Sept. 15, 1953 R. R. CYR 2,652,188

AUTOMATIC TANK PUMP DOWN

Filed July 8, 1948 4 Sheets-Sheet 1

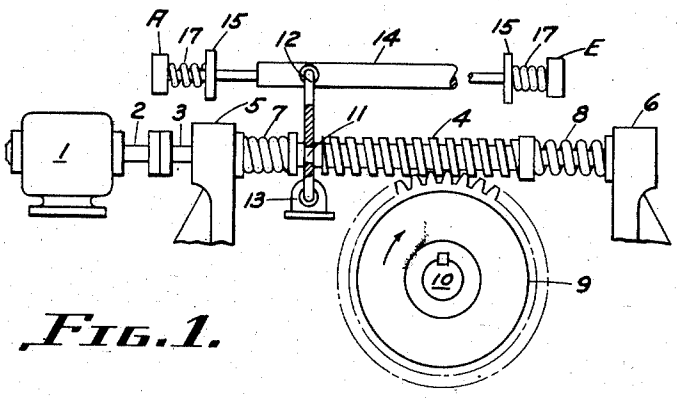


FIG. 1.

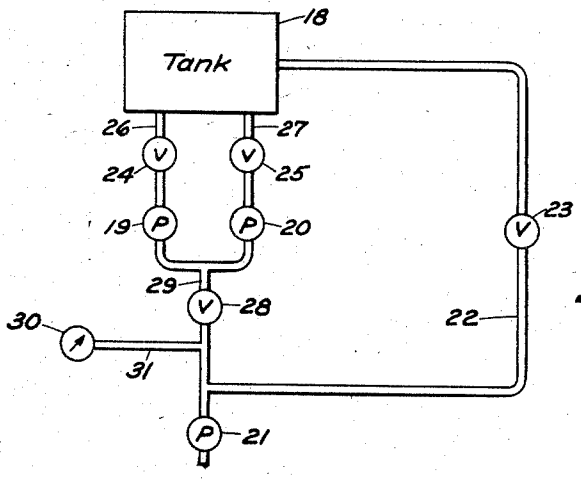


FIG. 2.

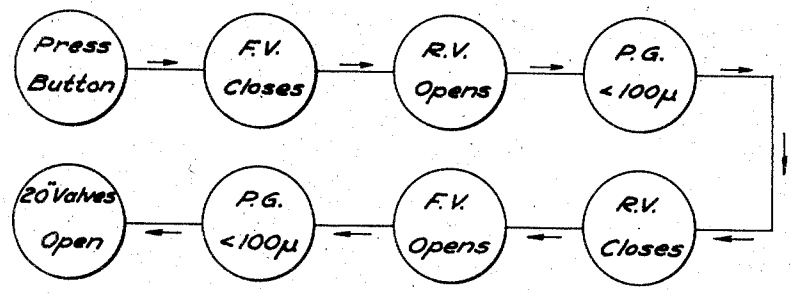


FIG. 4.

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AUTOMATIC TANK PUMP DOWN

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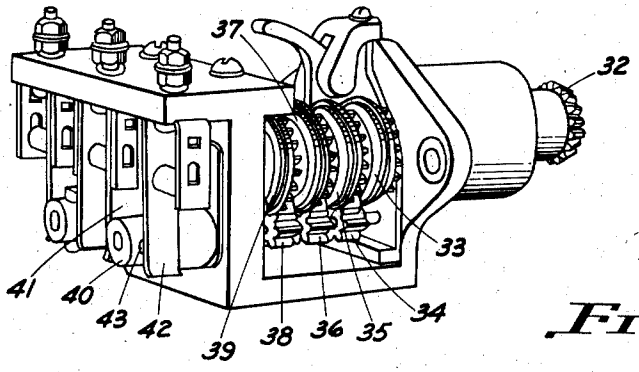


FIG. 3.

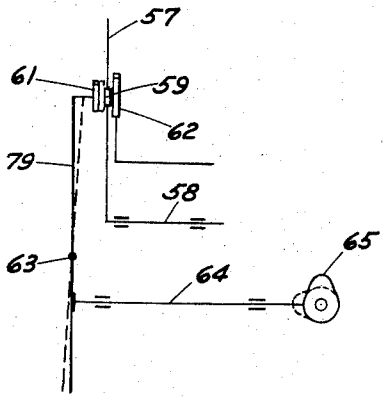


FIG. 5.

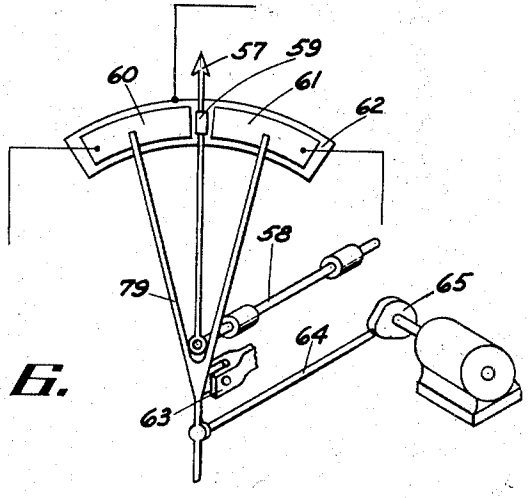


FIG. 6.

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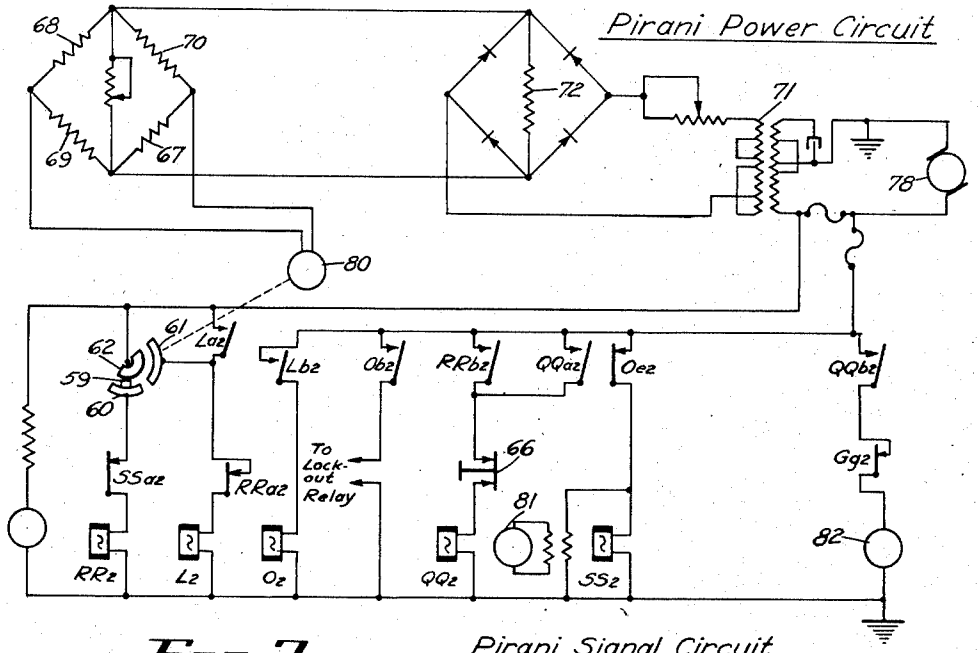


FIG. 7.

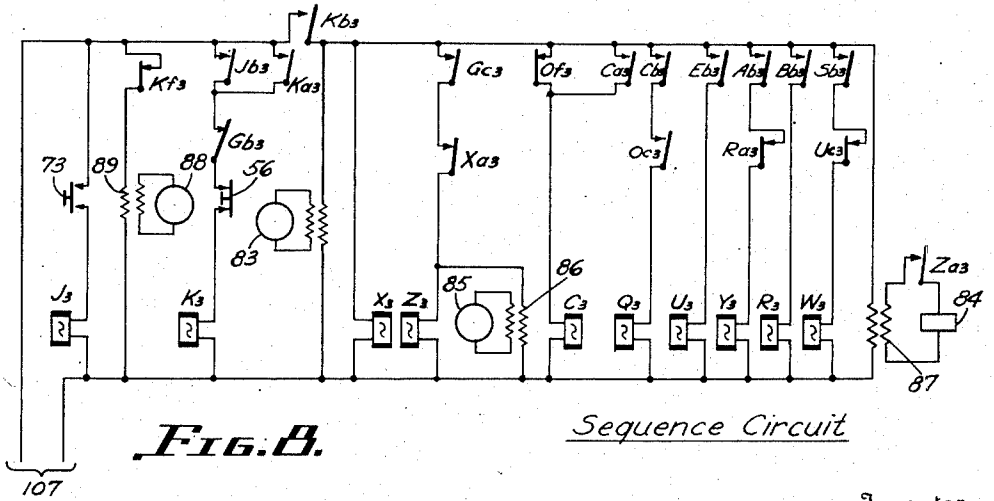


FIG. 8.

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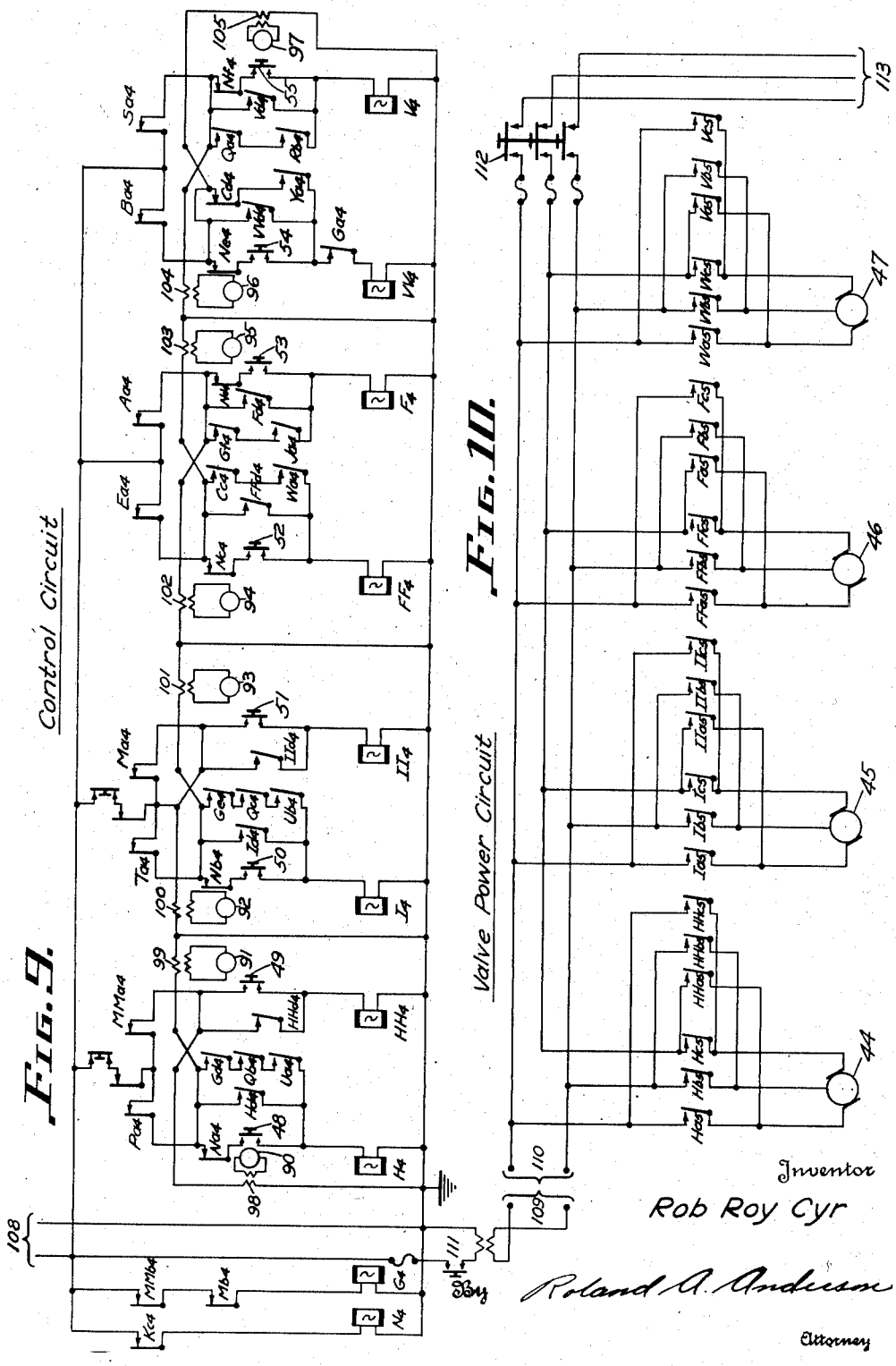


Fig. 9.

Fig. 10.

Patented Sept. 15, 1953

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UNITED STATES PATENT OFFICE

2,652,188

AUTOMATIC TANK PUMP DOWN

Rob Roy Cyr, Berkeley, Calif., assignor, by mesne assignments, to the United States of America as represented by the United States Atomic Energy Commission

Application July 8, 1948, Serial No. 37,681

8 Claims. (Cl. 230—2)

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My invention relates to vacuum systems, and more particularly to a system for automatically controlling the sequence of operations of a series of pumps for creating a vacuum.

The procedure involved in pumping down a tank or vacuum system in the past has been a manually controlled rather than an automatic procedure. In view of the low pressures required for certain processes, a mechanical pump is not suitable for that function. On the other hand, diffusion pumps capable of exhausting to low pressures will not operate against air pressure. Accordingly, it has been necessary to provide a vacuum system wherein both mechanical and diffusion pumps are arranged to work together. In this arrangement one or more diffusion pumps is connected to the tank or chamber to be exhausted, through gate valves. The outputs of the diffusion pumps are preferably tied together and fed through a finishing valve to the input of a mechanical pump so that the diffusion pumps may work into a pressure lower than atmospheric pressure. Either an additional mechanical pump may be provided for partially evacuating or making the initial evacuation of the tank or chamber, or a by-pass line may be provided so that by the use of a roughing valve, a single mechanical pump may be employed for roughing down purposes and for cooperation with the diffusion pumps in exhausting the tank or vacuum system to a low vacuum.

The actuation of these valves has been accomplished manually or through manual control. Under usual operating conditions the equipment in question is large and bulky. Pumps, tanks, and valves are ordinarily separated by considerable distances and may be located in different rooms or even different floors of a building. Intercommunication systems and several operators may be required to manually operate the controls in their proper sequence. When meters are at some distance from the valves, and a single operator is employed to take care of the manual controls, it requires a great deal of moving about from place to place where the different controls and meters are located. Further, manual controls are slower, and require continual watching of the gauges, and mistakes are quite often made in the manipulation of the valves or in the operation of the system. These mistakes are in some instances quite costly, causing damage not only to process materials but to the pumping fluids.

Applicant with a knowledge of all of these defects in and objections to the prior art has for an object of his invention the provision of a

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system for automatically pumping down a tank or reservoir to high vacuum by a sequence of operations.

Applicant has as another object of his invention the provision of an electrical control circuit for controlling the operation of a series of pumps in the proper sequence to pump down a tank or reservoir to high vacuum, or to evacuate a chamber.

Applicant has as a further object of his invention the provision of an electrical control circuit for automatically controlling the pumping down of a tank or reservoir to a high vacuum so that upon closing the circuit, the finishing valve, the roughing valve, and the main gate valves, which regulate the operation of a series of pumps, are made to open and close in a predetermined sequence.

Applicant has as a further object of his invention the provision of an electric circuit control for automatically associating mechanical and diffusion pumps in a certain predetermined sequence to pump a tank, reservoir, or chamber to high vacuum.

Other objects and advantages of my invention will appear from the following specification and accompanying drawings, and the novel features thereof will be particularly pointed out in the annexed claims.

In the drawings, Fig. 1 is a fragmental detail of a torque limiting switch, used on the valve operator in my improved system. Fig. 2 is a schematic of the pumping arrangement employed in connection with my improved system. Fig. 3 is a perspective of a gear limiting switch used on valves in my improved vacuum system. Fig. 4 is a diagram indicating the sequence of operation of the various valves and pumps shown in Fig. 2. Fig. 5 is a schematic of the hot wire gauge used in my improved system. Fig. 6 is a detail showing the relation of the segments used in the hot wire gauge. Fig. 7 is a schematic of the circuits known as the Pirani power supply circuit or Pirani power circuit and the Pirani signal circuit. Fig. 8 is a schematic of the sequence circuit. Fig. 9 is a schematic of the control circuit. Fig. 10 is a schematic of the valve power circuit.

The procedure involved in pumping down a tank in the past has been a manual rather than an automatic procedure, the sequence involved being that as shown in the flow diagram of Fig. 4 of the drawings. Briefly the automatic sequence is as follows: A manual push button is pressed which causes the finishing valve to close, the finishing valve being in open position when the

tank is down to air; next the roughing valve opens, and when it opens the pressure at the Pirani gauge will be at or will rise to a value above 100 microns; when it falls to a value below 100 microns the roughing valve closes and then the finishing valve opens; when the finishing valve opens, the air from within the diffusion pumps will again cause the pressure at the Pirani gauge to rise above 100 microns; when the pressure again falls below 100 microns, the mechanical pump being in operation, of course, the main gate valve will open, as indicated by the chart of Fig. 4.

The arrangement of the pumps and valves and their connections are as shown in the drawings, each element being identified by legend. It will be noted from Fig. 2 that the roughing valve **23** is in a by-pass line extending around the main gate valves **24, 25**, the diffusion pumps **19, 20** and the finishing valve **28**.

In this system it is contemplated that the roughing, finishing and gate valves will be electrically actuated. The valve operators used in connection with this system are preferably of the motor driven type such as those manufactured by the Philadelphia Gear Works of Philadelphia, Pennsylvania and sold under the name of "Limitorque." While the particular structure of these operators constitutes no part of applicant's invention, one form thereof is disclosed in Fig. 1 in order to give a better understanding of the system as a whole. In that figure a motor **1**, coupled to an appropriate power source, is directly connected through its shaft **2** by a flanged coupling to a splined shaft **3** carrying a worm **4** which floats thereon and is free to move longitudinally thereof. The shaft **3** is rotatably mounted in bearings **5, 6** and the coiled torque springs **7, 8** are interposed between the ends of worm **4** and the bearings **5, 6** and are disposed about shaft **3** in order to limit axial movement of worm **4**. The worm **4** drives a worm gear wheel **9** mounted directly on stem or shaft **10** which by rotation opens and closes the valve (not shown). Formed in worm **4** adjacent one end thereof is a circumferential groove **11** which is adapted to seat in an appropriate slot in pivoted arm **12** and is interlockingly engaged therewith. Arm **12** is pivotally mounted at its lower end on bracket **13**, and its upper end which is angularly bent is recess seated in shaft **14**, slidably mounted in standards **15, 15**. Engaged at opposite ends of shaft **14** are limiting switches such as A and E, and interposed between the limiting switches and their corresponding standards **15, 15** are compression springs **17, 17**. Operation of motor **1** rotates shaft **2** and in turn shaft **3**, carrying worm **4**. The rotation of shaft **3**, depending upon the direction of the rotation of motor **1**, rotates worm gear **4** in a clockwise or counterclockwise direction, turning gear wheel **9** and shaft **10**, to open or close the valve, as the case may be. When the valve stem has reached the limit of its travel, either in the closed or open position, worm gear wheel **9** stops rotating, and as motor **1** continues its rotation, worm **4** is forced to move longitudinally along shaft **3** compressing spring **7** or spring **8** depending upon the direction of rotation of motor **1**. Worm **4** carries pivoted arm **12** with the sliding shaft **14** in standards **15, 15** until the shaft actuates one or other of the limiting switches A or E opening the motor circuit and stopping the motor either directly or through appropriate control circuits.

It may be pointed out that the main gate valves referred to hereinafter employ both torque and gear limiting switches. The gear limiting switch is preferably of the type manufactured by the Philadelphia Gear Works. A suitable type is shown in Fig. 3 of the drawings wherein a motor operated gear **32** actuates a train of gears **33, 34, 35, 36, 37, 38**, and **39** connected after the fashion of speedometer gearing, to rotate member **40** carrying transversely extending contact **43** which bridges spring contacts **41, 42** suspended from terminals mounted on the frame, when in closed position. In this way many revolutions of gear **32** are required to rotate the insulated member **40** a single revolution. No detailed description of these elements and their operation is given, however, since they constitute no part of this invention but are well known in the prior art.

In one preferred form of the system, the main gate valves may be large 20 inch valves, and operators may be of the type described above. The finishing and roughing valves may be of the 6 inch type and may be operated by what are known as "Pee Wee" operators. These operators are of the same general type as those described above. The valves are preferably of the double seating type, i. e. the valve seats in both directions of movement of the stem. The operators for the small valves have torque limit switches operable on movement of the valve stems in both directions. The motors driving these valves are preferably of the three phase type and may be reversed to open and close them by reversing two of the three power leads as will appear from the connections of the two sets of switch contacts employed to operate the motors for these valves.

Referring to Fig. 2 showing a layout of the tank, pumps, and valves, **18** designates a tank or reservoir to be evacuated. Diffusion pumps **19, 20** are connected in series with mechanical pump **21**. The mechanical pump **21** is directly connected to the tank **18** through a by-pass line **22** having a roughing valve **23** therein. Gate valves **24, 25** are interposed in lines **26, 27** between diffusion pumps **19, 20** and reservoir tank **18**, and a finishing valve **28** is interposed in line **29** between the diffusion pumps and mechanical pump. A Pirani gauge **30** is connected into the system through line **31**.

In operation, the finishing valve **28** and gate valves **24, 25** are closed and the roughing valve **23** is open. This permits the mechanical pump **21** to exhaust the tank **18** through the by-pass line **22** until the Pirani gauge **30** indicates a pressure of less than 100 microns, approximately the lowest value which can be obtained by the mechanical pump. At this point the roughing valve **23** closes and the finishing valve **28** opens thereby causing the pressure of the Pirani gauge **30** to rise, temporarily, due to gas or air in the diffusion pumps and/or leaks in the system. Thereafter, the pressure of the Pirani gauge **30** again drops to a value below 100 microns at which point the gate valves **24, 25** open and the diffusion pumps **19, 20** and mechanical pump **21** function in series to evacuate the tank to a very low pressure.

For convenience in following the sequence of operation of the various circuits and the relays in Figs. 7–10, inclusive, letters have usually been employed for the main elements. Capital letters have generally been employed to designate relays. Where these capital letters also have been followed by a small letter, the legend refers to a sub-element, such as a particular armature of a relay, since relays may have a number of arma-

tures. In order to aid in locating a particular element or its sub-element, the circuits disclosed have been divided into five categories, namely, the Pirani power circuit, the Pirani signal circuit, the Sequence circuit, the Control circuit, and the Valve Power circuit. In those figures, the reference letters of each element, where such designation is used, will be followed with a suffix numeral of 1, 2, 3, 4, or 5, respectively, indicating in the order enumerated above the circuit in which the elements is located.

The Pirani power supply circuit, used to control various operations and their sequences, will first be considered and it will be noted that this circuit is conventional in the art. However, it will be referred to briefly in order to give a clear understanding of the relation it bears to the various other circuits described in detail hereinafter. The pressure responsive elements **67**, **68** of the usual Pirani gauge are exposed to pressure in the system and comprise a part of the gauge **30**. Together with resistance elements **69**, **70** they form the four legs of a Wheatstone bridge. Power is supplied from a power source **78** through a power transformer **71** and conventional rectifier arrangement **72**. The rectifier feeds into one set of opposite corners of the Wheatstone bridge while the other set of opposite corners are connected to the indicator or meter **80**.

The unbalance of the bridge resulting from a change in resistance of resistors **67**, **68** responsive to a change in pressure in the system, is reflected by the meter **80** whose arm **57**, in Figs. 5 and 6, moves across sectors **60** or **61** in response to changing pressure conditions.

In the meter of the Pirani system the arm **57**, which swings about a pivot **58**, carries a contact **59** which passes adjacent to sectors **60** and **61**, and between them and a third sector **62** which is fixedly mounted and substantially coextensive with them. The sectors **60** and **61** are preferably carried by an arm through a Bakelite or other insulating strip to insulate them from each other and are pivotally mounted at **63** through the arm. An extension **64** carried by the lower end of the arm and appropriately supported engages with a rotating cam **65**, preferably driven at a uniform rate. As cam **65** rotates, sector **60** or **61** is brought into engagement with contact **59** and presses it against sector **62** completing the circuit indicated hereinafter. Whether it is sector **60** or **61** depends upon the position of the needle or arm **57** with respect to those sectors. However, no claim is made to any invention in the construction of the meter. It may be the usual Allis-Chalmers Hot wire gauge which has been slightly modified by re-arranging the sectors as indicated above. The general mode of operation of that conventional gauge has not been changed, and the explanation herein is merely for the purpose of disclosing its function in this system.

The Pirani gauge meter finger is normally in the position between 0 and 100 microns, thus the contact **59** of the meter makes periodic engagement with sector **62** as the moving sector **61** acts upon it.

When contact **59** bridges sectors **61** and **62**, relay L_2 is energized through normally closed contacts RRa_2 leading to A. C. power source **78**, and seals itself in through contacts La_2. The energizing of relay L_2 closes contact Lb_2 and completes the circuit through relay O_2 referred to hereinafter. This closes contacts Ob_2 which completes the circuit through the lock out relay in the high voltage cubicle (not shown) which furnishes power to the equipment to be used in connection with the evacuated tank or chamber when it has been prepared. Contacts Ob_2, when closed, allow the high voltage cubicle control circuits to be energized. Naturally it is not desirable for these contacts to be closed when the tank is being roughed down. However, the prime purpose of this feature is to de-energize the high voltage cubicle if and when a failure in the vacuum system causes the pressure in the system to rise above 100 microns as pressures of this magnitude will allow discharges in the tank which may damage equipment in the tank as well as equipment in the high voltage cubicle. Normally closed contacts Oe_2 are opened extinguishing the red light **81** and de-energizing relay SS_2. When SS_2 is de-energized, contacts SSa_2 return to closed position completing the circuit through winding of relay RR_2 to sector **60** of the meter.

This feature is peculiar to this particular application and might not be necessary in other processes.

When the pressure rises above 100 microns, such as by the opening of the roughing valve, contact **59** moves opposite sector **60**, and it periodically completes contact between that sector and sector **62** energizing the winding of relay RR_2. Contacts RRa_2 are opened de-energizing the winding of relay L_2 and the relay in the high voltage cubicle, due to the opening of contacts Lb_2 and the de-energizing of relay O_2 which opens contacts Ob_2. Contacts RRb_2 close completing the circuit through QQ_2 and through push button contacts **66**. Relay QQ_2 then seals itself in through contacts QQa_2. It also closes QQb_2 ringing the bell **82** if the contacts Gg_2 are closed. Since the winding G_4 is in the circuit controlled by main gate valve contacts MMb_4, the normally closed contacts Gg_2 are closed only when the main gate valves **24**, **25** are open. Since winding O_2 is de-energized, contacts Oe_2 are closed which completes the circuit to and lights the red light **81** through the power transformer, and also energizes relay winding SS_2. When winding SS_2 is energized, normally closed contacts SSa_2 are opened breaking the circuit through the winding of relay RR_2. This is done to prevent segments **60** and **62** and finger **59** from periodically making and breaking the circuit to coil RR_2 which will result in damage to the contact surfaces from arcing. If it is desired to silence the bell **82**, push button **66** may be depressed de-energizing relay QQ_2 and opening the contacts QQb_2 which complete the power circuit to bell **82**.

Preliminary steps

In the sequence of operations detailed hereinafter it is necessary that the two main gate valves **24**, **25** be closed at the commencement thereof. To close the main gate valves **24**, **25** prior to commencement of the sequence, push buttons are depressed closing switches **49**, **51** in the control circuit. These switches complete circuits through windings of relays HH_4 and II_4, respectively, energizing those relays and closing contacts HHa_5, HHb_5, and HHc_5 in the power circuit of the driving motor **44** for gate valve **24** as well as closing contacts HHd_4 to provide a locking in circuit. Relay II_4 closes the power circuit to the driving motor **45** for valve **25** by closing contacts IIa_5, IIb_5, IIc_5 and completes a holding circuit by closing contacts IId_4. When the valves are closed, the contacts MMa_4, Ma_4, respectively, of torque limit switches thereon open breaking the circuits through windings of relays HH_4 and II_4, respec-

tively, and opening contacts HHa_5, HHb_5, HHc_5, and IIa_5, IIb_5, IIc_5, respectively, in the power circuits to the driving motors **44**, **45** for gate valves **24** and **25**. Contacts HHd_4 and IId_4 also open breaking the locking in circuits for the windings of relays HH$_4$, II$_4$. In addition the action of the torque limit switches permits contacts Mb_4 and MMb_4 to close completing a circuit through the winding of relay G$_4$ energizing it and changing the positions of many contacts to be referred to hereinafter.

To start the roughing down sequence, the push button **73** in the sequence circuit is depressed closing its contacts. This energizes the coil of relay J$_3$ which closes contacts Ja_4 in the control circuit to control the closing of the finishing valve **28** in Fig. 2, and contacts Jb_3 in the sequence circuit. Closing of contacts Jb_3 completes the circuit energizing coil of relay K$_3$ through push button **56** and contacts Gb_3, which are maintained in closed position by winding of relay G$_4$ which is normally energized through contacts Mb_4 and MMb_4, since the latter contacts are closed when the main gate valves **24**, **25** are in closed position. These contacts are a part of the switches controlled by the main gate valves **24**, **25** and open and close with them. When the coil of relay K$_3$ is energized, it seals itself in through the closing of armature contacts Ka_3 and also closes contacts Kb_3 which energizes the sequence circuit.

Normally closed contacts Kc_4 in the control circuit are opened de-energizing coil of relay N$_4$. This opens contacts Na_4, Nb_4, Nc_4, Nd_4, Ne_4, and Nf_4. It will be noted that these contacts are in the various control circuits for motors **44**, **45**, **46** and **47** which open and close gate valves **24**, **25**, finishing valve **28**, and roughing valve **23**, respectively, except in the closing circuits for the motors **44**, **45** of gate valves **24** and **25**. The action of these relays is to prevent operation of the valves by the accidental closing of their control circuits with the manually operated push buttons **48**, **50**, **52**, **53**, **54**, and **55**. As indicated, the circuits of switches **49**, **51** are not broken at this point, since the circuits control the closing of main gate valves **24**, **25** by motors **44**, **45**. As these valves are already closed, no false operation can be initiated through push buttons **49**, **51**, and a protective relay for each of those circuits would not be necessary.

The energizing of the sequence circuit energizes the winding of timing relay X$_3$, sequence starting pilot light **83**, and buzzer transformer **87** to provide energy for the buzzer alarm **84** when breakdown or other trouble develops in the system. Timing relay X$_3$ is set to close contacts Xa_3 at the end of a predetermined time, such as 20 minutes, in order to give the system an opportunity to complete its cycle in the normal course of events and to alter the condition of the relay circuit prior to the time of lighting the lamp or giving an alarm. Closing of contacts Xa_3 energizes relay Z$_3$ and trouble light **85** through contacts Gc_3 and step down transformer **86** to indicate that the main gate valves **24**, **25** are closed. It will be remembered that winding G$_4$ is energized through a circuit including contacts Mb_4 and MMb_4 which are closed when main gate valves **24**, **25** are closed. The energizing of relay Z$_3$ closes contacts Za_3 operating buzzer **84** from the transformer **87**, indicating that the cycle of operations has not been completed within the requisite time, i. e. that the main gate valves have not opened, that trouble of some kind exists within the system, and that proper vacuum level has not been reached.

Closing finishing valve

The first step in the evacuating operations is the closing of the finishing valve **28**. As previously indicated, the closing of switch **73** in the sequence circuit energizes relay coil J$_3$ which in turn closes contacts Ja_4 in the control circuit and starts the closing of the finishing valve. This is accomplished by completing a circuit which energizes relay F$_4$ through contacts Gf_4, which are normally closed when gate valves **24**, **25** are closed since relay G$_4$ is energized through closed contacts Mb_4 and MMb_4, and through the normally closed contacts Aa_4. The energizing of relay F$_4$ closes contacts Fa_5, Fb_5, Fc_5 completing the three phase power circuit to the motor **46** for operating it to close the finishing valve **28**. It also completes a locking in circuit by the closing of contacts Fd_4. When the finishing valve **28** has closed, torque limit switch contacts Aa_4 open breaking the circuit through relay F$_4$ and permitting contacts Fa_5, Fb_5, Fc_4 to open stopping the motor **46**. This action also closes normally open contacts Ab_3 of the torque limit switch in the sequence circuit.

Open roughing valve

The next step is to open the roughing valve **23**. Since the roughing valve is closed, limit switch contacts Bb_3 are open, and relay R$_3$ is de-energized. Contacts Ra_3 are normally closed when relay winding R$_3$ is de-energized. As contacts Ab_3 have been closed as previously indicated, a circuit through closed contacts Ra_3 and the coil of relay Y$_3$ is completed and the winding of that relay is energized so that contacts Ya_4 in the opening control circuit of the roughing valve **28** are closed. When the pressure in the header is below 100 microns at the start of the sequence operation, relay C$_3$, controlled by the Pirani pressure gauge in a manner heretofore described, remains de-energized by the action of relay O$_2$ in opening the contacts Of_3, permitting contacts Cd_4 in the opening control circuit of roughing valve to remain closed. Since contacts Ga_4 are closed by energizing relay G$_4$ in response to the closing of the main gate valves **24**, **25** and through relay contacts Mb_4 and MMb_4 as heretofore described, a circuit is completed through coil of relay VV$_4$ locking itself in by closing contacts VVd_4 and closing contacts VVa_5, VVb_5, VVc_5 for connecting the motor **47** of roughing valve **23** to the power supply for driving the roughing valve to open position. When roughing valve **23** opens, normally closed torque limit switch contacts Ba_4 are driven to open position breaking the circuit through winding of relay VV$_4$ and permitting contacts VVa_5, VVb_5 and VVc_5 as well as holding contacts VVd_4 to open removing the power from the motor and opening the holding circuit for winding of relay VV$_4$. In the same operation torque limit switch contacts Bb_3 are closed energizing relay R$_3$ in the sequence circuit which opens contacts Ra_3, and this de-energizes relay Y$_3$ and opens contacts Ya_4 to prevent any false operation of the opening control circuit for the roughing valve **23** by motor **47** later on in the sequence of operations. The energizing of relay R$_3$ also closes contacts Rb_4 in the closing control circuit of the motor **47** for the roughing valve **23**.

When the roughing valve is opened allowing air to enter the vacuum pump, the Pirani system acts in a manner hereinbefore described, to de-energize relay O$_2$, permitting contacts Of_3 to close energizing relay C$_3$ which seals in through

contacts Ca_3 and opens contacts Cd_4 in the opening control circuit for the roughing valve, thus preventing subsequent opening of the roughing valve **23** by motor **47** during the sequence when pressure may reach a level below 100 microns. By the same operation, contacts Cb_3 and Cc_4 are closed.

Closing roughing valve

The next step in the sequence is the closing of the roughing valve **23**, after the mechanical pump has completed the roughing operation.

With the contacts Rb_4 closed as previously described, the pressure having reached a point below 100 microns, the Pirani control system operates as hereinbefore described to energize relay O_2, open contacts Of_3 and close contacts Oc_3 to complete the circuit to relay winding Q_3 energizing it and closing contacts Qa_4 in the closing control circuit for the roughing valve. This completes the circuit through relay winding V_4. When winding V_4 is energized, contacts Va_5, Vb_5, Vc_5 are closed completing the power circuit to the driving motor **47** for the roughing valve **23**, causing it to drive the valve to closed position. This same action closes contacts Vd_4 creating a holding circuit for the relay winding V_4. When roughing valve **23** has closed, torque limit switch opens contacts Sa_4 breaking the circuit through the relay winding V_4 and opening contacts Va_5, Vb_5, Vc_5 removing the power from the motor **47**. The torque limit switch also closes contacts Sb_3 in the sequence circuit, completing the circuit through normally closed contacts Uc_3, and energizing relay winding W_3 which closes contacts Wa_4 in the opening control circuit for the finishing valve.

Opening finishing valve

The next step is the opening of the finishing valve **28**. When the pressure rose and relay O_2 was de-energized as heretofore described in connection with the Pirani control circuits, relay C_3 was energized. This took place when the roughing valve **23** was opened and the pressure rose, so that contacts Cc_4 in the opening control circuit for the motor **46** of the finishing valve **28** are closed, and the closing of locking in contacts Ca_3 keep relay C_3 energized while relay O_2 is still energized. Likewise, the energizing of relay W_3 through action of the torque limiting switch upon the closing of roughing valve **23** and closing of the contacts Wa_4 in the opening control circuit for finishing valve **28** as described above completes the circuit through coil of relay FF_4. This closes a locking-in circuit through contacts FFd_4, and also closes contacts FFa_5, FFb_5, FFc_5 completing the power circuit to the motor **46** for opening finishing valve **28**. When finishing valve **28** has opened, torque limiting switch opens contacts Ea_4 and breaks the circuit through relay FF_4 de-energizing that relay and permitting contacts FFa_5, FFb_5, FFc_5 to open, breaking the power circuit to the motor **46** driving finishing valve **28**. The opening of the finishing valve acts to close contacts Eb_3 of the torque limiting switch, energizing relay U_3. It may also permit the pressure in the vacuum chamber to rise above 100 microns when communication is established with vacuum pumps **19**, **20**.

Opening main gate valves

The last step in the sequence is the opening of the main gate valves. The energizing of relay U_3 described above closes contacts Ua_4 and Ub_4 in the opening control circuits for the main gate valves. When the pressure drops below 100 microns, or if it has remained below that level, relay O_2 is energized as described hereinbefore in connection with the Pirani system. Contacts Oc_3 are closed and relay Q_3 is energized. Contacts Qb_4 and Qc_4 are closed, and since contacts Mb_4 and MMb_4 are also closed when gate valves **24**, **25** are closed, relay G_4 is energized and contacts Gd_4 and Ge_4 are closed completing circuits through the opening control circuit for the main gate valves **24**, **25** to energize coils H_4, I_4. They close contacts Ha_5, Hb_5, Hc_5 and Ia_5 and Ib_5 and Ic_5 to operate the driving motors **44**, **45** for the main gate valves **24**, **25** to the power supply moving the main gate valves to open position, in addition they close locking in contacts Hd_4 and Id_4, respectively. When main gate valves **24**, **25** start to open, limit switches Mb_4 and MMb_4 are opened de-energizing relay G_4. This opens contacts Gb_3 which de-energizes relay K_3 and opens contacts Kb_3 which in turn opens the sequence circuit and permits contacts Kf_3 to close which lights sequence completed lamp **88** through transformer **89**. It also opens contacts Ga_4 in the opening control circuit for the motor **47** of roughing valve **23**, preventing accidental operation thereof. When main gate valves **24**, **25** have opened gear limit switches Pa_4 and Ta_4 open de-energizing relays H_4 and I_4, respectively, re-opening the power circuits to the operating motors **44**, **45** for valves **24**, **25** and stopping them. This completes the sequence.

When contacts Mb_4 and MMb_4 open at the finish of the sequence, relay G_4 is de-energized closing contacts Gg_2 which were open during the sequence operation. Since during the operation of the sequence the pressure rose above 100 microns, coil RR_2 was at one time energized closing contacts RRb_2. This action energized QQ_2 which sealed itself in through QQa_2 and closed contacts QQb_2. Thus when contacts Gg_2 close as described above, energy is supplied to the bell which rings signalling the end of the sequence operations. The bell can be silenced as indicated hereinbefore.

If at any time it is desirable to stop the sequence circuit, it can be done by merely depressing button **56** (sequence stop) located in the sequence circuit, which de-energizes relay K_3 and opens contacts Kb_3 and Kc_4. This disables the sequence circuit, de-energizes relay N_4, and returns all of the valve operation circuits to manual operation through manual switches **48** to **55**, inclusive, by the closing of contacts Na_4, Nb_4, Nc_4, Nd_4, Ne_4, Nf_4.

If desired, pilot lights **90**, **91**, **92**, **93**, **94**, **95**, **96**, and **97** may be connected to the various opening and closing control circuits of the valves **24**, **25**, **28** and **23** through appropriate coupling transformers **98**, **99**, **100**, **101**, **102**, **103**, **104** and **105** to indicate the operation of these various circuits.

It will also be understood that line **108** of the power circuit is connected to and feeds line **107**, and that lines **109** and **110** are connected together. Switches **111**, **112** serve to complete the circuit to the main power line **113** which furnishes power at conventional voltages and frequency.

Having thus described my invention, I claim:

1. A system for evacuating a chamber comprising a mechanical pump and a plurality of diffusion pumps, valve means connecting each of said pumps to the chamber and to each other, means responsive to pressures above a predetermined value for operating said valve means to connect the mechanical pump with the chamber to partially evacuate it, and means responsive to pres-

sures below the predetermined value for operating the valve means to connect the mechanical pump in series with the diffusion pumps to receive their outputs and evacuate the chamber to a high vacuum.

2. A control system of the character described comprising a chamber, a low vacuum mechanical pump, high vacuum diffusion pumps, valves for connecting the diffusion pumps to the chamber, a finishing valve for connecting the mechanical pump to the diffusion pumps, a by-pass line for connecting said mechanical pump to said chamber for roughing down purposes, a roughing valve in said by-pass line, means responsive to a predetermined pressure in the system for controlling the opening of the roughing valve to connect said mechanical pump with the chamber and partially evacuate it, and means responsive to a predetermined lower pressure for closing the roughing valve and opening the other valves to place the mechanical pump in series with the diffusion pumps and evacuate the chamber to a low pressure.

3. A vacuum system of the character described comprising a chamber, mechanical and diffusion pumps for evacuating the chamber, valves for connecting the diffusion pumps to the chamber, a finishing valve and a roughing valve for connecting the mechanical pump to the diffusion pump and to the chamber through a common inlet, a circuit for selectively actuating said first named valves, said finishing valve, and said roughing valve, and pressure responsive means in communication with said common inlet, said pressure means being responsive to predetermined changes in pressure for controlling the operation of said circuit to open and close the roughing valve in time relation to the opening of the other valves to connect the mechanical pump, and then the diffusion and mechanical pumps in series to said chamber and effect partial and substantially complete evacuation of the chamber.

4. A control system of the character described comprising a chamber to be evacuated, a high vacuum and a low vacuum pump, valve means for connecting said high vacuum pump and said low vacuum pump to the chamber in a predetermined sequence for evacuating the chamber, said means including a circuit responsive to pressure conditions in said chamber, a sequence circuit coupled to and responsive to the action of the circuit for determining the sequence of coupling of the high vacuum pump and the low vacuum pump to said chamber, and a power control circuit coupled to and responsive to said sequence circuit for carrying out the coupling sequence of the low vacuum pump and the high vacuum pump to said chamber in a predetermined manner.

5. A control system of the character described comprising a chamber, a high vacuum pump and a low vacuum pump, valve means for coupling said high vacuum pump to said chamber and said low vacuum pump to said chamber and said high vacuum pump, a pressure device responsive to pressure conditions in the system, a signal circuit coupled to and controlled by said pressure device, a sequence circuit coupled to and controlled by the signal circuit for determining the order of operation of the low vacuum pump and the high vacuum pumps in the system, and a power control circuit responsive to the action of the sequence circuit for altering the coupling of the high vacuum pump and low vacuum pump in the system.

6. A control system of the character described comprising a chamber, a high vacuum pump and a low vacuum pump, valve means for coupling the low vacuum pump to the chamber and to the output of the high vacuum pump, valve means for coupling the high vacuum pump to said chamber, means for controlling the action of said first and said second coupling means including a pressure controlled circuit responsive to pressure conditions in the system, a sequence circuit coupled to and activated by the pressure controlled circuit for determining the order of coupling of the low vacuum pump and the high vacuum pump to the chamber and to each other, and a power circuit coupled to and energized in response to the action of the sequence circuit to actuate the coupling means for the low vacuum pump in a predetermined manner and the high vacuum pump.

7. A control system of the character described comprising a chamber to be evacuated, a low vacuum pump and a high vacuum pump, means for controlling the order of coupling of the low vacuum pump and the high vacuum pump to the chamber and to each other, said means including a pressure responsive circuit responsive to predetermined pressure conditions within the system, a signal circuit mechanically coupled to said pressure responsive circuit and energized in response thereto, a sequence circuit coupled to and electrically controlled by the signal circuit for determining the coupling arrangement of the said low vacuum pump and the high vacuum pump at predetermined pressures, and a power control circuit activated by said sequence circuit to bring the low vacuum pump and the high vacuum pump into coupling relation in a predetermined manner.

8. A vacuum control system of the character described comprising a chamber, a low vacuum pump and a high vacuum pump, means for bringing the low vacuum pump and the high vacuum pump into communication with said chamber, a signal circuit, pressure responsive means coupled to the signal circuit for controlling its operation, a sequence circuit coupled to and operated by signals from said signal circuit, power control circuits connected to and responsive to the operation of said sequence circuit to actuate said communicating means and connect the low vacuum pump and high vacuum pump to said chamber in a predetermined sequence to exhaust said chamber to a high vacuum.

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