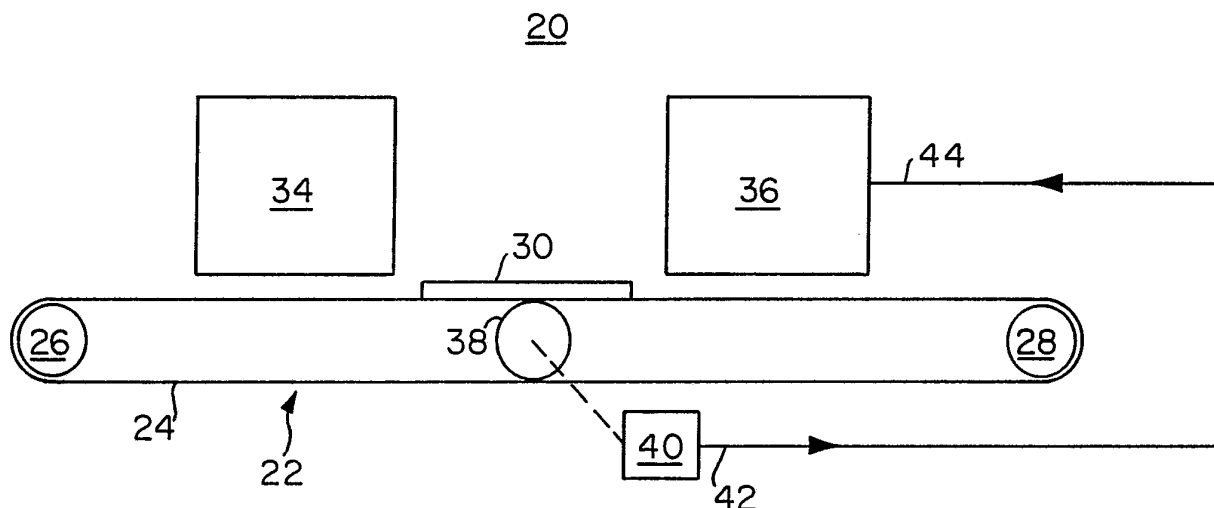




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(54) Title: ULTRAVIOLET LIGHT CURING APPARATUS AND PROCESS**(57) Abstract**

A process and apparatus (20) for curing an ultraviolet light curable material deposited on a substrate (30) by applicator (34), which is on the endless belt (24) driven by rollers (26 & 28). A signal (42) representing a parameter of the curing process is produced by tachometer and tachometer signal circuit (40) in combination with idle roller (38) and the conveyor (22). The substrate is positioned to receive ultraviolet light from a source (36). A characteristic of the ultraviolet light is selected from at least two non-zero values based on the curing process parameter signal received at a control input terminal (44) and the substrate is exposed to the selected ultraviolet light.

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ULTRAVIOLET LIGHT CURING
APPARATUS AND PROCESS

This invention relates to the curing of materials applied to substrates, such as printed or other manufactured articles, by means of ultraviolet light.

Inks and coatings that can be "cured" or hardened through exposure to ultraviolet light have gained wide application in recent years in part because they are less injurious to the environment than traditional solvent-based inks and coatings, and due to related work place safety considerations. They also afford efficient operation by providing more rapid curing than solvent-based inks and coatings.

Typically, ultraviolet light curable materials are applied by a printer or other application means to substrates and, as part of the same process, are thereafter cured by ultraviolet light projected from a lamp within an enclosed ultraviolet processor. The substrates are transported through the ultraviolet processor on a movable conveyor. In the alternative, substrates in the form of a continuous web can be passed through the processor by a system of application, tension and directional rolls.

The speed at which the substrate passes through the ultraviolet processor can vary for different reasons. For example, the operator may need to vary the substrate speed to accommodate a variable printing or application rate or variations in thickness, coverage or material composition.

However, it is necessary to carefully control the amount of exposure to ultraviolet light for several

reasons. Insufficient exposure can result in incomplete curing. Overexposure can damage many ultraviolet light sensitive substrates and conveyor belts, especially those made of organic materials. In addition, ultraviolet lamps typically produce potentially damaging amounts of heat and it is, thus, necessary to protect temperature sensitive substrates and conveyors from excessive heating by these lamps.

The amount of ultraviolet light and attendant heat to which the substrates and substrate conveyor are exposed varies with the speed at which they move through the ultraviolet processor. In order to avoid overexposure, it is known to provide automatic lamp shutters which only open to expose the substrates and conveyor when a minimum speed of operation has been achieved. While these devices serve to prevent overexposure, they do not provide a means of adjusting the amount of exposure once minimum operating speed has been achieved.

Accordingly, it is an object of the present invention to provide an apparatus and process which eliminate or alleviate the foregoing problems; more specifically, it is an object of the present invention to provide such an apparatus and process for curing an ultraviolet light curable material deposited on a substrate wherein a characteristic of the ultraviolet light employed is adjustable to accommodate variations in a curing process parameter, such as substrate speed.

Furthermore, it is an object to provide such an apparatus and process which automatically adjust the ultraviolet light exposure of the substrate to maintain such exposure within predetermined maximum and minimum

limits to achieve an adequate degree of curing without overexposure.

It is a further object of the present invention to provide a versatile ultraviolet light processor affording economical and reliable operation.

It is another object of the present invention to provide operating condition sensing circuitry for such a processor which is easily and reliably adjustable, relatively insensitive to environmental conditions, reliable in operation and economical to manufacture.

In accordance with one feature of the present invention, a curing process parameter, such as substrate speed, is monitored automatically to develop a signal which indicates such a curing process parameter. A characteristic of the ultraviolet light projected by a light source, such as its intensity, is adjusted based on the signal to automatically maintain the characteristic within desirable limits to optimize the curing of the material on the substrate. A reliable and economic means of controlling the curing process is, thus, afforded which results in less waste and higher quality of cure.

In accordance with a further aspect of the present invention improved circuitry for detecting ultraviolet lamp operating conditions is provided utilizing semiconductor solid state signal processing means. Costly and environmentally sensitive solenoid operated relays are thus replaced by reliable, inexpensive and environmentally stable circuit elements.

It is not intended that the invention be summarized here in its entirety. Rather, further

features, aspects and advantages of the invention will be set forth in or be apparent from the following description and drawings.

IN THE DRAWINGS:

5 Figure 1 is a schematic view of an apparatus for applying a material and curing the material through exposure to ultraviolet light;

 Figure 2 is a block diagram of an ultraviolet light processor for use in the apparatus of Figure 1;

10 Figure 3 is a schematic diagram of an automatic power control circuit of the processor of Figure 2;

 Figure 4 is a schematic diagram of a portion of a typical lamp control circuit of the processor of Figure 2;

15 Figure 5 is a schematic diagram of a lamp power circuit of the processor of Figure 2;

 Figure 6 is a schematic diagram of a further portion of the lamp control circuit of Figure 4 including lamp operation monitoring circuitry;

20 Figure 7 is a schematic diagram illustrating an alternative embodiment of an ultraviolet light processor providing continuously variable lamp power control;

25 Figure 8 is a schematic diagram of a further alternative embodiment of an ultraviolet light processor providing continuously variable lamp power control;

 Figure 9 is a schematic illustration of an ultraviolet light processor employing two lamps;

30 Figure 10 is a schematic diagram of lamp shutter control circuitry for the processor of Figure 9 providing independently operable shutter actuation; and

Figure 11 is a schematic illustration of a further embodiment of the present invention providing an ultraviolet light processor having adjustable lamp distance control.

5

GENERAL DESCRIPTION

Figure 1 illustrates a system 20 for applying an ultraviolet light (UV) curable material, such as UV curable ink, coatings, or adhesives to a substrate and subsequently curing the applied material by exposure to ultraviolet light. The system includes a belt conveyor 22 having an endless belt 24 driven by rollers 26 and 28 powered by an electric motor (not shown for purposes of simplicity and clarity). A substrate 30, such as a printed substrate or manufactured article, is shown as it is transported on an upper surface of the conveyor from left to right in the drawing.

The system 20 further includes a printer or other application means 34 for applying UV curable ink or other material to an upper surface of the substrate 30. In the illustration of Figure 1, the ink or other material has been applied to the substrate 30 and it is being transported by the conveyor 22 towards an ultraviolet light processor 36 which will project ultraviolet light onto the upper surface or edges of substrate 30 as it passes beneath the processor 36 through a light exposure position. The UV light incident on the substrate 30 cures or hardens the material applied thereto by the application means 34 through a photochemical reaction.

In accordance with one feature of the present invention, the speed of the conveyor 22, and therefore of substrate 30, is detected by the combination of an idle roller 38 of the conveyor 22 coupled with a

tachometer and tachometer signal circuit 40. The tachometer and circuit 40 provide a plurality of control signals at an output 42 thereof representing the speed at which the substrate moves with the conveyor 22 through the light exposure position beneath UV light processor 36. The tachometer and tachometer signal circuit 40 are described below in greater detail.

UV light processor 36 includes one or more UV light sources, such as mercury vapor lamps. Practical UV light sources generate substantial amounts of infrared emissions as well as high levels of UV light, and thus tend to rapidly heat the substrate and conveyor. Many substrates and conveyor materials are susceptible to damage caused by excessive heat and UV light exposure. Accordingly, it is necessary to limit the heat and UV light absorption of these materials.

At the same time, it is necessary to ensure that sufficient UV light is absorbed by the UV curable ink or other material on substrate 30 for an adequate cure. Accordingly, it is necessary to regulate the exposure of the substrate so that the total amount of UV light projected onto it by the processor is maintained within acceptable maximum and minimum amounts, as well as to regulate the UV exposure of sensitive conveyor materials, such as rubber or other UV sensitive organic substances.

In accordance with one feature of the invention, the intensity of the UV light projected onto the substrate by the processor 36 is selected from at least two non-zero intensity values as a function of the rate at which the substrate passes through the UV light exposure position, so that the UV exposure of the

substrate is maintained between acceptable maximum and minimum values. This is achieved in the embodiment of Figure 1 by providing such a processor 36 capable of projecting at least two different UV light intensities under the control of a signal received at a control input terminal 44 thereof. To achieve such UV light intensity control as a function of substrate speed, the output signal at terminal 42 of tachometer 40 is provided to the input 44 of processor 36. In this manner, a characteristic of the UV light, i.e. its intensity, projected onto the substrate by processor 36 can be maintained or adjusted based upon the signal received at its input 44 representing the value of a curing process parameter, in this case the substrate speed. It will be appreciated that the speed of the substrate is directly proportional to the duration of substrate exposure, and thus is representative thereof, as well as of the total amount of UV light received by the substrate so long as other process variables (such as UV light intensity profile and lamp input power) are held constant. Since the total intensity of UV light emitted by the lamp(s) varies with the input power applied thereto, it will be appreciated that, by selecting the lamp input power as a function of substrate speed, in accordance with the embodiment of Figure 1, the total UV light exposure of the substrate can be regulated.

Figure 2 illustrates the UV light processor 36 in block diagram format. Alternating current electrical power is supplied to processor 36 through power legs 48 and 50. Power is supplied to ventilation control circuits 52 through stepdown transformer 54, and to the remaining control circuits of processor 36

under the control of circuits 52 via its output terminal 56. Since the processor circuits handle relatively high electrical power levels and, thus generate substantial amounts of heat, the processor 36
5 is provided with heat ventilation subsystems for exhausting heated air from the lamp housing, as well as from its power and control circuits. It is essential that these ventilation units be operating satisfactorily as a condition of supplying power to the
10 lamps and circuitry. Accordingly, the ventilation control circuits control the provision of electrical power to the remaining circuitry of processor 36 to ensure their proper ventilation before power is applied thereto. Circuits 52 also include well known means for
15 automatically locking the high voltage lamp ballast or power supply circuit housings so long as power is applied and for affording an emergency power cutoff under manual control.

From power output terminal 56, power is
20 applied to a power input of automatic lamp power control circuits 58, which are shown in greater detail in Figure 3. As there shown, circuits 58 include variable power control relays energized by respective solenoids 1CR, 2CR and 3CR under control of normally
25 open relay contacts 60, 61 and 62, respectively. Relay contacts 60-62 are controlled by means of the control signals output by the tachometer and tachometer signal circuits 40. More specifically, the control signals
30 (a) serve to close contacts 60 upon the achievement of a minimum substrate speed level to enable low power lamp operation under the control of relay solenoid 1CR, (b) close contacts 61 (while contacts 60 remain closed) once a second substrate speed level greater than the

minimum speed level is achieved to enable medium or normal power lamp operation under the control of relay solenoid 2CR, and (c) close contacts 62 (while contacts 60 and 61 remain closed) once a third substrate speed
5 level greater than the second is achieved to enable high power operation under the control of relay solenoid 3CR.

Power from output terminal 56 is also applied to system condition monitors and interlock controls 64.
10 The monitors and controls 64 in known fashion monitor system variables to determine whether they are within acceptable levels and control the provision of power to the lamp power (or ballast) and control circuits accordingly.

15 The system of Figure 2 includes two mercury vapor ultraviolet lamps supplied with power through respective lamp power circuits or ballasts 66 having identical circuit configurations. Circuits 66 are described in greater detail below. It will be
20 appreciated that the number of lamps employed in accordance with the invention need not always be two and will vary depending on the particular UV processing application.

The power supplied to the lamps by circuits
25 66 is controlled by respective lamp control circuits 68, as indicated by dashed control lines 70. The total power level of the lamps under direct control by circuits 68 is indirectly controlled by lamp power control circuits 58, as indicated by dashed control
30 lines 72.

Control circuits 68 have identical circuit configurations and are illustrated schematically in Figure 4 as follows. Power is supplied to the circuits

from the system monitors and interlock controls 64 over power legs 74 and 76. System startup is controlled manually by switch LSS. As indicated in Figure 4, switch LSS is a three position, two pole switch having a first pole 78 which is closed only in the second or "on" position and in the third or "start" position. The "start" position is a momentary "on" position and is the only position at which second pole 80 is closed. A circuit breaker CB, described below in greater detail with reference to Figure 5, is shown in a "fault" or power cutoff position, so that in normal operation, the poles 78 and 80 are coupled through circuit breaker CB.

As used throughout herein, relay solenoids are indicated by circular circuit element symbols enclosing the identifying symbols therefor and the corresponding relay contacts are indicated by the same identifying symbols. Normally closed contacts (i.e., those forming a short circuit when the relay solenoid is not energized) are indicated by a diagonal line through the contact symbol, while normally open contacts are indicated by the absence of such a diagonal line.

In normal operation, and with reference also to Figure 5, advancing switch LSS to the "start" position will energize line contact solenoid LC (since circuit breaker CB provides a short circuit between poles 78 and 80 in the absence of a fault) which serves to apply power to the respective lamp power circuit 66 from power legs 48 and 50 through contacts LC (Figure 5) and protective fuses 82 and 84 to the primary winding of step-up power transformer 86. Transformer 86 has a center-tapped secondary winding which develops a voltage difference of several thousand volts between

its end contacts for energizing mercury vapor lamp 88 through a capacitor bank 90.

Capacitor bank 90 includes the parallel combination of (a) a capacitor 92, (b) a capacitor 94 in series with a normally open contact of relay NDK, and (c) a capacitor 96 in series with a normally open contact of relay HDK. It will be appreciated that, by closing the contacts of relays NDK and HDK, the total capacitance of bank 90 is increased, thus decreasing the impedance to the flow of current therethrough, increasing the current supplied to lamp 88 and, concomitantly, increasing its UV power output. Power circuit 66 includes a circuit breaker CB connected to the center tap of transformer 86 which serves to detect a fault in the secondary thereof to disable power to circuit 66 by deenergizing relay solenoid LC of the corresponding lamp control circuit 68.

The lamp 88 is provided with a pair of shutters (not shown for purposes of simplicity and clarity) which block the transmission of UV light to the conveyor 22 so long as an associated shutter solenoid (98 in Figure 4) is not energized, and which open upon energization of the solenoid 98 to permit such transmission. A typical shuttered UV lamp apparatus is disclosed in U.S. Patent No. 4,025,795 issued May 24, 1977 entitled ULTRAVIOLET LIGHT PROCESSOR HAVING ROTATING SHUTTERS which is incorporated herein by reference. Mercury vapor lamps, such as lamps 88, will not emit UV light when initially energized. Rather, upon the application of a sufficiently high voltage thereto, an arc is struck which initiates vaporization of the mercury therein and a gradual temperature rise within the lamp. At the

same time, the voltage across the lamp gradually rises (and the current therethrough gradually decreases) until an operating voltage level is achieved, whereupon the lamp is emitting sufficient UV light such that it is ready to begin curing operations. Thereupon the shutters are opened and the "ready" state is signalled by an indicator lamp or other suitable device.

The ready state is detected in the embodiment of Figure 2 by sensing the voltage across the lamp and determining by means of a solid state threshold detector that it has risen sufficiently to exceed a predetermined "ready" or threshold level. For this purpose, the circuit of Figure 5 includes a step down transformer 100 whose primary is connected across lamp 88 to sense the voltage thereacross. The transformer 100 is provided with a turns ratio of 100:1 so that the secondary winding produces a voltage proportional to that across lamp 88, but scaled down sufficiently for use by the detection circuitry. A voltmeter 102 (which may be switched between the various lamp power circuits 66 by the provision of suitable switching circuitry) provides a direct indication of lamp voltage to the operator.

With reference to Figure 6, a lamp voltage monitoring circuit 103 is illustrated having an input terminal 104 coupled to the secondary of transformer 100. Input terminal 104 provides the voltage from the secondary winding of transformer 100 to the input of a signal conditioning circuit 105 having a diode 106 and electrolytic capacitor 108 connected in series which serve to provide a peak detected version of the voltage from the secondary winding at their common node. The peak detected voltage is applied across a pair of

series connected resistors 110 and 112 of signal conditioning circuit 105 which, in turn, provide a scaled down version of the peak detected signal at their common node to the inverting inputs of two
5 semiconductor solid state operational amplifiers 114 and 116. The scaled down peak detected voltage is further smoothed by electrolytic capacitor 118 connected in parallel across resistor 112. Signal conditioning circuit 105 also includes a series
10 connected zener diode 120 and resistor 122. The cathode of diode 120 is connected to the common node of diode 106 and capacitor 108 and its anode is coupled in series through resistor 122 to ground. The series connection of diode 120 and resistor 122 serves to
15 protect the circuit 103 from excessive DC voltage levels.

Operational amplifier 114 together with its output circuitry serves to energize the solenoid of a "ready" relay once the voltage across lamp 88 has
20 achieved a "ready" or operational level. The noninverting input terminal of amplifier 114 is coupled to receive a reference voltage V_{Ready} which is set by an adjustable resistive voltage divider (not shown for purposes of simplicity and clarity). V_{Ready} is selected
25 such that it is equal to the voltage at the inverting input terminal of amplifier 114 when the voltage across the lamp 88 has reached an operating level. The cathode of a light emitting diode (LED) 124 is connected to the output terminal of amplifier 114 and
30 its anode is coupled through a normally closed contact of a "fail" relay FL to the first terminal of a ready relay solenoid RY and to the anode of a diode 126 connected in parallel across relay solenoid RY. The

second terminal of relay solenoid RY is coupled to the positive voltage supply level V_{cc} of the circuit's low voltage DC power supply (not shown for the sake of simplicity and clarity). Accordingly, once the voltage across lamp 88 has reached the operating value, the output of amplifier 114 will go low, thus energizing the ready relay solenoid and light emitting diode 124. The function of the ready relay RY is discussed below in connection with the circuit of Figure 4.

Operational amplifier 116 and its output circuitry serve to detect the failure of lamp 188 and to energize the fail relay solenoid FL which in turn serves to remove power from the corresponding lamp power circuit 66. The noninverting input terminal of amplifier 116 is connected to a source of reference voltage V_{Fail} which is set by an adjustable resistive voltage divider (not shown for purposes of simplicity and clarity). The output of amplifier 116 is connected to a first terminal of the fail relay solenoid and to the anode of a diode 128. The opposing terminal of fail relay solenoid FL and the cathode of diode 128 are connected to V_{cc} .

Lamp 88 can fail in several ways. For example, failure can occur upon an attempt to initially energize lamp 88 if this fails to strike an arc through the lamp. Failure can also occur during operation if, for some reason, an excessive amount of cooling air should cause lamp 88 to overcool. Upon lamp failure, it will open-circuit and the voltage thereacross will rise to the open circuit voltage across the secondary of transformer 86. This voltage level is typically several hundred volts above the operational voltage level of the lamp. Accordingly, one set of fail relay

contacts is connected in series with the ready relay solenoid in order to deenergize it upon lamp failure, since it will otherwise continue to indicate (erroneously) that the lamp is "ready".

5 Prior art circuits employed for detecting the "ready" and "fail" modes of ultraviolet lamps couple the secondary winding of the transformer 100 through a voltage doubler circuit and respective series connected potentiometers to the "fail" and "ready" relay
10 solenoids. For proper operation, such solenoids are required to be especially sensitive, and thus are likewise sensitive to temperature changes and motion. Since the voltage adjustments required for proper operation of this circuitry are high precision
15 adjustments, it is also necessary to utilize expensive multiple turn potentiometers which have the additional disadvantage of being difficult to adjust. In addition, each relay responds to voltage in a different manner, thus requiring individual adjustment.

20 In contrast to the prior art, the solid state circuitry of the Figure 6 embodiment is relatively less sensitive to motion and temperature changes and is relatively less expensive. In addition, there is far less variation in operation performance from circuit to
25 circuit utilizing the arrangement of Figure 6.

 As an alternative to the Figure 6 embodiment, a digital signal processor is coupled to receive the voltage provided at the common node of resistors 110 and 112. This voltage is converted to a digital signal
30 by an analog-to-digital signal converter by reference to a signal such as the predetermined voltage level that will appear at the common node of resistors 110 and 112 when the lamp fails and open-circuits. This

digital signal is then processed to detect lamp "ready" and "fail" conditions by comparison thereof with known digital representations of the "ready" and "fail" voltage levels. It will be readily appreciated that
5 such digital signal processing can be performed by any known digital processing means such as hard-wired logic circuits or microprocessor based signal processing means.

With reference again to Figure 4, when switch
10 LSS is initially moved to the start position and the line contact LC relay solenoid is energized to couple power into circuit 66 of Figure 5, the line contact relay solenoid is maintained in the energized condition by closing a normally open contact of the relay
15 shunting pole 80 of switch LSS so long as the switch remains in the "on" position and a fault has not occurred. This condition is indicated by lighting a lamp 130 of Figure 4. The warmup of lamp 88 is hastened by coupling the solenoid of relay NDK through
20 a normally closed contact of the ready relay, such that initially both of capacitors 92 and 94 are coupled to provide current to lamp 88, as shown in Figure 5. Once the voltage across lamp 88 has risen to the operating level, and the ready relay RY solenoid has been
25 energized, the normally closed contact of the ready relay which had been energizing the relay NDK solenoid is opened and a normally open contact of the ready relay indicated as 132 in Figure 4 is closed to energize a lamp ready indicator 134. The system is now
30 ready to begin normal operation under the control of the automatic power control circuits.

Once the conveyor 22 achieves minimal operating speed, the solenoid of relay 1CR of Figure 3

is energized. With reference again to Figure 4, the shutter solenoid 98 is connected in series with a fuse 136 and a normally open contact of solenoid 1CR. Accordingly, since the solenoid of the ready relay RY

5 has now been energized, it will be seen that once the minimal operating speed has been achieved solenoid 1CR operates to open the shutters by energizing the shutter solenoid 98. In the event that the conveyor again slows down so that it is moving at a speed less than

10 the minimal operating speed, relay 1CR will deenergize in order to close the shutters of the lamp 88 in order to prevent overexposure and overheating of the conveyor and any substrate that may be in proximity to the lamp 88. Once the second conveyor speed level which is

15 greater than the minimal speed level is achieved and the solenoid of relay 2CR has been energized, the solenoid of relay NDK is once again energized through a series connected pair of normally open contacts of relays 2CR and RY. With reference to Figure 5, it will

20 be appreciated that this will once again connect capacitor 94 into the circuit feeding power to the lamp 88, thus increasing the current supplied thereto, thereby increasing its power output. Once the third conveyor speed level (greater than the second) is

25 achieved, the solenoid of relay 3CR is energized which in turn energizes the solenoid of relay HDK to couple capacitor 96 of Figure 5 in parallel with capacitors 92 and 94 to maximize the current through lamp 88 and thereby maximize its power output. In this manner, the

30 power output of the lamp 88 varies directly with the speed of the conveyor. Since the total intensity of the lamps 88 also varies directly with the power applied thereto, it will be seen that the system of

Figures 2 through 6 provides a means for adjusting the intensity of the light projected onto the substrates carried by the conveyor based upon a signal representing the speed at which the conveyor, and
5 therefore the substrates, are moving through the light exposure position. By appropriately scaling the signals from tachometer circuits 40 with the speed of operation, it is possible by means of the system of Figures 2 through 6 to adjust the amount of light
10 projected onto the substrates based upon a substrate speed signal so that the total amount of ultraviolet light projected onto the substrates by the lamps is maintained within predetermined maximum and minimum amounts.

15 With reference again to Figure 4 it will be seen that when the solenoid of relay CRF is energized, it serves to deenergize the solenoid of the lamp contactor relay LC thus to disconnect power to the lamp power circuit 66. The solenoid of relay CRF will, in
20 turn, be energized upon lamp failure through the closing of normally open contacts 138, upon the occurrence of a secondary fault which trips the circuit break CB to energize the solenoid of relay CRS to close normally open contacts 140, as well as the occurrence
25 of excessive reflector temperature resulting in the deenergization of the solenoid of relay CRT thus reclosing normally closed contacts 142.

Figures 7 and 8 illustrate alternative embodiments of the invention providing continuous lamp
30 power level control as a function of conveyor and substrate speed. In Figures 7 and 8, elements corresponding to elements illustrated in Figures 1 through 6 bear corresponding labels.

The embodiments of Figures 7 and 8 include lamp control circuits 68' which perform the same functions as lamp control circuit 68 of the embodiment of Figures 2-6 with the exception of the lamp power control function performed thereby.

5 In the embodiment of Figure 7, a saturable core reactor 148 is connected in series with a capacitor 150 and the lamp 88. The saturable core reactor 148 is a current controlled variable inductance which serves to vary the current supplied to the lamp 88 continuously under the control of a DC current supplied to a control input thereof from the output terminal 146 of lamp control circuits 68'. Circuits 68' are coupled to an output terminal 152 of a tachometer signal circuit 151 providing a continuously variable signal representing conveyor and substrate speed to receive the signal therefrom. Circuits 68' condition this signal in order to output an appropriate control current to the saturable core reactor 148 in order to adjust the applied power level to the lamp continuously throughout a predetermined range of power levels such that the applied power level varies directly with the substrate speed on the conveyor on a continuous basis. The circuit of Figure 8 is identical to that of Figure 7 except that the saturable core reactor 148 has been connected instead in parallel with the capacitor 150 (rather than in series), and circuits 68' have been altered as necessary to provide an appropriately scaled control current to the saturable core reactor 148 in order to scale the power input to the lamp 88 based upon the signal provided at the output of the tachometer signal circuit 151. It will be appreciated that in place of the saturable core

reactors 148 of Figures 7 and 8, a mechanically variable inductance could be utilized together with appropriate control devices.

Figures 9 and 10 illustrate a further embodiment of the present invention utilizing a pair of lamps and corresponding reflectors illustrated schematically as 160 and 162, each having a first focus F1 and a second focus F2 located at or near the surface of the substrate 30. In the embodiment of Figures 9 and 10 the total intensity of the UV light incident at the surface of the substrate is varied under control of the substrate speed signal by means of the circuit shown in Figure 10. The circuit of Figure 10 includes a first shutter solenoid 166 for opening and closing a shutter of lamp and reflector combination 160, and a second shutter solenoid 168 for controlling the opening and closing of a shutter of the lamp and reflector combination 162 of Figure 9. Each of the solenoids 166 and 168 is connected in series with a respective normally open relay contact 170 and 172 to receive power therethrough from the ventilation control circuit power output terminals 56, as shown in Figure 1. Normally open contact 170 is made to close once the tachometer speed signal from the tachometer signal circuit 40 attains a first signal level indicating a minimum operating speed. Accordingly, shutter solenoid 166 is thereby energized to open the shutters of the lamp and reflector combination 160 so that ultraviolet light is projected toward its second focus F₂ on the surface of the substrate 30. At the same time, shutter solenoid 168 remains deenergized thus maintaining the shutter of the lamp and reflector combination 162 closed. Accordingly, at this lower speed, the

substrate 30 is exposed to a relatively low ultraviolet light intensity. As the speed of the substrate and conveyor increases past a second higher level, the substrate speed signal activates a solenoid to close normally closed contacts 172, so that shutter solenoid 168 is energized to open the shutters of the lamp and reflector combination 162. Accordingly, at and above this relatively higher conveyor speed, the substrate 30 is exposed to relatively higher intensity ultraviolet light provided by the combination of both lamps.

Figure 11 schematically illustrates a further embodiment of the present invention wherein the intensity of ultraviolet light to which the substrate and conveyor are exposed is varied directly with their speed by varying the distance of the ultraviolet light source from the substrate and conveyor. In Figure 11, the apparatus is supported from a floor on a base 180. An endless belt conveyor 182 includes idle rollers 184 and 186 mounted for rotation on the base 180 and whose speed of rotation varies directly with the speed of the conveyor. A housing 190 mounts an ultraviolet lamp, such as lamp 88 of Figure 5, which is operative to project ultraviolet light downwardly towards a substrate 192 moving with the conveyor 182.

Light housing 190 is mounted on a plurality of air cylinders 194 operative to raise and lower the housing in response to the application of a differential air pressure applied to opposite sides of air pistons slideably mounted therein. Compressed air is applied to opposite sides of the pistons of the air cylinders 194 through a solenoid operated air valve 196 which supplies compressed air to the cylinders 194

through a pair of air lines represented schematically by the dashed line 198 in Figure 11.

As in the case of the Figure 1 embodiment, a tachometer 200 is coupled with idle roller 186 to
5 generate a signal representative of the speed at which the conveyor 182 and substrate 192 are moving instantaneously. Tachometer 200 provides this substrate speed signal to an output terminal 202 thereof.

10 The relative height of the housing 190 over the conveyor 182 and substrate 192 is converted to an electrical signal by means of a potentiometer shown schematically at 206. A wiper arm of the potentiometer moves with the housing 190 to produce a voltage varying
15 directly with the height of the housing with respect to the conveyor and substrate. A differential amplifier 210 has a first differential input terminal coupled to the output 202 of the tachometer 200 to receive the substrate speed signal. A second differential input
20 terminal of amplifier 210 is coupled to the wiper arm of the potentiometer 206 to receive the housing height signal therefrom. Differential amplifier 210 serves to produce an error voltage at its output, indicated as 212, representing the difference between the substrate
25 speed signal and the housing height signal. The output 212 of the amplifier 210 is coupled to the solenoid operated air valve 196 to control the application of air pressure through the lines 198 to the cylinders 194 for raising and lowering the lamp housing 190. The
30 values of the potentiometer 206 and the DC voltage applied thereacross, together with the substrate speed signal from the tachometer 200 are scaled appropriately so that, as the speed of the conveyor 182 and substrate

192 varies, the height of the lamp housing 190 likewise will vary such that a desired level of ultraviolet light intensity is received by the substrate 192 and the conveyor 182 at any given operational speed of the conveyor and substrate.

In accordance with a further aspect of the present invention, a system is provided for applying and curing UV curable materials on a substrate wherein a curing process parameter, namely a property of the material applied to the substrate, is used to control a characteristic of the UV light to which the substrate is exposed.

In one embodiment according to this aspect, a property of a UV curable printing ink, namely its density, is measured to produce a density signal which serves to adjust the intensity of the UV light applied to the ink on a substrate to optimize the curing. With reference to Figure 1, in this embodiment the tachometer and tachometer signal circuit 40 are replaced by a reflective densitometer. The densitometer is disposed between the printer 34 and the UV light processor 36 to measure the density of the ink printed on the substrate before it passes through the UV light processor. The densitometer produces an output signal representative of the ink's density. The output signal is appropriately conditioned and, as such, is applied to the processor control input terminal 44. Under the control of the densitometer signal, the intensity of the light projected by the processor 36 is varied according to the measured ink density to effect an optimum cure thereof.

The above description of the invention is intended to be illustrative and not limiting. Various

changes or modifications in the embodiments described may occur to those skilled in the art and these can be made without departing from the spirit or scope of the invention.

CLAIMS

1. An apparatus for applying an ultraviolet light curable material to a substrate and curing the applied material comprising:

5 application means for applying the ultraviolet light curable material to the substrate; ultraviolet light curing means for projecting ultraviolet light onto the substrate when it is located at a light exposure position to cure the material
10 applied thereto by the application means;

sensing means for detecting a process variable indicating a process parameter of the apparatus and for producing a process variable signal representing a value of said process parameter; and
15 means for selecting the amount of ultraviolet light projected onto the substrate by the curing means by selectively adjusting the distance of the light curing means from the substrate based upon the process variable signal produced by the sensing means.

20 2. The apparatus of claim 1, further comprising transporting means for transporting the substrate through the light exposure position; and wherein the sensing means comprises means for detecting a speed at which the substrate is moving
25 through the light exposure position and for producing said process variable signal such that it represents such substrate speed.

3. An apparatus for applying an ultraviolet light curable material to a substrate and curing the applied material comprising:
30

application means for applying the ultraviolet light curable material to the substrate;

ultraviolet light curing means for projecting ultraviolet light onto the substrate when it is located at a light exposure position to cure the material applied thereto by the application means;

5 sensing means for detecting a characteristic of the material to be cured and for producing a process variable signal representing a value of said characteristic; and

10 means for selecting a characteristic of the light projected onto the substrate by the curing means by selecting said light characteristic from at least two non-zero values based upon the process variable signal produced by the sensing means.

15 4. The apparatus of claim 3, wherein the sensing means comprises means for detecting a density of the material to be cured and for producing said process variable signal as a representation of such density.

20 5. An apparatus for curing an ultraviolet light curable material deposited on a substrate, comprising:

light emitting means for projecting ultraviolet light onto the substrate when it is located at a light exposure position;

25 input means for receiving an input signal representing a value of a curing process parameter; and

control means for selecting the intensity of the ultraviolet light projected onto the substrate by the light emitting means from a continuous
30 predetermined range of intensities by selecting a power lever applied to the light emitting means which is variable continuously throughout a predetermined range of power levels based upon the input signal.

6. The apparatus of claim 5, wherein the input means comprises means for receiving a substrate speed signal indicating a speed at which the substrate is moving through the light exposure position.

5 7. An apparatus for curing an ultraviolet light curable material deposited on a substrate, comprising:

light emitting means for projecting ultraviolet light onto the substrate when it is located
10 at a light exposure position;

input means for receiving an input signal representing a characteristic of the material to be cured; and

control means for selecting a characteristic
15 of the ultraviolet light projected onto the substrate by the light emitting means by selecting said light characteristic from at least two non-zero values based upon the input signal.

8. The apparatus of claim 7, wherein the
20 control means comprises means for selecting the intensity of the ultraviolet light projected onto the substrate based on the input signal.

9. The apparatus of claim 7, wherein the
25 input means comprises means for receiving an input signal indicating a density of the material to be cured; and

wherein the control means comprises means for selecting the amount of the ultraviolet light projected onto the substrate based on the input signal.

30 10. An apparatus for curing an ultraviolet light curable material deposited on a substrate, comprising:

light emitting means for projecting ultraviolet light onto the substrate when it is located at a light exposure position;

5 input means for receiving an input signal representing a value of a curing process parameter; and

control means for selecting a characteristic of the ultraviolet light projected onto the substrate by the light emitting means by selectively adjusting a distance of the light emitting means from the
10 substrate.

11. A process for curing an ultraviolet light curable material deposited on a substrate comprising the steps of:

(a) producing a material characteristic
15 signal representing a characteristic of the material to be cured;

(b) positioning the substrate to receive ultraviolet light from an ultraviolet light source;

(c) selecting a characteristic of the
20 ultraviolet light from at least two non-zero values based upon the material characteristic signal; and

(d) exposing the substrate to said selected ultraviolet light.

12. The process of claim 11, wherein the
25 step of selecting a characteristic of the ultraviolet light comprises selecting the light's intensity based on the signal.

13. The process of claim 11, wherein the
30 step of producing the signal comprises producing a signal representing a density of the material to be cured.

14. A process for curing an ultraviolet light curable material deposited on a substrate comprising the steps of:

- 5 (a) producing a signal representing a parameter of the curing process;
- (b) positioning the substrate to receive ultraviolet light from an ultraviolet light source;
- (c) selecting the amount of the ultraviolet light received by the substrate by selecting a distance
10 of the ultraviolet light source from the substrate based upon the curing process parameter signal; and
- (d) exposing the substrate to said selected ultraviolet light.

15 15. The process of claim 14, wherein the step of positioning the substrate comprises moving the substrate into proximity of the ultraviolet light source; and

wherein the curing process parameter signal represents a speed at which the substrate is moved.

20 16. An apparatus for monitoring the operating condition of an ultraviolet lamp to produce a lamp condition signal, comprising:

means for measuring a power voltage applied to the lamp;

25 means for producing a lamp voltage signal representative of the voltage applied to the lamp;

means for monitoring the lamp voltage signal to produce a lamp condition signal having a first signal state indicating a first lamp operating
30 condition and a second signal state indicating a second lamp operating condition;

said monitoring means comprising semiconductor solid state signal processing means.

17. The apparatus of claim 16, wherein the semiconductor solid state signal processing means comprises means for comparing the lamp voltage signal against a reference signal to produce the lamp
5 condition signal.

18. The apparatus of claim 17, wherein the comparing means comprises a semiconductor solid state threshold detection circuit having an input coupled to receive the lamp voltage signal and an output providing
10 a first output signal level representing the first state of the lamp condition signal when the lamp voltage signal is below a predetermined threshold level and a second output signal level representing the
15 second state of the lamp condition signal when the lamp voltage signal is above said predetermined threshold level.

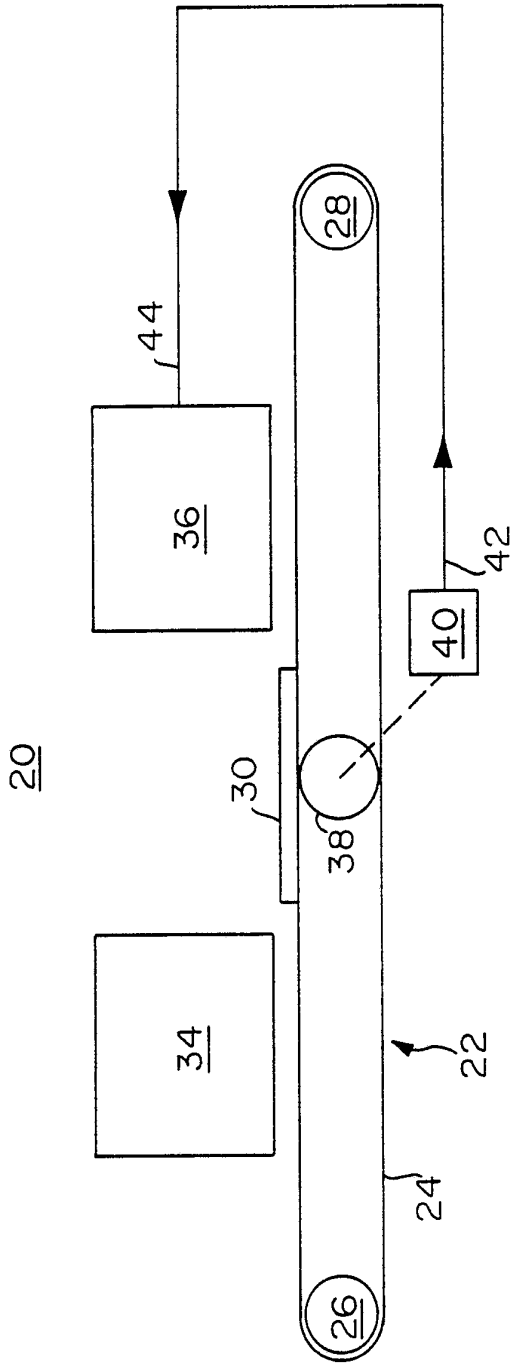
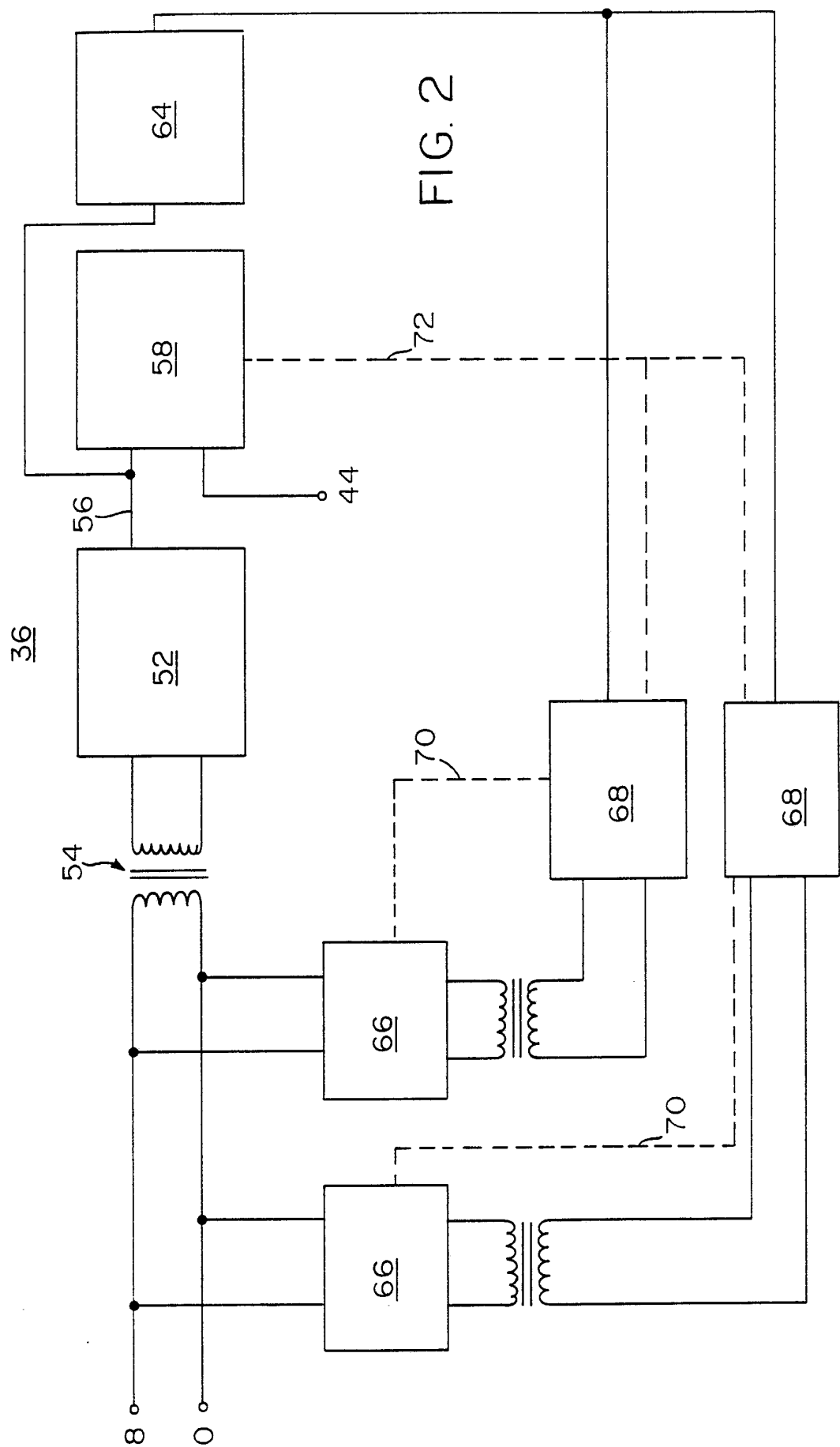


FIG. 1



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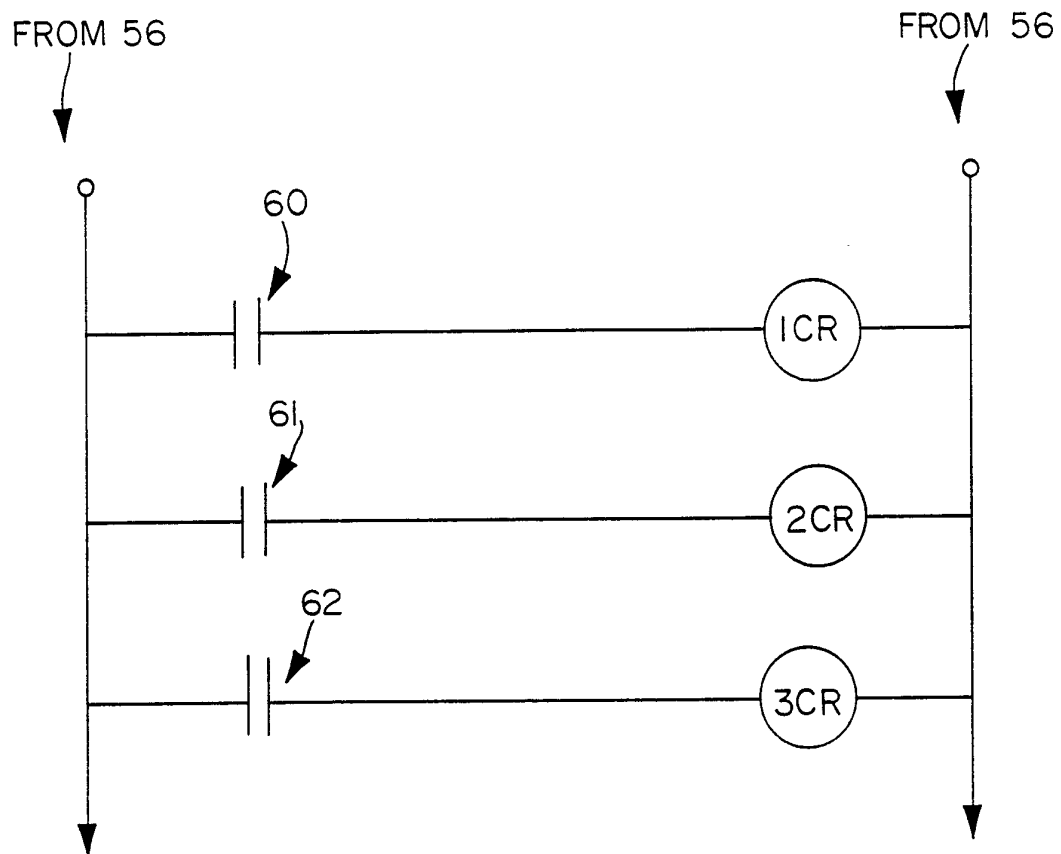
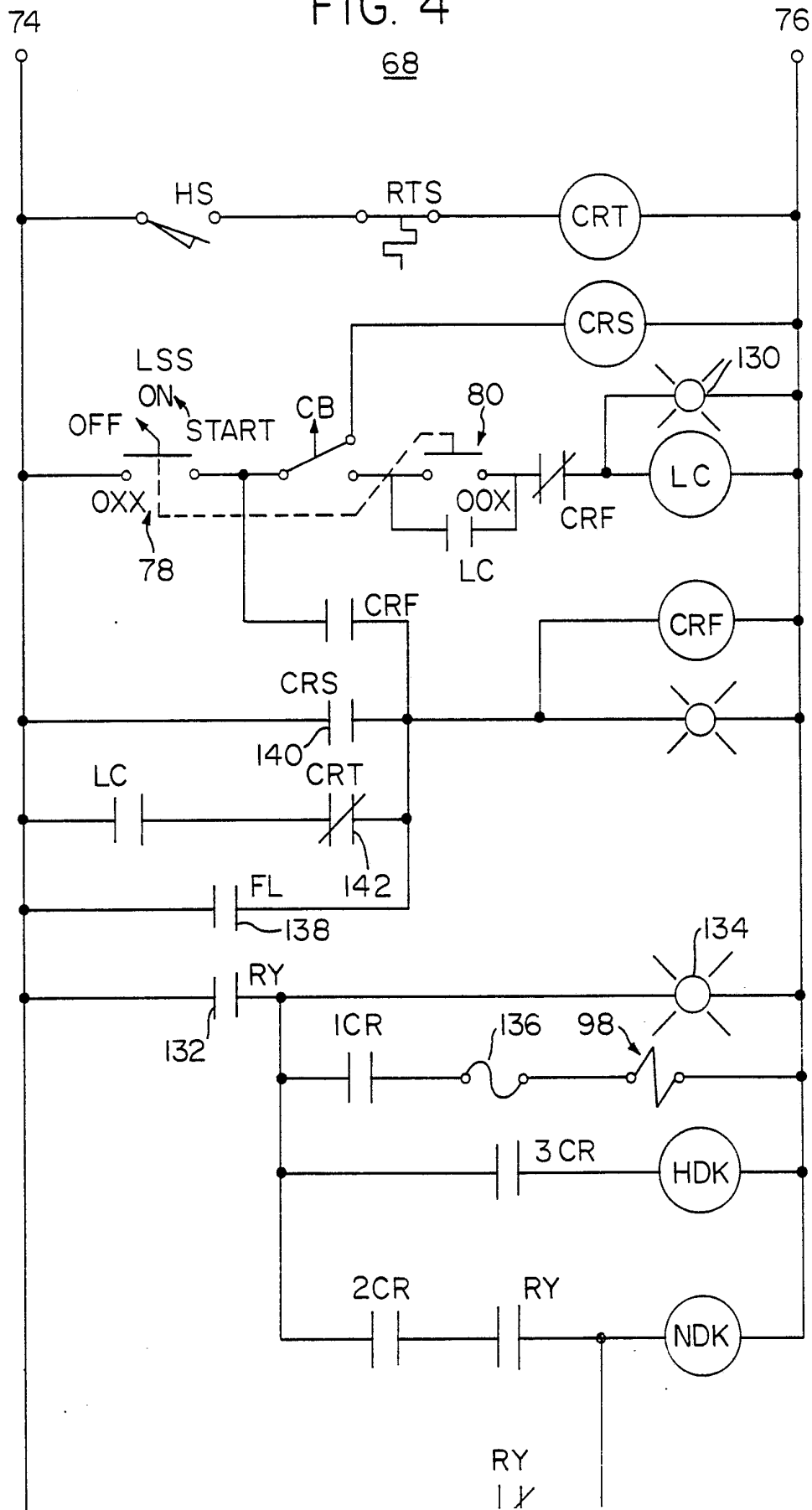


FIG. 3

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FIG. 4

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SUBSTITUTE SHEET

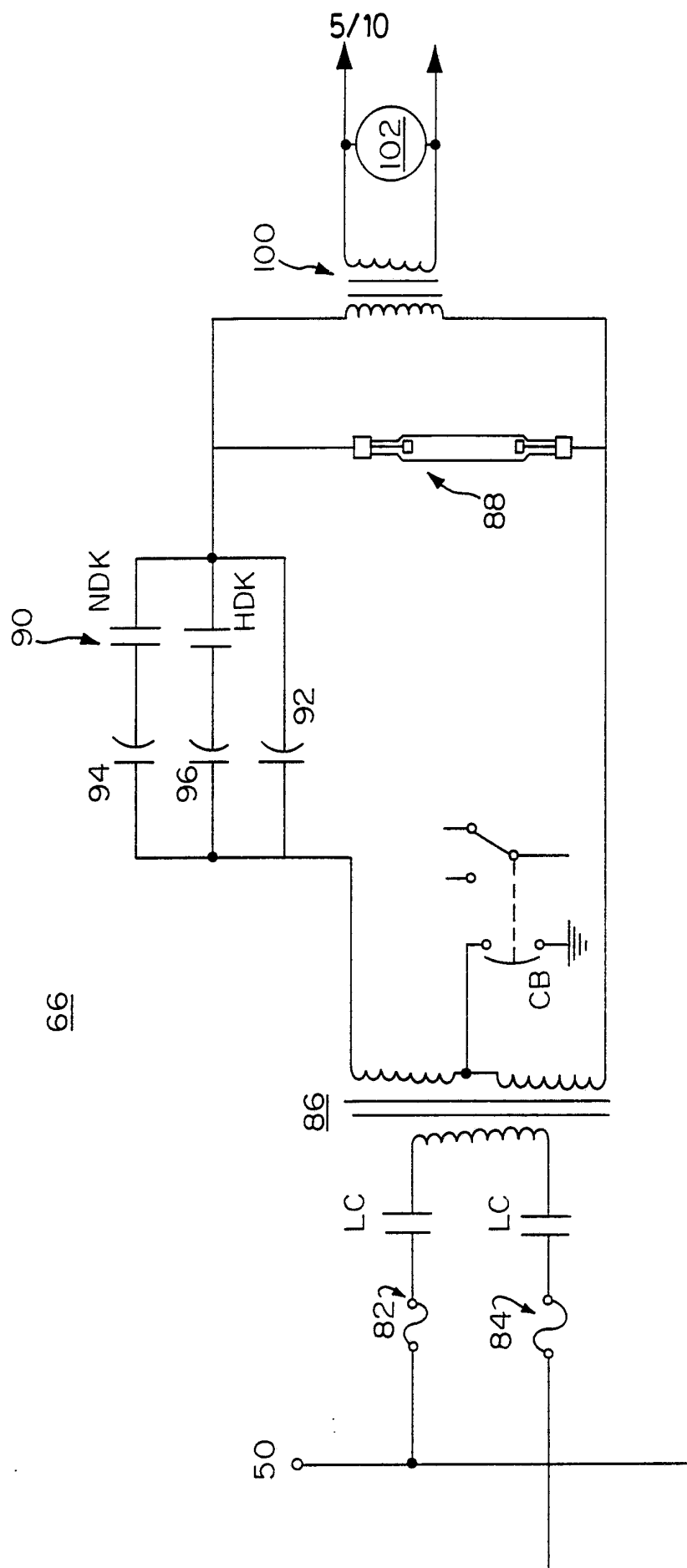
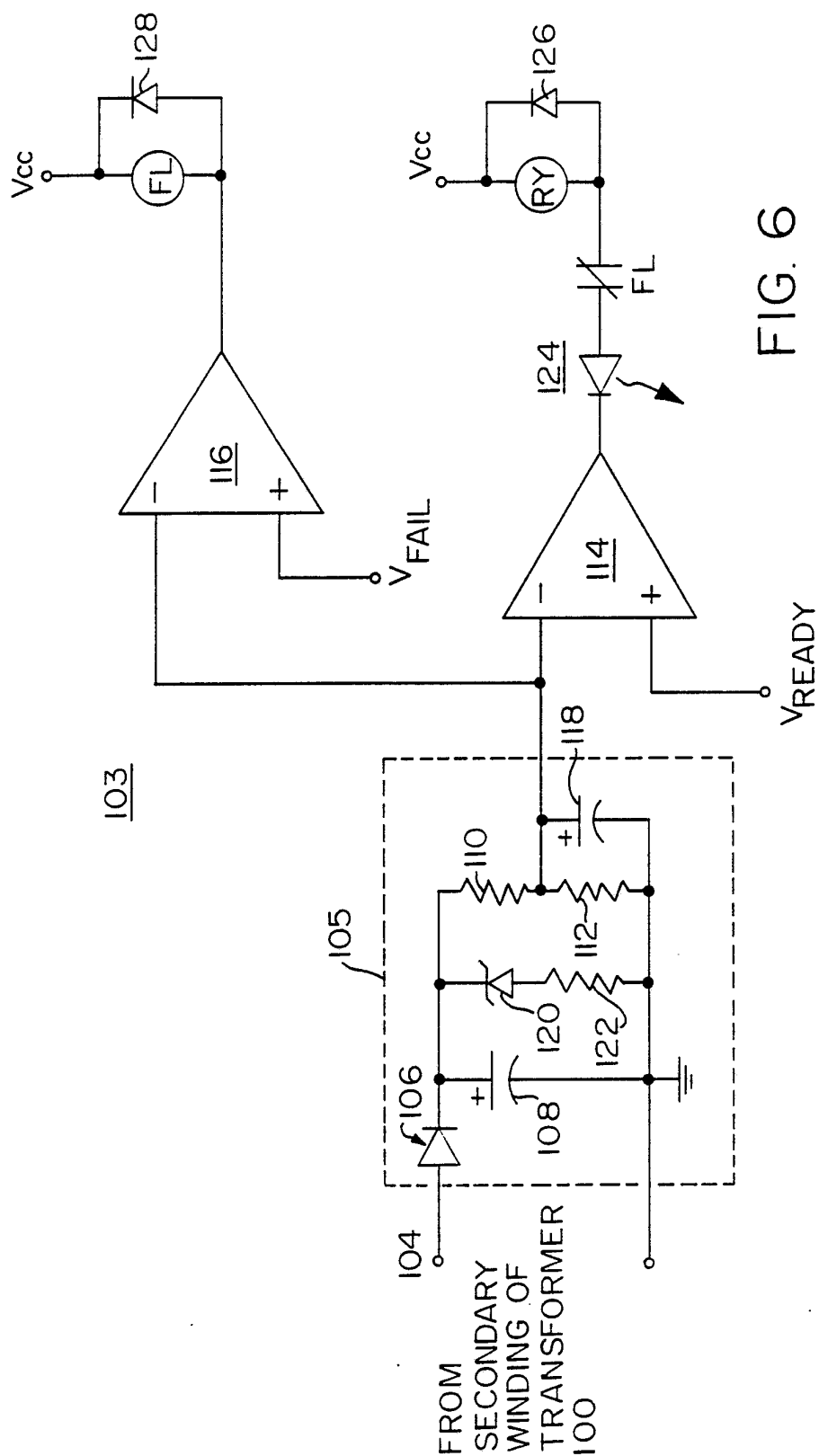


FIG. 5

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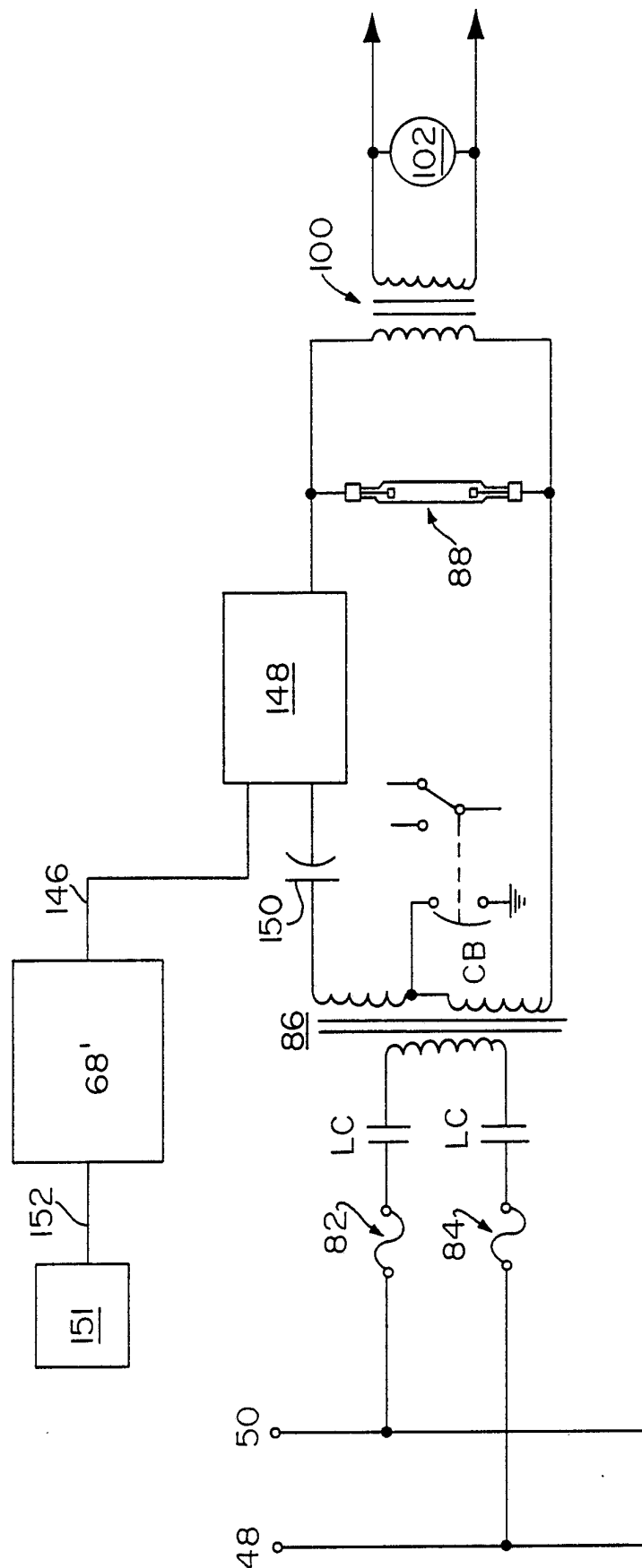


FIG. 7

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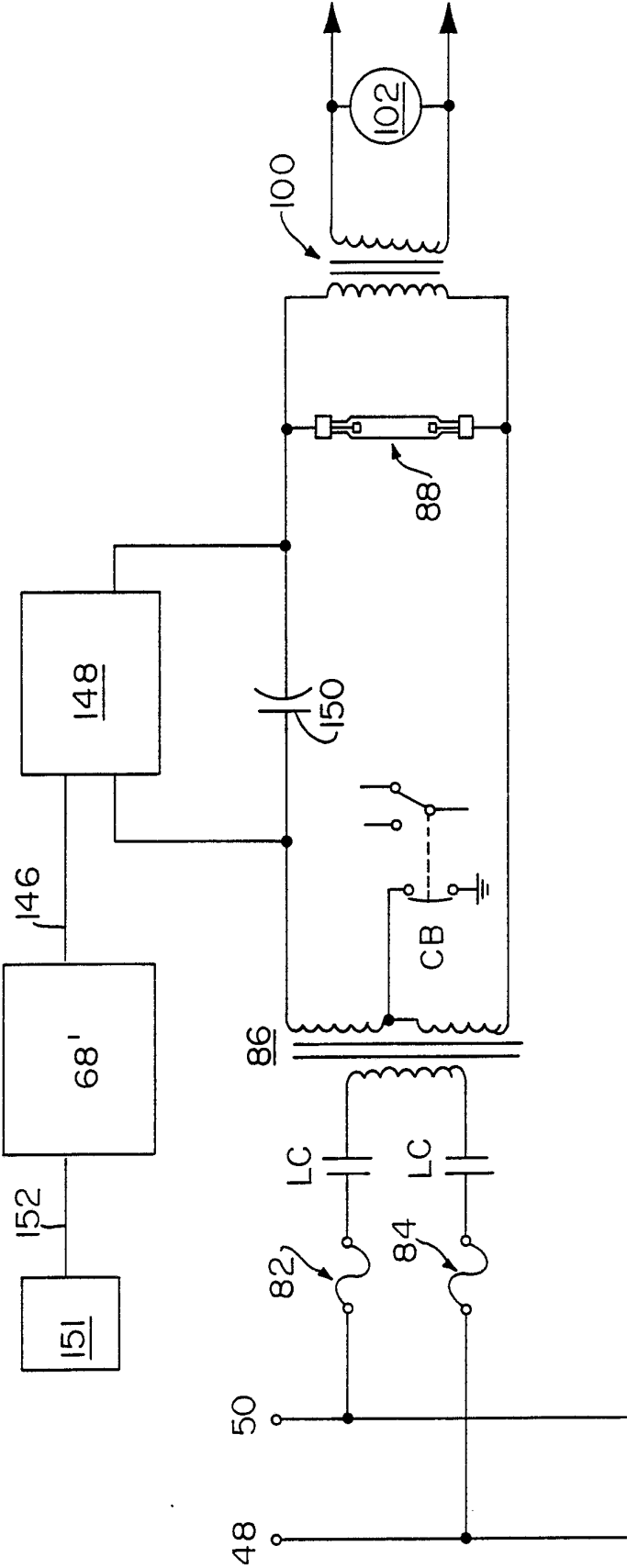


FIG. 8

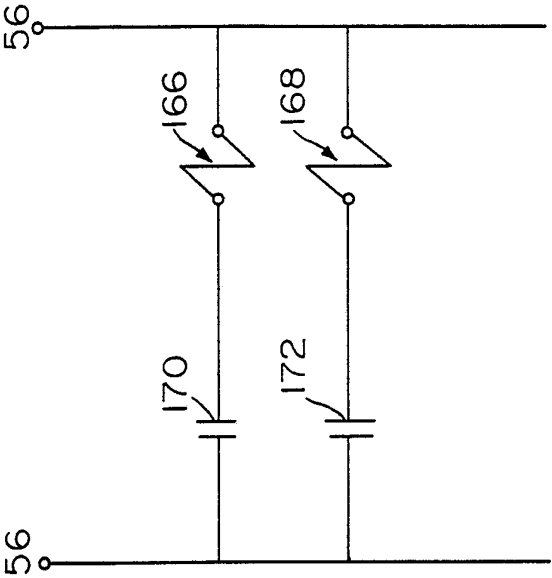


FIG. 10

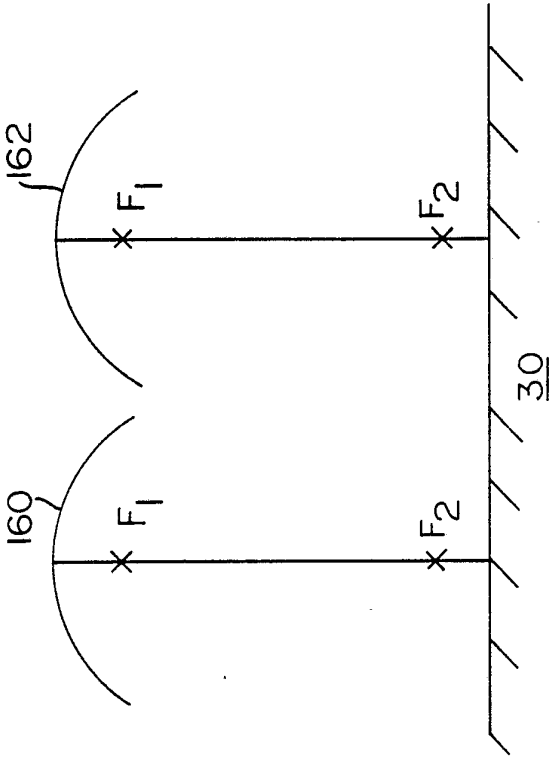
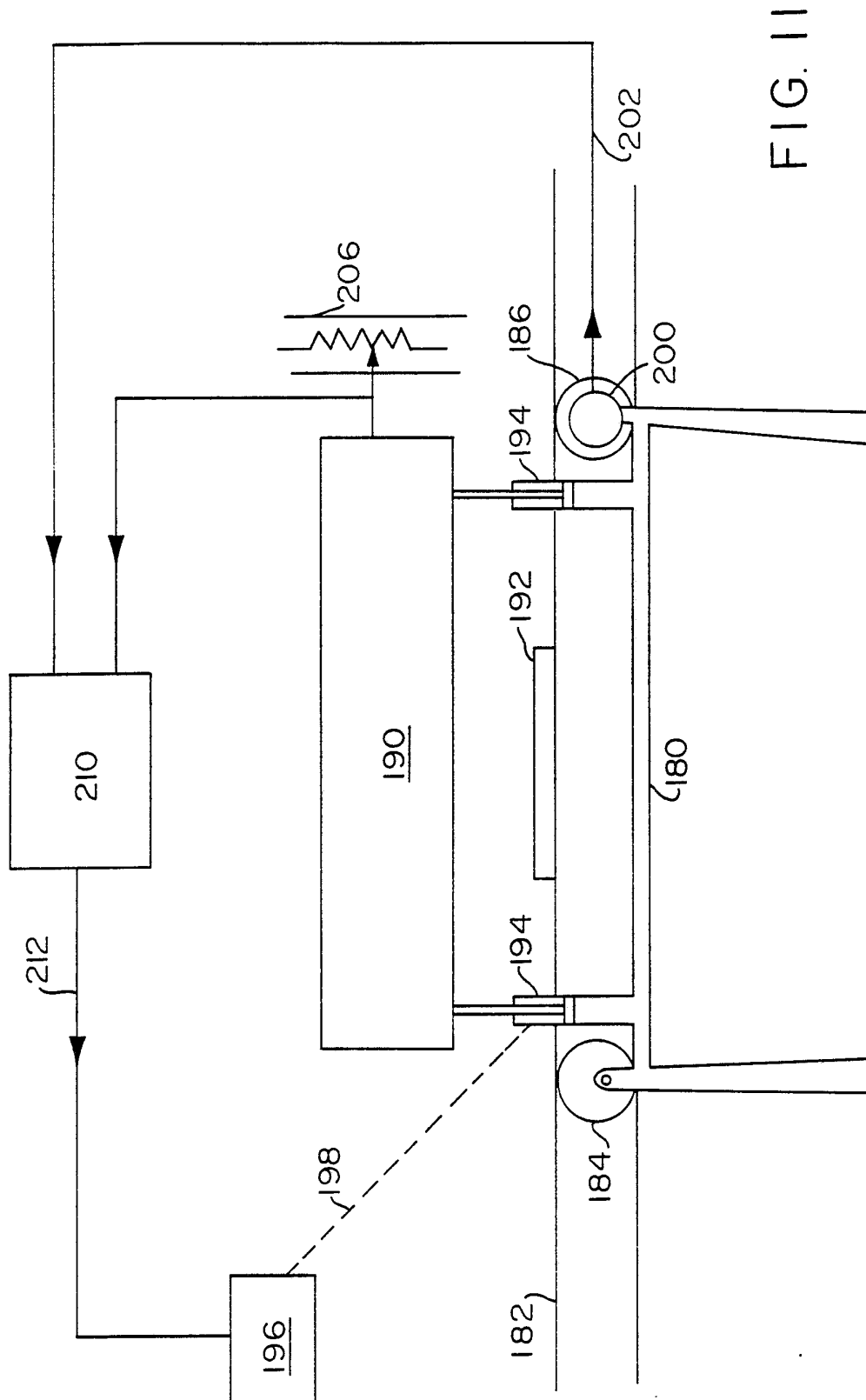
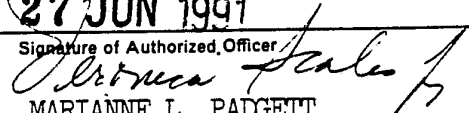


FIG. 9



INTERNATIONAL SEARCH REPORT

International Application No. PCT/US91/01281

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁶		
According to International Patent Classification (IPC) or to both National Classification and IPC		
IPC(5): B05D 3/06; B05C 11/00; G01R 31/00		
U.S. CL.: 427/8, 54.1; 118/672,674,688,708,712; 324/403,414		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁷		
Classification System	Classification Symbols	
U.S	427/54.1, 8, 10; 324/403, 414; 340/641; 118/668,672,674,686,688,708,712	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁸		
III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁹		
Category *	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
X	US, A, 4,831,564 (SUGA) 16 May 1989, See entire document.	16-18
Y	US, A, 4,886,680 (TINDALL) 12 December 1989, See entire document.	1-2,5-6,10, 14-15
Y	US, A, 4,687,677 (JONASSON) 18 August 1987, See entire document, esp. Col. 4, lines 64 to col. 5, line 4.	1-2,5-6,10 14-15
Y	US, A, 4,351,030 (ASTFALK ET AL.) 21 September 1982, See entire document.	3-4,7-9, 11-13
Y	US, A, 3,989,936 (FAY ET AL.) 02 November 1976, See entire document, esp. claims.	1-15
Y	US, A, 4,407,867 (BRUCK ET AL) 04 October 1983, See entire document.	1-2,5-6,10, 14-15
Y	JP, B, 59-66104 (TOSHIBA K.K.) 14 April 1984, See abstract.	3-4,7-9,11-13
* Special categories of cited documents: ¹⁰ "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art. "&" document member of the same patent family		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search		Date of Mailing of this International Search Report
22 MAY 1991		27 JUN 1991
International Searching Authority		Signature of Authorized Officer
ISA/US		 MARIANNE L. PADGETT

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

A	US, A, 4,806,183 (WILLIAMS) 21 February 1989, See abstract.	3-4,7-9,11-13
A	US, A, 3,567,923 (HUTCHINSON) 02 March 1971, See entire document.	3-4,7-9,11-13

V. ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE:

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers _____, because they relate to subject matter ¹² not required to be searched by this Authority, namely:
2. ☐ Claim numbers _____, because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out ¹³, specifically:
3. ☐ Claim numbers _____, because they are dependent claims not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI. ☐ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING²

This International Searching Authority found multiple inventions in this international application as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.
2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:
3. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:
4. ☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

- ☐ The additional search fees were accompanied by applicant's protest.
☐ No protest accompanied the payment of additional search fees.