

Sept. 19, 1950

P. C. SMITH

2,522,969

AUTOMATIC VACUUM SYSTEM

Filed Nov. 28, 1947

4 Sheets-Sheet 1

Fig. 1.

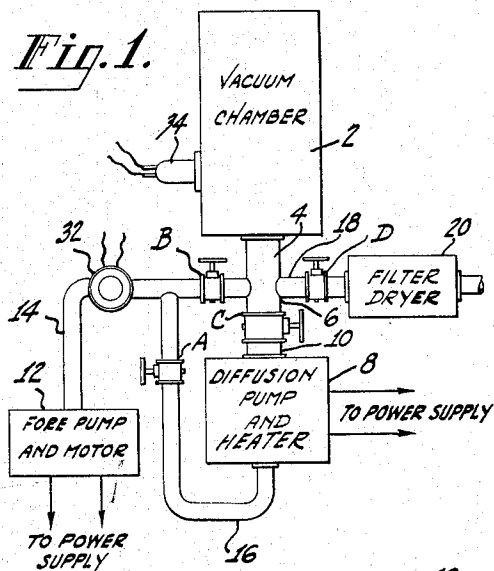


Fig. 2.

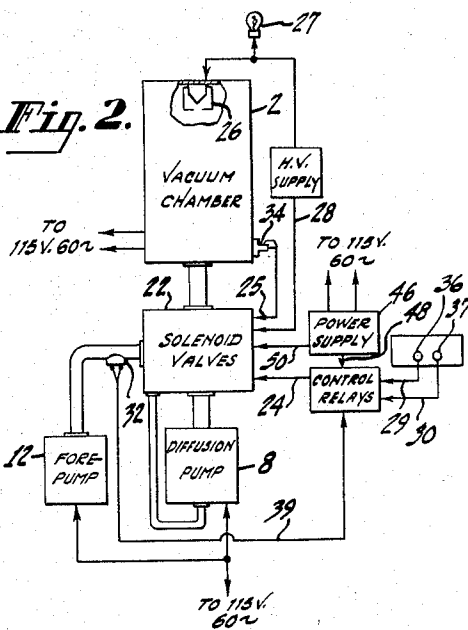
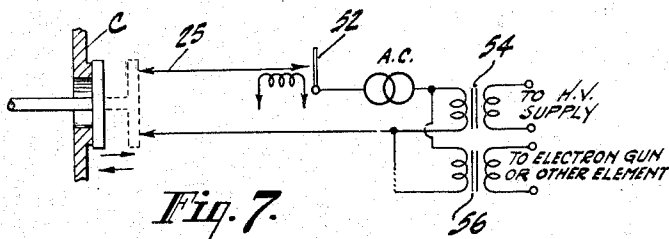
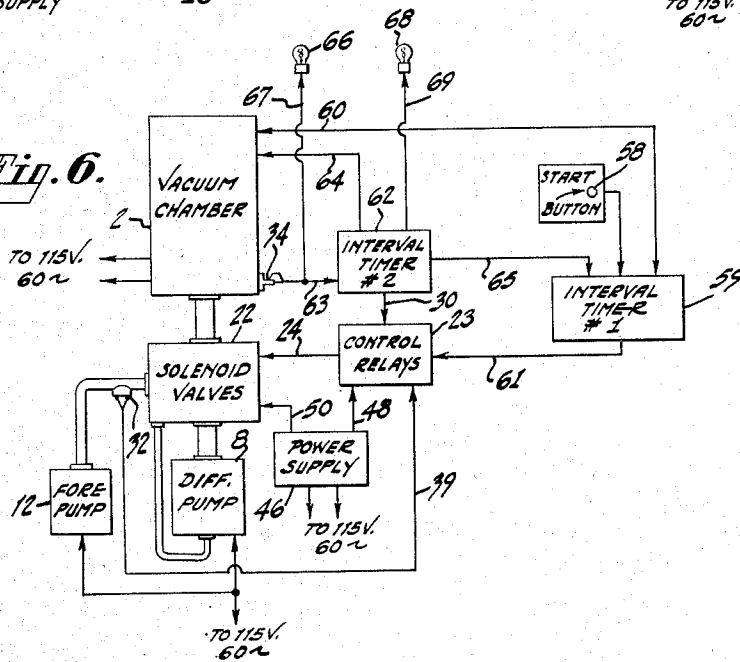


Fig. 6.



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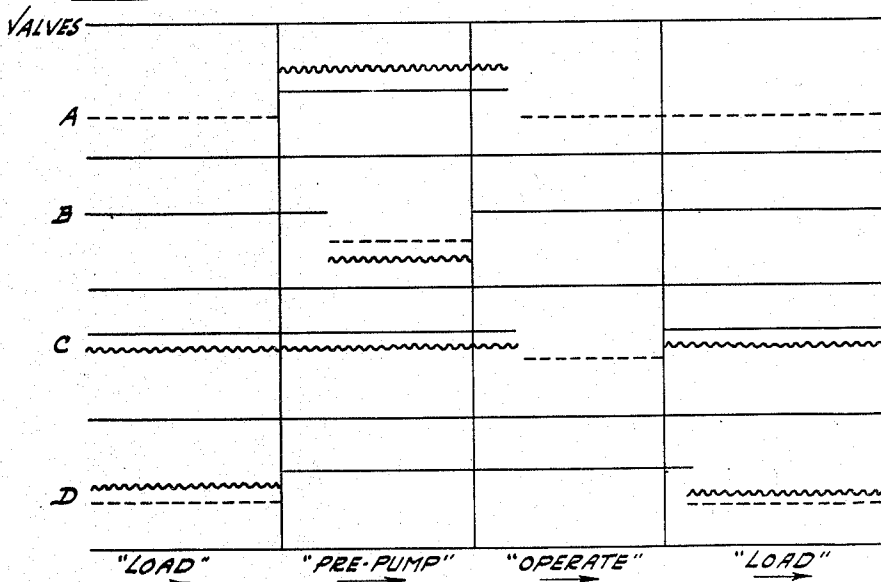
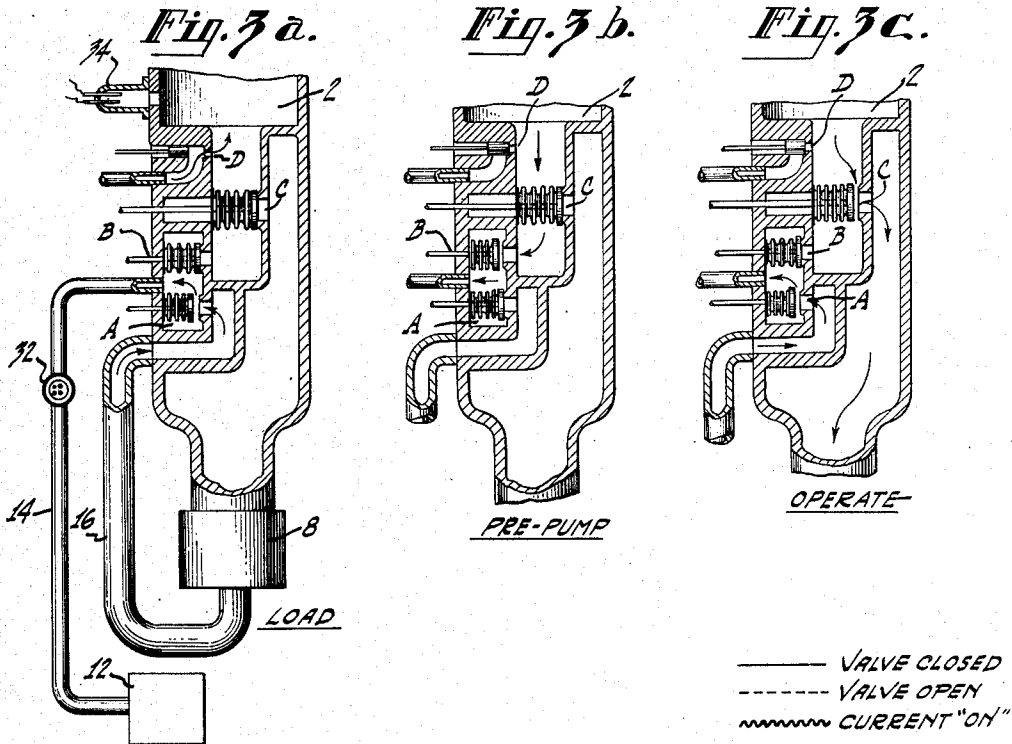
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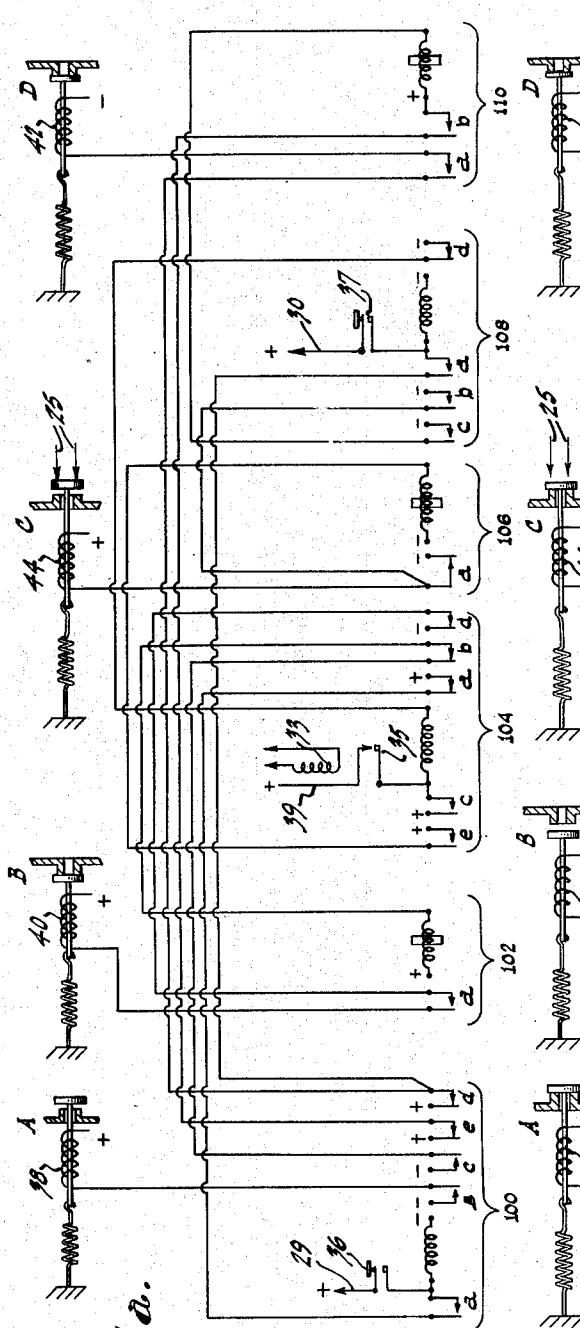


Fig. 4a.

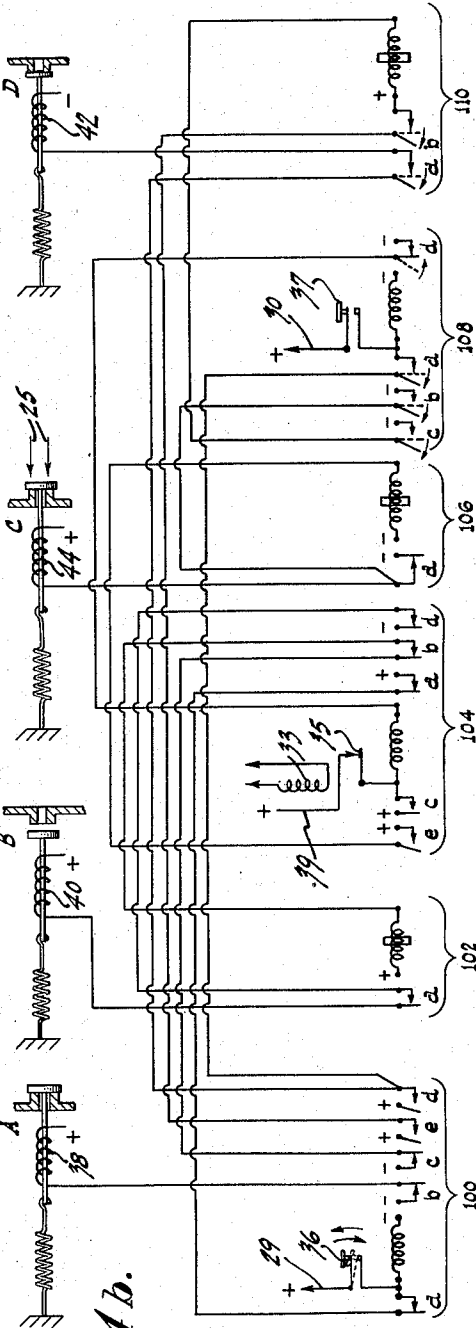


Fig. 4b.

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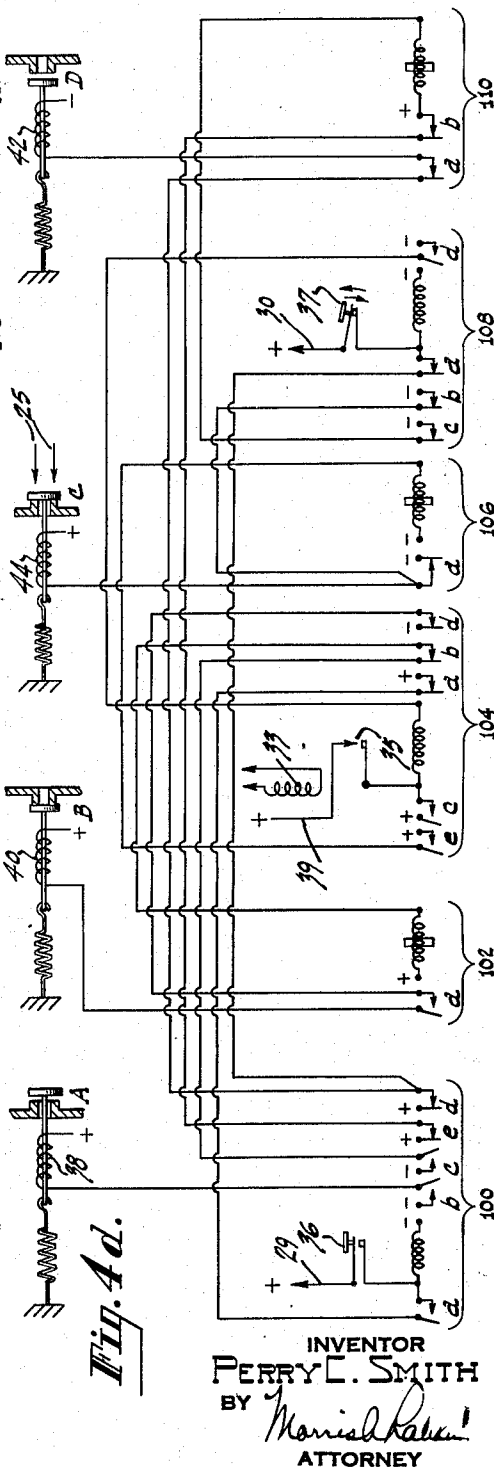
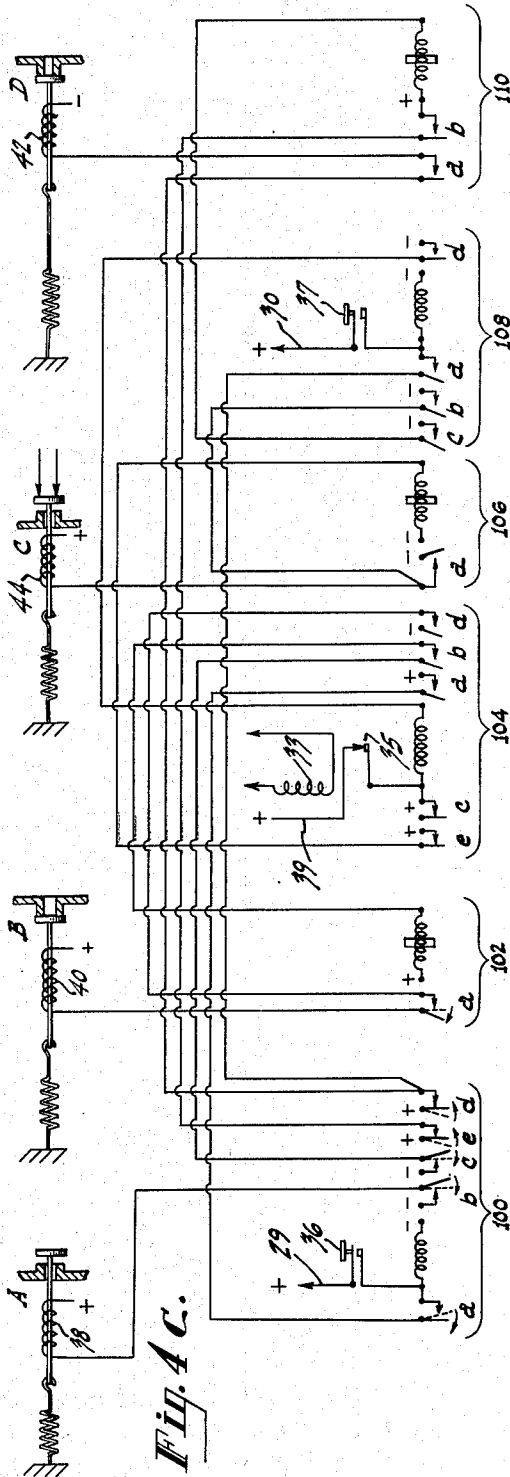
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2,522,969

AUTOMATIC VACUUM SYSTEM

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9 Claims. (Cl. 315—110)

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This invention relates to apparatus for automatically controlling vacuum pumping systems and, more particularly, to apparatus for automatically controlling systems having both a fore pump for low vacuum and a diffusion pump for high vacuum.

In general, there are two different types of apparatus utilizing chambers requiring the use of vacuum pumping systems for obtaining high vacuum conditions therein. One of these types is exemplified by the vacuum tube which comprises a sealed chamber containing a number of electrodes. Usually, the chamber is exhausted to a very high vacuum and permanently sealed so that the interior is never again exposed to the atmosphere during the life of the tube. The second type, which is exemplified by the specimen chamber of an electron microscope, also requires the obtaining of a very high vacuum but is frequently opened to the atmosphere for loading and unloading during its lifetime. This type needs a vacuum pumping system of a high degree of efficiency and dependability in order to keep it in proper working condition. Although the control system of the present invention may be used with either of these two types of equipment, it has particular advantages when used with the second type.

In any vacuum pumping system, for exhausting gases from a vacuum chamber, which includes both a fore or "roughing" pump and a diffusion pump, the use of four main valves represents optimum requirements. One of these valves is in the line connecting the intake of the fore pump to the outlet of the diffusion pump. A second is in the line connecting the vacuum chamber to the intake of the fore pump, a third is in the line connecting the intake of the diffusion pump to the vacuum chamber and a fourth is in the passageway leading from the vacuum chamber to the atmosphere. In previous vacuum systems, such as used in electron microscopes or high vacuum evaporation apparatus, these valves have been operated manually. This requires close attention on the part of the operator and diligence in making certain that the right valve is closed before others are opened, and vice versa.

Another type of manual control upon which the system of the present invention is an improvement is the use of a valve block containing all the valves used in the equipment and a system of gears and cams controlled by a crank lever for advancing the system through various operating steps. In this type of prior art system, the turning of the control crank results in ac-

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complishing the valving operations which accompany the particular operation being carried out with the equipment. Thus, in an electron microscope, for example, there are four positions of the crank corresponding to "loading," "pre-pump," "operate" and "neutral." This type, although an advance over systems requiring individual control, by the operator, of each separate valve, still requires the constant attendance and close attention of an operator who must constantly observe various gauges and meters in order to operate the crank at the proper times.

In any of these previously used manual systems of control, there are serious disadvantages, other than wasted operator's time, which the system of the present invention avoids. For example, in manual systems, there is always present the hazard of incorrect valving sequence. This cannot occur in the automatic control system of the present invention. In manual systems, which all depend to some extent on the judgment of the operator as to what is the proper time for manipulating the valves for the next step of the cycle, there is much lost time when the operating vacuum might be utilized for carrying out the work operation. Another great disadvantage in the manual and mechanically operated systems previously employed lies in the inefficiency of the vacuum seals which are commonly employed in connection with operating rods and levers which extend through the walls of the vacuum chamber. There have usually been employed Sylphon bellows, which are very thin flexible brass tubes subject to failure, due to fatigue and corrosion, particularly at the soldered junctions. Other improved seals including rubber grommets have been substituted for the Sylphon bellows but these require the use of a great deal of power to move the control rods extending through the rubber seals. In the automatic system of the present invention, electrically operated solenoid valves, having no such disadvantages, may be employed.

The principal object, then, of the present invention is to provide a vacuum pumping control system which is fully automatic.

Another object of the invention is to provide an improved vacuum control system which may be applied to any equipment having an evacuable chamber which must frequently be opened to the atmosphere between periods when it is under high vacuum.

Another object of the present invention is to provide an automatic system for controlling the operation of valves in a vacuum pumping system in response to predetermined signals.

Another object of the present invention is to provide an automatic system for controlling the operation of valves in a plurality of vacuum systems by a single operator.

Still another object of the present invention is to provide an improved automatically controlled evacuating system for maintaining the pressure within a vacuum chamber at a desired level.

Other objects of the invention will be apparent and the invention will be more readily understood from a reading of the following specification, including the accompanying drawings, of which:

Fig. 1 is a block diagram showing the arrangement of the principal valves in relation to the main components of a typical vacuum system with which the present invention may be used;

Fig. 2 is a block diagram indicating circuits connecting various parts of a control system constructed in accordance with the present invention;

Figs. 3a, 3b and 3c are diagrammatic cross sectional views of a typical vacuum chamber showing valve positions for different operating conditions;

Fig. 4a is a wiring diagram including the relays and valve solenoids showing the positions of the valve pistons and relay contacts with all relays and solenoids "at rest" or de-energized in a system constructed in accordance with the present invention;

Figs. 4b, 4c and 4d are similar wiring diagrams showing relay contact positions and valve piston positions during different portions of a complete operations cycle;

Fig. 5 is a diagram showing conditions of electrical current in relation to valve operation timing present during each part of a complete cycle of operation of a typical system constructed in accordance with the present invention;

Fig. 6 is a block diagram of another embodiment of the system shown in Fig. 2, and

Fig. 7 is a detail diagram of part of the circuit indicated more generally in Fig. 2 and Fig. 6.

Referring now to the drawings, a typical embodiment of the invention will be described in connection with the evacuation, to a high degree, of a vacuum chamber which may be the column of an electron microscope, although it obviously could be any other piece of equipment in which it was desired to obtain a condition of high vacuum.

In a typical system, as shown in Fig. 1, there may be an evacuable chamber 2 to which is connected an outlet passage 4 having a three-way opening 6. To one of these openings, there is connected the intake of a diffusion pump 8 through a passageway 10. A valve C for maintaining the passageway 10 in a closed or open condition, as desired, is positioned therein. To another of the openings, there is connected the intake of a fore or roughing pump 12 by means of a passageway 14. The passageway 14 has a valve B positioned therein. The outlet of the diffusion pump 8 is connected to the intake passageway 14 of the fore pump 12 through a passageway 16, the connection into the passageway 14 being located between the pump 12 and valve B. The passageway 16 also has in it a valve A. The third opening to the vacuum chamber 2 is connected through a passageway 18, having a valve D positioned therein, to the atmosphere, preferably through a filter dryer 20.

In a typical cycle of operation of the system, as applied to an electron microscope, for exam-

ple, including the valves, shown in Fig. 1, the valves may be opened and closed in proper sequence by a system of the general type shown in Fig. 2.

The complete system may comprise, in general, a vacuum pumping unit comprising a diffusion pump 8 and a roughing pump 12 which is designed to evacuate the vacuum chamber 2 to a desired degree of vacuum and maintain the vacuum as long as desired. The roughing pump is operated by a motor associated therewith. The vacuum system also includes a number of solenoid-operated valves, indicated generally at 22, which are controlled through the operation of a relay system 23 connected to the solenoid valves through the circuit indicated generally at 24.

The relay system is, in turn, partially controlled by the operator pressing the "start" switch 36 and the "release" switch 37 connected to the relay system through circuits 29 and 30, respectively. The relays also operate automatically in response to information received from the thermogage 32, through circuit 39.

A power supply 46 supplies D.-C. power to the relay system through circuits indicated generally at 48 in Fig. 2 and having connections more particularly shown in Figs. 4a-4d. The power supply 46 also supplies D.-C. power to the solenoid system indicated generally at 22 in Figs. 2 and 6, through circuits indicated generally at 50. The solenoid power connections are also illustrated in detail in Figs. 4a-4d.

The system further provides for turning the high voltage supply to the electron gun 26 on and off automatically in response to information received from the ionization gage, preferably by the switching means described in U. S. Patent 2,383,600 and for preventing the high voltage from being connected to the electron gun except when the pressure within the vacuum chamber has been reduced to the proper value, by means more particularly illustrated in Fig. 7.

A more specific embodiment of that part of the invention which includes the automatic operation of the vacuum system valves indicated in Fig. 1 will now be described with reference to Figs. 3a to 3c and Figs. 4a to 4d.

Referring first to Figs. 1 and 3a to 3c, the vacuum system is assumed to be in "load" condition (Fig. 3a) with the vacuum chamber 2 open to the atmosphere as for the insertion of a new specimen. Both pumps have previously been turned on and remain on throughout the operations. In the "load" condition, the valves are positioned, as shown in Fig. 3a, with valves A and D open and valves B and C closed. The fore pump 12 continuously pumps the diffusion pump 8. The operator then initiates an operations cycle by pressing a starting button 36. The apparatus first assumes the condition designated as "pre-pump" (Fig. 3b). Valves A and D close, after which valve B opens, valve C remaining closed. Thus, the passageway to the atmosphere is sealed off and the fore pump 12 switches from pumping the diffusion pump and begins to rough pump the vacuum chamber 2. At the same time, the diffusion pump 8 is held at low pressure due to the fact that valves A and C are closed.

When a certain pressure; i. e., about 10 microns of mercury, has been attained within the vacuum chamber 2, which pressure is indicated by a thermogage 32 in the fore pump line, another part of the cycle designated "operate" (Fig. 3c) automatically begins. For this part of the cycle, valve B closes and D remains closed. Valves A

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and C open after valve B is closed. This results in the fore pump 12 no longer being directly connected to the vacuum chamber 2. The opening of valve A connects the intake of fore pump 12 to the outlet of the diffusion pump 8 while the diffusion pump is now connected to the vacuum chamber 2 due to the opening of valve C. Both pumps are thus connected to the vacuum chamber in series.

With both pumps evacuating the vacuum chamber in series, the pressure within the chamber is reduced to a value required for certain operations within the chamber. In the case of an electron microscope, this may be 5×10^{-4} mm. of mercury. The low pressure reading is indicated, preferably, on an ionization type gage 34 connected to the chamber 2.

When the "operate" cycle is completed, the apparatus may be returned to the "load" position, by the operator pressing "release" switch 37, with the valves in the position described previously in connection with this part of the cycle and shown in Fig. 3a.

In order to accomplish the above cycle in a completely automatic manner, a novel system, forming an important part of the present invention, has been devised and one embodiment is shown schematically in Figs. 4a to 4d.

Fig. 4a illustrates the positions of the various relay contacts and valve pistons of this embodiment when no current is flowing in any of the relay coils or valve solenoids. In the relay 100, which controls the solenoid of valve A, contacts a, b and c are open, while contacts d and e are closed. In the relay 102 which controls the solenoid of valve B, the single contact a is open. In the relay 104, which is energized in response to information received from the thermogage 33, contacts e and c are open while contacts a, b and d are normally closed. In the relay 106, which controls the solenoid of valve C, the single contact a is closed. In the relay 108 which is energized by the release switch 37, the contacts a, b and c are open while contact d is closed. In the relay 110, which controls the solenoid of valve D, both contacts a and b are open. When any of these relays is energized, its contacts assume positions opposite to those indicated above.

It is also apparent, as illustrated in Fig. 4a, that when no current is flowing in any of the valve solenoids, valves A and C are open while valves B and D are closed.

When initiating a cycle of operations, a momentary impulse is given the relay 100 by the pressing of the starting button 36 by the operator.

As a result of the initiating impulse, the following events occur, resulting in the various relay contacts and valve pistons taking the positions shown in Fig. 4b:

1. Relay 100 is energized, closing its contacts a, b and c and opening its contacts d and e. It locks closed by being connected to the power supply 46, through the closed contacts 104a of unenergized relay 104 and through its own closed power contacts 100a.
2. The closing of contacts 100b energizes the solenoid 38 of valve A, thereby closing the valve A, which is between the fore pump 12 and diffusion pump 8.
3. The closing of contacts 100c applies power through the closed contacts 104b of unenergized relay 104 to energize the delayed-action relay 102. The closing of contacts 102a of re-

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lay 102 applies energizing power to the solenoid 40 of valve B and opens this valve. The slow-operating characteristics of relay 102 provide a desired time delay for the opening of valve B after the closing of valve A.

4. Simultaneously with the closing of valve A, and before the opening of valve B, contacts 100d of relay 100, which are connected through contacts 110a, breaks the power connection to the solenoid 42 of valve D, even though the contacts 110a of relay 110 may still be closed. This de-energizes solenoid 42 of valve D and closes the valve, thus disconnecting the vacuum chamber 2 from the atmosphere. (The valve D is adapted to close when its solenoid is de-energized.) The opening of contacts 100d, which are connected through a second path to contacts 108a, also removes locking current for relay 108 through its contacts 108a, thus de-energizing relay 108. The de-energizing of relay 108 opens contacts 108c which are connected to one side of relay 110, thus de-energizing relay 110.

5. The opening of contacts 100e of relay 100, which are connected to contacts 110b, also opens the locking current path to relay 110.

Through the occurrence of all of the above described operations, the "pre-pump" part of a cycle has been initiated.

Pre-pumping continues until the pressure within the vacuum chamber 2 is low enough to support the diffusion pump. When this point is reached, further solenoid valve switching takes place. This is accomplished as a result of impulses supplied by the thermogage portion 32 of the vacuum gage system. The thermogage 32 comprises a thermocouple located in the passage between the fore pump 12 and valve B. As the pressure is decreased, the energy radiated by the hot thermocouple is decreased, its temperature is increased, and the thermoelectric voltage through the thermocouple is increased.

When the circuit of thermogage 32 produces a current equivalent to that of a pressure of approximately 10 microns of mercury, a relay 33 associated therewith is actuated, closing contacts 35 which closes a power circuit energizing relay 104.

With the energizing of relay 104, the following events take place with the resulting final positioning of relay contacts and valve pistons as shown in Fig. 4c:

1. Contacts 104c close; thus relay 104 locks itself through contacts 104c, in series with the closed contacts 108d of de-energized relay 108, these two pairs of contacts being connected.
2. Contacts 104d are opened, thereby opening the circuit through contacts 102a, and thereby breaking the power circuit through solenoid 40 and thus de-energizing this solenoid which closes valve B. At the same time, contacts 104b are opened, de-energizing slow-operating relay 102, which opens the contacts 102a and, hence, also opens the circuit of the solenoid 40 of valve B. Although either one or the other of these two events would appear to be unnecessary, the de-energizing of relay 102 is undesirably slow because it is a delayed action type. Provision is therefore made for de-energizing solenoid 40 in a more rapid manner.
3. Contacts 104e are closed, energizing slow-operating relay 106, thereby opening contacts

106a, which, in turn, de-energizes the solenoid 44 of valve C and opens this valve.

4. Contacts 104a are opened, thereby unlocking relay 100 and de-energizing it. This opens the contacts 100b, de-energizing the solenoid 38 of valve A, opening the valve.

The above events result in the occurrence of the second or "operate" step of the cycle. Valve B closes just before valves A and C open. The fore pump thus switches from pumping the vacuum chamber 2 to pumping the diffusion pump 8 now, itself, connected to the vacuum chamber.

With both pumps exhausting the vacuum chamber 2, a pressure is soon attained which is sufficiently low to allow the desired work operation of the equipment to proceed. In the case of an electron microscope, a signal light or audible sound may be given to indicate that the instrument is in operating condition. The electron gun, as well as high voltage, may also be turned on automatically, allowing the operator to observe a specimen chamber. As applied to other types of equipment, such as molecular evaporation apparatus, heating current may be automatically turned on in the filaments. As applied to the microscope (Fig. 2), the impulse which initiates these operating functions may be supplied from a circuit, indicated generally at 28, associated with the ionization type gage 34, which is connected to the vacuum chamber 2. This gage may be of the type comprising a two element tube having a cold cathode. The tube passes an amount of current which depends upon the degree of ionization of the residual gas within the vacuum chamber to which it is connected. The degree of ionization is, in turn, a function of the pressure within the chamber.

The electronic circuit for turning on high voltage current to the electron gun is preferably as shown and described in U. S. Patent 2,383,600. However, in order to prevent this circuit from being energized while valve C is closed, an interlock circuit, Fig. 7, is provided as part of the present invention. With the opening of valve C, contacts 25 are closed. When the contacts of relay 52 are also closed in response to information received from ionization gage 34, current is supplied from high voltage supply to electron gun 26 through transformers 54 and 56. (Relay 52 corresponds to relay 21 in the above mentioned Patent 2,383,600.)

When the operator has finished observing the specimen within the chamber, where the equipment being operated is an electron microscope, he presses a button temporarily closing, then releasing the "release" contacts 37 and thus operating relay 108. The operation of relay 108 produces the following events, illustrated in Fig. 4d:

1. Contacts 108a are closed, locking relay 108 through closed contacts 100d of de-energized relay 100.
2. Contacts 108b close, thus energizing solenoid 44 and thereby closing valve C.
3. Contacts 108c close, energizing delayed action relay 110, which closes contacts 110b and locks the relay 110 through closed contacts 100e.
4. Contacts 110a close and through closed contacts 100d the solenoid 42 is energized, opening valve D.
5. Contacts 108d are opened, thereby breaking the circuit through relay 104 and de-energizing this relay.

With the completion of the above events, the vacuum chamber 2 has been placed in condition for reloading. Valve D has been opened after valve C has closed, thus connecting the vacuum chamber to the atmosphere. The fore pump 12 continues to pump the diffusion pump 8.

The complete cycle can now be repeated as above described and as soon as desired. However, in order to re-initiate the "pre-pump" portion of the cycle, additional circuit descriptions must be included.

Relay 100, on being energized by the start impulse caused by the operator pressing starting button 36, opens its contacts 100d, thereby de-energizing relay 108 by breaking the circuit through its locking contacts 108a. Upon the release of relay 108, contacts 108b open but valve C remains closed because contacts 106a remain closed. The opening of contacts 108c removes locking current from relay 110 while, at the same time, the opening of contacts 100d breaks the circuit through contacts 110a, de-energizing solenoid 42 and closing valve D. This double-series contact control permits the immediate de-energizing of solenoid 42, closing valve D through operation of relay 100, thereby overcoming the slower release characteristics of relay 110.

The pulse from the circuit controlled by thermogage 32 is continuous and relay 104 is held locked despite its own locking circuit until relay 108 is energized. The thermogage circuit is never opened, once closed, unless the pressure in the fore pump line increases to some small amount above 10 microns of mercury. This, of course, would be analogous, under normal conditions, to the point in the cycle where the system was switching from "load" to "pre-pump."

It will be noted that in the embodiment of the circuit operation described, the solenoids of some of the valves are energized when the valve is closed and, in others, current flows in the solenoids when the valve is opened. This is best illustrated in Fig. 5, which also shows the relative opening and closing occurrences of each valve. The reason for this apparent non-conformity is that it is desired to have no current flowing through the solenoids when the instrument is in "operate" condition, in the case of an electron microscope, since stray currents of all types affect the fine focusing of the electron beam. With other types of equipment, such as evaporators, it may not matter whether energizing of its solenoid opens or closes a particular valve.

Although the invention has been illustrated as applied to the operation of an electron microscope, it may be applied just as well to other types of vacuum equipment, either with or without further modification. For example, it may be applied to apparatus for depositing coating materials by evaporation techniques of the general type shown in U. S. Patent 2,338,234. The circuits for operating this type of system are shown diagrammatically in Fig. 6.

In operation, the operator presses a start button 58, releasing a first interval timer 59. This interval timer may be any of several conventional types well known to the industry, having a synchronous motor with gears, shafts, cams and cam operated contacts to control various associated circuits at desired intervals. This first timer 59 may, first of all, close a pair of contacts actuating a circuit 60, supplying current, causing vacuum chamber 2 to be closed off from

the atmosphere as by starting a motor for lowering a bell jar in place. After the bell jar is lowered in place, the timer may then cause the closing of starting button 36 through a circuit 61, similar to circuit 29 in Figs. 4a-4d, initiating an operations cycle of the vacuum equipment after the manner previously described.

The pumping cycle is automatically carried on, with proper valve switching as previously described under the "pre-pump" step, until information is received by the second interval timer 62 from ionization gage 34 over circuit 63 that a suitable low pressure has been reached.

When this information is received, the second timer 62 then starts up, generating another series of pulses which may close a circuit 64, energizing either a single filament evaporating a coating material, a plurality of filaments for simultaneously evaporating a number of materials, or a number of filaments in timed sequence for applying a plural layer coating. The valves are in the "operate" position previously indicated (Fig. 4c).

Just as in the previous example, means are provided to make certain that the valve C is in open position before energization of the filaments can take place. As indicated in Fig. 7, the contacts 25 must be closed due to the opening of valve C before the circuit can be completed through the power supply and the evaporation heater filament or filaments.

After a desired time interval, controlled by the setting of the second interval timer 62, the filaments are de-energized, the release switch 37 is actuated through circuit 30 and the system returns to the "load" condition (Fig. 4d).

When the heating filaments have been de-energized and the valves have returned to "load" condition, the second timer 62 sends an impulse to the first timer 59 over circuit 65 and the first timer again starts up, closing contacts reversing the bell jar controlling motor through circuit 60, thus raising the jar and placing the system in condition to be reloaded by the operator.

As in the previous example, pilot lights or other indicating devices may be utilized to indicate the condition of the system to the operator. The ionization gage 34 may operate a pilot light 66 through a circuit 67 indicating when the "operate" cycle is ready to begin and how long it continues, and another pilot light 68 may be operated by the second interval timer 62 through a circuit 69 to indicate when the cycle is complete and ready for "load" operation.

There has thus been described a system which provides for automatic operation of either one or up to several vacuum units by a single operator. The operator need only place the system in condition for operation by loading and unloading the vacuum chamber at the proper times, if applied to a vacuum processing unit or load, observe and unload the specimen chamber, if an electron microscope. The valving operations are all carried out automatically and various other steps are also accomplished without the operator touching the equipment.

I claim as my invention:

1. A vacuum system comprising an evacuable chamber, a vacuum gage connected to said chamber, means for exhausting said chamber, said exhausting means being responsive to information supplied thereto by said gage, and means within said chamber for performing a work operation, said work means being operative in response

to information supplied thereto by said vacuum gage and by said exhausting means.

2. A system according to claim 1 in which said vacuum gage is an ionization type gage.

3. A system according to claim 1 in which said work means comprises an electrically energizable filament.

4. A system according to claim 1 in which said work means comprises a source of electrons.

5. A vacuum system comprising an evacuable chamber, a vacuum gage connected to said chamber, means for exhausting said chamber, said exhausting means comprising a vacuum pump, an exhaust passage connected between said chamber and said pump, and solenoid valves controlling airflow through said passage, a relay system for operating said valves, and means for operating said relay system in response to the condition of said vacuum gage.

6. A vacuum system comprising an evacuable chamber, means for indicating the pressure of said chamber, means for exhausting said chamber, said exhausting means comprising at least one vacuum pump and solenoid valves, a relay system for operating said valves, means within said chamber for performing a work operation, and means operative in response to information received from said pressure indicating means for actuating said relay system and for actuating said work performing means.

7. A system according to claim 6 in which said work operation performing means comprises a source of electrons.

8. In a system for evacuating a vacuum chamber comprising a fore pump and a diffusion pump having a passageway, including a first valve, connecting the intake of said fore pump to the outlet of said diffusion pump, a passageway, including a second valve, connecting said fore pump to said vacuum chamber, a passageway, including a third valve, connecting said diffusion pump to said vacuum chamber, an air intake passageway, including a fourth valve, connecting said vacuum chamber to the atmosphere, a first relay energized by the closing of a starting switch for simultaneously closing said first and fourth valves, a second relay energized by operation of said first relay for opening said second valve a predetermined time after the closing of said first and fourth valves, a third relay energized in response to a predetermined pressure within said chamber for closing said second valve and opening said first valve, a fourth relay energized by operation of said third relay for opening said third valve, a fifth relay energized by an external source of energy for closing said third valve, and a sixth relay energized by operation of said fifth relay for opening said fourth valve a predetermined time after the closing of said third valve.

9. A system according to claim 8 including, in addition, means operative in response to another predetermined pressure within said chamber for energizing an electrical element within said chamber only when said third valve is open.

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REFERENCES CITED

The following references are of record in the file of this patent:

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