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(54) **A method and a system for controlling a plurality of compressors**

(57) A device and a method for controlling a plurality of compressors (1-3) arranged for jointly producing a pressurized fluid, wherein each of the compressors comprises a valve (7-9), the position of the valve determining the size of the flow of the fluid and the compressor having at least three different states: a shut-off state in which the compressor has zero voltage and the valve is in a closed position, an unloaded state in which the compressor is under a voltage and the valve is in a closed position, and a loaded state in which the compressor is under a voltage and the valve is an at least partly open position. Information about each of the compressors regarding the power that the compressor consumes in the loaded and the unloaded states and which flow or flows that the compressor can deliver are stored. Information is received regarding the pressure of the fluid (P_1-P_4) and current valve positions for the compressors are received. The current need of fluid is estimated, based on the current valve positions of the compressors, the flow that the compressor can deliver and the pressure in the fluid. The valve positions of the compressors are adjusted with regard to the current need of fluid and the energy consumption of the compressors in a number of possible sets of valve positions, which meet the current need of fluid.

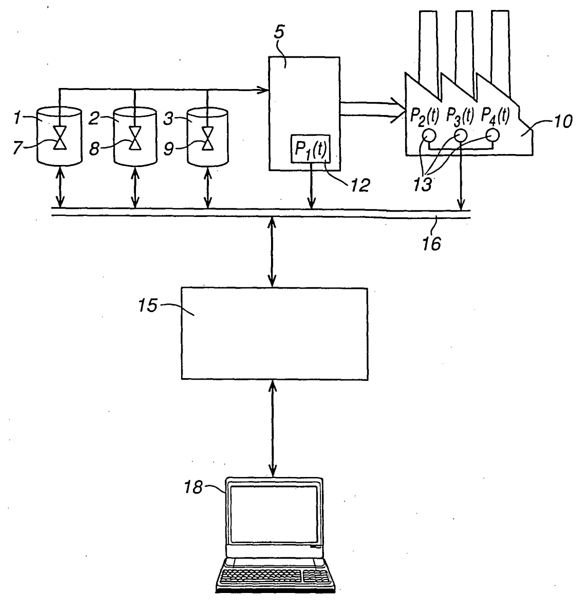

Fig. 1

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Description

FIELD OF THE INVENTION

[0001] The present invention relates to a system and a method for controlling a number of compressors arranged for jointly producing and delivering a pressurized fluid, such as air, freon, oil, or water, to a plant. Each of the compressors comprises a valve, wherein the position of the valve determines the size of the flow of the fluid. The compressors can have at least three different states: a shut-off state in which the compressor has zero voltage and the valve is in a closed position, an unloaded state in which the compressor is under a voltage and the valve is in a closed position, and a loaded state in which the compressor is under a voltage and the valve is in an at least partly opened position. The system according to the invention is advantageously used for controlling compressors for production of pressurized air, but may also be used for controlling other types of compressors, for example for refrigerate production.

PRIOR ART

[0002] In the industry, compressor centrals are often used for producing pressurized air for different purposes, for example pneumatic tools. A compressor central usually comprises a number of compressors, which are connected to a common container of pressurized air, which is connected to pneumatic devices in the plant, for example a pneumatic drill, a pressing tool, or a conveyor. The compressors of the compressor central may have different capacities for delivering air, i.e. the amount of delivered air per unit of time may vary between the compressors. Some of the compressors can only deliver a determined amount of air per unit of time, while others can deliver a varying amount of air per unit of time.

[0003] The pressure in the container is usually somewhere in the range 1-12 bar. The pressure in the container is measured by a gauge and in dependence of whether the pressure in the container exceeds or is lower than a predetermined limit, some of the compressors are started or shut off. Which of the processors is to be started or shut off is decided based on predetermined sequences. A sequence specifies on one hand which compressor is the base compressor, i.e. the compressor which shall be connected first and deliver the base pressure and on the other hand the order in which the other compressors are to be connected or disconnected, if the pressure is not enough or is too high. One or a plurality of sequences may control the compressor central. Different sequences can be used in dependence the time of the day, the day of the week, or the shift working. Those sequences are determined in advance based on previous experiences of the varying need of pressurized air during the day and night. If the pressure in the container exceeds the limit, the next compressor in the sequence is connected, and if the pressure is lower than the limit, the sequence decides which of the compressors to be disconnected.

[0004] A disadvantage with those compressor centrals is that they are very energy demanding and also have a low efficiency. The efficiency for incoming current to active mechanical work is about 4%. One of the reasons for the low efficiency is that the compressors during a great part of the time are in the unloaded state. A compressor in an unloaded state consumes energy without performing any work. The energy consumption in an unloaded state can be as much as 40-50% of the energy consumption in a loaded state. When a compressor, being in a loaded state, is to be shut off, it should first remain in the unloaded state for a certain period of time before it is passed to the shut-off state. If a compressor is shut off without first being in an unloaded state, the internal container of the compressor does not have enough time to be emptied and it will take additional time to start the compressor again.

SUMMARY OF THE INVENTION

[0005] The object of the present invention is to provide a method for controlling a plurality of compressors that jointly produce a fluid, which method makes it possible to lower the energy consumption and obtains a high efficiency in relation to the above discussed prior art.

[0006] This object is achieved by means of the initially defined method and is characterized in that the method comprises storing information for each of the compressors regarding the power that the compressor consumes in the loaded and the unloaded states and which flow or flows the compressor can deliver. Information regarding the pressure of the fluid and the current valve positions for the compressors are received. The current need of fluid is estimated, based on the current valve positions of the compressors, the flow that the compressors can deliver and the pressure in the fluid. The valve positions of the compressors are adjusted with regard to the current need of fluid and the energy consumptions of the compressors in a number of possible sets of valve positions that meet the current need of fluid. In a preferred embodiment, the set of valve positions that achieves the lowest energy consumption is produced. However, other sets having energy consumption close to the lowest energy consumption may achieve acceptable energy consumption, such as the set that is calculated to achieve the second lowest energy consumption. In one embodiment, the valve positions of the compressors, is for example adjusted with regard to a condition allowing the energy consumption of the compressors is to be at the most 10% larger than the energy consumption of the set of valve positions that achieves the lowest energy consumption.

[0007] Instead of, as in the prior art, decide in advance which compressors to be started or shut off based on previous experiences, new decisions are made all the time about which compressor or compressors to be started or shut off based on calculations regarding the energy consumption of the compressors with regard to the current need of fluid. Such a method achieves a dynamic adjustment of the states of the compressors to present circumstances for each occasion, with regard to unexpected events. Since it is always possible to choose a set of valve positions that achieves low energy consumption with regard to the current need of fluid, the total energy consumption is reduced and the efficiency is increased. The energy consumption is lowered thanks to the fact that the time that the compressors are in an unloaded state is minimized with such a method.

[0008] According to a preferred embodiment of the invention, a number of possible sets of different combinations of valve positions are produced. For each of said set of valve position, the flow that the set produces is calculated and from said sets of possible combinations of valve positions, one set of valve positions is chosen that meets the current need of flow with regard to the energy consumption of the compressors, based on the power consumed by the compressors in the loaded and unloaded states. In a preferred embodiment, it is decided for said chosen sets of valve positions which of the sets achieves the lowest energy consumption. By producing all possible combinations of valve positions for the compressors, calculating the flow that those combinations achieve, and then comparing the flows with the current need of fluid, it is possible to determine which combinations of valve positions meet the current need of fluid. When the combinations are decided, one of them is chosen in dependence of its energy consumption.

[0009] According to a preferred embodiment of the invention, the current need of fluid is estimated by calculation of the current flow, based on the current valve positions of the compressors and the flow that they can deliver, and whether the flow has to be changed or not is determined in dependence of the pressure in the fluid. Calculating the current flow, and using the pressure to decide whether the pressure has to be increased or decreased, obtain an estimation of the current need by means of a condition telling whether the flow shall be larger than or less than a certain value. By later trying whether a set of valve positions fulfils the condition or not, it can easily be established whether the set of valve positions fulfils the current need of fluid or not.

[0010] According to a preferred embodiment of the invention, the pressure in the fluid is compared with an upper and a lower limit for the pressure, and whether the flow has to be increased or decreased is determined in dependence of said comparison. Preferably, the upper limit for the pressure is more than 5% higher than the lower limit. By allowing a large span between the upper and the lower pressure limit, the compressors do not need to be started and stopped as often as with a more narrow span. Thus, wear and energy consumption for the compressors are reduced.

[0011] According to a preferred embodiment of the invention, the derivative for the pressure in the fluid is calculated, and whether the flow has to be increased or decreased is determined in dependence of the calculated derivative. By considering the derivative of the pressure during the judgment of whether the flow has to be changed, unnecessary starts and stops of the compressors can be prevented. For example, if the pressure is immediately below the lower limit at the same time as the pressure in the container is strongly increasing, it is not necessary to start another compressor and if the pressure is immediately above the upper limit at the same time as the pressure falls rapidly in the container, it is not necessary to stop another compressor. By considering the derivative, such unnecessary manoeuvres are avoided.

[0012] According to a preferred embodiment of the invention, the integral for the pressure in the fluid is calculated, and whether the fluid has to be changed is determined in dependence of the calculated integral. If the limits for the pressure are strictly followed during the judgment of the current need, the control will become jerky and sometimes leads to unnecessary starts and stops of the compressors. By also considering the integral of the pressure during the judgment of whether the flow has to be changed, not necessary starts and stops of the compressors are avoided in connection with occasional variations of the pressure in the container, for example at pressure peaks and minor breaks of the pressure limits. Accordingly, a more gentle control is obtained.

[0013] According to a preferred embodiment of the invention, the times that the compressors are in the unloaded state are measured, and when the time for any compressor exceeds a given limit, a control signal is generated for transferring the compressor to the shut-off state and information is stored about the fact that the compressor is shut off. A compressor being in an unloaded state may quickly change to a loaded state, but an unloaded compressor needs a period of time before it can start. By avoiding to shut off the compressor immediately when it is no longer needed and instead wait for a while and let the compressors stay in the unloaded position, there is still a possibility, if the need for fluid will increase again soon, to quickly start the processor again. In a preferred embodiment, it is possible to choose the limit and it is fed by the user. By storing information about the fact that the compressor is turned off, in connection with when it was turned off, it is possible to keep track of which compressors are in a shut-off state. Advantageously, the valve positions of the processors are adjusted with regard to the stored information about which of the compressors is shut off.

[0014] According to a preferred embodiment of the invention, the valve positions of the compressors are adjusted with regard to how many times each of the compressors is allowed to start during a given time interval. Advantageously, for each of the compressors, information is stored about the number of times per unit of time the compressor has changed from a shut-off state to a loaded state and the number of times per unit of time is compared with a maximum allowed number of times per unit of time, and in dependence of the comparison it is decided whether the compressor is available or not and during adjustment of the valve positions it is considered which compressors are available.

[0015] Another object of the present invention is to provide a computer program directly loadable into the internal memory of a computer, comprising instructions for causing a processor to execute the steps in the method according to the invention.

[0016] Another object of the present invention is to provide a computer readable medium comprising a computer program comprising instructions for making a processor execute the steps in the method according to the invention.

[0017] Another object of the present invention is to provide a system for controlling a plurality of compressors that jointly produce a fluid, which makes it possible to lower the energy consumption and to achieve a high efficiency. This object is achieved by the initially mentioned system and is characterized in that it comprises means for feeding and storing information about the power consumed by the compressors in the loaded and the unloaded states and which flow or flows the compressors can deliver, means for estimating the current need of fluid, based on current valve positions for the compressors, the flow which the compressors can deliver, and the pressure, as well as means for producing a set of valve positions with regard to the current need of fluid and energy consumption of the compressor, based on a number of possible sets of valve positions that meet the current need of fluid.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] The present invention will now be explained by means of different as examples described embodiments and with reference to the appended figures.

Fig. 1 shows a compressor central and a system for controlling the compressors according to the invention.

Fig. 2 shows, in the form of a flow diagram, a method for controlling the compressors in the compressor central according to the invention.

Fig. 3 shows a graph for how the pressure varies in the fluid after the compressors.

DETAILED DESCRIPTION OF EMBODIMENTS

[0019] Figure 1 shows a compressor central comprising three compressors 1, 2, 3 arranged for delivering pressurized air to a container 5. Each of the compressors 1-3 comprises a valve 7, 8, 9, the position of the valve deciding the size of the flow of air from the compressors. The compressors can have three different states: a shut-off state in which the compressor has a zero voltage and the valve is in a closed position, an unloaded state in which the compressor is under a voltage and the valve is in a closed position, and a loaded state in which the compressor is under a voltage and the valve is completely open. The compressor produces pressurized air only in the loaded state. The compressors are of the on/off type machines, i.e. either do they produce a maximum flow or they produce now flow at all. There are also compressors having a variable flow production. The invention is also useful for those compressors and further in the text an embodiment example is described with a compressor central comprising a compressor having a variable flow production.

[0020] All three compressors 1, 2, 3 deliver pressurized air to the container 5. From the container 5, the pressurized air is further delivered to a plant 10, where different consumers receive the air. The consumers are, for example, tools or conveyors driven by pressurized air. The pressure $P_1(t)$ in the container is measured by means of a pressure gauge 12 arranged in the container. The pressures $P_2(t)$, $P_3(t)$, $P_4(t)$ are also measured in three different locations in the plant, by means of three pressure gauges 13. The pressure gauges 13 are positioned at critical points, where it is important for the functioning that a certain pressure is maintained and the pressure is not allowed to be below given levels. Data from the compressors in the compressor central 1, 2, 3, the container 5, and the plant 10 are transferred to a system 15 for control of the compressors. Control signals and data are transferred between the system 15 and the compressors and a plant via a bus connection 16.

[0021] The system 15 comprises a processor, memories, and I/O units for communication with other units. From the compressors 1, 2, 3 information about current positions of the valves 7, 8, 9 is transferred to the system 15. From the container 5 and the plant 10 information regarding the pressure in the container 5 and in the critical points 13 is transferred to the system 15. The system 15 is also connected to a computer 18, which enables an operator to communicate with the system 15 and to feed data to the system. Data fed via the computer 18 is information regarding the power that each of the compressors consumes in the loaded and unloaded state, and the maximum flow that each of the compressors can deliver. One task of the system 15 is to estimate the current need of fluid and with regard to the current need of fluid determine the valve positions that achieve the lowest total energy consumption for all the compressors. Another task for the system 15 is to send control signals to the compressors regarding to change the state.

[0022] Fig. 2 shows, in the form of a flow scheme, how the system 15 produces the valve positions that achieve the lowest energy consumption. In a first step, box 20, data regarding the power that each of the compressors consumes in the loaded state P_n^P and the unloaded state P_n^a, and the flow f_n that the compressors deliver in the loaded state are read. Usually, the flow is specified in litres per minute. Those data regarding the compressors are stored and do not have to be read again until any information is changed. Thereafter, information regarding the pressure $P_1(t)$ in the container and the pressures $P_2(t)$-$P_4(t)$ in the critical points in the plant are read, box 21, and current valve positions δ_n for each of the compressors are read, box 22. Since the compressors are on/off-compressors, the valve positions have either the value 0 or the value 1. If the valve position has the value 0, the valve is closed and if it has the value 1, the valve is entirely open. The reading of input data is carried out with an optional time interval.

[0023] The flow production F that a set of compressors N, having valve positions δ_n, provides can be calculated according to the following equation:

$$F = \sum_n f_n \cdot \delta_n \qquad (1)$$

F = total flow
N = number of compressors
f_n = flow from the compressor n, when the valve is entirely open
δ_n = valve position for compressor n.

[0024] When all the input data are read, the current flow production F_A is calculated by equation 1, box 23.

[0025] For the pressure in the container and the pressures in the critical points, limits are set for the allowed pressure. In some of the critical points, it is enough with a lower limit that the pressure must exceed. For the pressure in the container, both an upper limit P_{max} and a lower limit P_{min} are provided, which present an interval for the allowed variation of the pressure. It is important to allow as large a pressure difference as possible between the upper and the lower limit without jeopardizing the function of the connected components. The difference between the limits P_{max}-P_{min} should be at least 5%, but preferably as much as 10%. How large a pressure difference to be allowed depends on several factors, such as the demands on the plant, the type of industry, and the size of the container. If the desired value, for example, is 7 bar, the upper limit is preferably set to 7,5 bar and P_{min} is preferably set to 6,5 bar. The larger difference between the limits, the fewer times the compressors have to be started and stopped, resulting in reduced wear and lower energy consumption.

[0026] The pressure in the fluid is compared with the lower limit P_{min}, box 24, and with the upper limit P_{max}, box 25, and if the pressure is within the limits, there is no adjustment of the valve positions, provided that it is not the first time that the program is run through. Should it be the first time that the program is run through, a determination of optimal valve positions is made, box 27, in the same way as is described ahead in the text, and control signals are generated for adjustment of the valve positions in accordance with the optimised valve positions, box 28. If the pressure in any of the measure points is lower than the lower limit, it is possible that another compressor has to be started. Before any step is taken, it is decided whether it really is necessary to increase the flow production. To be able to decide whether the flow really has to be increased, the derivative of the pressure $\frac{\delta P}{\delta t}$, box 31, is calculated. The derivative $\frac{\delta P}{\delta t}$ is calculated according to the following equation:

$$\frac{P(t+1)-P(t)}{\Delta t} \qquad (2)$$

[0027] If the value of the derivative is very large, i.e. if the pressure is strongly increasing and the value of the pressure is larger than $0{,}85 \cdot P_{min}$, the control system should not react by a further increase of the flow, since the pressure already is close to the limit and the pressure is strongly increasing. In the same way, the derivative is calculated, box 30, if the pressure is larger than the maximum limit. If the derivative has a large negative value, which means that the pressure is rapidly decreasing, and the pressure is less than $1{,}15 \cdot P_{max}$, the system is not allowed to react with a further lowering of the flow. Since the pressure is already decreasing and it is also close to the maximum limit, no measure is taken in this case.

[0028] Fig. 3 shows an example of how the pressure varies over time. At rapid changes in the pressure, the measurements of the derivative are uncertain. If the calculations of the derivative is based on the pressure in the points A and B, as shown in Fig. 3, the derivative will have the value 0, which is erroneous, since the derivative in the point B instead is strongly increasing. This example shows that a decision based only on an analysis of the derivative outside the upper P_{max} and the lower P_{min} limit for the pressure is not reliable. To exclude that it only is fast peaks, the integral for the pressure is also calculated when the pressure is outside the limits, boxes 32 and 33. The integral for the pressure is calculated as long as the pressure is below P_{min} or above P_{max}. As long as the pressure remains within the limits, the integral is not calculated.

[0029] The above described analysis leads to an insight of whether the current need of pressurized air is larger or less than the current production of pressurized air. If the analysis shows that the need of pressurized air is larger or less than the current production, boxes 34, 35, the system will continue to produce optimal valve positions, boxes 36 and 37, i.e. it decides the set of valve positions that provides the lowest energy consumption and at the same time fulfils the current need of pressurized air.

[0030] To be able to decide the optimal valve positions, the possible combinations of valve positions which can be achieved from the compressor central are first calculated. In this embodiment, the central comprises three compressors of the type on/off-machines, which means that there are seven possible sets of combinations of valve positions. The number of possible valve positions is given by the equation:

$$K(N, A) = \frac{N!}{A!(N - A)!} \qquad (3)$$

N = total number of compressors

A = number of machines chosen at different times.

[0031] For each of the sets of valve, the total flow F_i that those valve positions provide are calculated. The flow F_i, that each set provides is calculated by the equation 1. It is to be noted that several sets of valve positions may provide the same flow. The production of possible sets of valve positions and the flows obtained from those can be calculated once and for all. For the purpose of finding the sets of valve positions that fulfil the current need of fluid, the calculated flows F_i for the sets are compared with the calculated current flow F_A from equation 1. If the analysis above has shown that the flow should increase, the sets of valve positions that achieve a flow F_B next higher to the current flow F_A is chosen. If the flow is about to be increased, box 37, the following boundary condition is valid:

$$F_i \geq F_B > F_A \qquad (4a)$$

[0032] If the analysis above shows that the flow should be lowered, the sets of valve positions, whic provide a flow F_C that is next lower to the current flow F_A, are chosen. If the flow is to be lowered, box 26, the following boundary condition is valid:

$$F_i \geq F_c < F_A \qquad (4b)$$

[0033] The boundary condition 4b provides that F_i has to be larger or equal to F_C, to prevent that the answer from the calculation is that no flow at all is to be produced in the case when the flow is to be reduced. In reality, the combination of valve positions that gives $F_i = F_C$ will provide the lowest power output.

[0034] If it is the first time that the loop is run through and the flow does not have to be changed, box 27, the following boundary condition apply:

$$F_i \geq F_A \qquad (4c)$$

[0035] Which of those boundary conditions to be used, is determined by the current need of fluid. If the number of compressors is large, there are usually several sets of valve positions that fulfil the boundary condition. With consideration taken to a suitable boundary condition, the system calculates which set of valve positions provides the lowest electrical power output by a mathematic optimisation model. To be able to find the set of valve positions that provides the lowest power output, the following formula for the power output is set up:

$$\text{Min} \left(\sum_{n=1}^{N} [P_n^a (1-\delta_n) + P_n^p \cdot \delta_n] \right) \qquad (4d)$$

$$\delta_n = [0/1]$$

$$\sum_n f_n \cdot \delta_n \geq K \quad \text{where } K = F_A, F_B \text{ or } F_C$$

P^a = power output for compressor n in unloaded state
P^β = power output for compressor n in loaded state
N^n= number of compressors in the system
δ_n = valve positions in the set, which in this embodiment only can have the value 0 or 1.

[0036] The formula 4d constitutes an optimisation problem, which gives a matrix that can be solved either by commercial or private constructed optimising solutions. Which of the boundary conditions 4a, 4b, or 4c is used depends on the current need of fluid. The solution of the optimisation problem is the set of valve positions that provides the lowest power output. If the number of compressors is large, this calculation is time consuming and it is suitable to use any known optimisation method for finding a solution to the optimisation problem. The mathematical optimisation problem is the same for the boxes 27, 36, and 37. What is changed in the model, in dependence of whether the flow is about to be increased or decreased, is which of the boundary conditions 4a, 4b, and 4c to be used. When the optimal valve positions have been determined, control signals to the compressors are generated regarding which states they shall have and which positions the valves shall have, boxes 28, 38, and 39. This method for finding and adjusting the optimal valve positions is repeated with an optional interval, so that the compressors always have optimal valve positions.

[0037] In the above described embodiment example, all of the compressors are of an on/off type. The invention is also applicable to compressors having a variable, or partly variable, flow production. A compressor with a partly variable flow production has three distinct valve positions: a first position in which the valve is closed and no production of pressurized air will occur, a second state yielding a minimum production of pressurized air, and a third state in which the valve is completely open, and the compressor delivers the maximum of what it is able to deliver. The flow is variable between the second and the third position. According to the invention, the range between the second and the third position is divided into a plurality of discrete positions. The division of the discrete positions is optional and depends on the desired accuracy. During the calculation of the current flow production, a separate addition is also needed if the compressor central comprises compressors with a variable flow range.

[0038] The compressor central in the above-described example is supplemented with a compressor having a partly variable flow range, wherein the flow can be either 0 or vary between 5 and 10 flow units. A division of the range between 5 and 10 flow units is made in steps of 1 flow unit. Each discrete position is defined by a binary integer α_m that can either have the value 0 or 1. In this example, the number of discrete positions is = 7 (0, 5, 6, 7, 8, 9, 10). The flow from the fourth compressor is given by the equation:

$$\sum_m f_{4m} \cdot \alpha_{4m}(t) \qquad (5)$$

[0039] Together with the condition $\alpha_{41} + \alpha_{42} + \alpha_{43} ... + \alpha_{47} = 1$ it is secured that the flow F_4 for the fourth compressor only can have the values 0, 5, 6, 7, 8, 9, 10 in later optimisations. The expression for the total flow production for the four compressors is:

$$F = \sum_n f_n \cdot \delta_n + \sum_m f_{4m} \cdot \alpha_{4m} \qquad (6a)$$

n = 1, 2, 3
m = 1, 2, 3, 4, 5, 6, 7

[0040] Thus, it is also possible to decide optimum valve positions for non on/off-machines. All compressors with a variable flow range are divided into M discrete flow positions. This division can be made machine specific by means of a variable index. Each discrete flow position corresponds to a certain electrical power output.

[0041] The current flow production F_A is calculated in the case with four compressors by the equation 6. For the general case with d compressors, F_A is calculated by the following equation:

$$F_A = \sum_n f_n \cdot \delta_n + \sum_d f_{dm} \cdot \alpha_{dm} \qquad (6b)$$

[0042] In the same way as in the preceding example, the value for F_B or F_C is decided in dependence of whether the flow shall be increased or decreased. The boundary conditions in this embodiment example are given by 4a, 4b or 4c, wherein the total flow F_i that the valve positions can give is calculated by the following equation:

$$F_i = \sum_n f_n \cdot \delta_n + \sum_d \sum_m (f_{dm} \cdot \alpha_{dm}) \qquad (7)$$

[0043] If the system comprises compressors with a variable flow range, formula 8 is used for the optimisation of the valve positions instead of formula 4d, and the following optimisation problem is obtained:

$$\mathrm{Min}\left(\sum_{n=1}^{N} [P_n^a (1-\delta_n) + P_n^p \cdot \delta_n] + \sum_{d=1}^{D} [P_d^a \cdot \alpha_{d0} + \sum_{m=1}^{M} P_d^{pm} \cdot \alpha_{dm}] \right) \qquad (8)$$

$$\sum_n f_n \cdot \delta_n + \sum_d \sum_m (f_{dm} \cdot \alpha_{dm}) \geq K \text{ där } K = F_A, F_B \text{ eller } F_C$$

$$\sum_{m=0}^{M} \alpha_{dm} = 1$$

α_{dm} = [0/1], δn = [0/1] and other variables ≥ 0

d = 1, 2, ... D = index for compressors with variable flow ranges

n = index for compressors of on/off-type

m = number of discrete steps for the variable flow range

[0044] This optimisation problem is possible to solve by known optimisation methods.

[0045] A compressor should not be changed directly from a loaded state to an unloaded state. The compressor should first be in the unloaded state for a certain period of time, before it is transferred to the closed state. The system 15 keeps track of the states of all the compressors and when a compressor changes from a loaded state to an unloaded state, a logging of the time in the unloaded state is started. For each of the compressors, the period of time that the compressor should stay in the unloaded state before the motor is turned off, is fed. This period of time may be optionally chosen and depends, for example, on the compressor size. The measured period of time in the unloaded state is compared with the fed period of time and when the measured period of time exceeds the period of time that the compressor should stay in the unloaded state, the system sends a control signal to the motor and turns it off. Simultaneously, information about the fact that the compressor has been turned off is stored.

[0046] The system also keeps track of how many times per hour each of the compressors has been started. In the system, previuously fed data regarding how many starts per hour each of the compressors are allowed to make. The number of allowed starts per hour depends on the efficiency of the compressor. The number of allowed starts decreases with a higher motor efficiency. A rule of thumb is that compressors with a motor efficiency of 90 kW are allowed to make ten starts per hour, while a compressor with a motor efficiency of 5 kW is allowed to make fifty starts per hour. As soon as a compressor is started, the system keeps track of the number of starts the next hour. If the motor should be turned off without the compressor first being in the unloaded position, it will take about 30 seconds before the compressor is able to start again. That depends on the fact that the internal container of the compressor first has to be emptied before the motor is able to start again. Otherwise, the resistance will become too large. The time it takes for the internal container of the compressor to be emptied is about 30 seconds during unloading.

[0047] Alternatively, the number of starts during a certain period of time is based on the temperature in the motor.

[0048] At each optimisation occasion, the system must find out whether there is any compressors which are not allowed to be started. Depending on their size, the compressors could have been started three or ten times the last hour. Accordingly, when the combinations that fulfil the current need and during the calculation of the matrix 4 or 8, it is thus necessary to consider which compressors are available and which are not available.

[0049] The time from the shut-off state to full air production and from the unloaded state to full air production is adjustable for each machine. If an optimisation solution tells that a certain compressor, which is in the shut-off state, is to be started, a time gap occurs before the compressor is able to deliver full air production. A question that arises is how the system should act, if the optimisation has given that a turned off compressor should be started, but at the same time there is an unloaded compressor that can be started much faster. If the network that delivers the pressurized air to the consumers and the pressure container have enough inertia, the pressure is prevented from decreasing too much during the time gap, and the use of any unloaded compressor is not necessary. In another case, it is possible to make an analysis of the pressure change during the time gap and to decide whether an unloaded compressor should be used instead. If the pressure in the container, or in any of the critical points, is lower than $0,85 \cdot P_{min}$' the unloaded compressor is started to slow down the pressure fall. The unloaded compressor is working until P is larger than $0,9 \cdot P_{min}$ or until the started compressor delivers full capacity. A further alternative is to measure the pressure in the plant in a number of critical points, and if the pressure in any of the points is lower than a given value, the unloaded compressor is started.

[0050] The invention is not limited to the embodiments disclosed but may be varied and modified within the scope of the following claims.

Claims

1. A method for control of a plurality of compressors (1-3) arranged for jointly producing a pressurized fluid, wherein each of the compressors comprises a valve (7-9), the position of the valve determines the size of the flow of the fluid and the compressor can have at least three different states: a shut-off state, in which the compressor has zero voltage and the valve is in a closed position, an unloaded state in which the compressor is under a voltage and the valve is in a closed position, and a loaded state in which the compressor is under a voltage and the valve is in an at least partly opened position, **characterized in that** the method comprises:

   - storing information about each of the compressors regarding the power that the compressor consumes in the loaded and unloaded states and which flow or flows the compressor can deliver,
   - receiving information regarding the pressure of the fluid (P_1-P_4) and the current valve positions for the compressors,
   - estimating the current need of fluid, based on the current valve positions of the compressors, the flow that the compressors can deliver, and the pressure in the fluid,
   - adjusting the valve positions of the compressors with regard to the current need of fluid and the energy consumption of the compressors in a number of possible sets of valve positions which meet the current need of fluid.

2. A method according to claim 1, **characterized in that**,

   - a number of possible sets of different combinations of valve positions are produced,
   - for each of said sets of valve positions the flow that the set produces is calculated, and from said sets of possible combinations of valve positions one set of valve positions is chosen that meets the current need of fluid with regard to the energy consumption of the compressors, based on the power consumed by the compressors in the loaded and unloaded state.

3. A method according to claim 1 or 2, **characterized in that** the valve positions of the compressors are adjusted with regard to the fact that the energy consumption of the compressors is allowed to be at the most 10% larger than the energy consumption of the set of valve positions that achieves the lowest consumption.

4. A method according to claim 1 or 2, **characterized in that** the valve positions of the compressors are adjusted

with regard to which set of valve positions that achieves the lowest energy consumption.

5. A method according to any of the previous claims, **characterized in that** the current need of fluid is estimated by calculating the current flow based on the current valve positions of the compressors and the flow which they can deliver, and determining whether the flow has to be changed in dependence of the pressure in the fluid.

6. A method according to claim 5, **characterized in that** the pressure in the fluid is compared with an upper and a lower limit for the pressure and whether the flow has to be increased or decreased is determined in dependence of said comparison, and that the upper limit for the pressure is more than 5% higher than the lower limit.

7. A method according to claim 5 or 6, **characterized in that** the derivative for the pressure in the fluid is calculated and whether the flow has to be changed is determined in dependence of the calculated derivative.

8. A method according to any of the claims 5-7, **characterized in that** the integral for the pressure in the fluid is calculated and whether the fluid has to be changed is determined in dependence of the calculated integral.

9. A method according to any of the previous claims, **characterized in that** the time that the compressors are in the unloaded state are measured and when the time for any compressor exceeds a given limit a control signal is generated for transferring the compressor to a shut-off state and storing information about the fact that the compressor is shut off.

10. A method according to claim 9, **characterized in that** the valve positions of the compressors are adjusted with regard to the stored information about which of the compressors are shut off.

11. A method according to any of the previous claims, **characterized in that** the valve positions of the compressors are adjusted with regard to how many times each of the compressors is allowed to start during a given time interval.

12. A method according to claim 11, **characterized in that** for each of the compressors information is stored about the number of times per unit of time the compressor has changed from a shut-off state to a loaded state, said number of times per unit of time is compared with a maximum allowed number of times per unit of time, the valve positions of the compressors are adjusted with regard to said comparison.

13. A computer program directly loadable into the internal memory of a computer, comprising instructions for causing a processor to execute the steps in the method according to any of the claims 1-12.

14. A computer readable medium comprising a computer program comprising instructions for causing a processor to execute the steps in the method according to any of the claims 1-12.

15. A system for controlling a plurality of compressors (1-3) arranged for jointly producing a pressurized fluid, wherein each of the compressors comprises a valve (7-9), the position of the valve decides the size of the flow of the fluid and the compressor can have at least three different states: a shut-off state, in which the compressor has zero voltage and the valve is in a closed position, an unloaded state in which the compressor is under a voltage and the valve is in a closed position, and a loaded state in which the compressor has a voltage and the valve is in an at least partly opened position, **characterized in that** the system comprises:

- means (18) for feeding and storing information about the power consumed by the compressors in the loaded and the unloaded states and which flow or flows that the compressors can deliver,
- means for estimating the current need of fluid, based on current valve positions for the compressors, the flow which the compressors can deliver and the pressure in the fluid, and
- means for producing a set of valve positions with regard to the current need of fluid and the energy consumption of the compressors, based on a number of possible sets of valve positions that meet the current need of fluid.

16. A system according to claim 15, **characterized in that** said set of valve positions which are produced, is allowed at the most to have an energy consumption which is 10% higher than the energy consumption of the set of valve positions which has the lowest energy consumption.

17. A system according to claim 15, **characterized in that** said means for producing a set of valve positions is arranged for producing the set of valve positions which achieves the lowest energy consumption, based on the power consumed by the compressors in unloaded and loaded states.

18. A system according to claim 15, **characterized in that** said means for estimating the current need of fluid comprises a derivation means arranged for calculating the derivative of the pressure in the fluid, and that said means is arranged for estimating the current need in dependence of the calculated derivative.

19. A system according to claim 15, **characterized in that** said means for estimating the current need of fluid comprises an integration means arranged for calculating the integral of the pressure in the fluid, and that said means is arranged for estimating the current need in dependence of the calculated integral.

20. A system according to any of the claims 15 and 16, **characterized in that** it comprises means for measuring, for each of the compressors, the time the compressor is in unloaded state and means for generating a control signal for transferring the compressor to the shut-off state, when the time exceeds a given limit.

21. A system according to any of the claims 15-17, **characterized in that** it comprises means for, for each of the compressors, keeping track of the number of times per unit of time that the compressor has been changed from the shut-off state to the loaded state, means for comparing said number of times per unit of time with a maximally allowed number of times per unit of time and in dependence of said comparison determine whether the compressor is available or not.

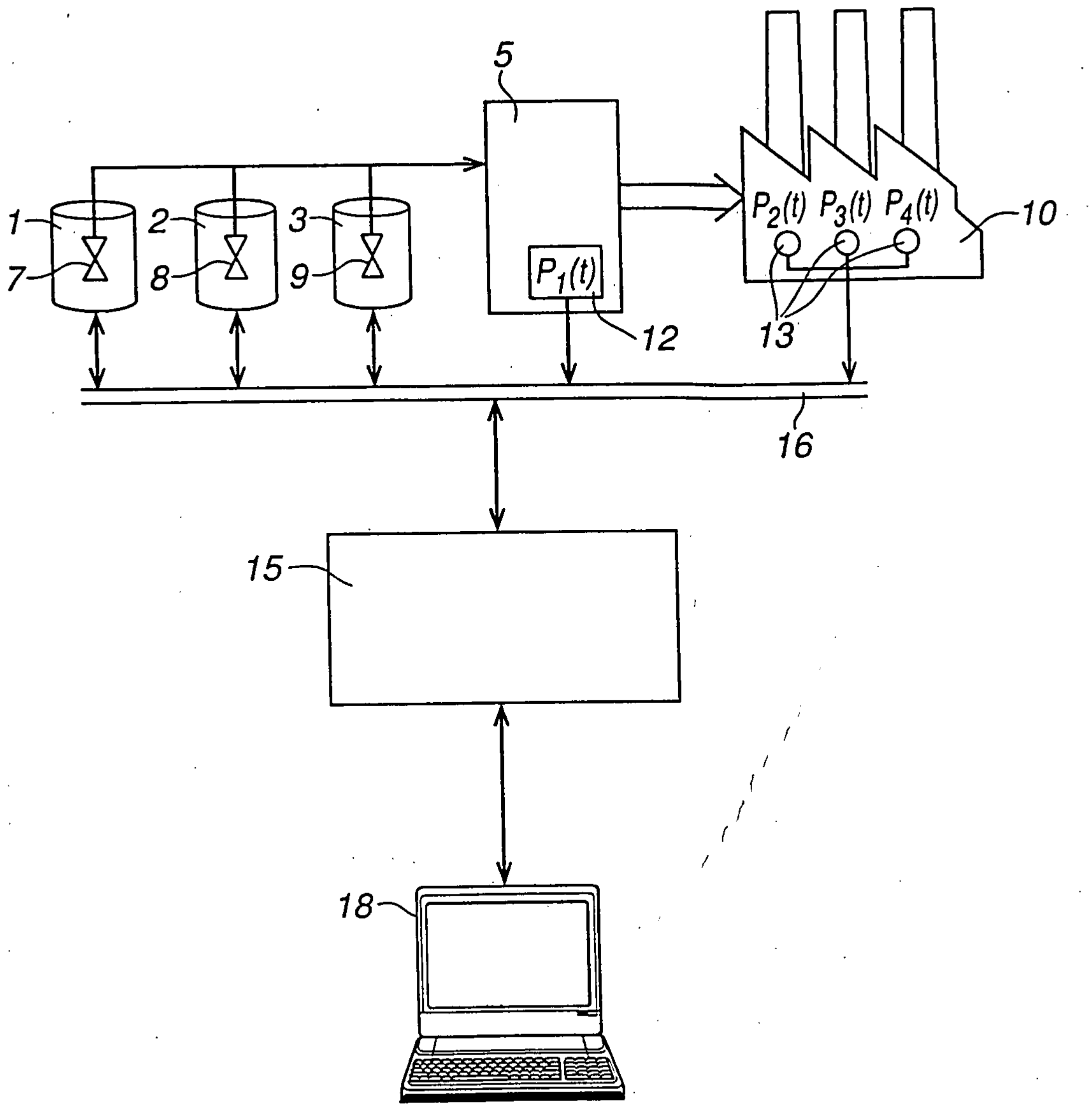
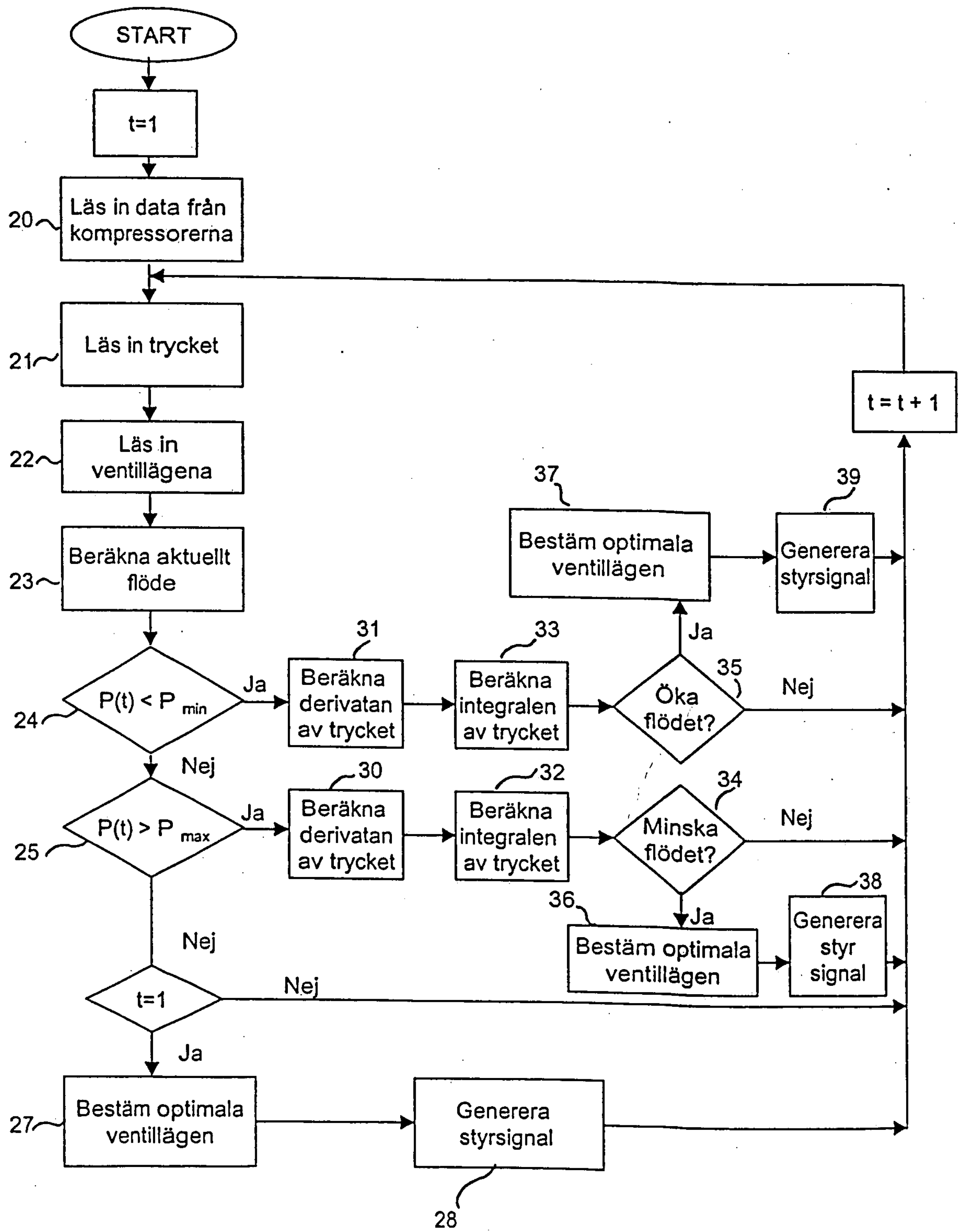


Fig. 1


START
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20
Läs in data från kompressorerna
21
Läs in trycket
22
Läs in ventillägena
23
Beräkna aktuellt flöde
24
P(t) < P min
Ja
Nej
31
Beräkna derivatan av trycket
33
Beräkna integralen av trycket
35
Öka flödet?
Ja
Nej
37
Bestäm optimala ventillägen
39
Generera styrsignal
t = t + 1
25
P(t) > P max
Ja
Nej
30
Beräkna derivatan av trycket
32
Beräkna integralen av trycket
34
Minska flödet?
Nej
Ja
36
Bestäm optimala ventillägen
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Ja
27
Bestäm optimala ventillägen
Generera styrsignal
28

Fig. 2

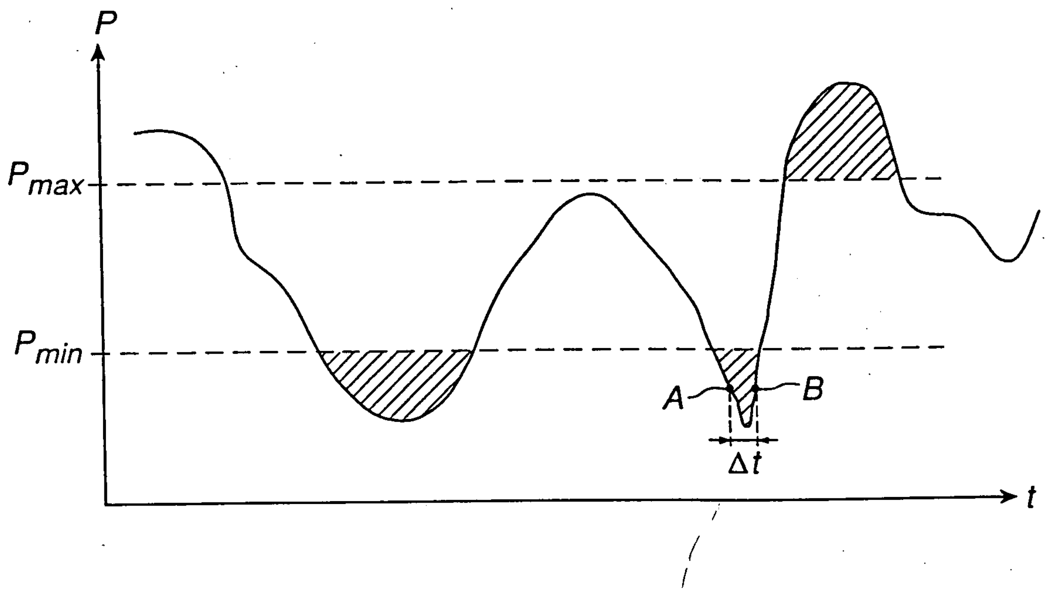

Fig. 3