

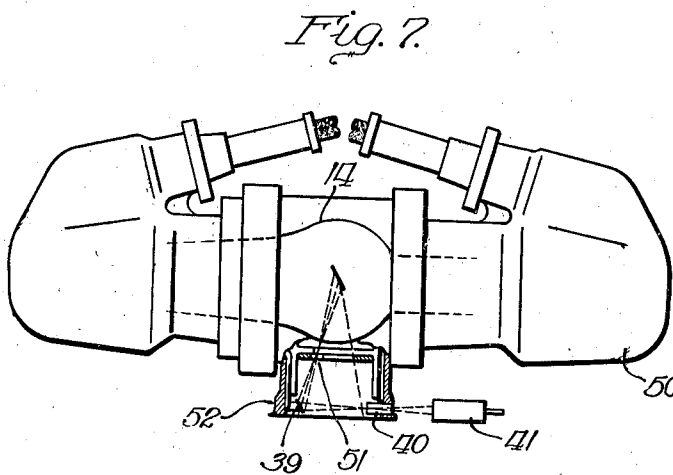
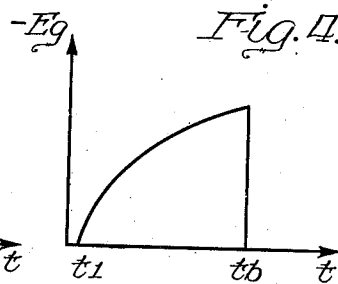
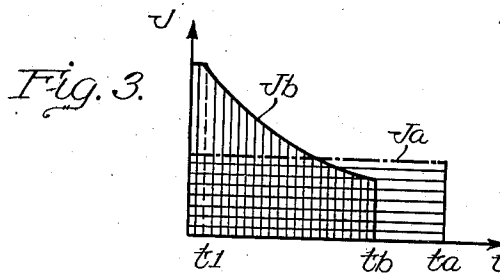
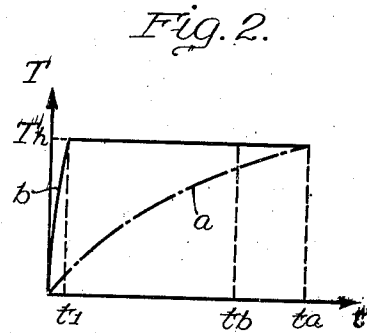
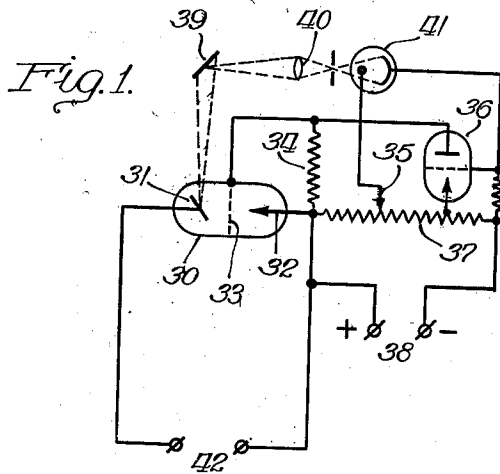
May 6, 1941.

K. BISCHOFF ET AL

2,240,478

X-RAY APPARATUS

Original Filed Oct. 7, 1937 2 Sheets-Sheet 1



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Fig. 5.

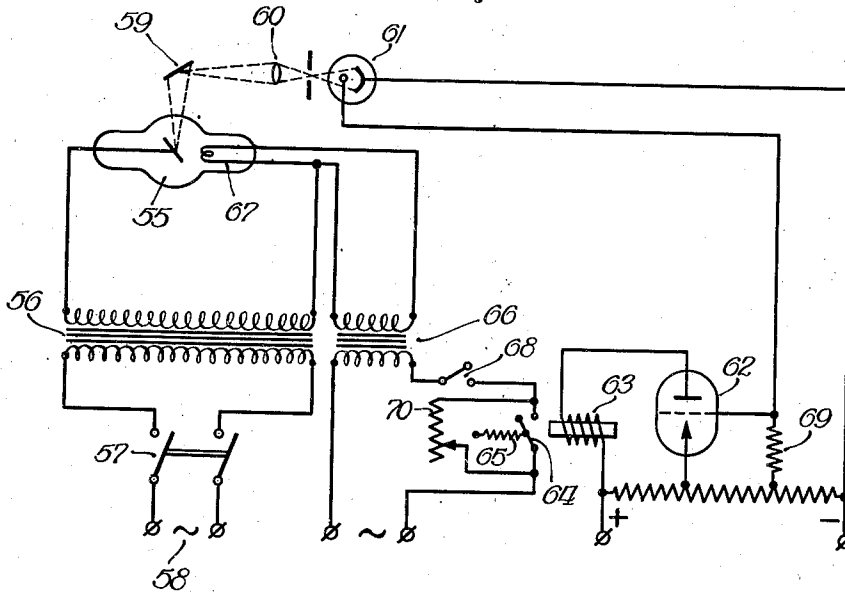
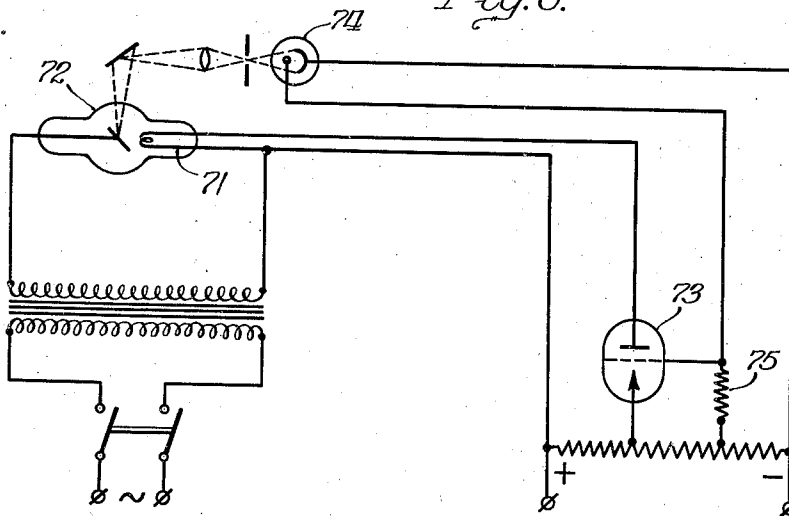


Fig. 6.



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UNITED STATES PATENT OFFICE

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X-RAY APPARATUS

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167,696. Divided and this application Decem-
ber 19, 1938, Serial No. 246,578. In Germany
October 19, 1936

16 Claims. (Cl. 250—103)

The present invention relates to Roentgen or X-ray apparatus, and is particularly concerned with arrangements for preventing overloading the Roentgen tube. These arrangements lend themselves advantageously to a new method of operating such tubes, with better results than have been attained heretofore.

The temperature of the focal spot of a Roentgen tube must not exceed a certain value, in order to avoid danger of destroying the anode, or at least doing it serious damage. Devices and control means have been suggested in the past which attempt to avoid the overloading of a Roentgen tube either by disconnecting the tube when the highest possible temperature of the anode is exceeded, or by regulating the tube current in such a manner that the temperature of the anode is maintained approximately at the highest permissible value during the entire operation of the apparatus. However, such devices have been found unsatisfactory and objectionable in several respects, since they do not provide either for a disconnection of the tube, which is free of delay, or for a substantially continuous control of the tube current for the purpose of obtaining a constant anode temperature.

The invention constitutes a considerable advance and improvement over what has been known in the art, by providing an arrangement using a photoelectric cell or other light-sensitive device which receives the light rays emanating from the focal spot of the Roentgen tube over an optical system and governs the actuation of the corresponding regulating or control means. The protective arrangement which is thus governed by the temperature of the focus point can be used and installed in Roentgen apparatus which is already in operation and may be grounded in apparatus where the anode of the tube is connected to a high tension current source. That is, in the case of a Roentgen tube having an anode operating at high potential, which is arranged within a high tension insulating and radiation-protecting housing with grounded wall, the arrangement according to the invention may be carried out in such a manner that the optical system and the light-sensitive device are at ground potential, with the light rays emanating from the focal spot of the Roentgen tube directed through an aperture or opening in the housing.

It is of importance for the practical realization of the invention to provide means for separating the Roentgen rays emanating from the focal spot of the X-ray tube from the light-sensi-

tive device or preventing such rays from reaching the device. The lenses used in the optical system may for this purpose be made of lead glass, for example, or a mirror may be arranged in the path of the rays from the focal spot, which deflects the light rays to the light-sensitive means, or photoelectric cell, the latter being properly located at the side of the apparatus.

In order to protect the Roentgen tube, the light-sensitive cell is generally adjusted to a value which lies below the load limit. In order to prevent destruction of the Roentgen tube due to failure of the equipment, a second light-sensitive device, e. g., a photoelectric cell, may be provided which disconnects the Roentgen tube when the highest permissible luminosity of the focal spot is exceeded.

The invention is useful for disconnecting the Roentgen tube when a certain permissible maximum focal spot temperature is reached or exceeded, and has the particular advantage that the connection and disconnection of the Roentgen tube current may be obtained by means of a grid-controlled valve provided either in the primary or the secondary circuit of the high tension transformer. The substantially instantaneous disconnection of the Roentgen tube can be accomplished in such a case by the use of relay means which operate without delay and which is actuated when the load limit is reached. Permanent interruption or disconnection of the Roentgen tube current may be obtained upon operative actuation of the light-sensitive device by using suitable switching means, for example, of the stay-put or locking type, and corresponding circuits.

Suitable arrangements for carrying out the invention in accordance with the foregoing, that is, by connecting and disconnecting the Roentgen tube in accordance with the luminosity of the focal spot, are described and claimed in our application, Ser. No. 167,696, filed October 7, 1937, of which the instant application is a division.

Instead of disconnecting the Roentgen tube at the moment when the highest permissible focal spot temperature is reached or exceeded, the invention may be used as previously intimated, so as to maintain the focal spot temperature substantially constant at a desirable value. This object may be accomplished by regulating the Roentgen tube current directly and substantially without delay in dependence on or as a function of the focal spot temperature. The Roentgen tube is equipped in this case with a control grid by means of which the light-sensitive device reg-

ulates the current flowing through the Roentgen tube in such a manner that the temperature of the focal spot cannot exceed a certain predetermined value.

Particularly advantageous is an arrangement whereby the light-sensitive device regulates the heating of the Roentgen tube so that the luminosity of the focal spot remains substantially constant. This may be accomplished by disconnecting or diminishing the heating of the Roentgen tube under the control of the light-sensitive device when the focal spot reaches a certain degree of luminosity, the re-connection or increased heating taking place upon decrease of luminosity of the focal spot below an adjustable value or after the lapse of a certain adjustable time period.

The heating of the Roentgen tube is, in this form of practicing the invention, preferably considerably increased or accelerated for the purpose of quickly reaching the load limit. If this greatly accelerated heating of the Roentgen tube would take place prior to connecting the high tension, the focal spot would be initially overloaded because the filament temperature would not drop quickly enough to the permissible value due to the inertia of the filament. The arrangement is for this reason operated so that the heating current is connected to the Roentgen tube upon starting the exposure simultaneously with connecting the high tension, so that the filament temperature is rising at that moment.

Inasmuch as the light-sensitive device takes care that the filament temperature can never exceed the highest permissible value (since the focal spot luminosity would otherwise also rise to an impermissible value), it follows that the heating current can be increased as desired, so that the speed with which the cathode and, therefore, also the focal spot reach the highest permissible temperatures can be accelerated at will. It is therefore entirely possible to heat a cathode intermittently with a current of, for example, 12 or more amperes, whose maximum permissible permanent heating current is about 8 amperes.

The heating of the Roentgen tube takes place preferably from a direct current source, or from an alternating current source of high frequency, in order to avoid the oscillations of the emission caused by the use of an alternating current of, for example, 50 cycles, thereby accomplishing more accurate work.

A milliamper-second relay is preferably provided, which disconnects the high tension connected to the Roentgen tube as soon as a milliamper-second product is reached which has previously been adjusted on this relay. The use of a known device for disconnecting the Roentgen tube as soon as a sufficient blackening of the film is accomplished incident to the exposure, is also very advantageous.

The above stated and other objects and features of the invention will appear from the detailed description presented below with reference to the accompanying drawings. In these drawings,

Fig. 1 represents an embodiment wherein the Roentgen tube current is continuously regulated in accordance with the focal spot temperature;

Figs. 2, 3, and 4 illustrate in form of curves various interdependent current and temperature conditions in an embodiment such as shown in Fig. 1;

Figs. 5 and 6 illustrate embodiments wherein the light-sensitive device regulates the filament

current for the purpose of maintaining the luminosity of the focal spot substantially constant; and

Fig. 7 shows a practical structure wherein the Roentgen or X-ray tube is enclosed in a high tension insulating and radiation-protecting grounded housing with means for transmitting the light rays from the focal spot through an optical system to the light-sensitive device.

The apparatus is represented in the drawings, except Fig. 7, in a conventional and more or less schematic manner. The general structure and operation of individual devices, such as photoelectric cells, electronic valves, gaseous discharge tubes, and others, as used in connection with the various structures herein described, is well known and will not be dwelled upon in detail except when necessary for an understanding of the invention.

Referring now to the embodiment shown in Fig. 1, the Roentgen tube 30 is provided with an anode 31, cathode 32 and a grid 33. The tube is connected to a high tension source 42. The light rays emanating from the anode 31 are directed to the mirror 39 and by way of the optical system 40 to the light-sensitive cell 41 which may be a photoelectric cell connected in the circuit of the direct current source 38. The Roentgen rays emanating from the tube are not reflected by the mirror and are thus prevented from reaching the photo cell 41. The grid 33 of the Roentgen tube 30 is connected with the cathode 32 by way of the resistance 34 and is thus connected to the positive pole of the direct current source 38, with a branch connection by way of the grid-controlled discharge tube 36 to a point of negative potential on the voltage divider 37 of the direct current source 38. The grid of the discharge tube 36 normally has a negative voltage so that no current can flow through this tube and the resistance 34. The grid 33 of the Roentgen tube 30 is therefore normally at the same potential as the cathode 32. In case the Roentgen tube 30 is loaded, the light rays emanating from the focal spot on the anode 31 will cause a current flow in the light-sensitive cell 41 through a part of the voltage divider 37, which reduces or eliminates the negative voltage on the grid of the discharge tube 36. Current can now flow through the discharge tube 36 and the resistance 34, which produces on the grid 33 of the Roentgen tube 30 an increasing negative voltage as compared with the voltage on cathode 32, whereby the current flow through the Roentgen tube is diminished. The arm 35 of the voltage divider 37 can be adjusted so that the temperature of the focal spot of the anode 31 is kept substantially constant at any desired value. The operation of the control apparatus involves a continuous correction of the temperature, which tends to exceed the desired value. Whenever the temperature of the focal spot gets too high it increases the current in the circuit of the light-sensitive device 41 enough to in turn change the voltage conditions between the grid 33 and the cathode 32 of the Roentgen tube so as to slightly reduce the current flow through the Roentgen tube, thereby reducing the temperature of the focal spot. The average temperature maintained can be adjusted, as previously stated, by means of the arm 35.

Fig. 2 illustrates the variation of the temperature T of the focal spot with relation to the load time t and explains the conditions that exist in the embodiment, Fig. 1, as compared with those in previously known Roentgen apparatus. While

in the Roentgen apparatus heretofore used the temperature of the focal spot rises slowly up to the highest permissible value T_h (dot-dash curve *a*), in the case of the embodiment, Fig. 1, the temperature rises so rapidly that the highest permissible temperature T_h is reached in the very short time t_l (curve *b*) and then remains substantially constant.

In Fig. 3 is illustrated the variation of the current J flowing through the Roentgen tube 30 in relation to the load time t . While in the previously known Roentgen apparatus the current J_a remains substantially constant, in the present embodiment according to Fig. 1, the Roentgen tube current J_b is initially considerably higher and drops during operation under the value J_a , as indicated. It will therefore be seen that in the Roentgen apparatus heretofore known, the time t_a (horizontally shaded area) was necessary for reaching a certain load, that is, milliamperere-second product ($J.t$). In the present embodiment, as explained with reference to Fig. 1, only the considerably shorter time t_b is required, as shown in the vertically shaded area in Fig. 3.

Fig. 4 shows the manner in which the negative voltage E_g of the grid 33 of the Roentgen tube 30 (Fig. 1) rises in dependence on the load time t .

It should be observed that a change in the Roentgen tube voltage cannot cause an overload, since the temperature, that is, the brightness, of the focal spot is dependent on the current fed to the Roentgen tube and the equipment operates always in such a manner that the highest permissible temperature of the focal spot cannot be exceeded.

Fig. 5 illustrates a Roentgen tube 55 which is supplied from the high tension transformer 56, the latter being connected to the current source 58 over a switch 57. The light rays emanating from the focal spot of the Roentgen tube 55 are reflected to the photoelectric cell 61 by means of the mirror 59 and the optical system 50. The current flowing through the photoelectric cell 61 is amplified by means of the instantaneously operating amplifier 62 and feeds a relay 63, the latter maintaining a switch 64 closed against the force of the spring 65. The switch 64 is connected in the circuit of the primary winding of the heating transformer 66, supplying current to the glow cathode 67 of the Roentgen tube 55.

The switch 64 is closed prior to beginning the exposure because relay 63 is energized by the anode current of the grid tube 62 which flows through the tube and also through the relay. If the manually operable switch 68, which is in series with the switch contacts 64, is now closed (preferably simultaneously with or immediately after actuation of the switch 57), the glow cathode 67 is very rapidly heated due to the high heating voltage, and the electron stream strikes the anode of the Roentgen tube 55 with great velocity in accordance with the high tube tension. Current flows through the photoelectric cell 61 due to the heating of the focal spot, consequently also through the resistance 69, so that the grid of tube 62 receives a negative potential whereby the anode current is reduced which flows through the tube 62; and when the anode current drops below a certain value, relay 63 is deenergized, the switch contact 64 is opened, and the primary heating current of the heating current transformer 66 flows now over the adjustable resistance 70 which is in parallel to the switch contact 64. This weakens the primary

heating current, and the temperatures of the glow cathode 67, and also the brightness of the focal spot of the Roentgen tube 55, are correspondingly decreased. The photoelectric cell 61 now receives less light; the potential of the grid of tube 62 becomes more positive; relay 63 energizes, closing the switch contact 64 again; and the operation cycle can be repeated. The heating current may also be entirely interrupted and the resistance 70 dispensed with in view of the inertia of the glow cathode 67.

It is possible in the above described manner to maintain the temperature of the focal spot of the Roentgen tube 55 substantially constant and, if desired, at the point of the highest permissible value, so that the maximum load capacity of the Roentgen tube is fully utilized at an optimum. The connection and disconnection of the heating current is preferably carried out by the use of grid controlled gaseous discharge tubes instead of by the use of a mechanical relay, because the maintaining of the desired temperature of the focus point is accomplished best when the relay 63 and the switch contact 64 operate substantially without inertia. The connection and disconnection, respectively, can also be controlled by two separate photoelectric cells.

In the embodiment shown in Fig. 6, the glow cathode 71 of the Roentgen tube 72 is heated from a direct current source, as indicated, and the anode current of the grid tube 73, which depends on the intensity of the light received by the photoelectric cell 74, supplies the glow cathode 71 of the Roentgen tube 72 directly. Numerical 75 indicates a resistance corresponding to the one shown at 69 in Fig. 5; other elements shown in Fig. 6 correspond to similarly represented parts also shown in Fig. 5 and have, of course, like functions.

In Fig. 7 is shown a practical embodiment of the invention wherein the Roentgen tube, the tube 30 in Fig. 1, for example, is provided with a high tension insulating and radiation-protecting housing 50, the outer wall of which is grounded. The light rays emanating from the Roentgen tube are transmitted through an opening 51 of the housing 50 to the outside and strike the mirror 39 which is located within the grounded shutter housing 52. The light rays are then conducted through the optical system 40 to the removably mounted light-sensitive cell 41. The optical system 40 and the light-sensitive cell 41 are therefore at ground potential, as they are mounted on the grounded housing 50.

The various devices shown in Figs. 1, 5 and 6 may, however, be mounted in any convenient and suitable manner so long as the relation of the equipment is maintained as indicated and described, for the purpose of obtaining the desired explained results. Fig. 7 merely shows one example of how the parts may be arranged.

What is desired to have protected by Letters Patent of the United States is particularly pointed out in the appended claims.

We claim:

1. The combination, with a Roentgen tube having a control grid, of a photoelectric cell responsive to light produced at the focal spot on the target in said tube, and means including said cell for controlling the potential on said grid.
2. The combination, with a Roentgen tube having a control grid, of a photoelectric cell responsive to light produced by a rise in temperature at the target in said tube, a space discharge device, and means including said cell and device for controlling the potential on said grid.

3. The combination, with a Roentgen tube having a control grid, of a circuit for said grid leading through a resistance to a source of positive potential, a space discharge device, a branch circuit leading through said space discharge device to a source of negative potential, and means including a photo-electric cell responsive to light emitted from an incandescent spot on the target in said tube for controlling the resistance of said space discharge device.
4. Apparatus for controlling the operation of a Roentgen tube of the heated cathode type, comprising a light-sensitive cell responsive to light produced at the focal spot on the target of the tube, a space discharge device controlled by said cell, and means including said device for governing the supply of heating current to the cathode of said tube.
5. Apparatus for controlling the operation of a Roentgen tube of the heated cathode type, comprising a space discharge device, means for rendering the conductivity of said device proportionate to the temperature of the focal spot of said tube, and means disposed in the supply circuit of the cathode of said tube for regulating the supply of heating current thereto responsive to changes in the conductivity of said discharge device.
6. Apparatus for controlling the operation of a Roentgen tube of the heated cathode type, comprising means in the circuit of the cathode of said tube for continuously regulating the supply of heating current thereto to maintain the temperature of the focal spot substantially constant, and means including a light-sensitive device responsive to fluctuations in the luminosity of the focal spot in said tube for governing said regulating means.
7. Apparatus for controlling the operation of a Roentgen tube of the heated cathode type, comprising a space discharge device disposed in the circuit of the cathode of said tube, and a light-sensitive cell governed by the luminosity of the focal spot of said tube for governing said device to regulate the supply of heating current to said cathode.
8. Apparatus for controlling the operation of a Roentgen tube of the heated cathode type, comprising current control means in the supply circuit of the cathode of said tube, a light-sensitive cell responsive to the light emitted at the focal spot of said tube, and a space discharge device controlled by said light-sensitive cell for regulating the actuation of said current control means to maintain the temperature of said focal spot substantially constant.
9. Apparatus for maintaining the temperature of the focal spot in a Roentgen tube at a substantially constant value, comprising means for continuously regulating the supply of power to the tube, means dependent on the luminosity of the focal spot in said tube for controlling said regulating means, and means for adjusting the point at which the temperature is maintained.
10. Apparatus for continuously regulating the anode current in a Roentgen tube, comprising a control grid in said tube, a space discharge device for controlling the potential on said grid, a photo cell exposed to light generated at the focal spot of said tube for controlling said space discharge device, and means for preventing X-rays generated at said focal spot from affecting said photo cell.
11. The combination, with a Roentgen tube, of a heating circuit for the cathode of said tube, a resistance associated with said circuit, switching means for rendering said resistance alternately effective and ineffective to restrict the current flow in said circuit, and means including a photo cell responsive to changes in the luminosity of the focal spot in said tube for controlling said switching means.
12. Apparatus for controlling the operation of a Roentgen tube, comprising means for continuously regulating the supply of power to the tube, and means dependent upon the luminosity of the focal spot in said tube for controlling said regulating means.
13. Apparatus for controlling the operation of a Roentgen tube, comprising a device for alternately decreasing and increasing the supply of power to the tube without interrupting said power supply, and means dependent upon the intensity of light produced at the anode of said tube for controlling said device.
14. The combination, with a Roentgen tube, of a photo cell responsive to light produced at the anode of said tube, and means including a space discharge device controlled by said photo cell to vary the current consumption of said tube within a predetermined limited range.
15. The combination, with a Roentgen tube, of means for varying the anode current through said tube within a narrow range which includes the normal operating current, said means including a space discharge device, and means including a photo cell responsive to light produced at the anode of said tube for controlling said device.
16. The combination, with a Roentgen tube, of means for supplying anode current to said tube, means for controlling the value of said anode current while the continuous flow thereof is maintained, and a light-sensitive cell responsive to light produced at the anode of the tube for governing the operation of said controlling means.

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