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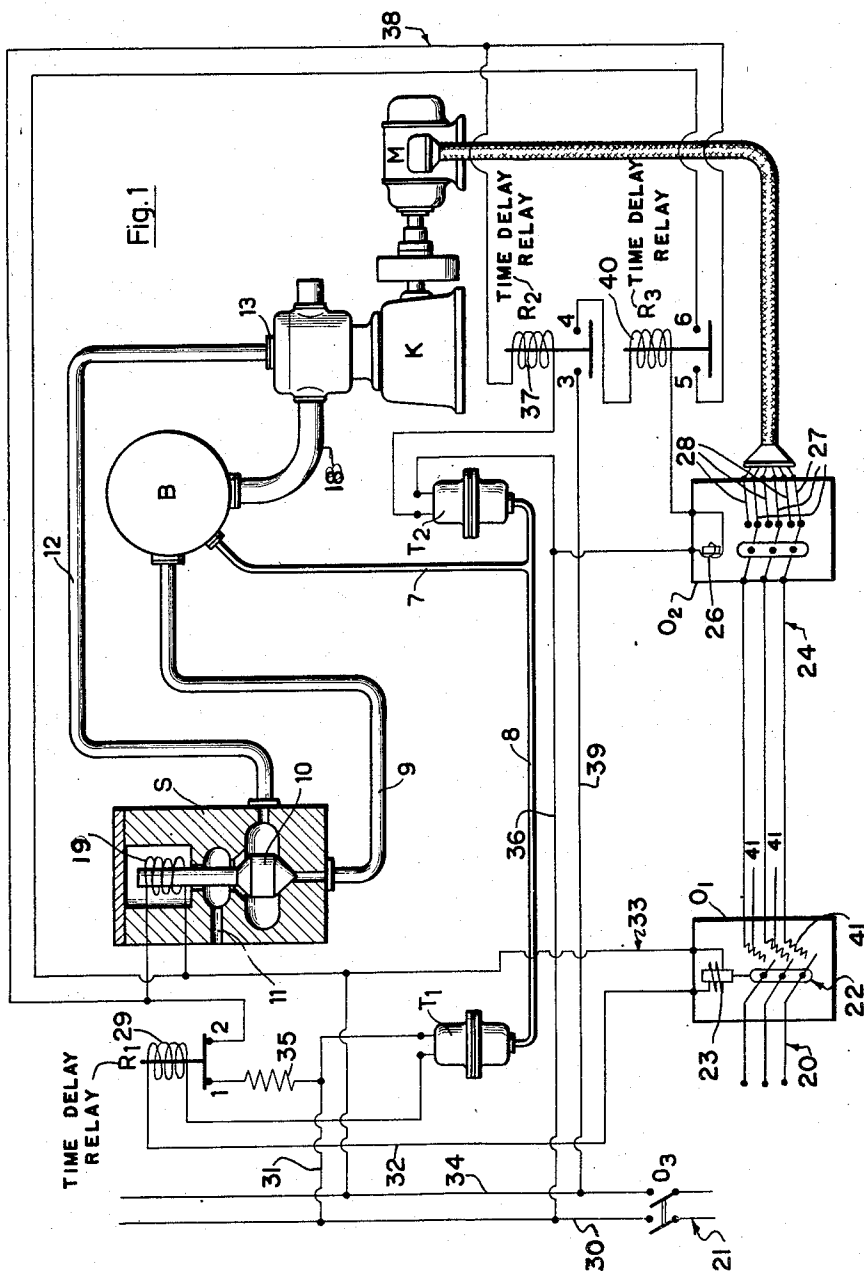
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2,646,205

COMPRESSOR PLANT

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3 Sheets-Sheet 1



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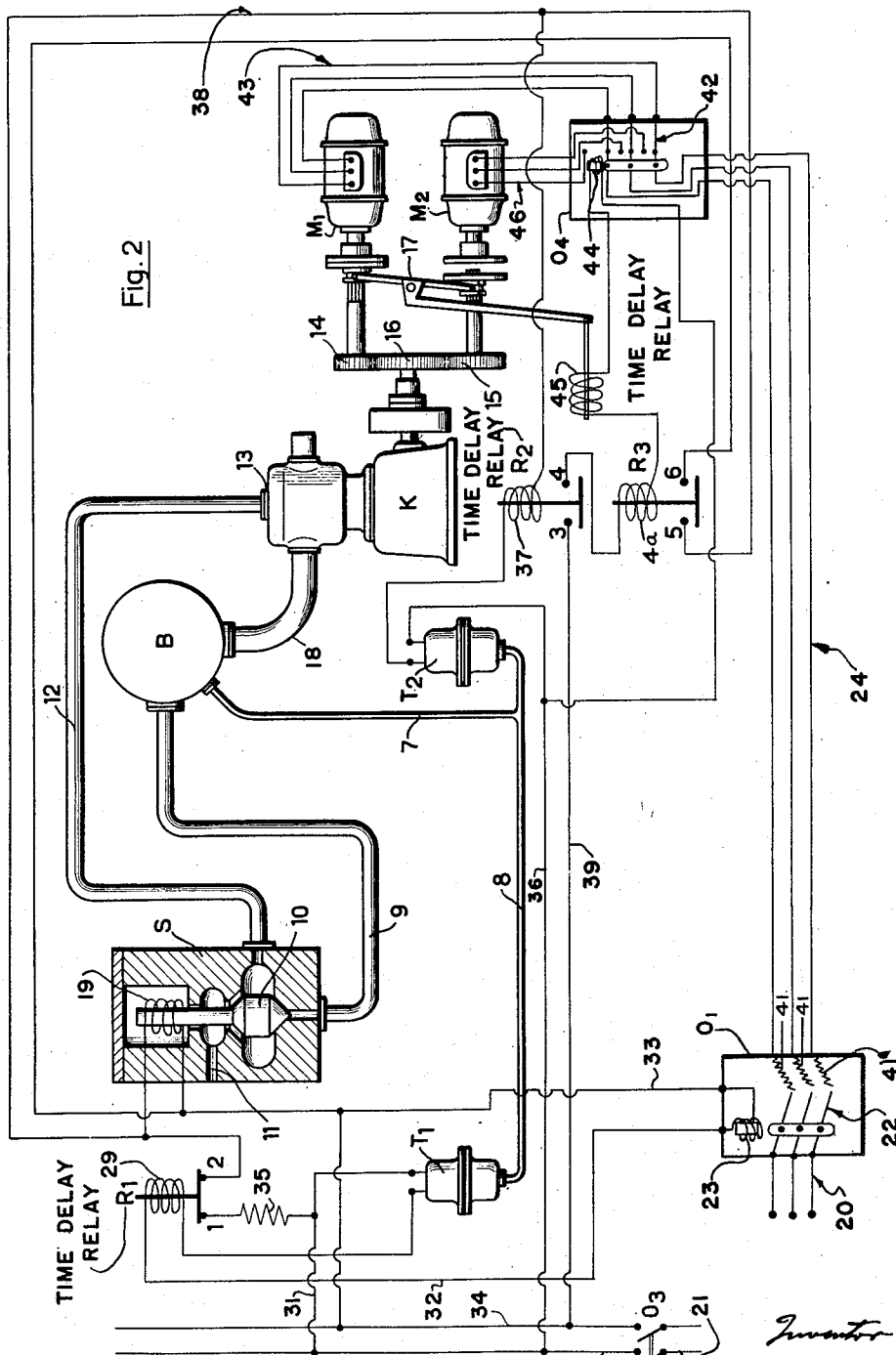
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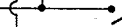
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COMPRESSOR PLANT

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3 Sheets-Sheet 2




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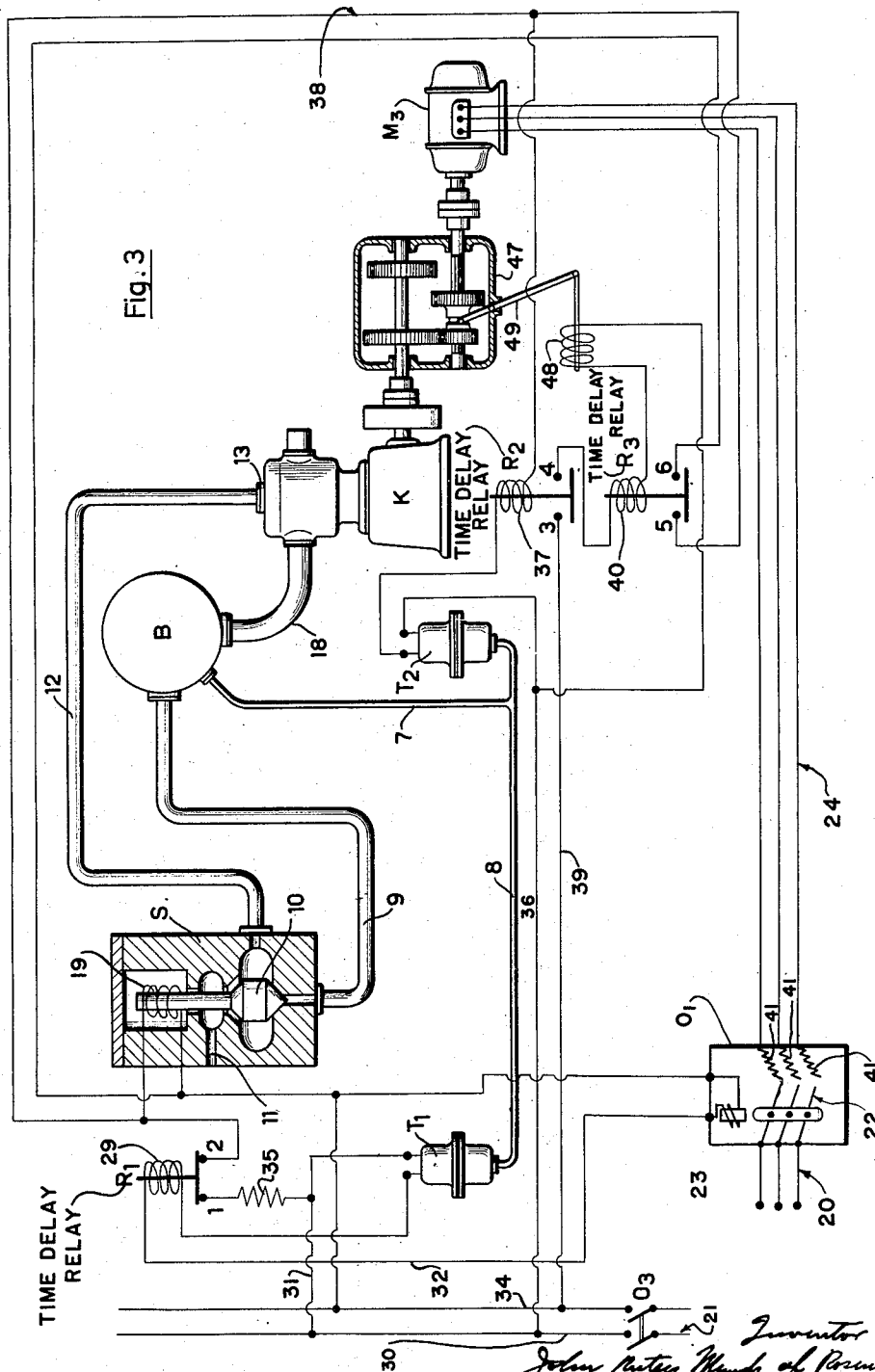
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3 Sheets-Sheet 3



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COMPRESSOR PLANT

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This invention refers to compressor plants comprising electromotor driven compressors operated at different numbers of revolutions and at different loads.

Conventional air and gas compressors are often driven by alternating-current motors, preferably asynchronous or auto-synchronous motors which between full load and idle speed operate at a constant or nearly constant number of revolutions. The regulation of the air quantity delivered by such compressors is usually obtained by unloading the compressor in one or more stages. For this purpose several known methods may be applied, such as throttling of the suction conduit, adding auxiliary "clearance spaces" to the compression chambers, keeping the suction valves open, and so on. All these methods have the disadvantage that the compression is carried out with reduced efficiency when the compressor is unloaded. This is usually expressed by stating that the specific power consumption of the compressor increases the more the compressor is unloaded.

One object of this invention is to provide a compressor plant which operates with increased efficiency at reduced load.

The present invention consists of a compressor plant comprising in combination a compressor, an electromotor for driving said compressor at different numbers of revolutions and at different loads, means for varying the number of revolutions at which the compressor is driven, a mechanism for unloading the compressor, a regulating device operative in response to a condition resulting from the compression work of the compressor to bring said means into action and upon an increase of the number of revolutions to bring the unloading mechanism into action for unloading the compressor. The means for varying the number of revolutions of the compressor may be mechanical speed shift gears and/or means for electrically changing the connections of the motor for driving the compressor with different numbers of revolutions. The regulating device may be responsive to changes in pressure or temperature of the compressed medium produced by the plant or any other medium responsive to the operation of the plant.

In a preferred embodiment the motor may be connected for operation with different pole numbers under the influence of the regulating device.

These embodiments of the invention which should only be considered as examples are described hereinafter with reference to the accompanying diagrammatic drawings in which:

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Fig. 1 is a diagrammatic view showing an electrically driven compressor plant and a control circuit therefore constructed in accordance with this invention;

Fig. 2, a view similar to Fig. 1 showing a modified compressor drive; and

Fig. 3, a view similar to Fig. 1 showing a still further modified compressor drive utilizing a change speed transmission.

In Fig. 1 a three-phase short-circuit motor M is connected directly to an air compressor K, which delivers compressed air through a conduit 18 to a receiver B forming part of a compressed air distribution system. The receiver is connected with a control means comprising two electric pressure switches T₁ and T₂ by pipes 7, 8. The pressure switch T₁ breaks its contact at a pressure P in the receiver B and T₂ at a lower pressure p. Furthermore, the receiver B is connected to a compressed air relay S by a pipe 9. Said relay consists of a valve member 10 which by a return force such as a spring not shown is normally kept in the lower one of two positions. In said normal position, which is illustrated in the drawing, pipe 9 is closed while there is an open communication between a passage 11 leading to the atmosphere and a pipe 12 leading to an unloading mechanism 13 on the compressor. The relay S is operated electromagnetically by means of the solenoid 19 which when energized causes the valve member 10 to move to the upper position in which the communication from the pipe 12 to the passage 11 is closed and a communication between the pipes 9 and 12 opened.

Three phase current is supplied to the plant from a line 20 and control current from an auxiliary line 21.

An electrically operated main switch O₁ of standard design is provided through which the three-phase current is supplied to the motor M, which may be a two speed pole change asynchronous motor, as soon as a control circuit for the switch is closed. For this purpose the switch O₁ may include three phase switch means 22 which is urged toward the off position by the force of gravity or other suitable means and which may be closed by energization of a solenoid 23. The main switch O₁ is connected to a pole changing switch O₂ through leads 24, switch O₂ including switch means 25 which by the force of gravity or other suitable means is urged toward low position and which may be moved to high position by energization of a solenoid 26. In low position switch means 25 connects leads 24 through leads 27 to the low speed winding of the motor M and

in high position connects leads 24 through leads 28 to the high speed windings of motor M. This change of connections takes place according to principles known per se, the stator winding of the motor consisting either of one single winding capable of being connected in different ways or of two or more different windings. In the illustrated embodiment it is assumed that the change of connections may be carried out so that two different pole numbers are obtained, of which one is twice the other. Furthermore, it is assumed that the pole changing switch O₂ normally takes the low position corresponding to the high pole number when the pertaining control circuit is broken and the high position corresponding to the low pole number when said circuit is closed.

The pressure switch T₁ controls a circuit containing the solenoid 29 of a relay R₁ and the control circuit of the main switch O₁ which runs from the line 21 through switch O₃, leads 30 and 31, solenoid 29 of relay R₁, lead 32, solenoid 23 of switch O₁ and leads 33 and 34 to switch O₃ and line 21. When the control circuit of the main switch is broken the main switch is assumed to take its off position and when the circuit is closed the switch is assumed to take its on position. The relay R₁ normally closes two contacts 1, 2 and when the solenoid 29 is energized the contacts are broken with a time delay sufficient to allow motor M to accelerate the compressor K from rest to low speed. This time delay is of the order of approximately ten seconds. The contacts 1, 2 form a part of the control circuit of the compressed air relay S. This control circuit runs from line 21 through switch O₃, leads 30 and 31, resistance 35, contacts 1 and 2 of relay R₁, solenoid 19 and leads 33 and 34 to switch O₃ and line 21.

The pressure switch T₂ controls a circuit from line 21 through switch O₃ and leads 30 and 36 to solenoid 37 of a relay R₂, lead 38 and solenoid 19 of the electrically operated valve S and leads 33 and 34 to switch O₃ and line 21. Normally the relay R₂ in deenergized state keeps two contacts 3, 4 open and closes them with a time delay when the solenoid 37 is energized. The contacts 3, 4 control a circuit from line 21 through switch O₃ and leads 34 and 39 to solenoid 40 of relay R₃, solenoid 26 of switch O₂ and leads 36 and 38 to switch O₃ and line 21. The contacts 5, 6 of relay R₃ are normally open but close with time delay when the solenoid 40 is energized.

The contacts 5, 6 of relay R₃ are connected in parallel with the solenoid 19 of the valve S and short-circuit said solenoid 19 when the solenoid 40 is energized.

As stated above relays R₁, R₂ and R₃ are of the time delay type and may be designed so that they operate with a delay of the order of approximately ten seconds. For example, relay R₁ breaks contacts 1 and 2 approximately ten seconds after solenoid 29 is energized and closes them immediately upon deenergization whereas relays R₂ and R₃ close contacts 3 and 4 and 5 and 6 respectively approximately ten seconds after energization of solenoids 37 and 40 respectively and break these contacts immediately upon deenergization.

The unloading mechanism 13 may in a manner known per se consist of a piston which under the influence of the compressed air in the pipe 12 and against a spring action lifts the suction valve or valves from their seats so that said valve

cannot close during the pressure stroke of the compressor piston and the air in the compressor cylinder flows out again through the suction valve. Thus during the operation of the compressor the air alternately flows out and in through the suction valve and no compression work is carried out. In other words the compressor is unloaded as soon as compressed air is admitted to the pipe 12. On the other hand, if compressed air is conducted away from the pipe 12, the piston of the mechanism 13 will be returned by the spring action so that the suction valve again takes its normal position and the compressor is rendered operative.

The compressor plant works in the following manner: If the compressor is at rest and the receiver B contains air of a pressure lower than the pressure at which the pressure switches T₁ and T₂ break their contacts the compressor may be started by closing the switch O₃. The circuits of the pressure switches T₁ and T₂ are immediately closed so that the main switch O₁ is immediately turned on. The motor starts and increases its speed to the low number of revolutions corresponding to the high pole number which is normally connected by the switch O₂ in the low position shown in Fig. 1. It will be obvious that the motor M is at this time supplied with full line voltage. The solenoid 19 of the valve S was immediately energized via the contacts 1, 2 and the valve was thereby moved to a position in which the unloading pipe 12 is connected with the receiver B through the pipe 9 so that the compressor is unloaded. After a time sufficient to accelerate motor M to low speed and corresponding to the above mentioned time delay the relay R₁ breaks its contacts 1, 2 whereupon, however, the solenoid 19 of the valve S is kept energized since current is supplied via the switch T₂ and the solenoid 37 of relay R₂. The relay R₂ closes its contacts 3, 4 after the time delay period so that the pole changing switch O₂ is switched over from the high to the low pole number or high speed connections to the motor which consequently immediately starts to increase its speed. It will be obvious that the motor M is likewise at this time supplied with full line voltage. The solenoid 40 of relay R₃ is energized upon closure of contacts 3 and 4 of relay R₂ and after the time delay period, during which the acceleration of motor M takes place, closes contacts 5 and 6 causing the solenoid 19 of the valve S to be short-circuited and the valve S to return to its normal position in which the air in the unloading pipe 12 is exhausted so that the compressor is loaded. The motor and compressor now have reached full speed and the compressor starts to pump air into the receiver B in which the pressure rises.

When the pressure has reached the first pressure limit *p* the pressure switch T₂ is turned off. The solenoid 37 of relay R₂ becomes deenergized and breaks the control circuit of the pole changing switch O₂ so that the switch means 25 moves to low position and the motor M is connected to a high pole number or low speed winding. Also the solenoid 40 of the relay R₃ is deenergized so that the short-circuit of the solenoid 19 of the valve S by the contacts 5, 6 is removed. The solenoid 19 of the valve S, however, remains deenergized since the pressure switch T₂ is open. The compressor then operates at about half speed and pumps air into the receiver at a slower rate.

Now, if the pressure rises to the upper pressure limit *P* the pressure switch T₁ also breaks its

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contacts and the solenoid 23 is deenergized so that the main switch O_1 controlled thereby disconnects the motor and stops the compressor, the contacts 1, 2 are closed and the solenoid 19 of the valve S is energized and the compressor unloaded.

It is assumed that this condition lasts until the pressure in the receiver has fallen below the upper pressure limit P , at which time the pressure switch T_1 is again turned on. The control circuit of the main switch O_1 is closed and the motor is started and runs up to the low number of revolutions since the switch O_2 is in low position. At first the contacts 1, 2 are closed and the solenoid 19 of the valve S energized so that the compressor remains unloaded via the pipe 12. After the time delay period of the relay R_1 the contacts 1, 2 are broken and the valve S moved so that the unloading pipe 12 is connected with the outlet passage 11 and the compressor starts to work.

If, however, more compressed air is drawn from the receiver B then the supply from the slow-running compressor the pressure will fall further and finally passes the low limit value p . The pressure switch T_2 then closes its contacts, the solenoid 37 of relay R_2 and solenoid 19 of valve S become energized, the unloading pipe 12 is connected to the pipe 9, and the compressor is unloaded. After the time delay period of the relay R_2 the contacts 3 and 4 close so that the pole changing switch O_2 is switched over to high position and the motor runs with low pole number and increases its speed. After the time delay period of relay R_3 this relay also closes its contacts and short-circuits the solenoid 19 of the valve S so that the compressor is again loaded. The motor now runs at full speed and the compressor works with maximum capacity.

A plant according to the invention has several important advantages. Firstly, instead of a reduced efficiency an improved efficiency is obtained at half-load at the low speed. A low specific power consumption is obtained since the air velocities in the valves and passages of the compressor at the low speed are reduced to about half the velocities at full speed and a more isothermic compression is obtained due to better cooling. The wear of the moving parts and the consumption of lubricant is also more favorable than in conventional plants having devices for reduction of the capacity of the compressor. A great advantage is that the starting current of the motor also in automatic plants is reduced causing the motor to start at a low speed where its maximum output is less than half the output at the high speed. Since the value of the starting current often prevents the use of the economical arrangement with automatic start and stop, the invention now makes it possible to use large compressors in such an arrangement.

The embodiment of the invention hereinabove described and illustrated in Fig. 1 is only an example and may be modified in many ways within the scope of the claims.

When a change from stop to running and from running at low speed to running at high speed is made, i. e. generally speaking, upon increase of speed, a heavy current flow takes place. The main switch O_1 as well as the pole changing switch O_2 may therefore be provided with current limiting devices known per se which are automatically connected during a certain period. This period should be suitably related to the time delay of the relays R_1 and R_3 . The current lim-

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iting devices may consist of constructions that during the beginning of a new running period of the motor connect the stator winding in star connection and only after some time change it over to mesh connection. Further the voltage on the motor at the moment when the connection is changed may be reduced by changing the connection of variable tapping points at a transformer, said tapping points being then connected for normal voltage in one or more steps. Also current limiting impedances or resistances may be used for this purpose as shown at 41 in Fig. 1.

The unloading mechanism 13 described hereinabove may be replaced by a throttle valve in the air inlet passage of the compressor which chokes said passage when the compressor is to be unloaded.

In order not to wear the switches O_1 and O_2 unnecessarily by frequent changes of the connections it may be suitable to design the pressure switches T_1 and T_2 with a certain inertia or hysteresis. This means for instance that a rising pressure causes a change of the connections in the direction towards reduced speed only when the pressure has risen to $P+D$ and $p+d$, respectively, where D and d are certain small pressure differences while a falling pressure causes a change of the connections in the direction towards increased speed, only when the pressure has fallen to $P-D$ and $p-d$, respectively.

The pressure switches T_1 and T_2 may be replaced by another regulating device with an equivalent function which upon actuation under the influence of the compressed air mechanically or through fluid pressure means actuates the switches O_1 and O_2 .

As described above the impulse for causing actuation of the switches O_1 and O_2 has been the pressure acting on the pressure switches T_1 and T_2 . However, it is also conceivable that certain other conditions indirectly dependent on the pressure produced by the compressor may be utilized as an impulse source. When the air passes through the compressor and is compressed it is heated more or less depending on the rate of compression. If a thermostat forming a part of a relay circuit is interconnected in the air passage immediately after the compressor the device may be such that when the temperature of the compressed air exceeds a certain value or certain values, respectively, the change in the connections previously mentioned is effected.

Furthermore, since the compressor consumes more and more power when the pressure rises this circumstance, which is indirectly dependent on the pressure, may be utilized instead of the air pressure itself. Consequently, a relay responsive to the output of the motor and provided in the supply circuit of the motor may be utilized to actuate the switches O_1 and O_2 so that an increase of the output of the motor beyond a certain limit causes a change to the low speed, whereas a reduction of the output below a certain other value may cause a change to the high speed. In similar manner a device may act which is actuated when the turning moment transmitted from the motor to the compressor which is indirectly dependent on the air pressure exceeds or falls below a certain value.

Still further secondary conditions responsive to the compressor work may be utilized for regulating purposes. For instance, if the compressor works together with a refrigerating plant the reduction in the temperature, for instance in the refrigerating space, below a certain limit may

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cause a change in the connections of the motor to low speed, and vice versa. Instead of the temperature in some part of the refrigerating plant the steam pressure produced in the coolers may be used as a source of impulse for the regulating device.

Hereinabove, it has been assumed that one electric motor capable of being connected for different speeds is used. However, there is nothing to prevent that, for instance, two motors are directly coupled to the compressor and that each motor is designed for a single speed differing from the speed of the other motor. Both motors may then be of standard design and are connected alternately by a switch while the motor which is not connected is carried along idle. This gives great liberty with regard to the speed relation and also with regard to the number of speeds, which may be more than two if several motors are used. The motors may also be arranged for alternating separate operation and operation in cascade connection providing great liberty with regard to speed.

Furthermore, different motors M₁ and M₂ with the same or different normal speeds may be used and arranged to drive the compressor over gear transmissions, as illustrated in Fig. 2, in which gears 14, 15 with different diameters engage a gear wheel 16 fixed on the driven shaft of the compressor K. These motors may be connected alternately by the switch O₄ over a suitable coupling mechanism 17. The switch O₄ and coupling mechanism 17 then replaces the switch O₂ of Fig. 1 whereas the other details of Fig. 2 may be the same and are similarly designated as in Fig. 1 and are consequently not described again. The change speed switch O₄ includes a switch means 42 which normally connects the lead 24 to leads 43 and the motor M₁ which through gears 14 and 16 drives the compressor K at low speed. The switch O₄ also includes a solenoid 44 in series with solenoid 40 of relay R₃ and a solenoid 45 which upon energization shifts mechanism 17 to a position uncoupling motor M₁ and coupling motor M₂ through gears 15 and 16 to drive compressor K at high speed. Upon energization of solenoids 40, 44 and 45 the switch means 42 operates to connect the leads 24 to the leads 46 of motor M₂ to drive the compressor K at high speed. Fig. 3 illustrates a plant of the same general arrangement as in Fig. 1 but having the pole changing switch O₂ and the motor M replaced by a speed change gear 47 and a conventional motor M₃ adapted to run at one speed only. In this case the leads 24 from the main switch O₁ are connected directly to the motor M₃. A solenoid 48 is connected in series with solenoid 40 of relay R₃ and upon energization shifts the mechanism 49 of speed change gear 47 to drive the compressor K at high speed.

In certain installations it is often desirable to provide means for limiting the current flow through the driving motor at the start gradually increasing this current as the speed increases from zero to some predetermined running speed. One method for providing such a current limiting control is illustrated diagrammatically in Fig. 1 in which the main switch O₁ is provided with a variable resistance 41 disposed in each power lead 24, the switch arm 22 gradually reducing the resistance in the line as the speed of the driving motor increases. Various devices of this nature are commercially available and any desired type may be utilized in the compressor plant of this

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invention, the showing and description being by way of illustration only.

What I claim is:

1. A compressor plant comprising in combination a compressor electric motor driving means coupled to said compressor for selectively driving the same at different work producing speeds, means supplying substantially constant voltage to said motor driving means at all work producing speeds, electrically operated speed changing means operatively associated with said motor for selecting any of said speeds for operating said compressor to produce compression work while said voltage remains substantially constant, unloading mechanism operatively associated with said compressor for loading or unloading said compressor and control means operatively associated with the output of said compressor and electrically connected with said speed changing means and with said unloading mechanism in such a manner that the speed of said compressor is changed in response to a change of a condition resulting from the compression work of said compressor and that said unloading mechanism is actuated to unload said compressor while the speed thereof is being increased from one of said speeds to another.

2. A compressor plant comprising in combination a compressor, multi-speed electric motor driving means coupled to said compressor for selectively driving the same at different work producing speeds, means supplying substantially constant voltage to said motor driving means at all work producing speeds, switch means for selecting any one of said speeds for operating said compressor to produce compression work while said voltage remains substantially constant, switch actuating means for operating said switch, unloading mechanism operatively associated with said compressor for loading or unloading said compressor and control means operatively associated with the output of said compressor and connected with said switch actuating means and with said unloading mechanism in such a manner that the speed of said motor is changed in response to a change of a condition resulting from the compression work of said compressor and that said unloading mechanism is actuated to unload said compressor while the speed thereof is being increased from one of said speeds to another.

3. A compressor plant comprising in combination a compressor, multi-speed electric motor driving means coupled to said compressor for selectively driving the same at different work producing speeds, said driving means including an electric motor having a plurality of groups of poles with a different number of poles in each group which may be selectively energized to operate said motor at different speeds, means for supplying substantially constant voltage to said motor driving means at all work producing speeds, switch means for selecting any one of said pole groups to thereby change the driving speed for operating said compressor to produce compression work while said voltage remains substantially constant, switch actuating means for operating said switch, unloading mechanism operatively associated with said compressor for loading or unloading said compressor and control means operatively associated with the output of said compressor and connected with said switch actuating means and with said unloading mechanism in such a manner that the speed of

said motor is changed in response to a change of a condition resulting from the compression work of said compressor and that said unloading mechanism is actuated to unload said compressor while the speed thereof is being increased from one of said speeds to another.

4. A compressor plant as defined in claim 1 in which said speed changing means comprises a change speed transmission coupling said motor to said compressor for selectively driving the same at different work producing speeds and transmission actuating means for changing the speed ratio of said transmission, said control means being electrically connected to said transmission actuating means.

5. A compressor plant as defined in claim 1 in which said control means includes pressure responsive means connected to the output of said compressor and electrically connected with said speed changing means and with said unloading mechanism in such a manner that the speed of said compressor is reduced upon an increase in pressure above a predetermined value and that the speed of said compressor is increased upon a reduction in pressure below a predetermined value and that said unloading mechanism is actuated to unload said compressor while the speed thereof is being increased from one of said speeds to another.

6. A compressor plant as defined in claim 1 in which said electric motor driving means includes an electric driving motor operable at one speed, a second electric driving motor operable at a different speed, coupling means for selectively coupling said first or second motor to said compressor to drive the same and actuating means for said coupling means, said control means being electrically connected to said actuating means.

7. A compressor plant as defined in claim 6 in which said coupling means comprises clutches.

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