

METHOD FOR CONTROLLING AT LEAST A PART OF A PUMP STATION

Technical Field of the Invention

The present invention relates generally to a method for controlling at least a part of a pump station. In particular, the present invention relates to a method for controlling at least a part of a pump station comprising a number of speed controlled pumps, the method being arranged to minimize the specific energy consumption E_{spec} of said at least a part of a pump station.

Background of the Invention and Prior Art

The cost of driving the pumps of a pump station intended for waste water, sewage, surface water, etc., is very large. Long way back in time, the pump of the pump station was started at highest speed when the liquid level of the pump station had risen to a predetermined pump start liquid level, and the pump was allowed to operate until a predetermined pump stop liquid level had been reached, but it was realized that this way of controlling was very expensive. As a solution, speed controlled pumps were introduced, for instance frequency controlled pumps wherein the current feed frequency to the pump was selected to a, from an energy consumption point-of-view, more optimal value determined via, for instance, calculations and/or tests. These calculations and/or tests resulted in miscellaneous, system dependent and/or pump dependent, curve charts from which the energy consumption per pumped volume in relation to, for instance, the current feed frequency or pump speed of the pump can be derived, said optimal value being a derived minimum point. The introduction of speed controlled pumps and utilization of optimum current feed frequency/pump speed based on the nominal curve chart of the pump entailed significant cost savings, as well as spared the pumps since they rarely or never were operated at maximum speed.

However, speed control based on the nominal curve chart of a pump is impaired by certain disadvantages. It is a disadvantage that the curve chart of a pump model is not necessarily exactly the same for each pump entity within
5 this pump model; furthermore, the nominal curve chart of the pump model is static over time, which is not true for the real curve chart of the specific pump entity. More precisely, the real curve chart of the pump entity will be changed concurrently with the parts of the pump being worn,
10 which entails that the optimum current feed frequency/pump speed of the pump entity does not coincide with the optimum current feed frequency/pump speed of the pump model. In addition, the design of the pump station and the surrounding pipe system will make effect on the real curve
15 chart of the pump entity, which effect may be difficult or impossible to anticipate and/or calculate.

Today, there are devices that measure pumped liquid volume and energy consumption at specific current feed frequencies/pump speeds, see, for instance, WO2009/053923.
20 However, it is expensive and complicated to measure pumped liquid volume and there is a need of extra equipment intended only for the purpose of measuring pumped liquid volume.

25 Summary of the Invention

Embodiments of the present invention seek to obviate the above-mentioned disadvantages and failings of previously known methods for controlling at least a part of a pump station and to provide an improved method.

30 Embodiments of the invention seek to provide an improved method for controlling at least a part of a pump station of the initially defined type, which does not require that the pumped liquid volume needs to be measured.

Embodiments of the present invention seek to provide a
35 method for controlling at least a part of a pump station,

which is self-regulating concurrently with the parts of the pump being worn and replaced, as well as is self-regulating based on the design of the pump station and the surrounding pipes.

5 Embodiments of the present invention seek to provide a method that in a preferred embodiment indirectly takes the size of the pumped volume into consideration without measuring the same.

10 According to an aspect, there is provided a method for controlling at least a part of a pump station comprising a number of speed controlled pumps, the method being arranged to minimize the specific energy consumption E_{spec} of said at least a part of a pump station, characterized in that the
15 same comprises a sub method (Find V3) comprising the steps of

- * obtaining input data in the form of a set of parameters corresponding to a fictitious or elapsed first operating period t_1 and a fictitious or elapsed second
20 operating period t_2 ,
- * determining, based on said set of parameters, the mutual relative relationship between a first value A_1 of a quantity that corresponds to a first pump speed V_1 and that is derived based on said set of parameters, which first
25 value A_1 relates to said first operating period t_1 , and a second value A_2 of said quantity that corresponds to a second pump speed V_2 and that is derived from said set of parameters, which second value A_2 relates to said second operating period t_2 , and between a first specific energy
30 consumption $E_{\text{spec}1}$ that is derived based on said set of parameters and that relates to said first operating period t_1 , and a second specific energy consumption $E_{\text{spec}2}$ that is derived from said set of parameters and that relates to said second operating period t_2 ,

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* determining, based on said determined mutual relative relationships and on parameters B3, B4, B5, and B6 of said quantity, output data in the form of a third value A3 of

said quantity corresponding to a third pump speed V_3 of a third operating period t_3 , wherein A_3 is set equal to $A_2 - B_3$ if the conditions $A_2 < A_1$ and $E_{spec2} < E_{spec1}$ are satisfied, A_3 is set equal to $A_2 + B_4$ if the conditions $A_2 > A_1$ and $E_{spec2} < E_{spec1}$ are satisfied, A_3 is set equal to $A_2 + B_5$ if the conditions $A_2 < A_1$ and $E_{spec2} > E_{spec1}$ are satisfied, and A_3 is set equal to $A_2 - B_6$ if the conditions $A_2 > A_1$ and $E_{spec2} > E_{spec1}$ are satisfied.

Accordingly, embodiments of the present invention are based on the understanding that the sum of the pumped liquid volume during a certain period of time, for instance 24 h or a multiple of 24 h, is more or less constant as seen over a longer period of time.

Preferred embodiments of the present invention are furthermore defined in the dependent claims.

Preferably, the set of parameters comprises said first value A_1 of said quantity and the associated first specific energy consumption E_{spec1} , as well as said second value A_2 of said quantity and the associated second specific energy consumption E_{spec2} .

Preferably, the first value A_1 of said quantity consists of the pump speed V_1 or a first current feed frequency F_1 , and the second value A_2 of said quantity consists of the pump speed V_2 or a second current feed frequency F_2 , and the third value A_3 of said quantity consists of the pump speed V_3 or a third current feed frequency F_3 .

Additional advantages and features of the invention are seen in the other dependent claims as well as in the following, detailed description of preferred embodiments.

Brief Description of the Drawings

A more complete understanding of the above-mentioned and other features and advantages of the present invention will be clear from the following, detailed description of

preferred embodiments, reference being made to the accompanying drawings, wherein:

- Fig. 1 is a schematic illustration of a pump station,
5 Fig. 2 is a flow chart showing a preferred embodiment of the method according to the invention,
Fig. 3 is a flow chart showing an alternative embodiment of the method according to the invention,
Fig. 4 is a flow chart showing the sub method "Find V3",
10 Fig. 5 is a diagram that shows schematically the relationship between specific energy consumption E_{spec} and pump speed V_{pump} , and
Fig. 6 is a diagram that shows schematically how the pump station liquid level h is changed over time T .

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Detailed Description of Preferred Embodiments

Initially, it should be pointed out that the term "specific energy consumption E_{spec} " as used in the claims as well as in the description relates to and is a measure of
20 energy consumption per unit of time of one or more pumps, or of one or more pump stations, etc. Herein, specific energy consumption is calculated according to $E_{\text{spec}} = k * E$, wherein E is real energy consumption during a certain elapsed period of time and k is a time parameter that is a measure of said
25 elapsed period of time, preferred embodiments of the determination of the time parameter k is described later in the context of different embodiment. In the simplest embodiment, k is equal to 1.

In Figure 1, a pump station is shown, generally
30 designated 1, comprising a number of speed controlled pumps 2, i.e., one or more and usually two, arranged to pump liquid from a sump 3 included in the pump station 1 to an outlet pipe 4 and further away from the pump station 1. Further, the pump station 1 comprises at least one level
35 instrument 5 arranged to determine the pump station liquid

level h; it should be pointed out that the level instrument 5 may be an individual device that is operatively connected to an external control unit 6, be operatively connected to one of said number of speed controlled pumps 2, be built-in in one of said number of speed controlled pumps 2, etc. Said number of speed controlled pumps 2 are preferably operatively connected to the external control unit 6 with the purpose of allowing regulation of the pump speed, alternatively at least one of said number of speed controlled pumps 2 may comprise a built-in control unit (not shown).

With the wording "speed controlled", all feasible ways to change the speed of a pump are embraced, above all current feed frequency control is intended, by means of a frequency converter, VFD, that is built-in in a pump or that is external, the external VFD preferably being arranged at the external control unit 6. However, also internally or externally controlled supply voltage control is intended, internal mechanical brake that preferably acts on the drive shaft of the pump, etc. Accordingly, on an overall level of the invention, it is not of central importance how the speed of the pump is controlled, only that the speed of the pump can be regulated/controlled.

The method according to the invention is aimed at controlling at least a part of such a pump station 1 that comprises a number of speed controlled pumps 2, with the purpose of minimizing the specific energy consumption E_{spec} of said at least a part of a pump station 1. Pump station 1 should in this connection be seen as a defined installation to which incoming liquid arrives and from which outgoing liquid is pumped. The pump station should, as regards the present invention, be regarded irrespective of the type of liquid and irrespective from where the liquid comes and where the liquid should be pumped. With the wording "a number of variable-speed controlled pumps", an integral number of pumps 2 is intended where the speed of the

individual pump can be controlled, preferably by the fact that the current feed frequency F to each pump can be controlled with the purpose of changing the speed of the specific pump, the speed being proportionate to the current feed frequency. Accordingly, such a pump station 1 may comprise one or more pumps, at least one pump 2 of which is speed controlled. In the case when the pump station comprises a plurality of speed controlled pumps 2, suitable alternation between them may be done, which is not handled herein.

Fundamental to the present invention is that the pumped liquid volume is not measured or employed in connection with the determination of specific energy consumption E_{spec} . The invention is instead based on the sum of the pumped liquid volume during a certain period of time, usually 24 h, being more or less constant as seen over a longer time. In this patent application, said period of time is henceforth denominated operating period and has preferably the time length $n \cdot 24$ h, wherein n is a positive integer. It should be realized that the operating period also may have another time length without the general idea of the present invention being deviated from, and/or that the time length of the operating period varies over the year. For instance, an operating period may be equal to one pump cycle, which comprises a period wherein the pump is active, i.e., pumps out liquid from a start level to a stop level, and a period in which the pump is inactive, i.e., when the liquid level rises from the stop level to the start level. The mutual order of the period in which the pump is active and the period in which the pump is inactive, respectively, is arbitrary.

It should be pointed out that the method according to the invention can be implemented for one or more complete pump stations, which directly or indirectly communicate with each other, for one pump or for several pumps, which directly or indirectly communicate with each other. The

method may, for instance, be implemented in a built-in control unit in a pump 2 or in the external control unit 6 of a control cabinet, the external control unit 6 being operatively connected to the pump 2. Henceforth, the invention will be described implemented in a pump 2 of a pump station 1 if nothing else is stated, but the corresponding applies when the invention is implemented in an external control unit 6.

The pump station 1 has a pump station liquid level, which is designated h and which in the present patent application is the distance between the liquid level in the sump 3 and the inlet of the pump 2 (see Figure 1), the pump station liquid level h is directly coupled to the real lifting height of the pump 2, which increases with falling pump station liquid level h . When the sump 3 is refilled with liquid, the pump station liquid level h rises, and when the pump 2 is active and pumps out liquid, the pump station liquid level h falls. It should be pointed out that the sump 3 can be refilled with liquid at the same time as the pump 2 is active and pumps out liquid.

Throughout this publication, the operating period in progress is also denominated the third operating period t_3 , which has been preceded by a fictitious or elapsed first operating period t_1 and a fictitious or elapsed second operating period t_2 . Fictitious operating periods are used when elapsed/actual operating periods have not yet occurred, for instance upon start-up or restart of the pump, the pump station, the register of the pump station, etc. The first operating period t_1 , the second operating period t_2 and the third operating period t_3 do not necessarily need to be in immediate succession, but may be separated by one or more operating periods for which parameters have not been registered. Accordingly, when the third operating period t_3 has been completed and parameters have been registered, the same will accordingly be regarded as a second operating period t_2 and a new operating period is running, possibly a

new third operating period t_3 , the previous second operating period will constitute the first operating period t_1 , and the previous first operating period will fall out of the register and/or possibly be filed in order to allow analysis of the progress of the pump station 1.

In Figures 2 and 3, preferred embodiments of a method are shown, generally designated 7, for controlling at least a part of a pump station 1 comprising a number of frequency controlled pumps 2. It should be pointed out that the method 7 according to the invention may be expanded with one or more sub methods, and/or be run in parallel/sequentially with other control methods. In connection with the description below, also Figure 5 should be taken into consideration, but it should be appreciated that the curve drawn into Figure 5 not necessarily is registered and is not needed for the method according to the invention.

Reference is now made to Figures 2 and 3 and to the method steps that are common to the preferred embodiments. The method 7 starts and then a check is made if the pump station 1 is in the middle of a third operating period t_3 in progress or if the third operating period t_3 precisely has been completed, i.e., whether the condition $T \geq t_3$ is satisfied, wherein T is an elapsed time of the operating period in progress. In connection with an operating period being completed and another one being initiated, the measurement of elapsed time T of the operating period in progress is set to zero. It should be pointed out that T also may be actual or absolute time and in that case, instead the relationship between actual time and a multiple of the third operating period is checked, i.e., for instance, every time the actual time strikes 00:00, a new operating period starts.

When an operating period precisely has been completed, the method 7 proceeds to a sub method, called "Find V_3 ", which aims at finding optimum pump speed V_3 of the third operating period t_3 that just has been started or that will

be started later, with the purpose of minimizing the specific energy consumption E_{spec} of said at least a part of a pump station 1. The sub method "Find V3" will be described more in detail below after the overall method 7 has been
5 described.

After the sub method "Find V3" or if the pump station 1 is in the middle of the third operating period t_3 in progress, i.e., if the condition $T \geq t_3$ is not satisfied, the method 7 continues to the next method step "Retrieve pump
10 station liquid level, h ".

The pump station liquid level h is determined by means of some form of customary level instrument arrangement, which may comprise one or more co-operating level
15 instruments. When the pump station liquid level h has been retrieved, a check is made if the pump station liquid level h in the sump 3 is lower than the liquid level that corresponds to a pump stop liquid level h_{stop} , i.e., whether the condition $h < h_{\text{stop}}$ is satisfied. If the condition $h < h_{\text{stop}}$
20 is satisfied, the pump speed V_{pump} is set equal to zero and the possibly activated pump 2 is switched off, and the method 7 is terminated and returns to start. If the condition $h < h_{\text{stop}}$ is not satisfied, a check is made if the liquid level in the sump 3 is higher than the liquid level
25 that corresponds to a pump start liquid level h_{start} , i.e., whether the condition $h > h_{\text{start}}$ is satisfied. If the condition $h > h_{\text{start}}$ is satisfied, the pump 2 is activated at a pump speed V_{pump} that is equal to the present pump speed V3 of the third operating period t_3 in progress, which earlier has
30 been determined by means of the sub method "Find V3". If the condition $h > h_{\text{start}}$ is not satisfied or after the pump 2 has been activated at the pump speed V3, the method 7 is terminated and returns to start according to the preferred embodiment according to Figure 2.

35 According to the alternative embodiment according to Figure 3, a check is made if the pump station liquid level h

in the sump 3 falls/decreases if the condition $h > h_{\text{start}}$ is not satisfied or after the pump 2 has been activated at the pump speed V_3 . If the pump station liquid level h falls, it shows that the pump 2 is active and pumps out liquid and
5 that the liquid level in the sump 3 falls but that the pump stop liquid level h_{stop} has not yet been reached. The method 7 is terminated and returns to start. It should be pointed out that the steps of checking the conditions $h < h_{\text{stop}}$ and $h > h_{\text{start}}$, together with the respective associated subsequent
10 method step, can interchange place without the method in other respects being affected.

If the pump station liquid level h does not fall, a check is made if the pump is active, i.e., whether the speed V_{pump} of the pump is different from zero. If the speed V_{pump} of
15 the pump is equal to zero, it indicates that the pump station liquid level h is between pump stop liquid level h_{stop} and pump start liquid level h_{start} and that the pump station is in a refill state in the operating period, after which the method 7 is terminated and returns to start. If
20 the speed V_{pump} of the pump is different from zero, normally it shows that the pump 2 is active and pumps out liquid but that the instantaneous liquid inflow to the pump station 1 is equal to or greater than the liquid outflow, alternatively it is an indication of the pump 2 not at all
25 being active, for instance as a consequence of the same being broken, alternatively it is an indication of the pump speed being less than a smallest possible pump speed V_{min} the pump 2 can have and still manage to pump liquid. When the pump station liquid level h does not fall, the pump speed
30 V_{pump} is increased by a parameter B_1 , preferably corresponding to a current feed frequency increase of 1-5 Hz, and in addition the present pump speed V_3 of the third operating period t_3 in progress is increased by a parameter B_2 , preferably corresponding to a current feed frequency
35 increase of 0,1-0,5 Hz. Next, the method 7 is terminated and returns to start.

It should be pointed out that during one and the same operating period, under normal operation, the pump 2 may be active several times. It should furthermore be pointed out that the pump station 1 may have a maximally allowed pump station liquid level $h_{\max}$, and if this is reached, preferably the pump speed of the pump 2 is increased to a higher pump speed or to a maximally allowed pump speed $V_{\max}$ to prevent the sump 3 from being flooded, and if this does not help, one or more further pumps are started, preferably at said maximally allowable pump speed $V_{\max}$, at the present pump speed V_3 of the third operating period t_3 in progress, or at another suitable pump speed. If the pump station 1 comprises several pumps, the alternating ones may be active during one and the same operating period.

In connection with the third operating period t_3 having been completed, in a preferred embodiment, the present pump speed V_3 of the third operating period t_3 and the present specific energy consumption $E_{\text{spec}3}$ of the third operating period t_3 are registered. In an alternative embodiment, it is registered whether the pump speed V_3 is greater or smaller than the pump speed V_2 of the second operating period t_2 and whether the specific energy consumption $E_{\text{spec}3}$ is greater or smaller than the specific energy consumption $E_{\text{spec}2}$ of the second operating period t_2 . Instead of the third pump speed V_3 , the corresponding third value A_3 of an equivalent quantity may be used in registration. The equivalent quantity may be current feed frequency, supply voltage, mechanical brake power of the drive shaft of the pump, or another corresponding equivalent quantity. It should be pointed out that if the method 7 according to the invention during a third operating period t_3 in progress needs to set the pump speed V_{pump} to any value that differs from, for instance, zero and V_3 , preferably the parameters of this operating period should not be registered.

The sub method "Find V_3 " is shown in Figure 4 and begins with the step of obtaining/retrieving input data in

the form of a set of parameters, this set of parameters may be set parameters corresponding to two fictitious operating periods, registered parameters corresponding to two elapsed operating periods, or a combination of set parameters

5 corresponding to a fictitious operating period and registered parameters corresponding to an elapsed operating period. Parameters set by operator/pump manufacturers/programmers are, for instance, used in the initial actual operating periods of the pump station 1,
10 until registered parameters are available.

Based on said set of parameters, the mutual relative relationship is then determined between a first value A1 of said quantity that corresponds to a first pump speed V1 and that is derived based on said set of parameters, which first
15 value A1 relates to a fictitious or elapsed first operating period t1, and a second value A2 of said quantity that corresponds to a second pump speed V2 and that is derived from said set of parameters, which second value A2 relates to a fictitious or elapsed second operating period t2, and
20 between a first specific energy consumption E_{spec1} that is derived based on said set of parameters and that relates to said first operating period t1, and a second specific energy consumption E_{spec2} that is derived from said set of parameters and that relates to said second operating period
25 t2.

Based on said determined mutual relative relationships, output data is then determined in the form of a third value A3 of said quantity corresponding to a third pump speed V3 of a third operating period t3, which may be the operating
30 period directly following the second operating period t2 or may be a coming operating period. The third value A3 of the quantity is set equal to A2-B3 if the conditions $A2 < A1$ and $E_{spec2} < E_{spec1}$ are satisfied, equal to A2+B4 if the conditions $A2 > A1$ and $E_{spec2} < E_{spec1}$ are satisfied, equal to A2+B5 if the
35 conditions $A2 < A1$ and $E_{spec2} > E_{spec1}$ are satisfied, and equal to A2-B6 if the conditions $A2 > A1$ and $E_{spec2} > E_{spec1}$ are satisfied,

wherein B3, B4, B5, and B6 are parameters of said quantity. Next, the sub method "Find V3" returns to the method 7.

The parameters B3, B4, B5, and B6, each of which constitutes the difference between the third value A3 and the second value A2, are preferably predetermined values, alternatively variables that, for instance, depend on the value of A2, the relationship between A1 and A2, and/or the relationship between E_{spec1} and E_{spec2} , etc. The parameters B3, B4, B5, and B6 have preferably the same value, but it is feasible that the parameters B3, B4, B5, and B6 have different values with the purpose of preventing the sub method "Find V3" from jumping to and fro between two values around an optimum pump speed. In an alternative embodiment, the parameter B3 is equal to B5, which is different from B4, which in turn is equal to B6. Each of the parameters B3, B4, B5, and B6 corresponds preferably to a current feed frequency change that is greater than 0,5 Hz, and smaller than 5 Hz, preferably smaller than 2 Hz, and most preferably 1 Hz. Preferably, a current feed frequency change of 1 Hz corresponds to approximately a change of the pump speed of 2-5 percentage units, where the maximally allowable pump speed V_{max} is used as the reference point 100 %. It is furthermore preferred that the parameters B3, B4, B5, and B6 are reduced, for instance halved or divided into three, if it turns out that the sub method "Find V3" jumps to and fro around an optimum pump speed. It should be pointed out that the above-mentioned parameter B2, when it is shown in the same quantity as the parameters B3, B4, B5, and B6, should be small in relation to B3, B4, B5, and B6, for instance in the order of less than 15 % of B3, B4, B5, and/or B6.

In preferred embodiments, the first value A1 of said quantity consists of the pump speed V1, a first current feed frequency F1, or a first supply voltage S1, and the second value A2 of said quantity consists of the pump speed V2, a second current feed frequency F2, or a second supply voltage S2, and the third value A3 of said quantity consists of the

pump speed V3, a third current feed frequency F3, or a third supply voltage S3.

In a preferred embodiment, the above-mentioned set of parameters comprises said first value A1 of said quantity
5 and the associated first specific energy consumption E_{spec1} , as well as said second value A2 of said quantity and the associated second specific energy consumption E_{spec2} . In an alternative embodiment, the set of parameters comprises, for instance, said second value A2 as well as the function of
10 the curve segment that extends between the second value A2 and the first value A1, after which the above-mentioned mutual relative relationships can be determined. In an additional alternative embodiment, the set of parameters comprises the second value A2 and the first value A1, as
15 well as the slope of the curve segment that extends between the two values of the quantity, after which the above-mentioned mutual relative relationships can be determined. It should be pointed out that there are further sets of parameters from which it is possible to determine the above-
20 mentioned mutual relative relationships, even if not more embodiment examples are shown here. It should be pointed out that values from additional fictitious or elapsed operating periods may be used to check if the sub method "Find V3" jumps to and fro around an optimum pump speed.

25 Below, different ways to calculate the specific energy consumption E_{spec} will be presented, more precisely how the time parameter k of the above-mentioned expression of the specific energy consumption $E_{spec}=k \cdot E$ is calculated. E_{spec} is essentially equal to consumed energy divided by pumped
30 volume during a certain elapsed time, or equal to instantaneous power consumption divided by instantaneous flow. According to the invention, a time parameter k is used instead of instantaneous flow or pumped volume, and this time parameter may be equal to 1 or make allowance for the
35 time length of the operating period, the vertical height between the pump start liquid level h_{start} and the pump stop

liquid level h_{stop} , the number of starts during an operating period, the time the pump has been active during an operating period, the time the pump has been inactive during an operating period, the speed of the liquid level, etc.

5 Below, some examples will be shown, but the invention is not limited thereto.

According to a first variant, the length of an operating period is $n \cdot 24$ h and the time parameter k is calculated according to $k = 1/(n \cdot 24)$. This variant is used
10 when the inflow is predictable and almost constant for an operating period as seen over a longer period of time.

According to a second variant, the length of an operating period is $n \cdot 24$ h and the time parameter k is calculated according to $k = 1/(c \cdot (n \cdot 24))$, wherein c is an
15 equalization parameter. This variant is used when the inflow is less predictable and more irregular for an operating period as seen over a longer period of time.

Preferably, the equalization parameter c may be calculated according to $c = x_{on}/\Sigma t_{on}$, wherein x_{on} is the number
20 of times a pump has been activated during an elapsed operating period, and Σt_{on} is the cumulative time for which the pump has been active in the elapsed operating period.

Alternatively, the equalization parameter c may be calculated according to $c = \Sigma L/\Sigma t_{on}$, wherein L is the vertical
25 height between the pump start liquid level h_{start} and the pump stop liquid level h_{stop} and ΣL is the cumulative height that has been pumped out during an elapsed operating period, regardless the inflow when the pump 2 has been active. Σt_{on} is the cumulative time for which the pump has been active in
30 the elapsed operating period.

According to a third variant, the length of an operating period is s seconds, wherein s is a positive integer and the time parameter k is calculated according to $k = 1/(c \cdot s)$, wherein c is the equalization parameter. See
35 Figure 6, wherein Δt_{on} is equal to Δt_{off} , each of which is equal to the length of the operating period, s seconds.

Preferably, the length s seconds of the operating period is in the range of 60-120 s.

The equalization parameter c is preferably calculated according to $c = (\Delta h_{on} + \Delta h_{off})$, wherein Δh_{on} is the pump station liquid level change during an elapsed operating period, which elapsed operating period takes place in connection with the end of an active period during which one of said number of speed controlled pumps 2 is active and which directly is followed by an inactive period during which said pump is inactive, and Δh_{off} is the pump station liquid level change during a following operating period, which following operating period takes place in connection with the beginning of the directly following inactive period. In this variant, it is assumed that the inflow in the beginning of an inactive period is the same as the inflow in the end of the preceding active period. By adding Δh_{on} and Δh_{off} , consideration is given to how large the inflow probably was when the pump 2 was active. Δt_{on} and Δt_{off} should be positioned as near as possible the instant of time when the pump station liquid level h reaches the pump stop liquid level h_{stop} , however Δt_{on} should be sufficiently far from the instant of time when the pump station liquid level h reaches the pump stop liquid level h_{stop} in order not to be influenced by so-called snoring effects of the pump 2, i.e., that the pump 2 sucks air, and Δt_{off} should be sufficiently far from the instant of time when the pump station liquid level h reaches the pump stop liquid level h_{stop} in order not to be influenced by so-called siphon effects of the outlet pipe 4, i.e., that liquid is pulled along in the outlet pipe 4 because of the inertia of the pumped liquid in spite of the pump 2 having been shut off, or reflux effect from the outlet pipe 4 when the pump 2 has been shut off.

According to a fourth variant, which is a mixture of several of the above variants, an operating period comprises a period when the pump is active, i.e., t_{on} , and a period in

which the pump is inactive, i.e., t_{off} ; note, the mutual order is unimportant. h_{on} is the pump station liquid level change during the period when the pump is active and h_{off} is the pump station liquid level change during the period when the pump is inactive. In this fourth variant, it is assumed that the inflow during the inactive period of the pump is the same as the inflow during the active period of the pump. It should be pointed out that t_{on} and t_{off} do not need to be equally large.

Preferably, the length of an operating period according to this variant is equal to one pump cycle, and L is the vertical height between the pump start liquid level h_{start} and the pump stop liquid level h_{stop} . Accordingly, in this preferred embodiment, each of h_{on} and h_{off} is equal to L , which implies that t_{off} is the time it takes for the pump station liquid level h to rise from the pump stop liquid level h_{stop} to the pump start liquid level h_{start} , t_{on} is the time it takes for the pump station liquid level h to fall from the pump start liquid level h_{start} to the pump stop liquid level h_{stop} .

The time parameter k is calculated according to $k=1/(c \cdot t_{\text{meas}})$, wherein c is the equalization parameter and t_{meas} is a subset of the period when the pump is active and during which consumed power is measured. Accordingly, t_{meas} should be equal to or less than t_{on} . Furthermore, consumed energy E during the period t_{meas} can be measured by instantaneous power being summed up during the period t_{meas} , alternatively, instantaneous power is measured some time during the period t_{meas} and then the measured instantaneous power is multiplied by the time t_{meas} .

Generally, the equalization parameter c is calculated according to $c=(h_{\text{off}}/t_{\text{off}} + h_{\text{on}}/t_{\text{on}})$, and in the preferred embodiment, the equalization parameter c is consequently calculated according to $c=(L/t_{\text{off}} + L/t_{\text{on}})$, i.e., c is a measure of pumped out quantity of liquid during the period t_{meas} .

According to a fifth variant, which is a special variant of the above fourth variant, the length of an operating period is equal to one pump cycle and consumed energy is determined for the entire period in which the pump is active, i.e., t_{meas} is equal to t_{on} . After simplification of the mathematical expression according to the fourth variant, the following is obtained.

Accordingly, a pump cycle comprises a period when the pump is active, i.e., t_{on} , and a period in which the pump is inactive, i.e., t_{off} , in other words, the length of the operating period is equal to $(t_{\text{on}} + t_{\text{off}})$. The time parameter k is calculated according to $k=1/(c \cdot (t_{\text{on}} + t_{\text{off}}))$, wherein c is the equalization parameter. The length of a pump cycle is preferably in the range of 1-10 min, but may also amount to one or several hours. It should be pointed out that t_{on} and t_{off} do not need to be equally large.

Preferably, the equalization parameter c is calculated according to $c=L/t_{\text{off}}$, wherein L is the vertical height between the pump start liquid level h_{start} and the pump stop liquid level h_{stop} . Furthermore, t_{off} is the time for which the pump has been inactive during the elapsed pump cycle. In this variant, it is assumed that the inflow during the inactive period of the pump is the same as the inflow during the active period of the pump. According to said fifth variant, consumed energy E during the operating period/pump cycle can be measured, or an instantaneous power can be measured some time during the period of the pump cycle in which the pump is active, i.e., during t_{on} , and then the measured instantaneous power is multiplied by the time t_{on} the pump has been active. According to a preferred embodiment, instantaneous power is measured at the end of the period of the pump cycle in which the pump is active.

The method 7 according to the invention may be implemented for controlling a pump, as described above.

Furthermore, the method 7 may be implemented in a pump station comprising several variable-speed controlled pumps

2, where registration and control preferably takes place in the external control unit 6. The control may either be effected for the entire pump station 1 independently of which pump that has been active, or for each pump
5 separately. When control is effected for the entire pump station 1, consideration is given to each registered operating period independently of which pump that has been active, which gives a faster movement toward the optimum speed for the individual pump than when the control is
10 effected for each pump separately, as well as that the external control unit 6 does not need to know how many variable-speed controlled pumps 2 that are connected. The advantage of the control being effected for each pump separately is that the characteristic of the individual pump
15 entity does not affect other pump entities, i.e., different types of pumps and differently old pumps can be used side by side. In an alternative implementation, registration and control are effected in a built-in control unit in each individual pump 2, preferably two such pumps may be
20 operatively interconnected to interchange information about the latest known third pump speed V3.

Feasible Modifications of the Invention

The invention is not limited only to the embodiments
25 described above and shown in the drawings, which only have the purpose of illustrating and exemplifying. This patent application is intended to cover all adaptations and variants of the preferred embodiments described herein, and consequently the present invention is defined by the wording
30 of the accompanying claims and the equivalents thereof. Accordingly, the equipment can be modified in all feasible ways within the scope of the accompanying claims.

It should also be pointed out that although the terms "speed control" and "pump speed" for the sake of simplicity
35 have been used in the claims as well as in the description,

it will be appreciated that also other equivalent values are included, such as current feed frequency control, supply voltage control, etc., which all aim at changing the speed of the pump, and which all have a unambiguous relationship to pump speed.

It should be pointed out that even if it is not explicitly mentioned that features from one specific embodiment can be combined with the features of another embodiment, this should be regarded as evident when possible.

Claims

1. Method for controlling at least a part of a pump station (1) comprising a number of speed controlled pumps (2), the method (7) being arranged to minimize the specific energy consumption E_{spec} of said at least a part of a pump station, **characterized** in that the same comprises a sub method (Find V3) that comprises the steps of

* obtaining input data in the form of a set of parameters corresponding to a fictitious or elapsed first operating period t_1 and a fictitious or elapsed second operating period t_2 ,

* determining, based on said set of parameters, the mutual relative relationship between

a first value A_1 of a quantity that corresponds to a first pump speed V_1 and that is derived based on said set of parameters, which first value A_1 relates to said first operating period t_1 , and a second value A_2 of said quantity that corresponds to a second pump speed V_2 and that is derived from said set of parameters, which second value A_2 relates to said second operating period t_2 ,

and between

a first specific energy consumption $E_{\text{spec}1}$ that is derived based on said set of parameters and that relates to said first operating period t_1 , and a second specific energy consumption $E_{\text{spec}2}$ that is derived from said set of parameters and that relates to said second operating period t_2 ,

* determining, based on said determined mutual relative relationships and on parameters B_3 , B_4 , B_5 , and B_6 of said quantity, output data in the form of a third value A_3 of said quantity corresponding to a third pump speed V_3 of a third operating period t_3 , wherein

A_3 is set equal to $A_2 - B_3$ if the conditions $A_2 < A_1$ and $E_{\text{spec}2} < E_{\text{spec}1}$ are satisfied,

A3 is set equal to $A2+B4$ if the conditions $A2>A1$ and $E_{spec2}<E_{spec1}$ are satisfied,
A3 is set equal to $A2+B5$ if the conditions $A2<A1$ and $E_{spec2}>E_{spec1}$ are satisfied, and
5 A3 is set equal to $A2-B6$ if the conditions $A2>A1$ and $E_{spec2}>E_{spec1}$ are satisfied.

2. Method according to claim 1, wherein the specific energy consumption of said at least a part of a pump station is
10 given as a predetermined value E_{spec} for a fictitious operating period or is calculated according to $E_{spec} = k \cdot E$ for an elapsed operating period, where E is consumed energy by at least one of said number of frequency controlled pumps during said elapsed operating period and k is a time
15 parameter, and wherein the value A of said quantity is given as a predetermined value for the fictitious operating period or is registered for said elapsed operating period.

3. Method according to claim 1 or 2, wherein the first value
20 $A1$ of said quantity consists of the pump speed $V1$, the second value $A2$ of said quantity consists of the pump speed $V2$, and the third value $A3$ of said quantity consists of the pump speed $V3$.

25 4. Method according to claim 1 or 2, wherein the first value $A1$ of said quantity consists of a first current feed frequency $F1$, the second value $A2$ of said quantity consists of a second current feed frequency $F2$, and the third value $A3$ of said quantity consists of a third current feed
30 frequency $F3$.

5. Method according to claim 1 or 2, wherein the first value $A1$ of said quantity consists of a first supply voltage $S1$, the second value $A2$ of said quantity consists of a second
35 supply voltage $S2$, and the third value $A3$ of said quantity consists of a third supply voltage $S3$.

6. Method according to any one of the preceding claims,
wherein the set of parameters comprises said first value A1
of said quantity and the associated first specific energy
consumption E_{spec1} , as well as said second value A2 of said
quantity and the associated second specific energy
consumption E_{spec2} .

7. Method according to any one of the preceding claims,
wherein the parameters B3, B4, B5, and B6 have predetermined
values, each of which corresponds to a current feed
frequency change that is greater than 0,5 Hz, and smaller
than 5 Hz, preferably smaller than 2 Hz.

8. Method according to claim 7, wherein each of the
parameters B3, B4, B5, and B6 corresponds to a current feed
frequency change of 1 Hz.

9. Method according to claim 7 or 8, wherein the parameter
B3 is equal to the parameter B5, and the parameter B4 is
equal to the parameter B6.

10. Method according to claim 2, wherein the length of an
operating period is $n \cdot 24$ h, where n is a positive integer,
and wherein the time parameter k is calculated according to

$$k = \frac{1}{n \cdot 24}$$

11. Method according to claim 2, wherein the length of an
operating period is $n \cdot 24$ h, where n is a positive integer,
and wherein the time parameter k is calculated according to

$$k = \frac{1}{c \cdot (n \cdot 24)}, \text{ where } c \text{ is an equalization parameter.}$$

12. Method according to claim 11, wherein the equalization parameter c is calculated according to

$$c = \frac{x_{pa}}{\sum t_{pa}}$$

5

where x_{on} is the number of times a pump has been activated during an elapsed operating period, and $\sum t_{on}$ is the cumulative time for which the pump has been active in the elapsed operating period.

10

13. Method according to claim 2, wherein the length of an operating period is s seconds, where s is a positive integer, and wherein the time parameter k is calculated according to

$$k = \frac{1}{c * s}, \text{ where } c \text{ is an equalization parameter.}$$

15

14. Method according to claim 13, wherein the equalization parameter c is calculated according to

$$c = (\Delta h_{pa} + \Delta h_{av})$$

20

where Δh_{on} is the pump station liquid level change during an elapsed operating period, which elapsed operating period takes place in connection with the end of an active period during which one of said number of speed controlled pumps is active and which directly is followed by an inactive period during which said pump is inactive, and Δh_{off} is the pump station liquid level change during a following operating period, which following operating period takes place in connection with the beginning of the directly following inactive period.

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