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(54) **METHOD FOR CONTROLLING A CIRCULATION PUMP**
VERFAHREN ZUR STEUERUNG EINER UMWÄLZPUMPE
PROCÉDÉ DE COMMANDE D'UNE POMPE DE CIRCULATION

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EP 4 508 331 B1

Description

TECHNICAL FIELD

[0001] The present disclosure is directed to a method for controlling a circulation pump being installed in a system for heating or cooling, wherein the system is equipped with one or more temperature-controlled valves. For example, the system may be an ordinary household heating system with radiators that are equipped with temperature-controlled valves, e.g. thermostatic radiator valves (TRVs). Alternatively, or in addition, the temperature-controlled valves of the system may be "smart valves" being remotely temperature-controlled by a smart valve application.

BACKGROUND

[0002] A circulation pump is typically installed at a piping system as a stand-alone circulation pump assembly comprising a pump, an electric motor for driving the pump and an electronics housing with electronics for controlling the speed of the motor. The circulation pump may be operated in different selectable control modes, e.g. constant pressure control mode or proportional pressure control mode. Each control mode may include a certain number of selectable pump control curves. If the pump is operated to follow a certain pump control curve, the operating point of the pump sticks to the pump control curve if possible.

[0003] When the piping system comprises temperature-controlled valves, the valves gradually close when the demand for thermal energy decreases and they gradually open when the demand for thermal energy increases in order to achieve a target temperature. Typically, the circulation pump as a stand-alone pump assembly does not get any direct information about how much the valves are opened or closed. If the pump sticks to its set pump control curve, it may run with an unnecessary high speed when the valves close or with a too low speed when the valves open. A too high speed of the pump waists energy saving potential and leads to undesired flow noise. A too low speed of the pump has a negative impact on the user comfort, because the cooling or heating system does not achieve its target temperatures, at least not within a desired time frame.

[0004] It is known in the prior art to automatically adapt the pump control curve in a closed-loop control based on a pipe resistance value as a feedback value. For example, EP 0 726 396 B1 or EP 1 323 986 B1 describe such an automatic adaptation of the pump control curve in a closed-loop control.

[0005] The document CN 110 337 568 discloses a pump where the change of the pump delivery flow caused by the decrease of the rotational speed is balanced by opening the thermostat valve of the heating body.

[0006] The document SE 2 251 177 describes a pump control where the operating point is formed by the intersection of the pump characteristic curve and the system characteristic curve.

[0007] It has shown that the known methods of automatic adaptation of the pump control curve successfully reduce the energy consumption and flow noise when the valves close. However, the known methods of automatic adaptation of the pump control curve have also shown to be too slow when the valves open during high thermal energy demand. The user thus experiences a lack of comfort, because the cooling or heating system does not achieve its target temperatures, at least not within a desired time frame.

[0008] It is therefore an object of the present disclosure to provide a method for controlling a circulation pump that on the one hand adapts the pump control curve quickly enough both when the proportional control valves in the system are closing and when they are opening. On the other hand, the energy consumption and the flow noise is still to be reduced as much as possible when the proportional control valves are closing.

SUMMARY

[0009] According to a first aspect of the present disclosure, a method is provided for controlling a circulation pump being installed in a system for heating or cooling, wherein the system is equipped with one or more temperature-controlled valves. The method comprises:

- operating the pump at an operating point, wherein the current operating point is defined as the intersection point of an adaptable pump characteristic curve and a variable system characteristic curve, wherein the system characteristic curve varies with a common degree of openness of the one or more temperature-controlled valves, wherein the pump characteristic curve is adapted by setting the speed of the pump, wherein the speed of the pump is controlled in such a way that the operating point follows an adjustable pump control curve; and
- automatically adjusting the pump control curve when the system characteristic curve changes in order to keep the common degree of openness of the one or more temperature-controlled valves in a desired range between a minimum common degree of openness and a maximum common degree of openness,

characterised in that,
automatically adjusting the pump control curve comprises determining a system variable being susceptible to system characteristic curve changes, and using the system variable as an input to provide a feed forward signal to automatically adjust the pump control curve in a feed forward control.

[0010] The term "common degree of openness" of the one or more temperature-controlled valves, i.e. in form of proportional control valves, is to be understood as an absolute or relative measure of how much open or closed all those temperature-controlled valves are through which the circulation pump pumps heating or cooling liquid, e.g. ranging from 0% to 100%. If only one valve exists in the system, the "common degree of openness" may simply be the opening degree of said valve. If there are two or more valves in the system, a weighted or unweighted average of the opening degrees of the valves may be considered as the "common degree of openness". A stand-alone pump assembly has no information about the common degree of openness, but it "feels" a pipe resistance that scales with the common degree of openness of the valves. When all valves of the system are open to a maximum degree, the pump experiences the lowest pipe resistance. When all of the valves but one are closed, and the one open valve is nearly closed, the pump experiences the highest pipe resistance. It can be assumed that the pipe resistance is constant as long as the common degree of openness of the valves does not change.

[0011] The system characteristic curve varies with the pipe resistance, i.e. it varies with the common degree of openness of the valves. If the system characteristic curve changes, the pump characteristic curve is adapted by changing the pump speed to keep the operating point on the pump control curve. If the pump control curve, e.g. a proportional pressure control curve in form of a linear line in a head-flow-diagram, is fixed, undesirable situations occur in which the pump does not run at full speed when the valves are fully open for high thermal energy demand and in which the pump runs too quickly when the valves are nearly or fully closed for low or no thermal energy demand. In other words, it is most desirable to have the common degree of openness of the valves in a desired range between a minimum common degree of openness and a maximum common degree of openness. In that desired range, the temperature-controlled valves can react to a rise and fall of the thermal energy demand. Thus, the pump control curve is not fixed, but adjustable to keep the common degree of openness of the valves within the desired range as much as possible.

[0012] The inventive idea is now to speed up the adjustment of the pump control curve by determining a system variable that is susceptible to system characteristic curve changes and by using the system variable as an input to provide a feed forward signal to automatically adjust the pump control curve in a feed forward control.

[0013] For example, the system variable may be the flow factor, also denoted as kv-value. The kv-value is, for example, defined in "Fluidic characteristic quantities of control valves and their determination", VDI, VDE, September 2007, 2173, retrieved 17 April 2020. The kv-value expresses the amount of water flow in units of m^3/h through the system at a given common degree of openness with a pressure drop of 1 bar across the valves. It should be noted that the complete definition says that the flow medium must have a specific gravity of 1000 kg/m^3 and a kinematic viscosity of 10^{-6} m^2/s, e.g. water. The kv-value is generally defined as $k_v = q\sqrt{\frac{SG}{\Delta p}}$, wherein q is the flow in units of m^3/h, Δp is the pressure drop across the valves in units of bar, and SG is the specific gravity of the flow medium (SG = 1 for water).

[0014] The pump is able to determine or estimate the system variable based on its current operating point and performance indicators, such as its provided head and/or flow, its current pump speed, power consumption and/or the electric current currently drawn by the pump drive motor. The determined or estimated system variable is then used as an input to provide a feed forward signal to automatically adjust the pump control curve in a feed forward control.

[0015] Optionally, the method may further comprise continuously or regularly monitoring a head value h indicative of the head currently provided by the circulation pump and a flow value q indicative of the flow currently provided by the circulation pump, wherein the head value h and the flow value q are used to determine the system variable, e.g. the kv-value. In order to avoid the need for a pressure sensor and/or a flow sensor, it is beneficial to derive the head value and the flow value from electric performance indicators of the pump moto, e.g. motor speed and power consumption.

[0016] Optionally, the step of automatically adjusting the pump control curve may further comprise:

- logging a maximum and a minimum of the system variable that has been determined over a past period of time; and
- determining a common degree of openness value indicative of the common degree of openness of the one or more temperature-controlled valves in dependence of the distance of the system variable from the logged maximum and/or logged minimum.

The maximum and minimum kv-values may be used to estimate over time the kv-values for the highest common degree of opening of the valves and the lowest common degree of opening of the valves, respectively.

[0017] Optionally, automatically adjusting the pump control curve may further comprise using a stored adaptable mapping between the system variable and the feed forward signal to be applied for the feed forward control. This is beneficial to account for deviations from the target opening degree as indicated by a PI controller. The mapping used for the feed forward may be adapted to keep the deviation from the target opening degree at a minimum.

[0018] Optionally, a deviation of the determined common degree of openness value from a pre-determined reference common degree of openness may be used as a further input in addition to the system variable to provide the feed forward signal, and wherein said deviation is used to update the stored adaptable mapping. It should be noted that this further input is, under normal operation, much smaller than the contribution of the system variable to the feed forward control. The contribution of the deviation of the opening degree from the target opening degree is rather a minor correction, e.g. in the range of +/- 5%, to the feed forward control.

[0019] Optionally, the stored adaptable mapping may comprise a list of relative values defining which pump control curve is applied within a total range of applicable pump control curves at pre-determined system variable points, wherein the relative values are interpolated between the pre-determined system variable points. For example, the applicable pump control curves may range between a lowest proportional pressure curve PP1 and a highest proportional pressure curve PP3. The stored adaptable mapping may comprise a list of relative values in terms of percentage ranging from 0% for the lowest proportional pressure curve PP1 and 100% for the highest proportional pressure curve PP3.

[0020] Optionally, the stored adaptable mapping may be updated only for the one or two relative value(s) at those pre-determined system variable point(s) that are closest to the currently determined system variable if the updated mapping has a throughout non-negative gradient, and wherein otherwise the stored adaptable mapping is updated in addition

- for the relative values at all higher pre-determined system variable points by shifting those relative values upward by an amount that is needed to avoid the updated mapping from having a negative gradient, and/or
- for the relative values at all lower pre-determined system variable points by shifting those relative values downward by an amount that is needed to avoid the updated mapping from having a negative gradient.

The mapping between the system variable and the feed forward signal to be applied for the feed forward control must not have a negative gradient, because the pump must not reduce the pump control curve when the valves open, i.e. the kv-value rises. Similarly, the pump control curve must not increased when the valves close.

[0021] Optionally, the adjustable pump control curve may be a proportional pressure curve. This is particularly beneficial if the valves are installed at heating radiators.

[0022] Optionally, the system may comprise one or more thermal energy consumers and the one or more temperature-controlled valves may be automatically and/or thermostatically actuated valves installed at said thermal energy consumers. Preferably, the thermal energy consumers are radiators of a heating system.

[0023] Optionally, the feed forward signal may be low-pass filtered with a predetermined time constant before it is used to automatically adjust the pump control curve in the feed forward control if the determined system variable is smaller than the previously determined system variable. This is particularly beneficial to avoid undesired rapid oscillations between the control curves. Such oscillations have shown to occur at households with low variations of the kv-value, where small changes of the opening degree of the valves may lead to larger changes of the pump head which the valves try to compensate. Preferably, in order to avoid such oscillations, a first order filter, for instance with a time constant of 1200 seconds, may be applied if the kv-value is dropping. A rising kv-value, however, may be used unfiltered as input into the feed forward control.

[0024] Optionally, the pump control curve may be adjustable without steps within a total range of applicable pump characteristic curves.

[0025] Optionally, the method may further comprise operating the pump in a first boost mode and/or in a second boost mode, wherein

a gain factor is applied in the first boost mode for stronger adjusting the pump control curve as long as a determined common degree of openness value indicative of the common degree of openness of the one or more temperature-controlled valves is within a predetermined low boost area adjacent to a minimum common degree of openness or within a pre-determined high boost area adjacent to a maximum common degree of openness, and wherein
the pump is operated at maximum speed in the second boost mode if

- the system variable is within a pre-determined speed boost area adjacent to a logged maximum of the system variable, and
- a maximum pump control curve is currently applied, and a predetermined period of maximum boosting time has not lapsed.

The first boost mode may be referred to as a PI controller boost. It is preferably applied as a first stage boosting when the kv-value and/or the opening degree is close to a maximum or minimum value, i.e. in a boost area. If the first boost mode is not successful to get the system out of the high boost area within a given time period, the second boost mode is activated to run the pump at maximum speed for a certain maximum boosting time.

[0026] According to another aspect of the present disclosure, a computer program is provided with instructions which, when the program is executed by a computer, cause the computer to carry out the previously described method.

[0027] According to another aspect of the present disclosure, a circulation pump is provided for being installed in a system for heating or cooling, wherein the circulation pump comprises control electronics being configured to carry out the previously described method or to execute the above-mentioned program.

[0028] Optionally, the circulation pump may be automatically programmed at a manufacturing site of the circulation pump to carry out the previously described method or to execute the previously described program. Thereby, the fully assembled circulation pump may leave the manufacturing site fully programmed for shipping to customers, such that there is no need for customers to program the circulation pump.

[0029] The method disclosed herein may be implemented in form of compiled or uncompiled software code that is stored on a computer readable medium with instructions for executing the method. Preferably, the software is installed on control electronics within the circulation pump according to the present invention. Alternatively, or in addition, the method may be executed by software in a cloud-based system and/or a building management system (BMS).

SUMMARY OF THE DRAWINGS

[0030] Embodiments of the present disclosure will now be described by way of example with reference to the following figures of which:

Fig. 1 shows schematically an example of a system for heating or cooling described herein;

Fig. 2 shows an example of a circulation pump described herein;

Fig. 3 shows schematically an example how the pump control curve is automatically adjusted according to the present disclosure;

Fig. 4 shows schematically an example how the common degree of openness is determined according to the present disclosure;

Fig. 5 shows a determined kv-value of a time for logging maximum and minimum kv-values according to the present disclosure;

Fig. 6 shows schematically an example how the valve position is controlled according to the present disclosure;

Fig. 7 shows a head-flow-diagram with indicated boost areas for the valve position control according to the present disclosure;

Fig. 8a shows an example of an initial mapping between the kv-value and the feed forward signal according to the present disclosure;

Fig. 8b shows an example of a control curve in a head-flow-diagram after it has been adapted to a heating system;

Fig. 9 shows schematically an example how the mapping between the kv-value and the feed forward signal is updated according to the present disclosure; and

Fig. 10 shows an example of the mapping before an update, after an update, and with the restriction to avoid a negative gradient.

DETAILED DESCRIPTION

[0031] Fig. 1 shows a system 1 for heating or cooling as it is typically installed in a household. For the sake of simplicity, the system 1 is referred to in the following as a heating system, but it could equally be a cooling system without departing from the spirit of the present disclosure. The system 1 comprises a thermal energy source 3, e.g. a gas boiler, a heat exchanger, a heating coil or a heat reservoir. The thermal energy source 3 is connected to a piping system 4 filled with a fluid, e.g. water, for transferring thermal energy to one or more thermal energy consumers 5, e.g. radiators, underfloor heating, or heat exchangers. At least one circulation pump 7 is installed in the system 1 to circulate the fluid for thermal energy transfer from the thermal energy source 3 to the one or more thermal consumers 5.

[0032] The system 1 is further equipped with one more temperature-controlled valves 9, e.g. thermostatic radiator valves (TRVs), smart valves or other kinds of temperature-controlled valves. Each of the temperature-controlled valves 9 may be installed in the vicinity of one of the thermal consumers 5 to control the fluid flow through that respective thermal energy consumer 5. The thermal energy consumers 5 are installed in parallel in the system 1, such that each of the thermal energy consumers 5 has a fluid inlet connected to a feed line of the system 1 and a fluid outlet to a return line of the system 1. The associated temperature-controlled valve 9 is preferably installed at a fluid inlet of the thermal energy consumer 5.

[0033] Usually, there is no direct control connection between the circulation pump 7 and the temperature-controlled valves 9. The temperature-controlled valves 9 are each controlled by a closed-loop control using a thermostat, wherein a temperature sensor is used to determine the current temperature and a target temperature can be set for the thermostat. In case of a heating system, for example, the valves 9 open when the measured temperature is below a target temperature in order to increase the flow of the heating fluid through the respective thermal energy consumer 5. Analogously, the valve 9 closes when the measured temperature is above a target temperature in order to reduce the flow of the heating fluid through the thermal energy consumer 5.

[0034] It is in principle known that it is useful to adapt the speed of the circulation pump 7 depending on the common degree of openness of the temperature-controlled valves 9. As the circulation pump 7 is a stand-alone device without direct knowledge of the opening degree of the temperature-controlled valves 9, it would in principle run too fast when the common degree of openness of the valves 9 is low or too slow when the common degree of openness of the valves 9 is high. This would lead to the undesirable situation that the circulation pump 7 consumes unnecessary power and produces unnecessary flow noise when the valves 9 are nearly closed. Furthermore, the circulation pump 7 may not provide sufficient flow when the valves 9 are open to a maximum degree during times of high thermal energy demand. Therefore, there may be a lack of comfort during times of high thermal energy demand, because it takes too long to reach the target temperature. It has shown that known "auto adapt"-algorithms do not react quickly enough to provide the required thermal energy flow in situations of high thermal energy demand.

[0035] Figure 2 shows a circulation pump 7 as it is installed in a heating or cooling system 1 as shown in figure 1. The hardware of the circulation pump 7 as shown in figure 2 may not differ from a circulation pump as known in the prior art. However, it differs in the way it is programmed and thus controlled to operate. The circulation pump 7 comprises a pump housing 11 with a suction inlet 13 and pressure outlet 14. The section inlet 13 and the pressure outlet 14 comprise coaxially aligned flanges directed into opposite directions in order to be installed in a piping system 4 of a cooling or heating system 1 as shown in figure 1. The pump housing 11 accommodates an impeller (not visible) that is rotatable around a rotor axis R in order to drive a fluid flow (e.g. water flow) from the suction inlet 13 to the pressure outlet 14. The circulation pump 7 is a wet-running circulation pump with an integrated permanent magnet synchronous motor (PMSM) within a motor housing 15.

[0036] Furthermore, the circulation pump 7 comprises control electronics (not visible) within the motor housing 15 in order to control the speed of the circulation pump 7. A lid 17 of the motor housing 15 comprises a front face 19 with human-machine-interface elements, such as a display, LED indicators, one or more buttons or switchers. A user may manually set the circulation pump 7 to follow a fixed control curve or to run in an "auto adapt" control mode to automatically adapt the applied control curve. For example, in case of a heating system 1 with radiators as thermal energy consumers 5, the circulation pump 7 may be set to one of three fixed proportional pressure curves PP1, PP2 and PP3. For example, figure 8b shows an example of three fixed control curves as linear lines in a head(h)-flow(q)-diagram.

[0037] The circulation pump 7 may further comprise a wireless interface or a connector via which the control electronics within the circulation pump 7 can be programmed, reprogrammed or updated. The circulation pump 7 may thus be programmed at the time of manufacturing and assembly and/or when it is already installed in a cooling or heating system 1.

[0038] Figure 3 shows how the circulation pump 7 of figure 2 is programmed to be controlled. As already mentioned above, it is known in the prior art, for example from EP 0 726 396 B1 or EP 1 323 986 B1, to automatically adapt the pump control curve in a closed loop control based on a pipe resistance value as a feedback value. So, the circulation pump 7 is known to react to a change of the opening degree of the valves 9 and to set the pump control curve accordingly. As this has shown to be too slow to provide sufficient comfort in situations of high thermal energy demand, the idea of the present invention to use a system variable, e.g. a pipe resistance or a kv-value, as an input to provide a feed forward signal to automatically adjust the control curve in a feed forward control. In other words, the circulation pump 7 is more proactively used to indirectly control the valve position. It should be noted that there is no direct control communication between the circulation pump 7 and the valves 9. The circulation pump 7, however, knows that the valves 9 open when they do not get sufficient thermal energy flow and that they close when they get too much thermal energy flow.

[0039] Therefore, the control schematics shown in figure 3 comprise a valve position control 21 and an opening degree estimation 23. It is the goal of the valve position control 21 to automatically adjust the control curve when the pipe resistance changes in order to keep the common degree of openness OD of the valves 9 in a desired range between a minimum common degree of openness OD_{min} and a maximum common degree of openness OD_{max}. Here, the common degree of openness OD in kept as close as possible to a predetermined fixed reference or target opening degree OD_{ref}, e.g. OD_{ref} = 0.55, wherein OD_{min} = 0 and OD_{max} = 1. A central range of the common degree of openness is desirable, because it leaves upward and downward control room to adjust the valve position to the current thermal energy demand.

[0040] The valve position control 21 takes two variables as an input, i.e. a current system variable in form of a kv-value and an estimated value $\widehat{OD}$ of the current common degree of openness OD. The opening degree estimation 23 provides both the kv-value and the estimated common degree of openness value $\widehat{OD}$ as an output to provide these values as input into the valve position control 21. The opening degree estimation 23 takes as input a head value $\hat{h}$ and a flow value $\hat{q}$. The circulation pump 7 continuously or regularly monitors the head value $\hat{h}$ which is indicative of the head h currently provided by the circulation pump 7. In the same way, the circulation pump 7 continuously or regularly monitors the flow value $\hat{q}$ which is indicative of the flow q currently provided by the circulation pump 7. It should be noted, however, that neither the head h nor the flow q is necessarily measured by a pressure sensor and/or a flow sensor. Instead, electronic performance variables of the circulation pump 7, e.g. current motor speed, current consumed electric power, or drawn electric motor current, may be used to estimate the current head value $\hat{h}$ and the current flow value $\hat{q}$. The opening degree estimation 23 is explained in more detail with reference to figures 4 and 5. The details of the valve position control 21 are explained in more detail with reference to figure 6. The output of the valve position 21 is a reference value h_{ref} indicating which proportional pressure curve is to be applied by the circulation pump 7. The reference value h_{ref} is the sum of the outputs from a PI controller 25 and an adaptive feed forward signal 27.

[0041] Figure 4 shows the opening degree estimation 23 in more detail. It starts with calculating a kv-value based on the monitored head value $\hat{h}$ and monitored flow value $\hat{q}$. The kv-value, also denoted as flow factor, is used as system variable to express the amount of water flow in units of cubic meters per hour through the system 1 at a given common degree of openness OD of the valves 9 with a pressure drop of one bar across the valves 9. So, the kv-value is calculated as $kv = \frac{\hat{q}}{\sqrt{\hat{h}}}$. The kv-value is further limited to be above a predetermined minimum value, e.g. 3.5 m^3/h. If the head value $\hat{h}$ is below a lower limit, e.g. 0.5 mH_2O, the kv-value may be set to $kv = OD_{ref}(kv_{high} - kv_{low}) + kv_{low}$. Figure 5 describes how a filter is applied to the calculated kv-value in order to determine the current maximum kv-value kv_{high} and the current minimum kv-value kv_{low}. A timer is implemented to ensure that the system 1 has stabilised since the control authorism has been started. The estimated opening degree value $\widehat{OD}$ is only estimated if a predetermined minimum time duration, e.g. 10 minutes, has passed since the control algorithm was started.

[0042] If the start delay has passed, it is checked whether the kv-value shows a spike, for example after a start-up following a night set back. The opening degree estimation 23 is suppressed as long as the kv-value shows such a high gradient that indicates a kv-spike. If there is no kv-spike, the calculated kv-value is filtered to determine the minimum kv-value kv_{low} and the maximum kv-value kv_{high} which represent the lowest and highest kv-value within a certain time frame. They are calculated using a peak detection filter with a forgetting factor. This is implemented by low-pass filtering the kv-value, wherein the time constants for the filtering change based on the relation between kv, kv_{low} and kv_{high}. For kv_{high}, the changing time constants give a signal that is fast changing towards higher values and slower towards lower values. For kv_{low}, the changing time constants give a signal that is fast changing towards lower values and slow towards higher values. The filtering is illustrated in figure 5. The opening degree $\widehat{OD}$ is estimated according to the following formula:

$$k_{v,\Delta} = max\,(k_{vhigh} - k_{vlow}\ ,\ k_{vBandMin})$$

$$\hat{OD} = \begin{cases} OD_{ref} & if\ k_{v,\Delta} < k_{v,dynband,min} \\ \frac{k_v - k_{vlow}}{k_{v,\Delta}} & else \end{cases}$$

$$0 <= \hat{OD} <= 1$$

[0043] It should be noted that $k_{vBandMin}$ is used to protect the algorithm against divisions by zero and may be set to 0.03 for example. $k_{v,dynband,min}$ may be used to stop a re-estimation when the kv-value variations are too small, i.e. $k_{v,dynband,min}$ may be set to 0.05. The estimated opening degree value $\widehat{OD}$ is set to the reference value OD_{ref} in case of very small variations of the kv-value. This is done to ensure that the values kv_{low} and kv_{high} have initialised and that there is sufficient signal-to-noise ratio in the kv-signal to perform a meaningful control.

[0044] Figure 6 shows the valve position control 21 in more detail. When it starts, it receives the calculated kv-value and the estimated opening degree value $\widehat{OD}$ as input variables. The kv-value is used to calculate an output Out_{ff} of an adaptive feed forward control 29 as a feed forward signal 27. The adaptive feed forward control 29 comprises using a stored adaptable mapping between the kv-value and the feed forward signal 27 Out_{ff}. Figure 8a shows an example of such an adaptable mapping as it is initially stored in the control electronics of the circulation pump 7. The feed forward signal 27 Out_{ff} may be calculated as a linear interpolation between the stored mapping points as

$$Out_{ff} = ff_{href,0} + (ff_{href,1} - ff_{href,0}) \cdot \frac{kv - ff_{kv,0}}{ff_{kv,1} - ff_{kv,0}}$$

wherein $ff_{kv,0}$ is the point just below the current kv-value and $ff_{href,0}$ is the corresponding relative proportional pressure curve. $ff_{kv,1}$ is the point that is just above the current kv-value kv and $ff_{href,1}$ is the corresponding relative proportional pressure curve. The relative proportional pressure curve value of the first and the last point in the mapping are used if the kv-value is outside the range of the mapping.

[0045] The PI controller 25 takes the difference between the reference common degree of openness OD_{ref} and the estimated common degree of openness value $\widehat{OD}$ as an input error to be minimised. The PI controller 25 may comprise controller parameters, such as gain, time constants and controller limitation parameter that may be predetermined for normal operation. However, the controller parameters may be set to specific values when the system 1 is in a boost area as shown in figure 7. In particular, the controller gain and controller limitation parameter may be multiplied by a certain factor when a boost control is activated in the PI controller 25 when the system 1 is in the boost area. The boost of the PI controller 25 by applying a gain factor is a first boost mode according to an embodiment of the present disclosure. The circulation pump may in situations of particularly high thermal energy demand be operated in a second boost mode, in which the circulation pump 7 is set to maximum speed if the kv-value is within a boost area adjacent to the kv_{max}-value and a maximum pump control curve is applied and a predetermined period of maximum boosting time has not lapsed.

[0046] The output 28 Out_{PI} of the PI controller 25, i.e. a deviation of the estimated common degree of openness $\widehat{OD}$ from the predetermined reference common degree of openness OD_{ref} is used to update the stored adaptable mapping of the feed forward control 29. Furthermore, the output of the valve position control 21 h_{ref} is the sum of the feed forward signal 27 Out_{ff} and the output 28 Out_{PI} of the PI controller 25. It should be noted, however, that the output 28 Out_{PI} of the PI controller 25 provides under normal operation, i.e. outside of any of the boost modes, a much smaller contribution, e.g. +/-5%, to the output of the valve position control 21 h_{ref} than the feed forward signal 27 Out_{ff} which ranges from 0% to 100% and is based on the kv-value that is used as input into the feed forward control 29.

[0047] Figure 7 shows a head(h)-flow(q)-diagram with a pump characteristic curve 31 of maximum pump speed and three displayed system characteristic curves 33a-c. The system characteristic curve 33a represents the situation when the valves 9 have a minimum degree of openness (OD = 0) and the kv-value is at its minimum kv_{min}. The system characteristic curve 33b represents the situation in which the common degree of openness OD of the valves 9 is at the reference value OD_{ref}, e.g. OD_{ref} = 0.55. It is the goal of the valve position control 21 to operate the circulation pump 7 in such a way that the common degree of openness of the valves 9 is at or around the reference value OD_{ref}. The system characteristic curve 33c represents a situation in which the common degree of openness OD is at a maximum (OD = 1) and the kv-value is at its maximum kv_{max}. The boost areas for applying the first boost mode of the PI controller 25 are the bands close to the extreme system characteristic curves 33a and 33c.

[0048] Figure 8a shows an initial mapping of 26 kv-values between zero and 2.5 m^3/h to the relative proportional pressure curve to be applied in terms of percent. A relative proportional pressure curve value of 100% may represent the highest proportional pressure curve PP3. A relative proportional pressure curve value of 0% may represent the lowest proportional pressure curve PP1. The feed forward signal Out_{ff} as the output 27 of the feed forward control 29 is an interpolation between the mapping points in figure 8a. The mapping of figure 8a is then stored in the control electronics of the circulation pump 7.

[0049] Fig. 8b shows an example of a control curve in a head(h)-flow(q)-diagram after it has been adapted to the heating system 1. The lowest proportional pressure curve PP1 is only followed for a flow below or 0.1 m^3/h. For flows between 0.1 and 0.2 m^3/h, the proportional pressure curve is gradually increased to apply the proportional pressure curve PP3 for flow values between 0.2 and 0.9 m^3/h. Above 0.9 m^3/h, the circulation pump 7 reaches in the shown example its maximum and follows its maximum pump characteristic curve 31 for flow values above 0.9 m^3/h. As the pump has reached its maximum speed limit, the head drops with an increase of flow above 0.9 m^3/h.

[0050] Figure 9 shows how the mapping of figure 8a as used by the feed forward control 29 is adapted based on the output 28 Out_{PI} of the PI controller 25. The output 28 Out_{PI} of the PI controller 25 is used as an indicator to decide whether the feed forward signal 27 Out_{ff} is too high or too low. If the current feed forward signal 27 Out_{ff} is perfect for the current thermal energy demand, the output 28 Out_{PI} of the PI controller 25 is zero. If the output of PI controller 25 is positive, there is a need to increase the feed forward signal 27 Out_{ff}. Likewise, a negative output 28 Out_{PI} of the PI controller 25 suggests a decrease of the feed forward signal 27 out_{ff}. The stored mapping is adapted by changing the mapping points located closest to the current kv-value. Over time, the mapping is adapted to give the appropriate relative proportional pressure curve value h_{ref} needed for a certain kv-value.

[0051] The adaptation of the feed forward control 29 is only performed if the variation of the kv-value is above a noise level, i.e. $k_{v,\Delta} \geq k_{v,dynband,min}$ and there is no kv-spike currently detected. A limitation of the output 28 Out_{PI} of the PI controller 25 based on a PI controller limiting parameter prevents a too aggressive adaptation when the PI controller 25 is operated in the first boost mode. A non-zero output 28 Out_{PI} of the PI controller 25 shows as a deviation of the current kv-value from the interpolated mapping and triggers a correction of the closest two mapping points in proportion to the output 28 Out_{PI} of the PI controller 25 such that the interpolation between those two corrected mapping points lies on the current kv-value. If the current kv-value is outside of the mapped range of kv-values, only the lowest or highest mapping point is adapted accordingly. The adapted mapping points are limited to relative proportional pressure curve values between 0% and 100%.

[0052] In order to avoid a negative gradient in the mapping, the mapping points at all kv-values above the adapted higher closest mapping point are shifted upward by the minimum amount that is needed to avoid the updated mapping from having a negative gradient. Similarly, in case of a downward adaptation of the lower closest mapping point, all mapping points with kv-values below said downward adapted closest lower mapping point are shifted downward by an amount that is needed to avoid the updated mapping from having a negative gradient. Finally, the updated mapping is stored for the subsequent iteration of the feed forward control 29.

[0053] Figure 10 shows an example how the mapping may look like before an update (on the left), after an update (in the middle) and after the mapping is adapted to avoid a negative gradient (on the right). Figure 10 shows on the left the mapping as it is stored before it is updated. A positive output 28 Out_{PI} of the PI controller, however, suggests that the mapping around the current kv-value should be increased. Therefore, the neighbouring mapping points are shifted upward accordingly. The shifting is weighted according to the distance of the current kv-value to the mapping point. In the shown case, the closest higher neighbouring mapping point is shifted more upward than the closest lower neighbouring mapping point. As this would lead to a negative gradient in the mapping between the closest higher neighbouring mapping point and the next-to-closest higher mapping point, all mapping points with kv-values above the closest higher neighbouring mapping point are shifted upward by the least amount A that is necessary to avoid a negative gradient.

[0054] Where, in the foregoing description, integers or elements are mentioned which have known, obvious or foreseeable equivalents, then such equivalents are herein incorporated as if individually set forth. Reference should be made to the claims for determining the true scope of the present disclosure, which should be construed so as to encompass any such equivalents. It will also be appreciated by the reader that integers or features of the disclosure that are described as optional, preferable, advantageous, convenient or the like are optional and do not limit the scope of the independent claims.

[0055] The above embodiments are to be understood as illustrative examples of the disclosure. It is to be understood that any feature described in relation to any one embodiment may be used alone, or in combination with other features described, and may also be used in combination with one or more features of any other of the embodiments, or any combination of any other of the embodiments. While at least one exemplary embodiment has been shown and described, it should be understood that other modifications, substitutions and alternatives are apparent to one of ordinary skill in the art and may be changed without departing from the scope of the subject matter described herein, and this application is intended to cover any adaptations or variations of the specific embodiments discussed herein.

[0056] In addition, "comprising" does not exclude other elements or steps, and "a" or "one" does not exclude a plural number. Furthermore, characteristics or steps which have been described with reference to one of the above exemplary embodiments may also be used in combination with other characteristics or steps of other exemplary embodiments described above. Method steps may be applied in any order or in parallel or may constitute a part or a more detailed version of another method step. It should be understood that there should be embodied within the scope of the patent warranted hereon all such modifications as reasonably and properly come within the scope of the contribution to the art. Such modifications, substitutions and alternatives can be made without departing from the scope of the disclosure, which is determined from the appended claims.

List of reference numerals:

[0057]

1	cooling or heating system
3	thermal energy source
4	piping system
5	thermal energy consumer
7	circulation pump
9	temperature-controlled valve
11	pump housing

13	suction inlet
14	pressure outlet
15	motor housing
17	motor housing lead
19	front face of motor housing lead
R	rotor axis
21	valve position control
23	opening degree estimation
25	PI controller
27	output Out_{ff} of the feed forward control
28	output Out_{PI} of the PI controller
29	adaptive feed forward control
31	pump characteristic curve of maximum speed
33a-c	system characteristic curves
PP1	proportional pressure curve
PP2	proportional pressure curve
PP3	proportional pressure curve
A	shifting amount needed to avoid negative gradient

Claims

1. A method for controlling a circulation pump (7) being installed in a system (1) for heating or cooling, wherein the system (1) is equipped with one or more temperature-controlled valves (9), wherein the method comprises:

- operating the pump at an operating point, wherein the current operating point is defined as the intersection point of an adaptable pump characteristic curve and a variable system characteristic curve (33a-c), wherein the system characteristic curve (33a-c) varies with a common degree of openness (OD) of the one or more temperature-controlled valves (9), wherein the pump characteristic curve is adapted by setting the speed of the pump (7), wherein the speed of the pump (7) is controlled in such a way that the operating point follows an adjustable control curve; and
- automatically adjusting the control curve when the system characteristic curve (33a-c) changes in order to keep the common degree of openness (OD) of the one or more temperature-controlled valves (9) in a desired range between a minimum common degree of openness (OD_{min}) and a maximum common degree of openness (OD_{max}),

characterised in that
automatically adjusting the control curve comprises determining a system variable (*kv*) being susceptible to system characteristic curve changes, and using the system variable (*kv*) as an input to provide a feed forward signal (27) to automatically adjust the control curve in a feed forward control (29).

2. The method of claim 1, further comprising continuously or regularly monitoring a head value ($\hat{h}$) indicative of the head (h) currently provided by the circulation pump (7) and a flow value ($\hat{q}$) indicative of the flow (q) currently provided by the circulation pump (7), wherein the head value ($\hat{h}$) and the flow value ($\hat{q}$) are used to determine the system variable (*kv*).

3. The method of claim 1 or 2, wherein automatically adjusting the control curve further comprises:

- logging a maximum (kv_{high}) and a minimum (kv_{low}) of the system variable (*kv*) that has been determined over a past period of time; and
- determining a common degree of openness value ($\widehat{OD}$) indicative of the common degree of openness (OD) of the one or more temperature-controlled valves (9) in dependence of the distance of the system variable (*kv*) from the logged maximum (kv_{high}) and/or logged minimum (kv_{low}).

4. The method of any of the preceding claims, wherein automatically adjusting the control curve further comprises using a stored adaptable mapping between the system variable (*kv*) and the feed forward signal (27) to be applied for the feed forward control (29).

5. The method of claim 4, wherein a deviation of the determined common degree of openness value ($\widehat{OD}$) from a pre-determined reference common degree of openness (OD_{ref}) is used as a further input to provide the feed forward signal (27), and wherein said deviation is used to update the stored adaptable mapping.

6. The method of claim 4 or 5, wherein the stored adaptable mapping comprises a list of relative values defining which control curve is applied within a total range of applicable control curves at pre-determined system variable points, wherein the relative values are interpolated between the pre-determined system variable points.

7. The method of claim 6, wherein the stored adaptable mapping is updated only for the one or two relative value(s) at those predetermined system variable point(s) that are closest to the currently determined system (1) variable (*kv*) if the updated mapping has a throughout non-negative gradient, and wherein otherwise the stored adaptable mapping is updated in addition

- for the relative values at all higher pre-determined system variable points by shifting those relative values upward by an amount that is needed to avoid the updated mapping from having a negative gradient, and/or
- for the relative values at all lower pre-determined system variable points by shifting those relative values downward by an amount that is needed to avoid the updated mapping from having a negative gradient.

8. The method of any of the preceding claims, wherein the adjustable control curve is a proportional pressure curve (PP1, PP2, PP3).

9. The method of any of the preceding claims, wherein the system (1) comprises one or more thermal energy consumers (5) and the one or more temperature-controlled valves (9) are automatically and/or thermostatically actuated valves installed at said thermal energy consumers (5).

10. The method of any of the preceding claims, the feed forward signal (27) is low-pass filtered with a predetermined time constant before it is used to automatically adjust the control curve in the feed forward control (29) if the determined system variable (*kv*) is smaller than the previously determined system variable (*kv*).

11. The method of any of the preceding claims, wherein the control curve is adjustable without steps within a total range of applicable pump characteristic curves.

12. The method of any of the preceding claims, further comprising operating the pump in a first boost mode and/or in a second boost mode, wherein

a gain factor is applied in the first boost mode for stronger adjusting the control curve as long as a determined common degree of openness value ($\widehat{OD}$) indicative of the common degree of openness (OD) of the one or more temperature-controlled valves (9) is within a pre-determined low boost area adjacent to a minimum common degree of openness (OD_{min}) or within a pre-determined high boost area adjacent to a maximum common degree of openness (OD_{max}), and
wherein the pump is operated at maximum speed in the second boost mode if

- the system variable (*kv*) is within a pre-determined speed boost area adjacent to a logged maximum (kv_{high}) of the system variable (*kv*), and
- a maximum control curve is currently applied, and
- a pre-determined period of maximum boosting time has not lapsed.

13. A computer program comprising instructions which, when the program is executed by a computer, cause the computer to carry out the method of any of the preceding claims.

14. A circulation pump (7) for being installed in a system (1) for heating or cooling, wherein the circulation pump (7) comprises control electronics being configured to carry out the method of any of the claims 1 to 12 or to execute the program of claim 13.

15. The circulation pump (7) of claim 14, wherein the circulation pump (7) is automatically programmed at a manufacturing site of the circulation pump (7) to carry out the method of any of the claims 1 to 12 or to execute the program of claim 13.

Patentansprüche

1. Verfahren zum Steuern einer Umwälzpumpe (7), die in einem System (1) zum Heizen oder Kühlen installiert ist, wobei das System (1) mit einem oder mehreren temperaturgesteuerten Ventilen (9) ausgestattet ist, wobei das Verfahren

   ein Betreiben der Pumpe bei einem Betriebspunkt, wobei der aktuelle Betriebspunkt als der Schnittpunkt einer anpassbaren Pumpenkennlinie und einer variablen Systemkennlinie (33a bis c) definiert ist, wobei sich die Systemkennlinie (33a bis c) mit einem gemeinsamen Offenheitsgrad (OD) des einen oder der mehreren temperaturgesteuerten Ventile (9) verändert, wobei die Pumpenkennlinie durch Festlegen der Geschwindigkeit der Pumpe (7) angepasst wird, wobei die Geschwindigkeit der Pumpe (7) auf eine solche Weise gesteuert wird, dass der Betriebspunkt einer einstellbaren Regelkurve folgt; und

   - ein automatisches Einstellen der Regelkurve, wenn sich die Systemkennlinie (33a bis c) ändert, um den gemeinsamen Offenheitsgrad (OD) des einen oder der mehreren temperaturgesteuerten Ventile (9) in einem gewünschten Bereich zwischen einem kleinsten gemeinsamen Offenheitsgrad (OD_{min}) und einem größten gemeinsamen Offenheitsgrad (OD_{max}) zu behalten,

   umfasst, **dadurch gekennzeichnet, dass**
   das automatische Einstellen der Regelkurve ein Bestimmen einer Systemvariablen (kv), die für Änderungen der Systemkennlinie anfällig ist, und ein Verwenden der Systemvariablen (kv) als Eingang, um ein Vorwärtsregelungssignal (27) zum automatischen Einstellen der Regelkurve bei einer Vorwärtsregelung (29) bereitzustellen, umfasst.

2. Verfahren nach Anspruch 1, ferner umfassend ein fortlaufendes oder regelmäßiges Überwachen eines Förderhöhenwerts ($\hat{h}$), der die Förderhöhe (h), die aktuell durch die Umwälzpumpe (7) bereitgestellt wird, angibt, und eines Durchflusswerts ($\hat{q}$), der den Durchfluss (q), der aktuell durch die Umwälzpumpe (7) bereitgestellt wird, angibt, wobei der Förderhöhenwert ($\hat{h}$) und der Durchflusswert ($\hat{q}$) zur Bestimmung der Systemvariablen (*kv*) verwendet werden.

3. Verfahren nach Anspruch 1 oder 2, wobei das automatische Einstellen der Regelkurve ferner

   - ein Protokollieren eines Höchstwerts (kv_{high}) und eines Mindestwerts (kv_{low}) der Systemvariablen (*kv*), der über einen vergangenen Zeitraum bestimmt wurde; und

   - ein Bestimmen eines Werts des gemeinsamen Offenheitsgrads ($\widehat{OD}$), der den gemeinsamen Offenheitsgrad (OD) des einen oder der mehreren temperaturgesteuerten Ventile (9) in Abhängigkeit von dem Abstand der Systemvariablen (kv) von dem protokollierten Höchstwert (kv_{high}) und/oder dem protokollierten Mindestwert (kv_{low}) angibt,

   umfasst.

4. Verfahren nach einem der vorhergehenden Ansprüche, wobei das automatische Einstellen der Regelkurve ferner ein Verwenden einer gespeicherten anpassbaren Zuordnung zwischen der Systemvariablen (*kv*) und dem Vorwärtsregelungssignal (27), das auf die Vorwärtsregelung (29) angewendet werden soll, umfasst.

5. Verfahren nach Anspruch 4, wobei eine Abweichung des bestimmten Werts des gemeinsamen Offenheitsgrad ($\widehat{OD}$) von einem vorherbestimmten gemeinsamen Referenz-Offenheitsgrad (OD_{ref}) als ein weiterer Eingang, um das Vorwärtsregelungssignal (27) bereitzustellen, verwendet wird, und wobei diese Abweichung verwendet wird, um die gespeicherte anpassbare Zuordnung zu aktualisieren.

6. Verfahren nach Anspruch 4 oder 5, wobei die gespeicherte anpassbare Zuordnung eine Liste von relativen Werten aufweist, die definiert, welche Regelkurve innerhalb eines gesamten Bereichs von anwendbaren Regelkurven an vorherbestimmten Systemvariablenpunkten angewendet wird, wobei die relativen Werte zwischen den vorherbestimmten Systemvariablenpunkten interpoliert werden.

7. Verfahren nach Anspruch 6, wobei die gespeicherte anpassbare Zuordnung nur hinsichtlich des einen oder der beiden relativen Wert(e) an den vorherbestimmten Systemvariablenpunkt(en), die der aktuell bestimmten Variablen (*kv*) des Systems (1) am nächsten liegen, aktualisiert wird, wenn die aktualisierte Zuordnung einen durchgehend

nicht-negativen Gradienten aufweist, und wobei die gespeicherte anpassbare Zuordnung andernfalls zusätzlich

- hinsichtlich der relativen Werte an allen höheren vorherbestimmten Systemvariablenpunkten, indem diese relativen Werte um ein Ausmaß nach oben verschoben werden, das nötig ist, um zu vermeiden, dass die aktualisierte Zuordnung einen negativen Gradienten aufweist, und/oder
- hinsichtlich der relativen Werte an allen niedrigeren vorherbestimmten Systemvariablen, indem diese relativen Werte um ein Ausmaß nach unten verschoben werden, das nötig ist, um zu vermeiden, dass die aktualisierte Zuordnung einen negativen Gradienten aufweist,

aktualisiert wird.

8. Verfahren nach einem der vorhergehenden Ansprüche, wobei die einstellbare Regelkurve eine Proportionaldruckkurve (PP1, PP2, PP3) ist.

9. Verfahren nach einem der vorhergehenden Ansprüche, wobei das System (1) einen oder mehrere Wärmeenergieverbraucher (5) aufweist und das eine oder die mehreren temperaturgesteuerten Ventile (9) automatisch und/oder thermostatisch betätigte Ventile sind, die an den Wärmeenergieverbrauchern (5) installiert sind.

10. Verfahren nach einem der vorhergehenden Ansprüche, wobei das Vorwärtsregelungssignal (27) mit einer vorherbestimmten Zeitkonstanten tiefpassgefiltert wird, bevor es verwendet wird, um die Regelkurve bei der Vorwärtsregelung (29) automatisch einzustellen, wenn die bestimmte Systemvariable (*kv*) kleiner als die zuvor bestimmte Systemvariable (*kv*) ist.

11. Verfahren nach einem der vorhergehenden Ansprüche, wobei die Regelkurve innerhalb eines gesamten Bereichs der anwendbaren Pumpenkennlinien stufenlos einstellbar ist.

12. Verfahren nach einem der vorhergehenden Ansprüche, ferner umfassend ein Betreiben der Pumpe in einem ersten Boost-Modus und/oder in einem zweiten Boost-Modus, wobei
in dem ersten Boost-Modus ein Verstärkungsfaktor angewendet wird, um die Regelkurve stärker einzustellen, solange ein vorherbestimmter Wert des gemeinsamen Offenheitsgrads $\widetilde{OD}$, der den gemeinsamen Offenheitsgrad (OD) des einen oder der mehreren temperaturgesteuerten Ventile (9) angibt, innerhalb eines vorherbestimmten niedrigen Boost-Bereichs neben einem kleinsten gemeinsamen Offenheitsgrad (OD_{min}) oder innerhalb eines vorherbestimmtem hohen Boost-Bereichs neben einem größten gemeinsamen Offenheitsgrad (OD_{max}) liegt, und
wobei die Pumpe in dem zweiten Boost-Modus mit einer Höchstgeschwindigkeit betreiben wird, wenn

- die Systemvariable (*kv*) innerhalb eines vorherbestimmten Geschwindigkeits-Boost-Bereichs neben einem protokollierten Maximum (kv_{high}) der Systemvariablen (*kv*) liegt, und
- aktuell eine maximale Regelkurve angewendet wird, und
- ein vorherbestimmter Zeitraum der maximalen Boost-Zeit nicht abgelaufen ist.

13. Computerprogramm, das Befehle enthält, die bei Ausführung des Programms durch einen Computer den Computer dazu bringen, das Verfahren nach einem der vorhergehenden Ansprüche durchzuführen.

14. Umwälzpumpe (7) zur Installation in einem System (1) zum Heizen oder Kühlen, wobei die Umwälzpumpe (7) eine Steuerelektronik aufweist, die so eingerichtet ist, dass sie das Verfahren nach einem der Ansprüche 1 bis 12 durchführt oder das Programm nach Anspruch 13 ausführt.

15. Umwälzpumpe (7) nach Anspruch 14, wobei die Umwälzpumpe (7) an einem Produktionsstandort der Umwälzpumpe (7) automatisch programmiert wird, das Verfahren nach einem der Ansprüche 1 bis 12 durchzuführen oder das Programm nach Anspruch 13 auszuführen.

Revendications

1. Procédé de régulation d'une pompe de circulation (7) installée dans un système (1) de chauffage ou de refroidissement, dans lequel le système (1) est équipé d'une ou plusieurs vannes thermorégulatrices (9), dans lequel le procédé comprend :

- le fonctionnement de la pompe à un point de fonctionnement, dans lequel le point de fonctionnement est défini comme le point d'intersection d'une courbe caractéristique de pompe adaptable et d'une courbe caractéristique de système variable (33a-c), dans lequel la courbe caractéristique de système (33a-c) varie proportionnellement à un degré d'ouverture (OD) commun de la ou des vannes thermorégulatrices (9), dans lequel la courbe caractéristique de la pompe est adaptée par le réglage de la vitesse de la pompe (7), dans lequel la vitesse de la pompe (7) est régulée de telle sorte que le point de fonctionnement suive une courbe de régulation ajustable ; et
- le réglage automatique de la courbe de commande lorsque la courbe caractéristique de système (33a-c) varie afin de maintenir le degré commun d'ouverture (OD) de la ou des vannes thermorégulatrices (9) dans une plage souhaitée entre un degré commun d'ouverture minimal (OD_{min}) et un degré commun d'ouverture maximal (OD_{max})

caractérisé en ce que
le réglage automatique de la courbe de comman de consiste à déterminer une variable de système (kv) sensible aux variations de la courbe caractéristique de système et à utiliser cette variable de système (kv) comme entrée pour fournir un signal d'anticipation (27) afin de régler automatiquement la courbe de commande dans une commande d'anticipation (29).

2. Procédé selon la revendication 1, comprenant en outre la surveillance continue ou régulière d'une valeur de hauteur manométrique ($\hat{h}$) indiquant la hauteur manométrique (h) actuellement fournie par la pompe de circulation (7) et d'une valeur de débit ($\hat{q}$) indiquant le débit (q) actuellement fourni par la pompe de circulation (7), dans lequel les valeurs de hauteur manométrique ($\hat{h}$) et de débit ($\hat{q}$) sont utilisées pour déterminer la variable de système (kv).

3. Procédé selon la revendication 1 ou 2, dans lequel le réglage automatique de la courbe de commande comprend en outre :

- l'enregistrement d'un maximum (kV_{high}) et d'un minimum (kv_{low}) de la variable de système (kv) qui ont été déterminées sur une période passée ; et
- la détermination d'un degré commun de valeur d'ouverture ($\widehat{OD}$) indiquant le degré d'ouverture commun (OD) de la ou des vannes thermorégulatrices (9) en fonction de la distance entre la variable de système (kv) et le maximum (kv_{high}) et/ou le minimum (kv_{low}) enregistrés.

4. Procédé selon une quelconque des revendications précédentes, dans lequel l'réglage automatique de la courbe de commande comprend en outre l'utilisation d'une cartographie adaptable mémorisée entre la variable de système (kv) et le signal d'anticipation (27) à appliquer pour la commande d'anticipation (29).

5. Procédé selon la revendication 4, dans lequel un écart entre le degré commun déterminé d'ouverture de vanne ($\widehat{OD}$) et un degré d'ouverture commun de référence prédéterminé (OD_{ref}) est utilisé comme entrée supplémentaire pour fournir le signal d'anticipation (27) et dans lequel ledit écart est utilisé pour mettre à jour la cartographie adaptable mémorisée.

6. Procédé selon la revendication 4 ou 5, dans lequel la cartographie adaptable mémorisée comprend une liste de valeurs relatives définissant quelle courbe de commande est appliquée dans une plage totale de valeurs de commande applicables à des points de variables de système prédéterminés, dans lequel les valeurs relatives sont interpolées entre les points de variables de système prédéterminés.

7. Procédé selon la revendication 6, dans lequel la cartographie adaptable mémorisée est mise à jour uniquement pour la ou les valeurs relatives au point(s) de variable de système prédéterminés qui sont les plus proches de la variable de système (kv) actuellement déterminée (1) si la cartographie mise à jour présente un gradient non négatif et dans lequel sinon, la cartographie adaptable mémorisée est également mise à jour

- pour les valeurs relatives à tous les points de variable de système prédéterminés supérieurs, en décalant ces valeurs relatives vers le haut d'une valeur nécessaire pour éviter que la cartographie mise à jour ne présente un gradient négatif, et/ou
- pour les valeurs relatives à tous les points de variable de système prédéterminés inférieurs, en décalant ces valeurs relatives vers le bas d'une valeur nécessaire pour éviter que la cartographie mise à jour ne présente un gradient négatif.

8. Procédé selon une quelconque des revendications précédentes, dans la courbe de commande réglable est une courbe de pression proportionnelle (PP1, PP2, PP3).

9. Procédé selon une quelconque des revendications précédentes, dans lequel le système (1) comprend un ou plusieurs consommateurs d'énergie thermique (5) et la ou les vannes thermorégulatrices (9) sont des vannes à commande automatique et/ou thermostatique installées sur lesdits consommateurs d'énergie thermique (5).

10. Procédé selon une quelconque des revendications précédentes, dans lequel le signal d'anticipation (27) est filtré passe-bas avec une constante temporelle prédéterminée avant d'être utilisé pour ajuster automatiquement la courbe de commande dans la commande d'anticipation (29) si la variable de système déterminée (kv) est inférieure à la variable de système précédemment déterminée (kv).

11. Procédé selon une quelconque des revendications précédentes, dans lequel la courbe de commande est réglable sans étapes dans une plage totale de courbe caractéristiques de pompe applicables.

12. Procédé selon une quelconque des revendications précédentes, comprenant en outre le fonctionnement de la pompe dans un premier mode de suralimentation et/ou dans un second mode de suralimentation, dans lequel

un facteur de gain est appliqué dans le premier mode de suralimentation pour un réglage plus précis de la courbe de commande tant qu'une valeur de degré d'ouverture commune ($\widehat{OD}$) déterminée, indiquant le degré d'ouverture commun (OD) de la ou des vannes thermorégulatrices (9) se situe dans une zone de suralimentation basse prédéterminée adjacente à un degré d'ouverture commun minimal (OD_{min}) ou dans une zone de suralimentation haute prédéterminée adjacente à un degré d'ouverture commun maximal (OD_{max}) et
dans lequel la pompe est actionnée à vitesse maximale dans le second mode de suralimentation si

- la variable de système (kv) se situe dans une zone de suralimentation de vitesse prédéterminée adjacente à un maximum enregistré (kv_{high}) de la variable de système (kv), et
- une courbe de commande maximale est actuellement appliquée, et
- une période prédéterminée de suralimentation maximale n'est pas écoulée.

13. Programme informatique comprenant des instructions qui, lorsque le programme est exécuté par un ordinateur, amènent l'ordinateur à mettre en œuvre le procédé selon une quelconque des revendications précédentes.

14. Pompe de circulation (7) destinée à être installée dans un système (1) de chauffage ou de refroidissement, dans lequel la pompe de circulation (7) comprenant une électronique de commande configurée pour mettre en œuvre le procédé selon une quelconque des revendications 1 à 12 ou pour exécuter le programme selon la revendication 13.

15. Pompe de circulation (7) selon la revendication 14, dans lequel la pompe de circulation (7) est automatiquement programmée sur un site de fabrication de la pompe de circulation (7) pour mettre en œuvre le procédé selon une quelconque des revendications 1 à 12 ou pour exécuter le programme selon la revendication 13.

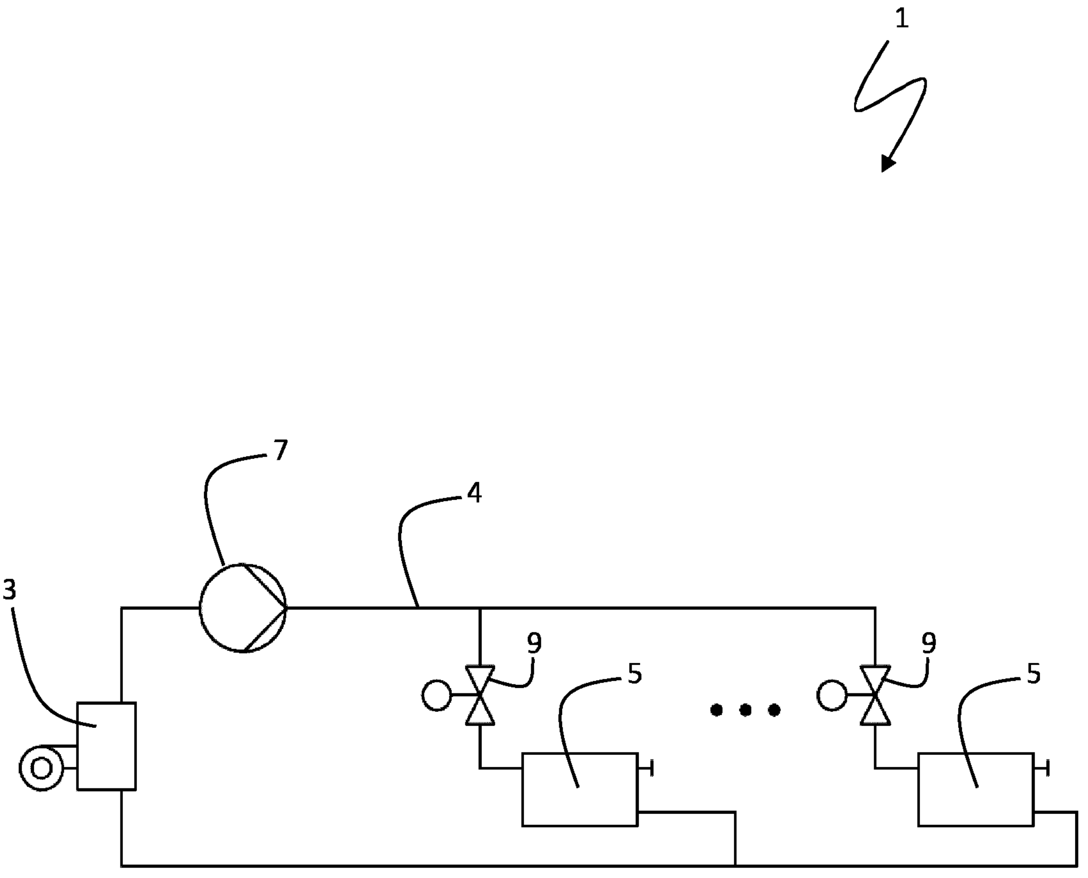


Fig. 1

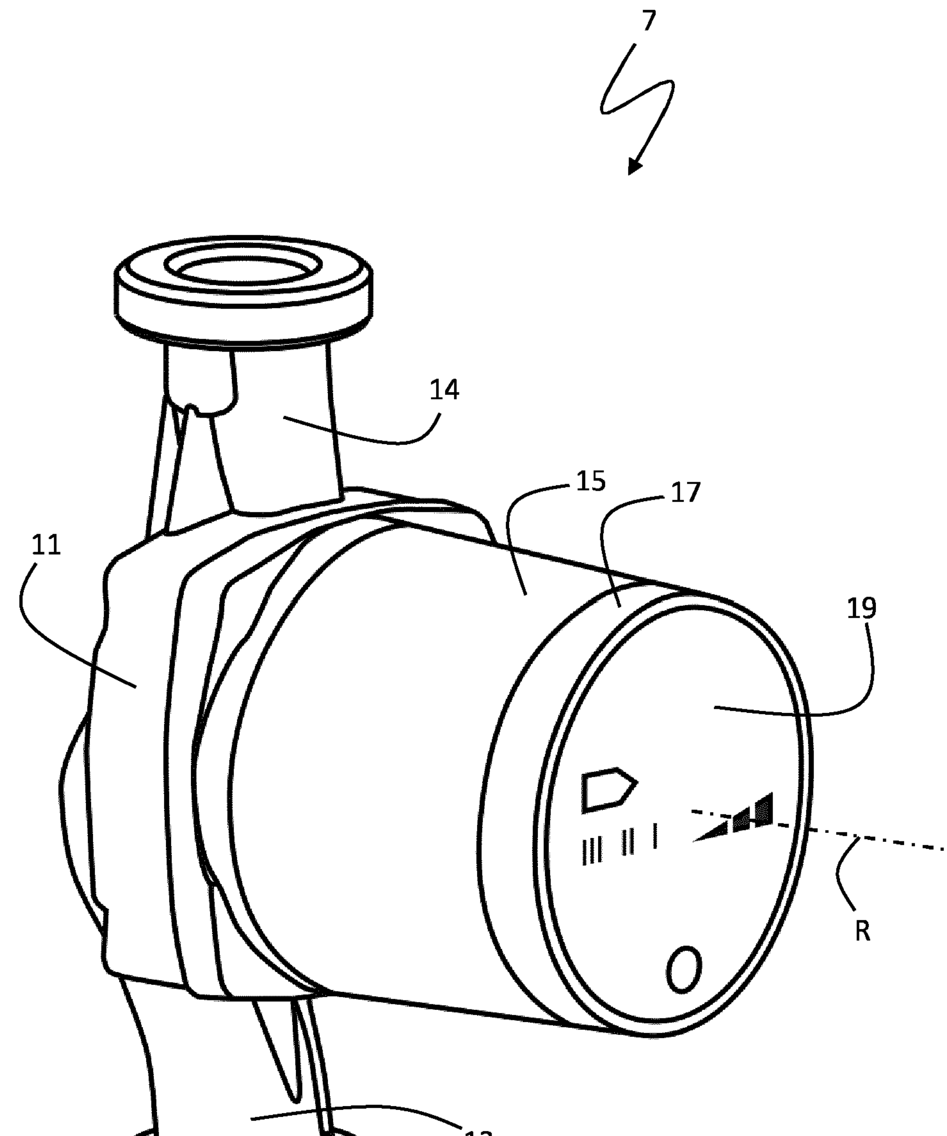
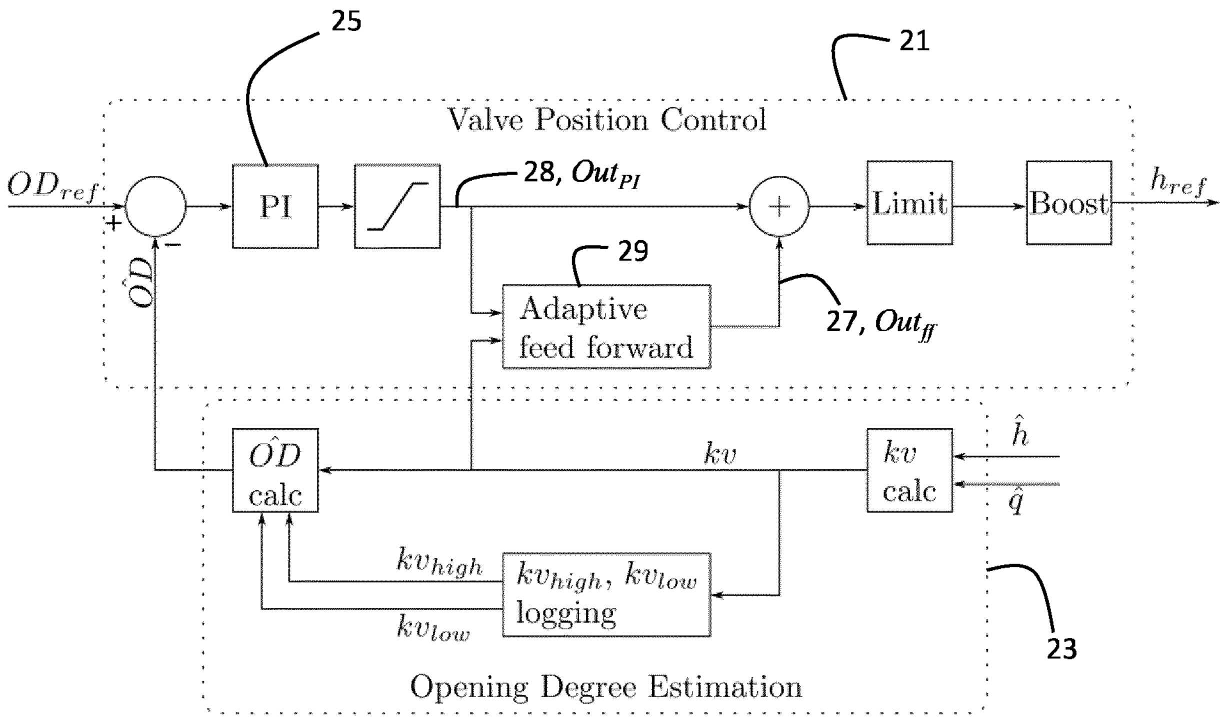


Fig. 2



25
21
Valve Position Control
OD_{ref}
+
−
PI
28, Out_{PI}
h_{ref}
Limit
Boost
29
Adaptive
feed forward
27, Out_{ff}
$\hat{OD}$
$\hat{OD}$
calc
kv
kv
calc
$\hat{h}$
$\hat{q}$
kv_{high}
kv_{high}, kv_{low}
logging
kv_{low}
23
Opening Degree Estimation

Fig. 3

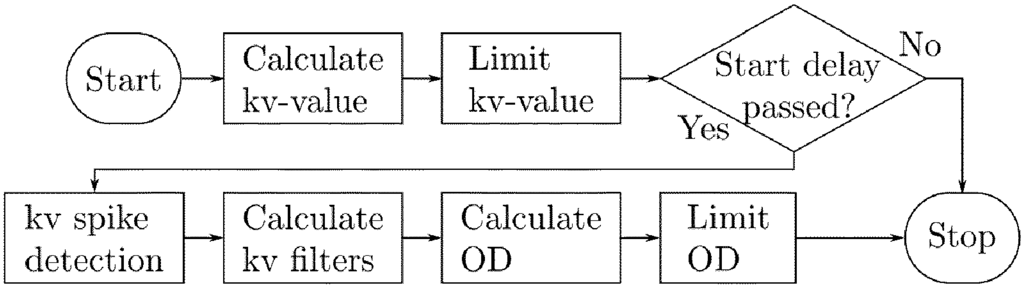
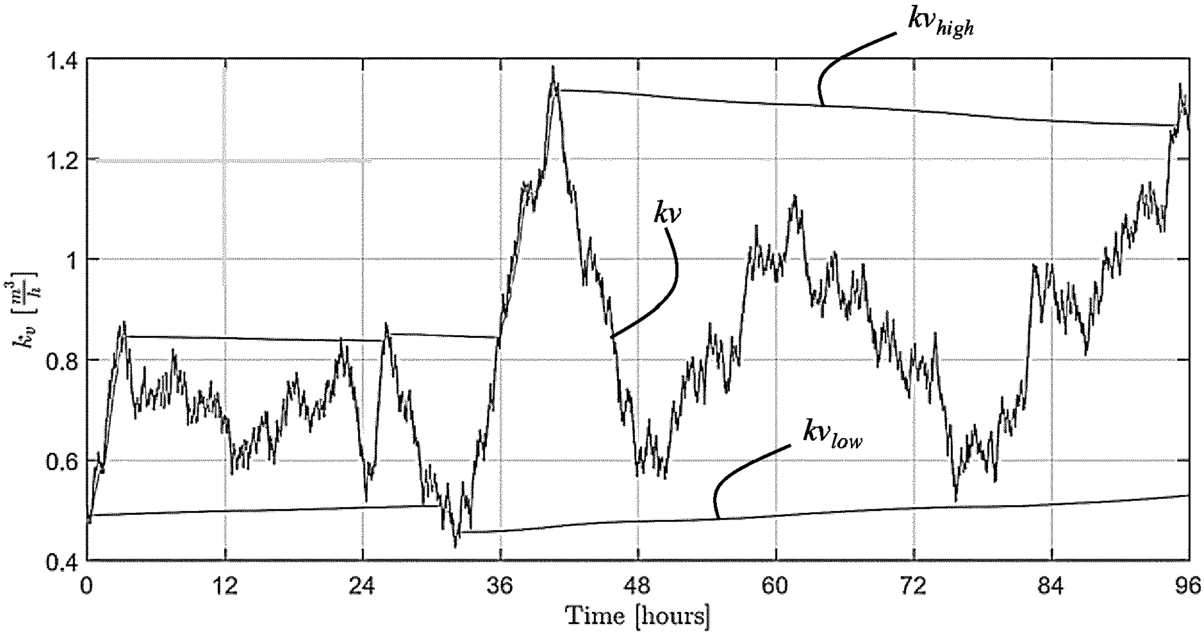

Start
Calculate kv-value
Limit kv-value
Start delay passed?
No
Yes
kv spike detection
Calculate kv filters
Calculate OD
Limit OD
Stop

Fig. 4


kv_{high}
1.4
1.2
1
0.8
0.6
0.4
k_v $[\frac{m^3}{h}]$
kv
kv_{low}
0
12
24
36
48
60
72
84
96
Time [hours]

<u>**Fig. 5**</u>

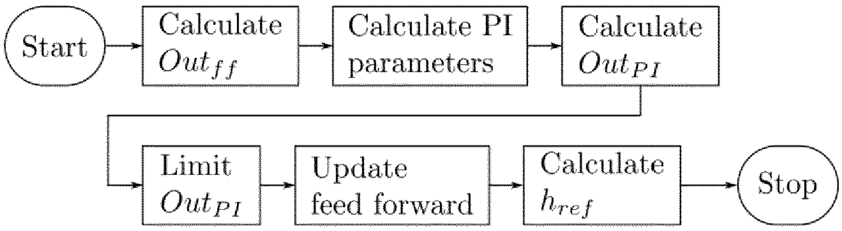

Start
Calculate Out_{ff}
Calculate PI parameters
Calculate Out_{PI}
Limit Out_{PI}
Update feed forward
Calculate h_{ref}
Stop

Fig. 6

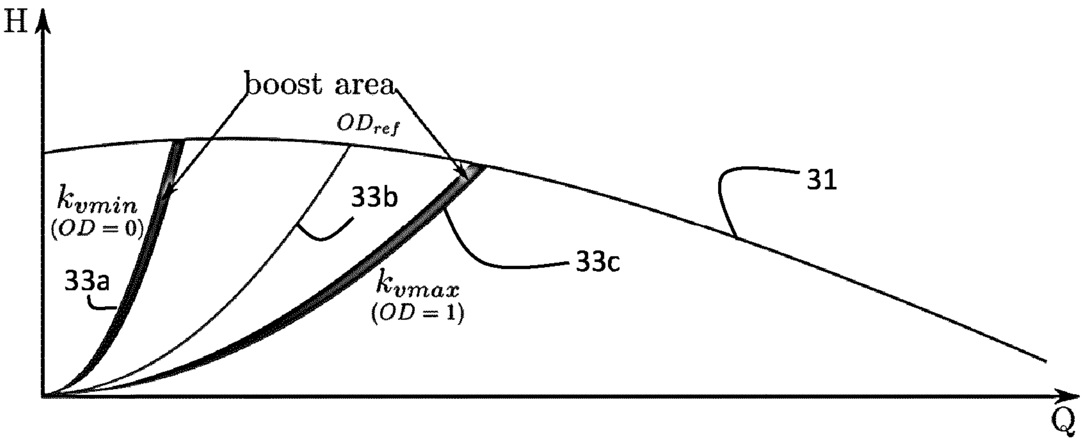


Fig. 7

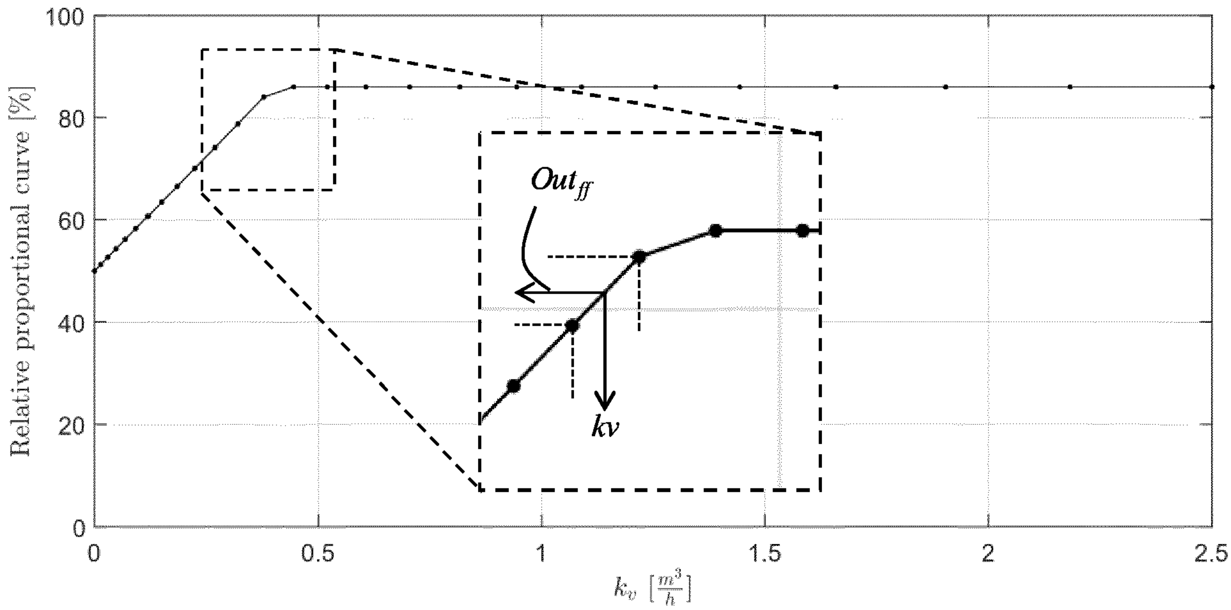

Relative proportional curve [%]
100
80
60
40
20
0
0
0.5
1
1.5
2
2.5
k_v $[\frac{m^3}{h}]$
Out_{ff}
kv

Fig. 8a

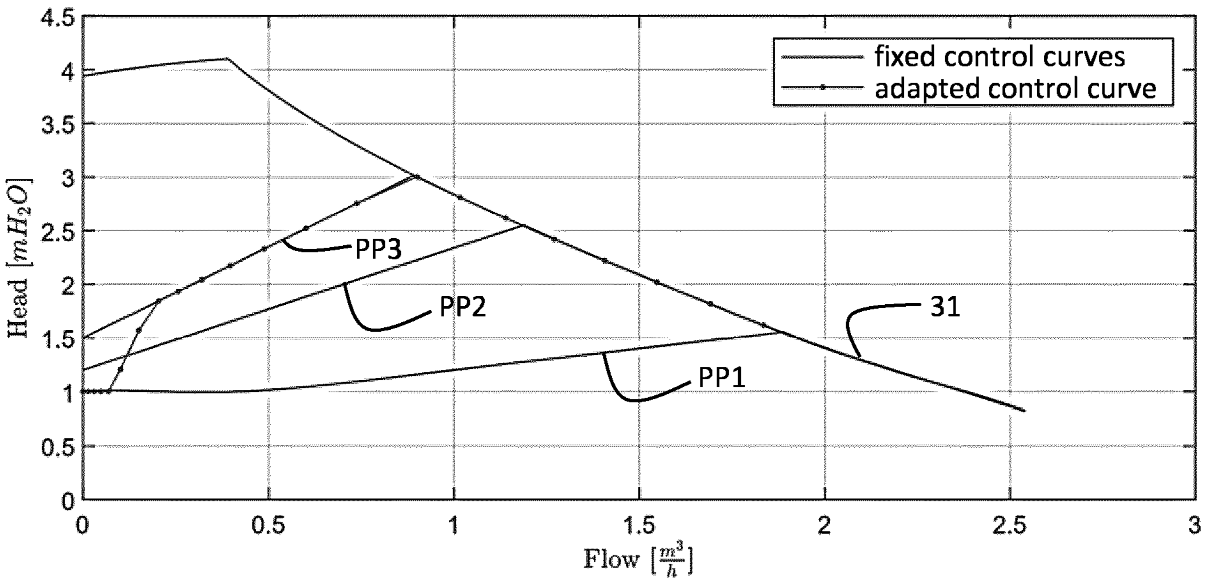

fixed control curves
adapted control curve
Head $[mH_2O]$
Flow $[\frac{m^3}{h}]$
PP3
PP2
PP1
31
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5
3

Fig. 8b

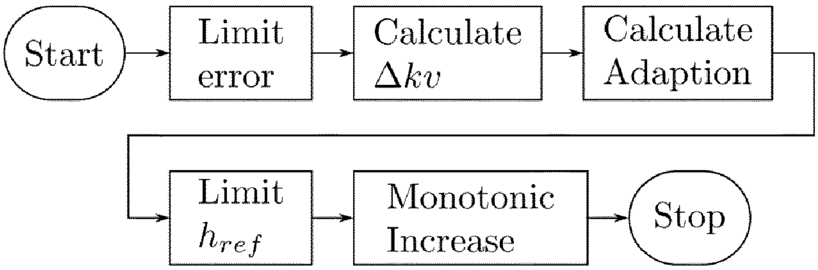

Start
Limit error
Calculate Δkv
Calculate Adaption
Limit h_{ref}
Monotonic Increase
Stop

Fig. 9

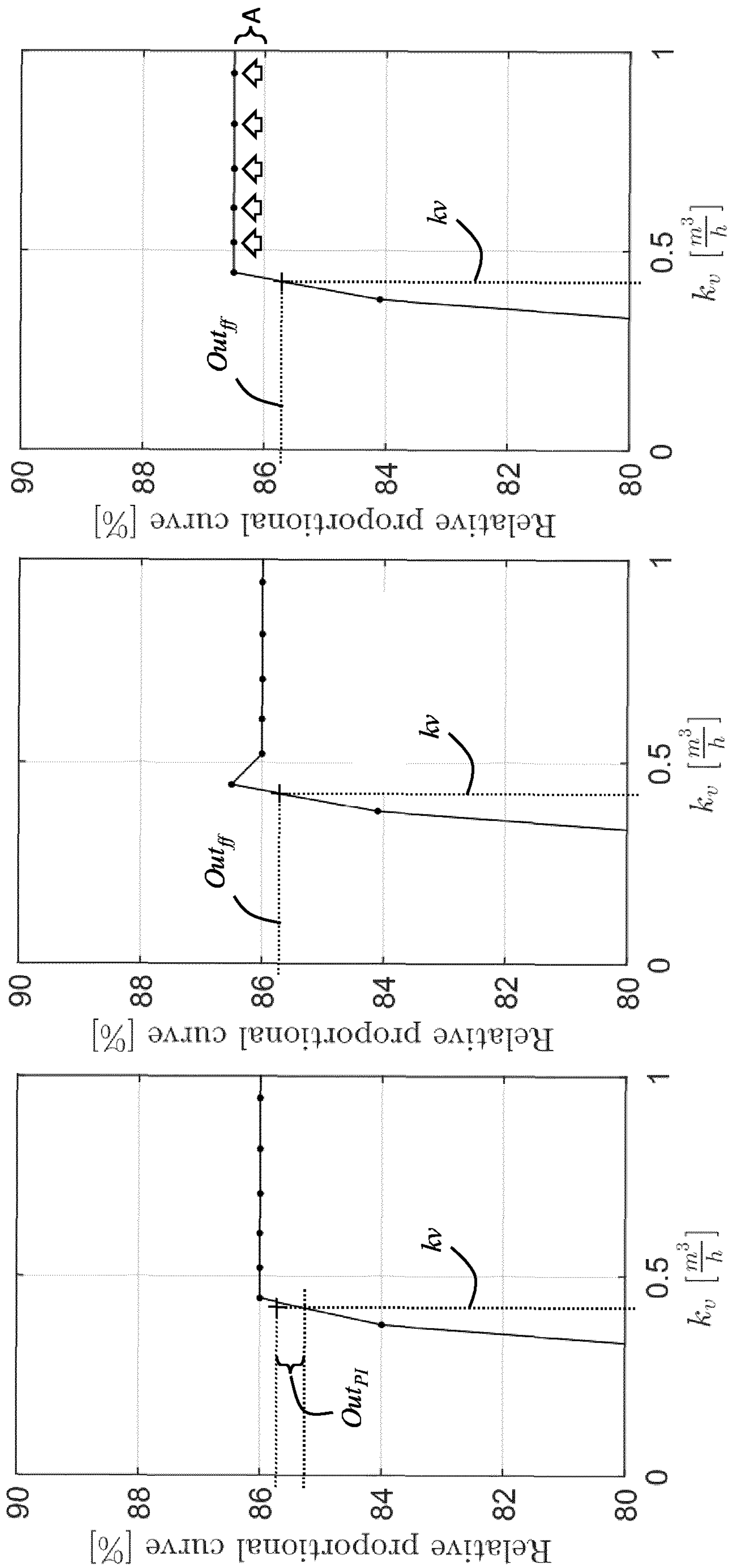

Relative proportional curve [%]
90
88
86
84
82
80
0
0.5
1
$k_v \left[\frac{m^3}{h}\right]$
kv
Out_{ff}
Out_{PI}
A

Fig. 10

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- EP 0726396 B1 **[0004] [0038]**
- EP 1323986 B1 **[0004] [0038]**
- CN 110337568 **[0005]**

Non-patent literature cited in the description

- Fluidic characteristic quantities of control valves and their determination''. *VDI, VDE*, 17 April 2020 **[0013]**