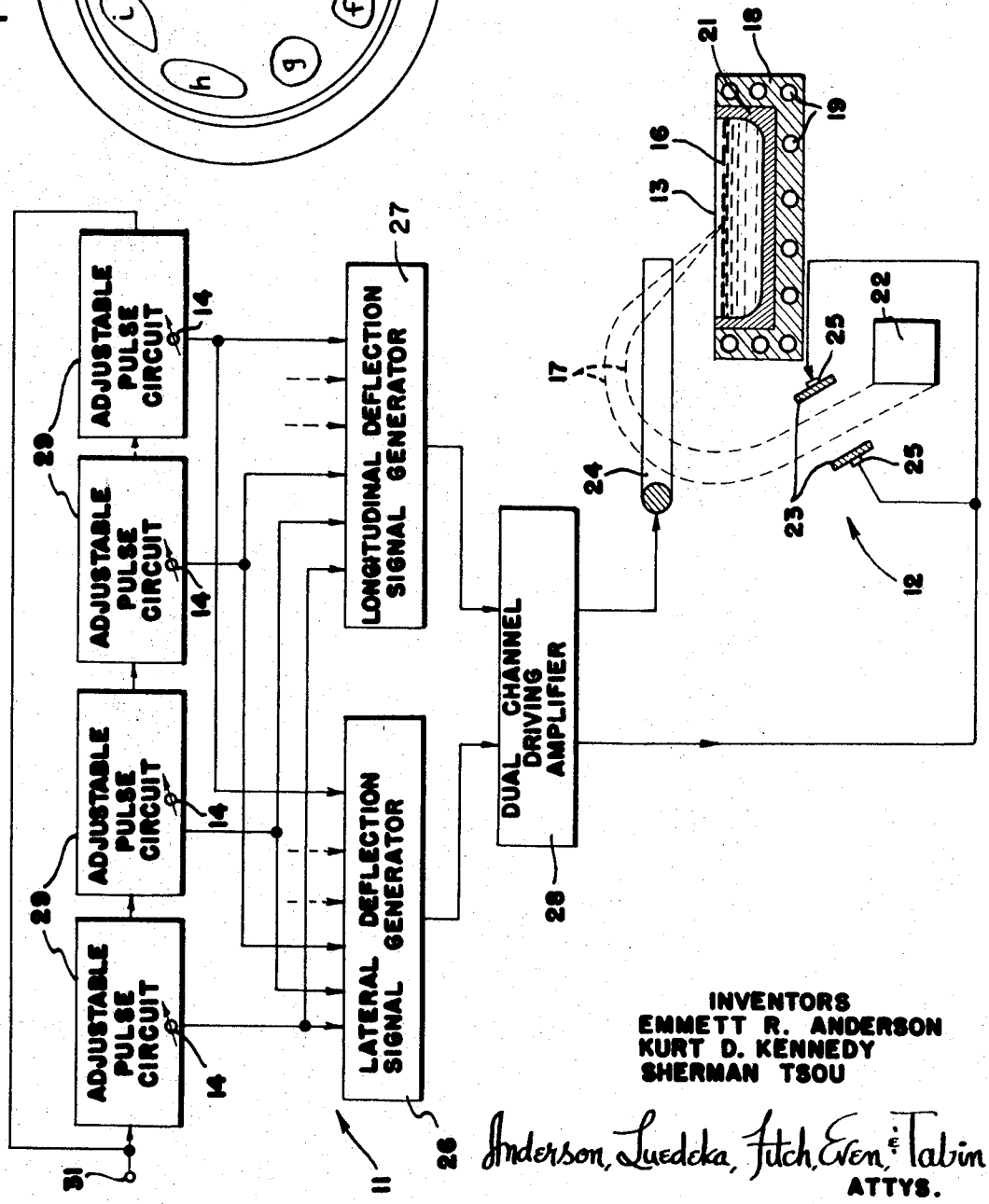


FIG.1



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FIG.3

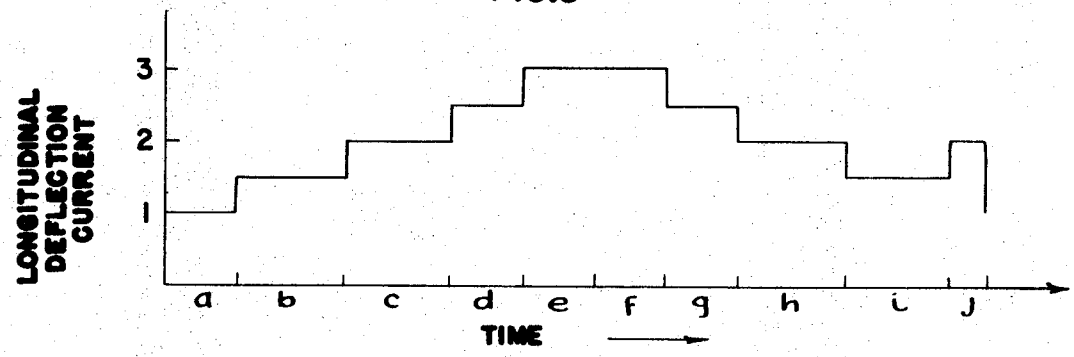


FIG.4

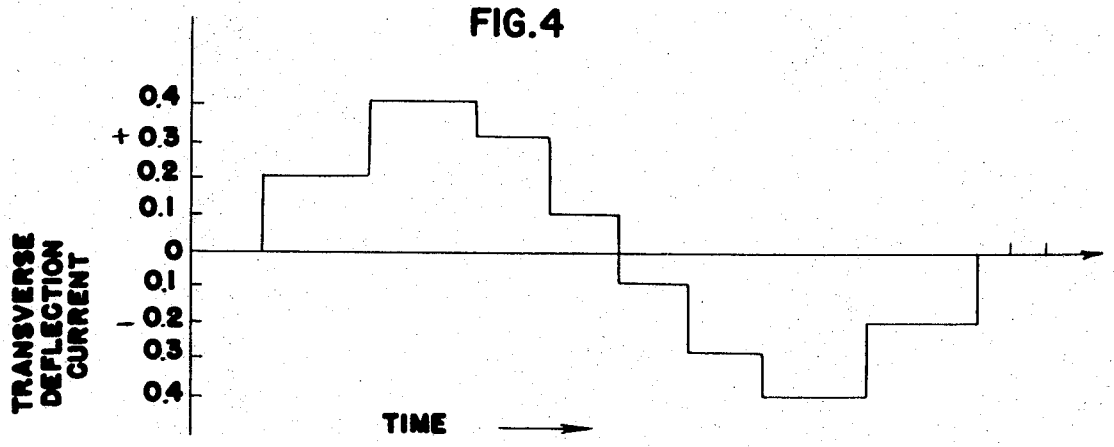
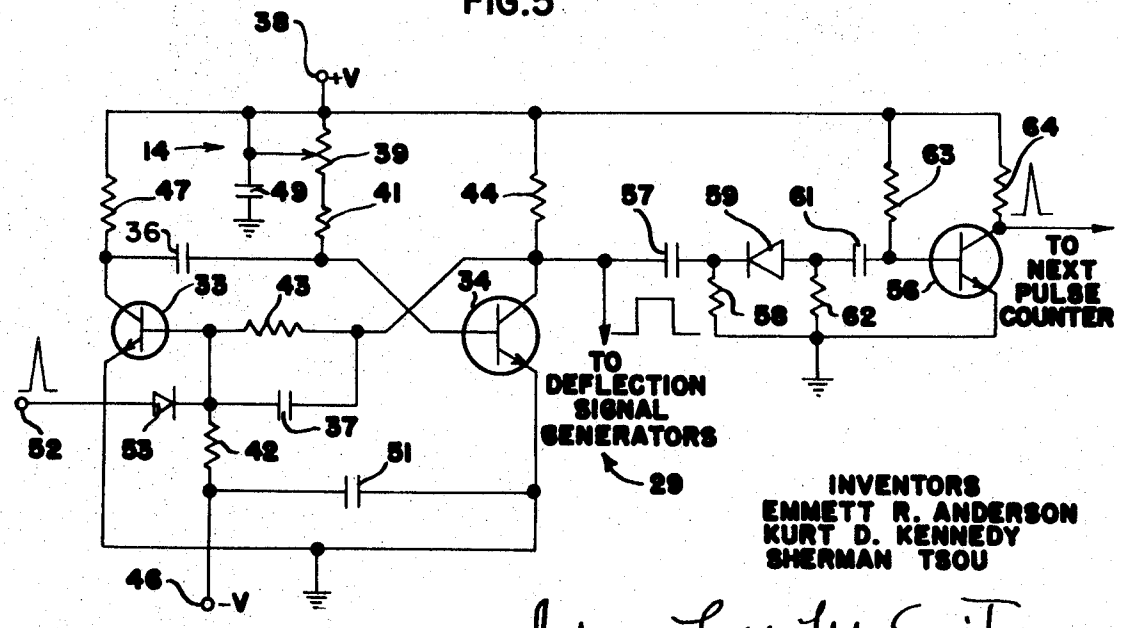


FIG.5



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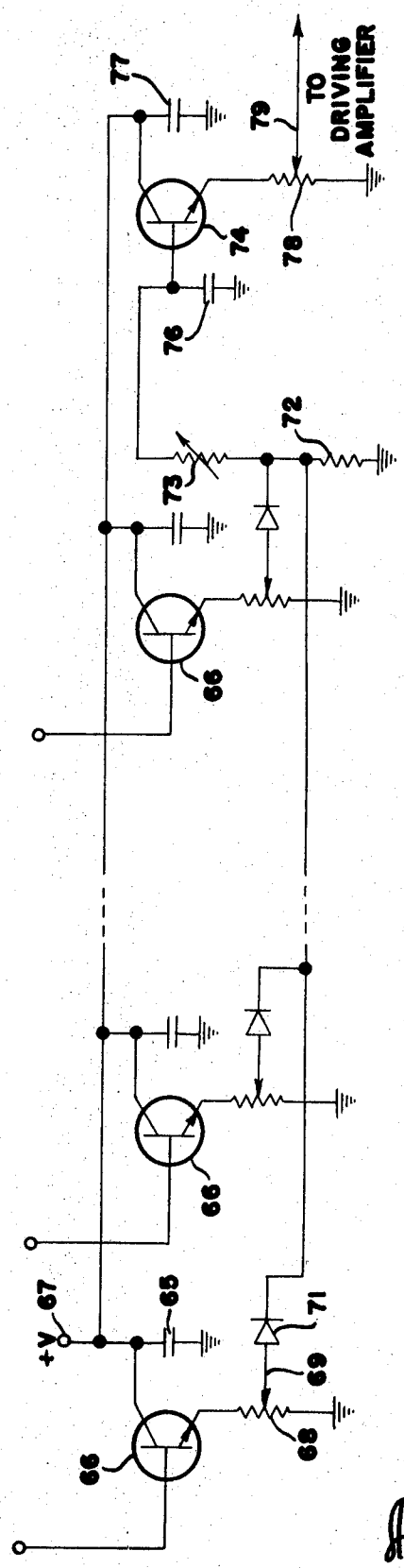


FIG.6

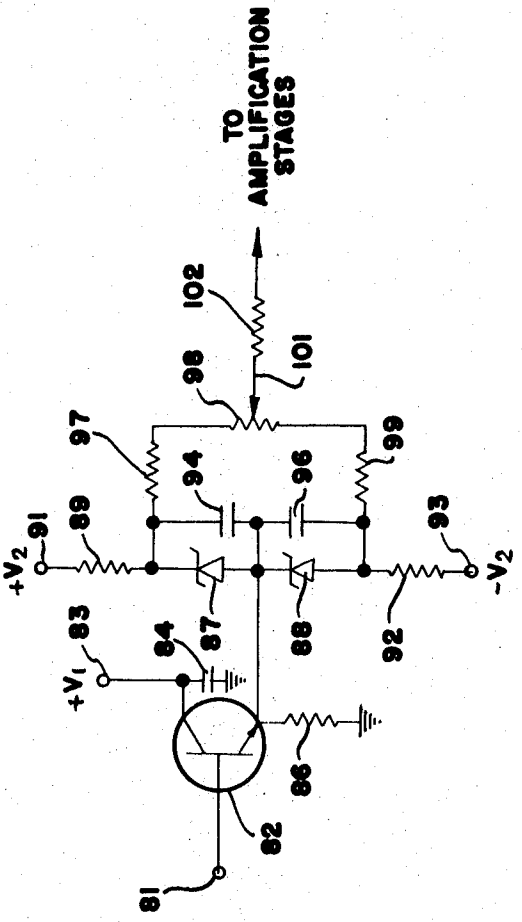


FIG.7

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ELECTRON BEAM HEATING APPARATUS AND CONTROL SYSTEM THEREIN

This invention relates to electron beam heating and, more particularly, to electron beam heating apparatus for heating a target surface and to a control system for use therein.

Electron beam furnaces of a variety of designs are useful in the processing of many metals, alloys or other materials, for example where high standards of purity are to be achieved by outgassing or by avoiding reaction with oxygen and nitrogen, or where a substrate is to be coated by vaporization and condensation of the material. The electron beams are a particularly useful form of heating in that it is possible to inject heat into a melt locally. Electron beam furnaces typically include an evacuated enclosure, a container for the molten material being processed, and an electron beam heating system comprising one or more electron beam guns with associated deflection and control systems for directing and focusing the beams.

Depending upon the particular type of processing being carried out, the container for the molten material may take a variety of forms. In a situation where it is desired to evaporate the material in the container and subsequently condense the material on a suitably supported substrate to coat the substrate, a typical container consists of an open-top upright crucible. Electron beam heating enables the crucible itself to be cooled and thereby form a skull of solidified molten material between the crucible and the molten material. This protects the purity of the molten material and makes it unnecessary to use high temperature refractories for the crucible construction.

Another type of processing is the purification of metals and alloys by passing the molten metal or alloy over a shallow hearth. Exposure to the vacuum with coincident electron beam heating of the surface causes many volatile impurities and occluded gases to be drawn off of the molten material and thereby produces a purified product. Other forms of containers which may be utilized include tundishes, launders, and ladles for transferring molten material between various points. Electron beam heating may be utilized to maintain the material in a molten condition while in such containers.

During the processing of molten material in an electron beam furnace, vaporized material may present ionization problems or may coat the various parts of the electron beam gun, impairing its operation. Moreover, spalling of condensed materials from cool surfaces of the vacuum enclosure, and splashing and splattering of the molten material from the crucible, may also impair operation of the electron beam gun. By positioning the electron beam gun underneath the container of the molten material and by deflecting the electron beam through a curving path of 180° or more, contamination and shorting of the electron beam gun is minimized.

In electron beam furnaces in which large target surfaces are to be heated, it is often desirable to sweep the beam through a predetermined pattern over the target surface in order to minimize the number of electron beam guns required. In order to achieve the desired electron beam sweeping while deflecting the beam through more than 180°, transverse magnetic fields which are variable in strength are typically utilized. If an orthogonal sweep pattern along x- and y-axes is desired, two transverse fields in the electron beam path may be utilized. Such fields have their flux lines oriented to cross the beam path generally perpendicular thereto and from directions which, in relation to the beam path, are effectively normal to each other.

Typically, magnetic field strength is varied by varying the current flowing through the windings of the electromagnet used to establish the field. The position of the beam on the target along the particular axis which the field controls is then some function of the current that is applied to the electromagnet. When the beam is to be swept in a repetitive pattern, a correspondingly repetitive current wave is applied to the electromagnet. If a triangle wave is applied, a sweep will be generated in which a constantly varied beam motion will occur. However, there are occasions on which it is desirable to

inject more power into certain parts of the target than into other parts. This may be accomplished by generating a specially shaped wave to vary the sweep rate or direction of the beam, but it is often difficult to synthesize a wave of a complex shape that may be necessary for all possible heat patterns desired.

To alleviate the foregoing problem and thereby provide for varying the power injected into certain parts of a target without necessitating the generation of complex waves, control systems have been developed which synthesize the sweep wave digitally. This is done by producing a staircase waveform which approximates the analogue wave that is desired. Heretofore known systems of utilizing this principle have varied the heat pattern by varying the concentration of digitally determined beam impact positions on a given section of the target surface as compared with other sections of the target surface. Since only a fixed number of impact positions are typically available, however, it is necessary to shift the total distribution of positions when it is desired to redistribute the heat pattern. Some limitations in achieving certain desired heat patterns are encountered in such systems. Moreover, the necessity for changing the overall position distribution, when it is desired to change the heating pattern, introduces a considerable degree of inconvenience and complexity.

Accordingly, it is an object of the present invention to provide improved electron beam heating apparatus for heating a target surface.

Another object of the invention is to provide an improved control system for use in electron beam heating apparatus.

A further object of the invention is to provide a control system for use in electron beam heating apparatus in which the energy applied to the target surface by the beam may be applied in a wide variety of patterns.

It is another object of the invention to provide a control system for use in electron beam heating apparatus wherein the energy applied at the target surface by the beam at any of a plurality of digitally determined impact positions during a beam sweep is controllable in accordance with the length of the time during which the beam is directed at such position.

Other objects of the invention will become apparent to those skilled in the art from the following description, taken in connection with the accompanying drawings wherein:

FIG. **1** is a partially schematic and partially block diagram of electron beam heating apparatus incorporating the invention;

FIG. **2** is a schematic plan view illustrating a sequence of beam impact positions on the surface of a target for purposes of an example of one particular manner in which the invention may be operated;

FIGS. **3** and **4** are plots of current versus time illustrating examples of output signals which may be produced by the control system of the invention;

FIG. **5** is a schematic diagram of an adjustable pulse circuit which may be utilized in the system of FIG. **1**;

FIG. **6** is a schematic diagram of a signal generator which may be utilized in the system of FIG. **1**; and

FIG. **7** is a schematic diagram of a portion of a driving amplifier which may be utilized in the system of FIG. **1**.

Very generally, the control system of the invention comprises signal-generating means **11** for producing at least one electrical signal of varying amplitude to cause the heating apparatus **12** to sweep an electron beam over a target surface **13**. The electrical signal has a plurality of discrete levels representative of a corresponding plurality of beam impact positions on the target surface. Control means **14** are provided in the signal-generating means for controlling the time interval for which the signal is at any of the discrete levels.

Referring now more particularly to FIG. **1**, the electron beam heating apparatus **12** incorporating the invention is illustrated. The illustrated target is a pool of molten material **16** which is heated by injecting heat into its exposed surface **13** by means of an electron beam, the envelope of which is indicated by the dotted lines **17**. The molten pool **16** is contained within

a crucible **18** having a plurality of coolant passages **19** therein through which a suitable fluid coolant is circulated. Cooling of the crucible forms a skull **21** of solidified molten material between the molten pool **16** and the inner walls of the crucible **18**. This aids in maintaining the purity of the molten material and in avoiding interaction between the molten material and the crucible material.

The electron beam **17** is produced by a suitable electron beam gun **22**. In the illustrated system, the electron beam gun is located below the level of the surface **13** beneath the crucible **18** in order to protect the gun from evolved vapors and splattered material. The illustrated gun produces an electron beam **17** which is of a cross section approximating an elongated oval, such beam typically being referred to as a ribbon-shaped electron beam. Such beams are produced by the use of an elongated emitter or filament from which the electrons are accelerated in a path which is normal or nearly normal to the filament. An electron beam gun of suitable construction for this purpose is shown and described in U.S. Pat. No. 3,170,019 assigned to the present assignee. It is to be understood, however, that the invention is not limited to the employment of such electron beam guns.

The electron beam is directed onto the surface **13** of the molten pool **16** by means of a suitable deflection system. The particular illustrated system is intended to be only one example of a system capable of sweeping the beam as described below. For example, other deflection systems capable of sweeping the beam are shown and described in U.S. Pat. Nos. 3,446,934; 3,235,647; and 3,390,222, all assigned to the present assignee. Step waveforms may be produced in accordance with the present invention to operate such deflection systems as described in the above patents, or other types of deflection systems as well. The nature of such waveforms is dependent upon the type of deflection system used and upon the desired sweep pattern.

The illustrated deflection system includes a pair of magnetic pole pieces **23** and a further pair of magnetic pole pieces **24**, only one of which is visible. The pole pieces **23** are energized by the signal-generating means **11** by providing an electrical current through suitable energizing coils **25**. The passage of current through the coils causes a magnetic field to be established extending between the pole pieces **23** transversely to the path of the electron beam **17**. A magnetic field is established between the pole pieces **24** in a similar manner by appropriate energizing coils, not shown, to which electrical signals from the signal-generating means **11** are applied. It may be noted that the direction of the magnetic fields extending between the pole pieces **23** and the pole pieces **24** are oriented 90° with respect to each other and the path of the electron beam. Variation in the strength of the magnetic fields between the pole pieces **23** and between the pole pieces **24** may thereby be effected to cause movement of the beam along *x*- and *y*-axes. By applying appropriate signals to the energizing coils for the deflection plates **23** and **24**, the electron beam **17** may be swept in a pattern or raster over the surface **13** to effect heating of the molten material by injecting heat therein to at the surface. The magnetic field between the plates **24** is varied about a predetermined DC level in order to maintain a field strength sufficient to bend the beam through a curving path down onto the surface **13**. The field between the deflection plates **23** and **24** also has a focusing affect on the electron beam to alter the beam cross section to an approximately round shape at the target surface.

In order to produce electrical signals of varying amplitude to cause the heating apparatus to sweep the electron beam over the target surface, the illustrated signal-generating means **11** include a pair of deflection signal generators **26** and **27**. The lateral deflection signal generator **26** provides signals through one channel of a dual-channel driving amplifier **28** to the energizing coils **25** for the pole pieces **23**. The longitudinal deflection signal generator **27** provides similar signals through the other channel of the amplifier **28** for the unillustrated energizing coils of the pole pieces **24**. A preferred deflection signal generator for this purpose is described below, but other types of circuits for producing a step function voltage or current output in response to input control signals may be used under some circumstances. Accordingly, control over the electron beam on the respective *x*- and *y*-axes is effected by changing the strength of the deflecting fields between fixed levels.

In order to provide control signals for the signal generators **26** and **27** and thereby cause the signal generators to change their output levels and thus move the electron beam to a new position on the surface of the target, the signal-generating means include a series of pulse circuits **29**, each having a first pulse output connected to each of the deflection signal generators **26** and **27** and a second pulse output connected to the next succeeding pulse circuit. The series of pulse circuits **29** form a ring counter. The adjustable nature of each of the pulse circuits **29** enables adjustment of the time between receipt of an input pulse from the immediately previous pulse circuit and the production of an output pulse at each of the two outputs. The first of the pulse circuits **29** is coupled to a start terminal **31**. The output of the last pulse circuit is fed back to the input of the first pulse circuit. The number of pulse circuits utilized corresponds to the number of discrete target positions desired for the beam sweep. The ring counter operation may be initiated by applying a suitable momentary pulse to the terminal **31**, and may be stopped by removing B+, not shown.

By way of example, and referring to FIG. **2**, a circular target surface **13** is shown for molten material contained within a circular crucible **18**. A 10-position sweep pattern is shown on the surface **13** designated by the spots labeled *a*—*j*. Assuming that a zero current output from the signal generator **26** and a 2-ampere current output from the signal generator **27** positions the beam at the spot *j*, the necessary output signals from the deflection signal generators **26** and **27** to sweep the beam through the positions from *a* to *j* are shown in FIG. **3** and FIG. **4**, respectively. Thus, at position *a*, the output signal from the signal generator **26** is at 0 while the output signal from the signal generator **27** is at 1 ampere. At position *b*, the lateral output is moved to 0.2 whereas the longitudinal output moves to 1.5. The output signals continue in this manner until the beam is moved through a succession of positions *a*—*i* and back to the position *j* once again. A feedback signal from the last pulse circuit to the first pulse circuit may start the sequence all over again. As will be explained, each change in current levels by the deflection signal generators **26** and **27** in accordance with a programmed pattern is initiated by receipt of a pulse from a respective one of the pulse circuits **29**.

In order to vary the residence time of the beam at any particular one of the lettered positions, the pulse circuits **29** are made adjustable by the control means **14**. Thus, the length of time the output signals from the deflection signal generators **26** and **27** remain at any given level may be adjusted by suitable adjustment of the pulse circuits **29**. By way of example, but not intending to be limited thereby, one possible way of utilizing the invention will now be discussed. In the sweep pattern of FIGS. **3** and **4**, it may be desirable that the beam remain longer at the positions *b*, *c*, *h* and *i* than at the remaining positions, since the beam spot size may be larger at these positions due to the nature of the deflection system, with a corresponding reduction in heat transfer rate. By holding the beam longer at these regions of slower heat transfer, a more uniform temperature distribution in the molten pool may be achieved. On the other hand, the residence time required for the beam at the position *j* may be quite small, since the heat losses from the pool at this position are minimal and since the beam is sharply focused at this position. As may be seen in FIGS. **3** and **4**, the length of the time during which the signals are appropriate for directing the beam to the positions *b*, *c*, *i* and *j* is 50 percent longer than the duration of the time during which signal levels are appropriate for directing the beam to the locations *a*, *d*, *e*, *f* and *g*. Moreover, the signals are at appropriate levels for directing the beam to the position *j* for a duration of time

which is only one-third that of the time at which the beam is at positions *b*, *c*, *h* and *i*. Those skilled in the art will perceive that many variations are possible depending upon the particular heating pattern desired. By heating in this manner, the distribution of the various beam impact positions may remain the same, but the heat pattern may be radically changed by suitable variation of the time at which the beam is directed at any of the impact positions.

Referring now to FIG. 5, a particular circuit suitable for use as one of the pulse circuits **29** is shown. The pulse circuit is a unistable multivibrator followed by a trigger stage. The multivibrator portion of the pulse circuit includes a pair of NPN transistors **33** and **34** having common emitters. The transistors are connected in typical multivibrator fashion, with the collector of the transistor **33** being connected to the base of the transistor **34** through a capacitor **36**, and with the collector of the transistor **34** being connected through a capacitor **37** to the base of the transistor **33**. The transistor **34** is normally biased to conduction from a positive voltage source **38** through a variable resistor **39** and a fixed resistor **41** connected to the base of the transistor **34**. The transistor **33** is normally biased to cut off by connection through a resistor **42** to a source **46** of negative voltage. The resistor **43** couples the base of the transistor **33** to the collector of the transistor **34**, and the resistor **44** connects the collector of the transistor **34** to the positive source **38**. A collector resistor **47** is provided for the collector of the transistor **33** connected between the collector of the transistor and the positive source **38**. The tap on the variable resistor **39** is connected to the positive source **38**, and is provided with a filter capacitor **49** to ground. The emitter of the transistor **34** is connected through a filter capacitor **51** to the negative source **46**, and the input terminal **52** of the multivibrator is connected through a diode **53** to the base of the transistor **33**.

As previously mentioned, the transistor **34** is normally conducting and, therefore, the output of its collector is at reference or ground potential. Moreover, the transistor **33** is normally biased to cut off by the negative source **46**. An input pulse of the shape indicated adjacent the terminal **52** is provided to initiate triggering of the multivibrator. This pulse may be provided from the start terminal **31** (FIG. 1) or by feedback from the last pulse circuit (FIG. 1). In either case a positive pulse applied through the diode **53** to the base of the transistor **33** turns on the transistor **33**. This effectively grounds the base of the transistor **34** through the capacitor **36** and the transistor **33**, cutting off the transistor **34**. The output at the collector of the transistor **34** is a square wave pulse, the width of which is determined by the off time of the transistor **34**. The off time of the transistor **34** is determined by the control means **14**, which is an RC circuit consisting of the capacitor **36** and the resistors **39** and **41**. When the transistor **34** is turned back on due to the return of its base potential to positive, the voltage on the collector drops back effectively to ground, allowing the negative source **46** to bias the transistor **33** to cut off once again.

The square wave output at the collector of the transistor **34** produced by operation of the multivibrator is applied to the deflection signal generators as indicated by the arrow, and the shape of such wave is indicated adjacent the arrow. The width of this wave determines the duration at which the respective signal generators **26** and **27** (FIG. 1) remain at the desired output levels. The width of this wave is regulated or controlled by varying the position of the tap on the variable resistor **39**.

In addition to application to the deflection signal generators, the output signal of the multivibrator portion of the illustrated circuit is applied to a trigger circuit including an NPN transistor **56**. The signal is applied to the base of the transistor **56** through a differentiator including a capacitor **57** and resistor **58**. A diode **59** passes the negative portion of the differentiated pulse, and a coupling capacitor **61** applies this negative pulse to the base of the transistor **56**. The junction between the diode **59** and capacitor **61** is connected to ground through a resistor **62**. The transistor **56** is normally biased to conduction through a resistor **63** connecting the base of the transistor to the positive source **38**. The transistor **56** conducts from the positive source **38** through a collector resistor **64** to ground, thereby maintaining the output at the collector of the transistor at reference or ground. Upon receipt of a differentiated pulse at the base of the transistor **56**, the transistor is briefly cut off, causing the output at the emitter to pulse as indicated in the waveform adjacent thereto. The emitter is coupled to the next succeeding pulse circuit as shown by the arrow, or in the case of the last pulse circuit, it is coupled back (FIG. 1) to the input side of the first stage.

Although a particular circuit has been shown and described in connection with the pulse circuits **29**, it is to be understood that any other suitably appropriate circuit may be utilized. Such circuit should provide for variable output time in order that the dwell time of the beam at any of the given impact positions is readily controllable. Accordingly, the energy applied to the target surface by the beam at any of the plurality of impact positions through which it is swept is controllable.

Referring now to FIG. 6, a portion of a signal generator which may be utilized as either the lateral deflection signal generator **26** or the longitudinal deflection signal generator **27** is illustrated schematically. The signal generator includes a series of transistor stages **66**, each corresponding to a different one of the 10 beam positions *a*—*j*. The base of each of the transistors **66** is connected to a respective one of the pulse circuits **29**, to the collector of the transistor **34** (FIG. 5) therein. This is true for the corresponding stages in both signal generators, so that each pulse circuit controls one stage in each signal generator. Preferably, the connection of the bases of the transistors **66** to the respective pulse circuits **29** is made through a suitable gate circuit which will remove any spurious pulses produced by the ring counter and thus ensure that the transistor stages **66** operate only one at a time.

Each of the transistor stages **66** has its collector connected to a power supply terminal **67** for supplying a positive voltage which is equal to or exceeds the maximum desirable output amplitude of the transistor **66**. The emitter of each transistor **66** is connected to ground through a resistor **68** having a variable tap **69** thereon. The variable tap **69** of each resistor **68** is connected through a respective diode **71** to connect the portion of each of resistors **68** below the tap across a load resistor **72**. The collector of each of the transistor stages **66** is grounded through a capacitor **65**.

The signal developed across the load resistor **72** is connected through a variable resistor **73** to the base of an output transistor **74**. The base of the transistor **74** is connected to ground through a capacitor **76**, and the capacitor **76** and the variable resistor **73** form an RC circuit having an adjustable time constant. The collector of the transistor **74** is connected to the power supply terminal **67** and to ground through a capacitor **77**. The emitter of the transistor **74** is connected through a resistor **78** to ground, and the output of the signal generator is derived at a variable tap **79** on the resistor **78**.

In operation, each transistor stage **66** of the signal generator is triggered into conduction upon receipt of a pulse from the corresponding one of the pulse circuits **29**, and is cut off upon termination of such pulse. The amplitude of the output of each of the transistor stages **66** is adjusted as desired for the corresponding one of the positions *a*—*j* by adjusting the tap **69**. As each transistor stage **66** is turned on, its amplitude is set to the level in the step wave form corresponding to one position *a*—*j*, and when it is turned off and the next succeeding stage is turned on, the next stage is set to the level desired for the next level in the step function waveform. The RC circuit consisting of the variable resistor **73** and the capacitor **76** enables adjustment of the corners of the square output pulses provided by the transistors **66** to round the corners off and thus slow down switching and minimize spikes in the coil load. The variable tap **79** may be adjusted to adjust the amplitude of the total wave form output of the signal generator. When the termination of the output pulse of an adjustable circuit **29** coincides with the beginning of the output pulse of the next succeeding

pulse circuit, the termination of the output of one of the transistors **66** coincides with the beginning of the output of the next succeeding transistor stage. Accordingly a step form output is generated in accordance with the settings of the taps **69**.

Referring now to FIG. **7**, the initial portion is shown of one of the two channels of the driving amplifier **28** of FIG. **1**. The output of the appropriate signal generator is applied to one of the two input terminals **81** of the driving amplifier **28**. The input terminal **81** is for one of the two channels of the driving amplifier, and the channels are identical. Accordingly, only the initial portion of one channel will be described. An initial transistor stage **82** is provided having its base coupled to the terminal **81** and its collector coupled to a plus V1 source **83** of positive potential. The collector of the transistor **82** is also coupled to ground through a capacitor **84**. The emitter of the transistor **82** is coupled to ground through a resistor **86** and is also coupled to the juncture of a pair of Zener diodes **87** and **88**. The cathode side of the Zener diode **87** is coupled through a resistor **89** to a plus V2 source **91** of positive potential which is substantially higher than the plus V1 source **83**. The anode of the Zener diode **88** is connected through a resistor **92** to a minus V2 source **93** of negative potential of a magnitude corresponding to that of the plus V2 source **91**. A capacitor **94** is connected across the Zener diode **87** and a capacitor **96** is connected across the Zener diode **88**. The junction between the Zener diode **87** and the resistor **89** is connected through a resistor **97** to one end of a resistor **98**. The junction between the Zener diode **88** and the resistor **92** is connected through a resistor **99** to the other end of the resistor **98**. A variable tap **101** is provided on the resistor **98**, and this tap is coupled through a resistor **102** to further amplification stages, not illustrated, in the particular channel of the dual-channel amplifier **28**.

The output of the signal generator is applied to the corresponding channel in the amplifier **28**. The initial transistor stage **82** thereof isolates the remaining portions of the driving amplifier from the signal-generating circuitry. The two Zener diodes **87** and **88** provide a fixed reference voltage across the resistor **98**. Thus, for example, the reference voltage with the tap **101** at the upper end of the resistor **98** may be 6.2 volts and the reference voltage with the tap **101** at the lower end of the resistor **98** may be minus 6.2 volts. With the tap positioned directly in the middle of the resistor **98**, the reference voltage may be zero. By appropriately adjusting the tap **101**, the step waveform output of the signal generator may be superimposed on a desired DC reference level to move this waveform to the desired relationship with respect to zero. Thus, although the actual output of the longitudinal deflection signal generator is of the shape shown in FIG. **3** but with the position *a* voltage at zero, by adjusting the tap **101** on the appropriate channel of the driving amplifier, a DC reference level of 1 a. may be achieved. This moves the waveform to the desired position as shown in FIG. **3**. Similarly, by superimposing the output of the lateral deflection signal generator on a negative DC reference, the waveform of FIG. **4** may be produced, having negative portions even though a positive output only is obtained from the signal generator transistor stages **66** (FIG. **6**).

The unillustrated amplification stages in the channel of the driving amplifier illustrated in FIG. **7** may be of any suitable type and will not be discussed in detail herein. For example, a suitable series of amplification stages may be provided terminating in a dual transistor push-pull type of output. Appropriate circuitry to provide the necessary amplification will be apparent to those skilled in the art.

Although the invention has been described in connection with a system wherein a ring counter having adjustable width pulse-producing stages is connected to drive the deflection system through a signal generator and amplifier, it may be possible to design satisfactorily operating systems wherein the deflection coils are driven directly by the ring counter. In such a system, the pulse width which governs the so-called dwell time, that is, the time interval for which the beam is directed at any one of the impact positions, is adjustable.

It may therefore be seen that the invention provides improved electron beam heating apparatus employing an improved control system therein for controlling the energy applied to a target surface by the electron beam. Beam sweeping is effected digitally, but the heating pattern may be readily changed by merely varying the dwell time of the beam at any of the various impact positions through which it is swept, without changing the distribution pattern of such positions.

Various modifications of the invention in addition to those shown and described herein will become apparent to those skilled in the art from the foregoing description and accompanying drawings. Such modifications are intended to fall within the scope of the appendant claims.

What we claim is:

1. A control system for use with electron beam heating apparatus for heating a target surface, comprising, signal-generating means for producing at least one electrical signal of varying amplitude to cause the heating apparatus to sweep the electron beam over the target surface, said electrical signal having a plurality of discrete levels representative of a corresponding plurality of beam impact positions on the target surface, said signal-generating means including control means for controlling the time interval for which said signal is at any of said discrete levels, whereby the energy applied to the target surface by the beam at any of the plurality of beam impact positions during a beam sweep is controllable in accordance with the length of the time during which the beam is directed at such position.

2. A system according to claim **1** wherein said signal generating means comprise a pair of signal generators generating respective coordinate signals, wherein each signal has a plurality of discrete levels, and wherein said control means are capable of varying the time intervals for both signals.

3. A system according to claim **2** wherein said signal-generating means comprise a plurality of pulse circuits operable sequentially to cause said signal generators to change the amplitude of said signal sequentially from one of said discrete levels to the next.

4. A system according to claim **1** wherein said signal-generating means include a ring counter comprising a series of one-shot multivibrator stages, each having means for varying the duration of its output pulse.

5. A system according to claim **1** wherein said signal-generating means comprise, a pair of signal generators for generating respective deflection signals, each signal generator having a separate stage for generating one of a series of discrete levels comprising the output wave form of each said signal generator, a plurality of pulse circuits operable sequentially to activate in succession the stages of each of said signal generators, and wherein said control means comprise an RC circuit in each of said pulse circuits.

6. A system according to claim **5** wherein said signal-generating means further include a dual channel drive amplifier having its respective channels connected to said signal generators, respectively.

7. Electron beam heating apparatus for heating a target surface, comprising, means for producing an electron beam, deflection means for deflecting the electron beam over the target surface, signal-generating means for producing at least one electrical signal of varying amplitude to cause the deflection system to sweep the electron beam over the target surface in a predetermined pattern, said electrical signals having a plurality of discrete levels representative of a corresponding plurality of beam impact positions on the target surface, said signal-generating means including control means for controlling the time interval for which said signal is at any of said discrete levels, whereby the energy applied to the target surface by the beam at any of the plurality of beam impact positions during a beam sweep is controllable in accordance with the length of the time during which the beam is directed at such position.

8. Electron beam heating apparatus for heating a target surface, comprising, means for producing an electron beam, *x*-

and y-axes deflection means for deflecting the electron beam in mutually perpendicular axes, a pair of signal generators, each connected to a respective one of said deflecting means for producing an electrical signal of varying amplitude to cause said deflecting means to sweep the electron beam in its associated axis, said electrical signals produced by said signal generators each having a plurality of discrete levels representative of a corresponding displacement in the x- or y-axis, and pulse means connected to said signal generators and operable sequentially to cause said signal generators to change the amplitude of the signal produced thereby sequentially from one of said discrete levels to the next for deflecting the beam in a predetermined sweep pattern.