



(51) International Patent Classification:

F04D 13/08 (2006.01) **F04B 49/20** (2006.01)
F04D 15/00 (2006.01) **F04D 13/16** (2006.01)
F04B 49/06 (2006.01)

(21) International Application Number:

PCT/IB20 14/06 1209

(22) International Filing Date:

5 May 2014 (05.05.2014)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

1350552-4 7 May 2013 (07.05.2013) SE

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,

BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— of inventorship (Rule 4.17(iv))

Published:

— with international search report (Art. 21(3))

— before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))

(54) Title: METHOD FOR CONTROLLING A PART OF A PUMP STATION

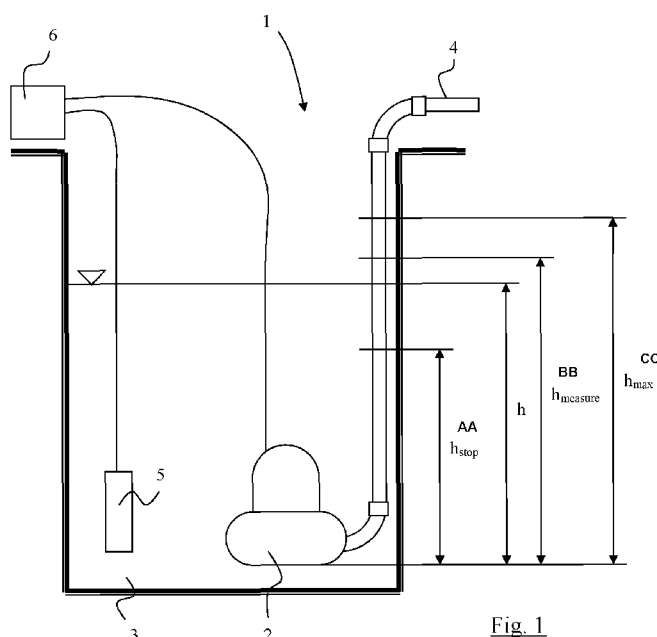


Fig. 1

(57) Abstract: The invention relates to a method for controlling at least a part of a pump station (1) comprising at least a speed controlled pump (2) arranged in a container (3), wherein the method comprises a sub-method (Determine E_{spec}) that is arranged for determining the specific energy consumption E_{spec} of said at least one pump (2), and which involves the steps of operating said pump (2) for at least two different speeds ($n_1, n_2, \dots$) and for each of said at least two speeds ($n_1, n_2, \dots$) in connection to one predetermined measurement level ($h_{measure}$) in the container (3) determining consumed power $P(n_1, n_2, \dots)$ and determining outgoing fluid flow $Q(n_1, n_2, \dots)$ from the container (3), and deriving the pump's (2) power curve $P(n)$ from the at least two determined values of consumed power $P(n_1, n_2, \dots)$, and deriving the pump's (2) pump flow curve $Q(n)$ from the at least two determined values of outgoing fluid flow $Q(n_1, n_2, \dots)$, and determining the pump's (2) specific energy consumption (E_{spec}) as the quotient of the pump's (2) power curve $P(n)$ divided with the pump's (2) pump flow curve $Q(n)$.

METHOD FOR CONTROLLING A PART OF A PUMP STATION

Technical field of the invention

The present invention relates in general to a method for controlling a part of a pump station. More specifically, the present invention relates to a method for controlling a part of a pump station comprising at least one speed controlled pump provided in a container, wherein the method comprises one sub-method (determine E_{spec}), which is adapted to determine the specific energy consumption E_{spec} of said at least one pump.

Background of the invention and prior art

The cost for operating the pumps in a pump station, or pumping station, intended for soiled water, sewage, surface water, etc., are considerably large. For a long time and up to now, the majority of pumps that have been installed in such pump stations are controlled to start at maximum speed, nominal speed, when a fluid level of the pump station has risen to one pre-determined start level for the pump, and thereafter controlled to operate until one pre-determined stop level for the pump is reached, but it is realised that this way of control is very expensive. As a solution, speed controlled pumps have been introduced in some applications, e.g. frequency controlled pumps where the supply current frequency to the pump is selected to one, from an energy consumption view, more optimal value determined by means of calculations and/or tests. These calculations and /or tests result in a diversity, system depending and/or pump depending, of curve diagrams from which the energy consumption per pumped volume in relation to e.g. speed or supply current frequency can be derived, whereby said optimal value is a derived minimum point. The introduction of speed controlled pumps and the adjustment of supply current frequency/ speed values based on the nominal performance curve of the pump type results in

cost savings, and save the pump as they very rarely or never are operated at the maximum speed.

However, speed control based on the nominal performance curve of a pump type has some drawbacks. It is a drawback that the nominal performance curve of a pump type not necessarily is exactly the same for each individual pump of the pump type, the nominal performance curve of a pump type is further static over time, which is not true for the real performance curve of the specific individual pump. More definitely, the real performance curve of the specific individual pump will change in relation to the wear of the parts of the pump. To that must be added that the design of the pump station and surrounding piping system, and the upgrading thereof, will have influence on the performance curve of the pumping station, which influence can be difficult or impossible to predict and/or calculate .

Short description of the objects of the invention

The present invention aims at removing the above described drawbacks and shortcomings of earlier known methods for controlling a part of a pumping station, and to provide an improved method. One basic object with the invention is to provide an improved method of the initially described type, which by means of a minority of measurement provides a situation adapted, real image of the specific energy consumption $E_{spe\ c}$ of said at least one pump.

One further object of the present invention is to provide a method for controlling at least one part of a pump station, which is self-regulating in relation to the wear of the parts of the pump and are substituted, and that is self-regulating based on the design of the pumping station in itself and the surrounding pipes.

Short description of the features of the invention

In accordance with the invention, at least one of the basic objects is achieved by means of the initially defined method, of which features are defined in the independent claim.

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

In accordance with the present invention, a method is provided of the initially defined type, which is characterized by a sub-method (determine E_{spec}) comprising the steps of:

- 10 - operating said pump at at least two different speeds ($n_1, n_2, \dots$) and for each one of said at least two different speeds ($n_i, n_2, \dots$), in connection to one predetermined measurement level (h_{measure}) in the container, determine consumed power $P(n_i, n_2, \dots)$ and determine outgoing fluid flow $Q(n_i, n_2, \dots)$
- 15 from the container;
- deriving a power curve $P(n)$ of the pump from the at least two determined values of consumed power $P(n_i, n_2, \dots)$;
- deriving a pumping flow curve $Q(n)$ of the pump from the at least two determined values of the fluid flow $Q(n_1, n_2, \dots)$;
- 20 and
- determining a specific energy consumption curve (E_{spec}) of the pump as the quotient of the pump's power curve $P(n)$ and the pump's pumping flow curve $Q(n)$.

Thus, the present invention is based on the understanding
 25 that even few measurements provides a situation adapted, real image of the specific energy consumption E_{spec} of said at least one pump, which provides better result than control based on the pump's nominal performance curve and the pump station's system curve.

30 According to a preferred embodiment of the present invention, said pump is operated at three different speeds n_1, n_2, n_3 respectively, and according to a second embodiment said pump is driven at two different speeds n_1 and $\frac{3}{4}$, respectively. The advantage by operating the pump at three different speeds

is that a greater accuracy for the pump's specific energy consumption as a function of the speed is obtained, and the advantage of operating the pump at two different speeds is that the specific energy consumption can be determined in a quicker manner.

Further advantages with and features of the invention are evident from remaining dependent claims and by the following, detailed description of preferred embodiments.

10 Short description of the drawings

A more complete understanding of the above mentioned and other features and advantages of the present invention will be obvious by the following, detailed description of preferred embodiments with reference to the enclosed drawings, of which:

15

Fig. 1 is a schematic illustration of a pump station;

Fig. 2 is a schematic flowchart showing one embodiment of
OPERATION OF PUMP STATION;

Fig. 3 is a schematic flowchart showing one preferred
embodiment of the process step INITIATION; and

20

Fig. 4 is a schematic flowchart showing two preferred
embodiments of the process step LEARNING SEQUENCE.

Detailed description of preferred embodiments

25 By way of introduction, it should be mentioned that the term "specific energy consumption E_{spec} " used in the claims as well as in the description means and is a measure of the energy consumption during operation of a pump. Specific energy consumption is calculated herein according to the formula

30 $E_{\text{spec}}(n) = P(n) / Q(n)$, where $P(n)$ is consumed power as a function of speed n , and $Q(n)$ is the outgoing fluid flow as function of speed n .

In figure 1, a schematic illustration of a pump station, generally denoted as 1, is showed comprising at least one

speed controlled pump 2, i.e. one or more and usually two pumps. Pump 2 is arranged for pumping fluid from one in the pumping station involved container 3 to an outlet pipe 4 and further away from the pump station 1. The container 3 is even
5 known as sump, tank, etc. Further, the pump station 1 comprises at least one level meter means 5 arranged for determining the fluid level h of the pump station, it should be pointed out that the level meter means 5 can be one separate apparatus, which is operatively connected to said
10 pump 2 being integrated in said pump 2, etc. Said at least one speed controlled pump 2 is preferably operatively connected with the external control unit 6 on purpose to allow control on the pump's 2 speed n , alternatively said at least speed controlled pump 2 comprises an integrated control unit (not
15 shown) .

With the wording "speed controlled" is included all thinkable ways of changing the speed of the pump 2, preferably in that the supply current frequency f can be controlled in purpose to change the speed of pump 2, whereby the speed is
20 proportional to supply current frequency. Above all, it means control of supply current frequency by a frequency converter, VFD, which is integrated in a pump or which is external, whereat an external VFD preferably is arranged at the external control unit 6. However, it also means internally or
25 externally controlled supply voltage regulation, internal mechanical brake that preferably acts on the driving shaft of the pump, etc. Thus, it is on an overall level of the invention not central how the speed of the pump is controlled, only that the speed of the pump 2 can be regulated/controlled.

30 The inventive method is directed to control a part of such a pumping station 1 that comprises at least a speed controlled pump 2 for the purpose of minimising the specific energy consumption $E_{spe\ c}$ of said pump 2. The pump station 1 shall in this context be regarded as a limited plant to which the

incoming fluid arrives, incoming fluid flow, and from which outgoing fluid is pumped, outgoing fluid flow. Pump station 1 shall, concerning the present invention, be regarded independent of type of fluid and independent from where the fluid comes and to where the fluid shall be pumped. Such a pumping station 1 can as been mentioned above comprise one or more pumps, of which at least one pump 2 is speed controlled. In the case when the pump station comprises a plurality of pumps 2, suitable altering or co-ordination can take place between them, which is not dealt with herein.

The method may for example be implemented as an integrated control unit in a pump 2 or in the external control unit 6 in a control cabinet, whereby the external control unit 6 is operatively connected with the pump 2. Henceforth in the description, the described embodiment of the invention is implemented in an external control unit 6 of the pump station 1 if nothing else is indicated, but the description is also valid for the corresponding case when the invention is implemented in a control unit in the pump 2.

Pumping station 2, and the container 3, has a fluid level that is denoted h and that in the present document is the distance between the instantaneous fluid surface in the container 3 and the inlet of the pump 2 (see figure 1). The fluid level h is directly connected to the real geodesic pressure head of the pump 2, which pressure increases with sinking fluid level h . When the container 3 is being filled with fluid, the fluid level h rises, and when the pump 2 is active pumping out fluid, the fluid level h sinks. It should be mentioned that the container 3 may be filled with fluid at the same time as the pump 2 is active and pumps out fluid.

It should be mentioned that the innovative method could be extended with one or more sub-methods, and/or be operated in parallel or sequentially with other control methods.

Reference is now made to figure 2, in which the operation of a pump station 1 schematically is illustrated in a flowchart. It should be realized that before the upstart of the pump station 1, a diversity of input data to the control method may be needed, e.g. different limit values for permitted fluid level, etc. After pump station 1 upstart, the first process step occur which is called Initiation, generally denoted 7, which purpose is to determine certain operation parameters, which will be used in the following process step called Learning sequence, generally denoted with 8. The process step Learning sequence 8 is meant to determine the pump's specific energy consumption $E_{spe\ c}$, which in turn shall be processed and the result of that shall be used in the following process step Operation, generally denoted with 9. During operation of the pump station 1 a return from the process step Operation 9 to the process step Learning sequence 8 may occur within predetermined time periods, to be able to adjust finely the specific energy consumption $E_{spe\ c}$ of the pump 2. It is also possible that during operation of a pump station 1 in the process step Operation 9 to restart from the process step Initiation 7 within predetermined time periods and/or when a pump has been replaced, the conditions upstream or downstream of the pump station have changed, etc.

To be able to minimise the geodesic pressure head of the pump station 1, one shall theoretically pump in such a way that the fluid level in the container 3 the whole time is close to an allowed fluid level h_{max} when the pump is active. However, this is not practicable as it would imply that a pump 2, operating in an energy optimal speed and which generates an outgoing fluid flow corresponding to an inflow in average, is considerably undersized for the pumping station and will not manage variable inflow over time, alternatively it would imply that a pump 2 that is sized for a variable inflow is forced to operate at a speed different from/lower than the energy

optimal speed during long periods of the operation time. A correctly dimensioned pump station 1 manages a variable inflow and the pump 2 is active between a start level and a stop level and it is operated at a favourable speed.

5 With reference now to figure 3, in which the process step Initiation 7 is showed in a flowchart. During the process step Initiation 7, the pump's 2 stop level h_{stop} is determined and also a measurement level h_{meas} is determined, see even figure 1. The pump's 2 stop level h_{stop} shall preferably be maximized
10 to correspond to the level in the container 3 that in practice implies feasible as well as optimal operation of the pump with a suitable number of starts per hour.

The pump's 2 stop level h_{stop} can be predetermined to be equal to a predetermined value, alternatively be calculated
15 based on the specific pump station 1.

The measurement level h_{meas} shall be between the maximal allowed fluid level h_{max} and the pump's 2 stop level h_{stop} . The measurement level h_{meas} is preferably directly dependent of the determined stop level h_{stop} , and/or of the maximum allowed
20 fluid level h_{max} . According a preferred performance the measurement level h_{meas} according to the formula: $h_{meas} = h_{stop} + k * (h_{max} - h_{stop})$, where k preferably is in the range 0,5 - 0,75. Alternatively, the measurement level h_{meas} can be determined by calculation based on the specific pump station
25 1.

With reference to figure 4, in which the process step Learning sequence 8 is schematically viewed in a flowchart, this process step is even called Sub-method Determine E_{spec} . The process step Learning sequence 8 is basically meant to operate
30 said pump 2 with at least two different speeds ($n_1, n_2, \dots$) and for each of said at least two different speeds ($n_1, n_2, \dots$) in connection to the predetermined measurement level (h_{meas}) determine consumed power $P(n_1, n_2, \dots)$ and to determine based on fluid flow $Q(n_1, n_2, \dots)$ from the container 3, thereafter is the

pump's 2 power curve $P(n)$ derived from the at least two determined values of consumed power $P(n_1, n_2, \dots)$, the pump's 2 pump flow curve $Q(n)$ is derived from the at least two determined values of outgoing fluid flow $Q(n_1, n_2, \dots)$, and

5 finally determine the pump's 2 specific energy consumption (Espec) as the quotient of the pump's 2 power curve $P(n)$ divided with the pump's 2 pump flow curve $Q(n)$.

The measurement level h_{measure} shall be sufficiently high to allow the determination of an outgoing fluid flow Q before the
10 fluid level h in the container 3 becomes too low, e.g. sinks below the stop level h_{stop} .

With the term "in connection to", as used in the claims as well as in the description in connection to the measurement level h_{measure} , is meant that the determination of consumed power
15 P and outgoing fluid flow Q occurs firstly if/when a stable outgoing fluid flow is achieved/obtained. For example, the pump 2 is started when the fluid level h in the container is equal to the measurement level h_{measure} , then stable outflow is awaited to have been achieved/obtained, which is considered to
20 have been fulfilled when for example a predetermined delay time has ended or when a stable outflow is determined by measurement. According to one alternative, equivalent, embodiment the pump 2 is started at a fluid level h in the container 3 that is located on a predetermined level above
25 said measurement level h_{measure} , so it is ensured that a stable outgoing fluid flow has been achieved/obtained when the fluid level h in the container 3 reaches the measurement level h_{measure} .

The Learning sequence 8 will now be described according to
30 a first, preferred embodiment. In the learning sequence 8 according to this the first embodiment the pump 2 is operated at three different speeds. These three speeds is determined preferably on a first manner the first time the Learning sequence 8 takes place during operation of the pump station 1,

and in a second manner the other times the Learning sequence 8 takes place.

Here below, the Learning sequence 8 according to the first embodiment will be described the first time it takes place.

5 The pump 2 is started/activated at a start level h_{start} , which is situated above the measurement level $h_{measure}$, and it begins thereby to pump fluid from the container 3. At the starting up of a pump 2 a certain delay time is used before so called stable operation is obtained, depending on that there
10 is inertia in the fluid which is situated in the downstream located pipes 4. This will be seen exactly at up start of the pump 2, the current consumption is differently/more variable than at stable operation, even denoted as stable outgoing fluid flow, at the same time as the outgoing fluid flow is
15 less than at stable operation. The start level h_{start} shall be situated at such a level above the measurement level $h_{measure}$ that a stable operation has been obtained when the fluid level h in the container 3 reaches the measurement level $h_{measure}$.

The pump 2 is started, and when the fluid level h in the
20 container 3 reaches the measurement level $h_{measure}$, the pump 2 is operated at a first speed n_1 . The first speed n_1 is preferably equal to the pump's 2 nominal speed n_{nom} , which corresponds to that the pump 2, which is designed for the existing power mains frequency (f_{net}), is operated directly by the power mains
25 frequency (f_{net}). In connection to the fluid level h in the container 3 is equal to the measurement level $h_{measure}$, the consumed power $P(n_1)$ and the outgoing fluid flow $Q(n_1)$ corresponding to the first speed n_1 is determined. When the consumed power $P(n_1)$ and the outgoing fluid flow $Q(n_1)$ have
30 been determined, the pump 2 is switched off for allowing the fluid level h to rise again in the container 3, eventually the pump 2 operation is continued for a certain time or to a certain fluid level after that the consumed power $P(n_1)$ and the outgoing fluid flow $Q(n_1)$ have been determined, for example the

pump 2 is switched off at the stop level h_{stop} . The pump 2 is started and when the fluid level h in the container 3 reaches the measurement level $h_{measure}$, the pump 2 is operated at the second speed n_2 . The second speed n_2 is equal to a factor 0.9 times the first speed n_1 . In connection to that the fluid level h in the container 3 is equal to the measurement level $h_{measure}$, the consumed power $P(n_2)$ and the outgoing fluid flow $Q(n_2)$ corresponding to the second speed n_2 are determined. The pump 2 is thereafter switched off as described above allowing the fluid level 2 to rise again in the container 3. The pump 2 is started and when the fluid level h in the container 3 reaches the measurement level $h_{measure}$, the pump 2 is operated at a third speed n_3 . In connection to that the fluid level h in the container 3 is equal to the measurement level $h_{measure}$, the consumed power $P(n_3)$ and the outgoing fluid flow $Q(n_3)$ corresponding to the third speed n_3 are determined. The pump 2 is thereafter switched off as described above allowing the fluid level 2 to rise again in the container 3.

To be able to determine the third speed n_3 , and to avoid not working/ functional frequencies, information regarding a zero-flow speed $n_{Q=0}$ is needed, and one predetermined lowest allowed speed $n_{minid\ ef\ a\ uit}$. The zero-flow speed $n_{Q=0}$ is determined by extrapolating of the linear function which intersect the two determined values for the outgoing fluid flows $Q(n_1)$ and $Q(n_2)$, where $Q(n_{Q=0})$ is set to zero. The third speed n_3 is then determined to the highest of the predetermined lowest allowed speed $n_{minid\ ef\ a\ uit}$ and the quotient $(n_{Q=0} + n_2)/2$. If the third speed n_3 is higher than or equal to a factor 0.85 times the first speed n_1 multiplied with, the third speed n_3 is replaced by the second speed n_2 , and an updated second speed n_2 is used which is equal to a factor 0.95 times the first speed n_1 . In other words, the earlier determined value for consumed power $P(n_2)$ corresponding to the second speed n_2 now becomes consumed power $P(n_3)$ corresponding to the third speed n_3 , and the

earlier determined value for outgoing fluid flow $Q(n_2)$ corresponding to the second speed n_2 becomes outgoing fluid flow $Q(n_3)$ corresponding to the second speed n_3 , whereat new values for consumed power $P(n_2)$ and outgoing fluid flow $Q(n_2)$ corresponding to the second speed n_2 is thereafter determined at operation of the pump 2 at the updated second speed $n_2 = 0.95 * n_i$.

After each operation, the zero-flow speed $n_{Q=0}$ and is determined based on the three determined values for the outgoing fluid flow $Q(n_i)$, $Q(n_2)$ and $Q(n_3)$.

The other times when the Learning sequence 8 occur, the three different speeds n_1 , n_2 , and n_3 are determined in the following way.

The first speed n_i is preferably equal to the nominal speed n_{nom} - The second speed n_2 is equal to $n_{min} + 2/3 * (n_i - n_{min})$, and the third speed n_3 is equal to $n_{min} + 1/3 * (n_i - n_{min})$. n_{min} is the lowest speed that the pump 2 can have, and it is determined as the highest of the zero-flow speed $n_{Q=0}$, the predetermined lowest allowed speed $n_{min,default}$, and the speed $n_{Q=min}$ when the pump 2 generates the lowest outgoing fluid flow. It should be mentioned that in some applications $n_{Q=0}$ and $n_{Q=min}$ have the same value, and in some applications there is no zero-flow speed whereat $n_{Q=min}$ constitutes a minimum point for the outgoing fluid flow.

The purposes of the different ways to determine the different speeds n_i , n_2 , and n_3 are to obtain a uniform distribution among them, and a good spreading over the useful region of the speed of the pump 2.

The consumed power $P(n)$ is determined preferably by measurement by means of a sensor that measure suitable variable, and in those cases the pumping station 1 comprises a flow meter (not showed) which is operatory connected to the pump 2, the outgoing fluid flow $Q(n)$ is measured with said flow meter. However, it is common that pump stations 1 do not

involve a flow meter but only level meter 5, and then said level meter 5 is used for determining the outgoing fluid flow $Q(n)$. The level meter shall be of so called analogous or continuous type.

5 More precisely, the value of the outgoing fluid flow $Q(n_i)$ corresponding to the first speed n_i is determined by the steps to measure the fluid level variation $dhdt_{i_n}(n_i)$ in the container 3 when the pump 2 is inactive, measure the fluid level variation $dhdt_{pump}(n_i)$ in the container 3 when the pump 2 is operated at the first speed n_i , and thereafter determine the outgoing fluid flow $Q(n_i)$ corresponding to the first speed n_i by calculating the absolute value of the difference of the measured fluid level variation $dhdt_{i_n}(n_i)$ in the container 3 when the pump 2 is inactive minus the measured fluid level variation $dhdt_{pump}(n_i)$ in the container 3 when the pump 2 is operated at the first speed n_i , where $dhdt_{pump}(n_i)$ and $dhdt_{i_n}(n_i)$ is given with their direction dependent sign, respectively. The fluid level variation $dhdt_{i_n}(n_i)$ in the container 3 when the pump 2 is inactive is preferably measured in direct connection to when the corresponding fluid level variation $dhdt_{pump}(n_i)$ in the container 3, when the pump 2 is active at the first speed n_i , is measured. Most preferably, the fluid level variation $dhdt_{i_n}(n_i)$ in the container 3 when the pump 2 is inactive is measured before the corresponding fluid level variation $dhdt_{pump}(n_i)$ in the container 3 when the pump 2 is active at the first speed n_i , is measured. Preferably, the outgoing fluid flow $Q(n_i)$ corresponding to the first speed n_i is determined by performing several measurements and use an average value or median value.

30 When a fluid level variation $dhdt_{i_n}(n_i)$ in the container 3, when the pump 2 is inactive, is to be measured after the pump 2 has been active, a delay time must pass after the pump 2 has been switched off before a measurement is performed. The reason is that, when the pump 2 has been switched off, there

is certain inertia in the outgoing fluid flow which imply that the outgoing fluid flow continues further a short time period after that the pump 2 has been switched off, a back flow will thereafter return to the container 3 from the downstream

5 situated pipes 4, which phenomenon will produce misleading values without delay time at measurement of the real fluid inflow to the container 3.

A new value is preferably determined and used for the fluid level variation $dhdti_n(n_i)$ in the container 3 when the pump 2
10 is inactive each time a new value for the outgoing fluid flow Q shall be determined, but it should be realised that a determined value used for the fluid level variation $dhdti_n(n_i)$ in the container 3 when the pump 2 is inactive can be used for determination of several values for the outgoing fluid flow Q
15 corresponding to different speeds.

It should be realised that the outgoing fluid flow $Q(n_2)$ corresponding to the second speed n_2 and the outgoing fluid flow $Q(n_3)$ corresponding to the third speed n_3 is also determined as described above.

20 The pump's 2 power curve $P(n)$ is derived from the three determined/measured values for consumed power $P(n_i)$, $P(n_2)$, and $P(n_3)$, corresponding to the first speed n_i , corresponding to the second speed n_2 , and corresponding to the third speed n_3 , respectively. In the preferred embodiment, the pump's 2 power
25 curve $P(n)$ is equal to the polynomial $a_1 \cdot n + a_2 \cdot n^2 + a_3 \cdot n^3$, where a_1 , a_2 , and a_3 are constants which are obtained via the equation system:

$$P(n_i) = a_1 \cdot n_i + a_2 \cdot n_i^2 + a_3 \cdot n_i^3$$

$$P(n_2) = a_1 \cdot n_2 + a_2 \cdot n_2^2 + a_3 \cdot n_2^3$$

$$30 \quad P(n_3) = a_1 \cdot n_3 + a_2 \cdot n_3^2 + a_3 \cdot n_3^3$$

Each time the pump's 2 power curve $P(n)$ is determined the previous value of a_1 , a_2 , and a_3 , respectively, is considered and weighted, preferably with 50%, i.e. $a_i = 0.5 \cdot a_{i, \text{new}} + 0.5 \cdot a_{i, \text{previous}}$.

The pump's 2 pump flow curve $Q(n)$ is derived from the three determined /measured values for outgoing fluid flow $Q(n_1)$, $Q(n_2)$, and $Q(n_3)$, corresponding to the first speed n_1 , the second speed n_2 , and the third speed n_3 , respectively. In the preferred embodiment, the pump's 2 pump flow curve $Q(n)$ equal to the polynomial $b_1 + b_2 \cdot n + b_3 \cdot n^2$, where b_1 , b_2 , and b_3 are constants which are obtained via the equation system:

$$Q(n_1) = b_1 + b_2 \cdot n_1 + b_3 \cdot n_1^2$$

$$Q(n_2) = b_1 + b_2 \cdot n_2 + b_3 \cdot n_2^2$$

$$10 \quad Q(n_3) = b_1 + b_2 \cdot n_3 + b_3 \cdot n_3^2$$

Each time the pump's 2 pump flow curve $Q(n)$ is determined the previous value of b_1 , b_2 , and b_3 , respectively, is considered and weighed, preferably with 50%, i.e. $b_1 = 0.5 \cdot b_{1, \text{new}} + 0.5 \cdot b_{1, \text{previous}}$.

15 The pump's 2 specific energy consumption ($E_{\text{spe c}}$) is thereafter determined as the quotient of the pump's 2 power curve $P(n)$ divided with the pump's 2 pump flow curve $Q(n)$, whereupon the pump's 2 specific energy consumption ($E_{\text{spe c}}$) is used for determining the pump's 2 optimal speed n_{opt} , which is equal to the speed corresponding to the lowest value for the pump's 2 specific energy consumption $E_{\text{spe c, min}}$. The optimal speed n_{opt} is numerically derived.

25 The Learning sequence 8 will now be described according to a second embodiment. In the Learning sequence 8 according to this second embodiment, the pump 2 is operated at two different speeds. These two speeds are preferably determined in the following way.

The pump 2 is started, and when the fluid level h in the container 3 reaches the measurement level h_{measure} , the pump 2 is operated at a first speed n_1 . The first speed n_1 is preferably equal to the pump's 2 nominal speed n_{nom} , which corresponds to that the pump 2, which is designed for the existing power mains frequency (f_{net}), is operated directly by the power mains frequency (f_{net}). In connection to the fluid level h in the

container 3 is equal to the measurement level $h_{\text{meas ureA}}$ the consumed power $P(n_i)$ and the outgoing fluid flow $Q(n_i)$ corresponding to the first speed n_i is determined. When the consumed power $P(n_i)$ and the outgoing fluid flow $Q(n_i)$ have been determined, the pump 2 is switched off for allowing the fluid level h to rise again in the container 3, eventually the pump 2 operation is continued for a certain time or to a certain fluid level after that the consumed power $P(n_i)$ and the outgoing fluid flow $Q(n_i)$ have been determined, for example the pump 2 is switched off at the stop level h_{stop} . The pump 2 is started and when the fluid level h in the container 3 reaches the measurement level $h_{\text{meas ureA}}$ the pump 2 is operated at the second speed $\frac{3}{4}$. The second speed $\frac{3}{4}$ is equal to a factor 0.9 times the first speed n_i , the first time the Learning sequence occurs. In connection to that the fluid level h in the container 3 is equal to the measurement level $h_{\text{meas ureA}}$ the consumed power $P(n_2)$ and the outgoing fluid flow $Q(n_2)$ corresponding to the second speed $\frac{3}{4}$ are determined. The pump 2 is thereafter switched off as described above allowing the fluid level 2 to rise again in the container 3. The values of consumed power $P(n_i)$ and $P(n_2)$ corresponds to the first speed n_i , and the second speed $\frac{3}{4}$, respectively, and the values of the outgoing fluid flow $Q(n_i)$ and $Q(n_2)$ corresponds to the first speed n_1 and the second speed $\frac{3}{4}$, respectively, are determined in the same way as mentioned above in connection to the first preferred embodiment of the Learning sequence 8.

The pump's 2 power curve $P(n)$ is derived from the determined/measured values of consumed power $P(n_i)$ and $P(n_2)$, corresponding to the first speed n_i and the second speed $\frac{3}{4}$, respectively, In the second embodiment, the pump's 2 power curve $P(n)$ equal to the power function $P_{\text{nom}} * (n/n_{\text{nom}})^c$, where P_{nom} is the pump's 2 nominal power consumption and n_{nom} is the pump's 2 nominal speed, which corresponds to that the pump 2 is operated directly by the power mains frequency f_{net} , and c

is a constant that is obtained by means of the equation: $P(n_2) = P_{nom} * (\eta_2 / \eta_{n_{opt}})^c$. Each time the pump's 2 power curve $P(n)$ is determined, the previous value of c is considered and weighted, preferably with 50%, i.e. $c = 0.5 * c_{new} + 0.5 * c_{previous}$.

5 The pump's 2 pump flow curve $Q(n)$ is derived from the determined/measured values of outgoing fluid flow $Q(n_1)$ and $Q(n_2)$, corresponding to the first speed n_1 and the second speed n_2 , respectively. In the second embodiment, the pump's 2 pump flow curve $Q(n)$ equal to the linear function $((n/n_{nom} - d) / (1 - d)) * Q_{nom}$, where Q_{nom} is the pump's 2 nominal pump flow and n_{nom} is the pump's 2 nominal speed, which corresponds to that the pump 2 is operated directly by the power mains frequency f_{net} , and d is a constant that is obtained by means of the equation: $Q(n_2) = ((n_2/n_{nom} - d) / (1 - d)) * Q_{nom}$. Each time the pump's 2
10 pump flow curve $Q(n)$ is determined, the previous value of d is considered and weighted, preferably with 50%, i.e. $d = 0.5 * d_{new} + 0.5 * d_{previous}$.

The pump's 2 specific energy consumption (E_{spec}) is thereafter determined as the quotient of the pump's 2 power curve $P(n)$ divided with the pump's 2 pump flow curve $Q(n)$, whereupon the pump's 2 specific energy consumption (E_{spec}) is used for determining the pump's 2 optimal speed n_{opt} , which is equal to the speed corresponding to the lowest value for the pump's 2 specific energy consumption $E_{spec, min}$. The optimal speed
25 n_{opt} is obtained by deriving the pump's specific energy consumption E_{spec} and set the derivative to zero. The optimal speed is then obtained according to the formula $n_{opt} = b * c * n_{nom} / (c - 1)$. The optimal speed n_{opt} , that is updated each time the Learning sequence is performed, is thereafter used
30 preferably as the second speed n_2 the other times the Learning sequence 8, according to the second embodiment, takes place.

Now, reference is again made to figure 2. In the process step Operation 9, the obtained optimal speed n_{opt} is used. According to a first embodiment, the pump 2 is operated at an

operation speed n_{ope} that is equal to the optimal speed n_{opt} . According to the second embodiment, the pump 2 is operated at a operation speed n_{ope} that is higher than the optimal speed n_{opt} , i.e. the operation speed $n_{ope} = n_{opt} + k * (n_{nom} - n_{opt})$, where
 5 k preferably is in the order 0.10 - 0.30, with the purpose to ensure that the operation speed n_{ope} not is lower than the real optimal speed n_{opt} . It should be mentioned that higher as well as lower values of k may be used momentary. Based on the optimal speed n_{opt} , the operation speed n_{ope} may be different
 10 for different values of the fluid level h in the container 3, and the pump's 2 speed may thereby change, during the process step Operation 9, in correspondence to the change of the fluid level when the pump 2 is active.

It should also be pointed out, that the Learning sequence 8
 15 may be performed at different measurement levels $h_{measured}$ i.e. the optimal speed n_{opt} may be different for different levels in the container 3 and is therefore related to the fluid level h in the container, an optimal speed is thereby obtained as a function of the fluid level in the container, $n_{opt}(h)$.

20

Possible modifications of the invention

The invention is not limited only to the above described and in the drawings illustrated embodiments, which only purposes are illustrative and exemplifying. This document is
 25 meant to cover all adjustments and variants of the preferred embodiments described herein, and the present invention is consequently defined by the wording in the enclosed claims, and the equipment may be modified in every possible way within the scope of the enclosed claims.

30 It is only pointed out that all information about/concerning terms like above, under, upper, lower, etc. shall be interpreted/read with the equipment oriented in accordance with the figures, with the drawings oriented in such a way that the reference numbers are correctly read.

Thus, such terms indicates only the mutual relations in the illustrated embodiments, which relations may be changed if the innovative equipment is provided with another construction/design .

- 5 It must be pointed out that even though it is not explicitly mentioned that the features of a specific embodiment can be combined with the features of another embodiment, it should be considered as obvious when it is possible .

Patent claims

1. Method for controlling at least a part of a pump station
 (1) comprising at least a speed controlled pump (2) arranged
 in a container (3), wherein the method comprises a sub-method
 5 (Determine E_{spec}) that is arranged for determining the specific
 energy consumption E_{spec} of said at least one pump (2), and
 which involves the steps of:

- operating said pump (2) for at least two different speeds
 ($n_1, n_2, \dots$) and for each of said at least two speeds ($n_1, n_2,$
 10 $\dots$), in connection to a predetermined measurement level
 (h_{measure}) in the container (3), determine consumed power $P(n_1,$
 $n_2, \dots)$ and determine outgoing fluid flow $Q(n_1, n_2, \dots)$ from the
 container (3),
- deriving the power curve $P(n)$ of the pump (2) from the at
 15 least two determined values of consumed power $P(n_1, n_2, \dots)$,
- deriving the pump flow curve $Q(n)$ of the pump (2) from the at
 least two determined values of outgoing fluid flow $Q(n_1, n_2,$
 $\dots)$, and
- determining the specific energy consumption (E_{spec}) of the
 20 pump (2) as the quotient of the power curve $P(n)$ of the pump
 (2) divided with the pump flow curve $Q(n)$ of the pump (2).

2. Method according to claim 1, wherein the specific energy
 consumption (E_{spec}) of the pump (2) is used for determining the
 25 optimal speed (n_{opt}) of the pump (2), which is equal to the
 speed that corresponds to the lowest value for the specific
 energy consumption ($E_{\text{spec, min}}$) of the pump (2).

3. Method according to claim 1 or 2, wherein the predetermined
 30 measurement level (h_{measure}) in the container (3) is situated at
 a distance above a stop level (h_{stop}) for the pump (2), wherein
 said distance is in the region 0.5 - 0.75 times the difference
 between a maximal allowed fluid level (h_{max}) in the container
 (3) and the stop level (h_{stop}) of the pump (2).

4. Method according to any of the claims 1 - 3, wherein a first speed (n_i) is equal to the nominal speed (n_{nom}) of the pump (2), which corresponds to the pump (2) being operated directly by the power mains frequency (f_{net}).

5. Method according to claims 1 - 4, wherein the sub-method (Determine E_{spec}) comprises the steps of:

- operating said pump (2) at a first speed (n_i) and for the first speed (n_i) in connection to the predetermined measurement level (h_{meas}) determining consumed power $P(n_i)$ and determining outgoing fluid flow $Q(n_i)$,
- operating said pump (2) at a second speed ($\frac{3}{4}$) and for the second speed ($\frac{3}{4}$) in connection to the predetermined measurement level (h_{meas}) determining consumed power $P(n_2)$ and determining outgoing fluid flow $Q(\frac{3}{4})$,
- operating said pump (2) at a third speed (n_3) and for the third speed (n_3) in connection to the predetermined measurement level (h_{meas}) determining consumed power $P(n_3)$ and determining outgoing fluid flow $Q(n_3)$,
- deriving the power curve $P(n)$ of the pump (2) from the three determined values of consumed power $P(n_i)$, $P(n_2)$, and $P(n_3)$,
- deriving the pump flow curve $Q(n)$ of the pump (2) from the three determined values of outgoing fluid flow $Q(n_i)$, $Q(\frac{3}{4})$, and $Q(n_3)$,
- determining the specific energy consumption (E_{spec}) of the pump (2) as the quotient of the power curve $P(n)$ of the pump (2) divided with the pump flow curve $Q(n)$ of the pump (2).

6. Method according to claim 5, wherein the first speed (n_i) is higher than the second speed ($\frac{3}{4}$), and wherein the second speed ($\frac{3}{4}$) is higher than the third speed (n_3).

7. Method according to claim 6, wherein the difference between the first speed (n_1) and the second speed (n_2) is equal to the difference between the second speed (n_2) and the third speed (n_3).

5

8. Method according to any of the claims 5 - 7, wherein said three values of the outgoing fluid flow $Q(n_1)$, $Q(n_2)$, and $Q(n_3)$ is measured by means of a flow meter connected to the pump (2).

10

9. Method according to any of the claims 5 - 7, wherein the value of the outgoing fluid flow $Q(n_1)$ corresponding to the first speed (n_1) is determined by the steps of:

- measuring the fluid level variation $dhdt_{n(n_1)}$ in the container (3) when the pump (2) is inactive,
- measuring the fluid level variation $dhdt_{pump(n_1)}$ in the container (3) when the pump (2) is operated at the first speed n_1 , and
- determining the outgoing fluid flow $Q(n_1)$ corresponding to the first speed (n_1) by calculating the absolute value of the difference of the measured fluid level variation $dhdt_{n(n_1)}$ in the container (3) when the pump (2) is inactive minus the measured fluid level variation $dhdt_{pump(n_1)}$ in the container (3) when the pump (2) is operated at the first speed (n_1).

25

10. Method according to any of claims 5 - 9, wherein the power curve $P(n)$ of the pump (2) is equal to the polynomial $a_1 \cdot n + a_2 \cdot n^2 + a_3 \cdot n^3$, where a_1 , a_2 , and a_3 are constants which are obtained via the equation system:

$$\begin{aligned}
 P(n_1) &= a_1 \cdot n_1 + a_2 \cdot n_1^2 + a_3 \cdot n_1^3 \\
 P(n_2) &= a_1 \cdot n_2 + a_2 \cdot n_2^2 + a_3 \cdot n_2^3 \\
 P(n_3) &= a_1 \cdot n_3 + a_2 \cdot n_3^2 + a_3 \cdot n_3^3 .
 \end{aligned}$$

11. Method according to any of claims 5 - 10, wherein the pump flow curve $Q(n)$ of the pump (2) is equal to the polynomial $b_1 + b_2 \cdot n + b_3 \cdot n^2$, where b_1 , b_2 , and b_3 are constants which are obtained via the equation system:

$$\begin{aligned} 5 \quad P(n_1) &= b_1 + b_2 \cdot n_1 + b_3 \cdot n_1^2 \\ P(n_2) &= b_1 + b_2 \cdot n_2 + b_3 \cdot n_2^2 \\ P(n_3) &= b_1 + b_2 \cdot n_3 + b_3 \cdot n_3^2 . \end{aligned}$$

12. Method according to claims 1 - 4, wherein the sub-method

10 (Determine E_{spec}) comprises the steps of:

- operating said pump (2) at a first speed (n_1) and for the first speed (n_1) in connection to the predetermined measurement level ($h_{measured}$) determining consumed power $P(n_1)$ and determining outgoing fluid flow $Q(n_1)$,
- 15 - operating said pump (2) at a second speed (n_2) and for the second speed (n_2) in connection to the predetermined measurement level ($h_{measured}$) determining consumed power $P(n_2)$ and determining outgoing fluid flow $Q(n_2)$,
- deriving the power curve $P(n)$ of the pump (2) from the two
- 20 determined values of consumed power $P(n_1)$, and $P(n_2)$,
- deriving the pump flow $Q(n)$ of the pump (2) from the two determined values of outgoing fluid flow $Q(n_1)$, and $Q(n_2)$,
- determining the specific energy consumption (E_{spec}) of the pump (2) as the quotient of the power curve $P(n)$ of the pump
- 25 (2) divided with the pump flow curve $Q(n)$ of the pump (2) .

13. Method according to claim 12, wherein the first speed (n_1) is higher than the second speed (n_2) .

30 14. Method according to claim 12 or 13, wherein the power curve $P(n)$ of the pump is equal to the power function $P_{nom} \cdot (n/n_{nom})^c$, where P_{nom} is the nominal power consumption of the pump (2) and n_{nom} is the nominal speed of the pump (2), which corresponds to that the pump (2) is operated directly by

the power mains frequency $\{f_{net}\}$, and c is a constant that is obtained by means of the equation: $P(n_2) = P_{nom} * (n_2/n_{nom})^c$.

15. Method according to claims 12 - 14, wherein the pump flow
 5 curve $Q(n)$ of the pump (2) is equal to the linear function
 $((n/n_{nom} - d) / (1 - d)) * Q_{nom}$, where Q_{nom} is the nominal pump flow
 of the pump (2) and n_{nom} is the nominal speed of the pump (2),
 which corresponds to that the pump (2) is operated directly by
 the power mains frequency $\{f_{net}\}$, and where d is a constant
 10 that is obtained by means of the equation: $Q(n_2) = ((n_2/n_{nom} -$
 $d) / (1 - d)) * Q_{nom}$.

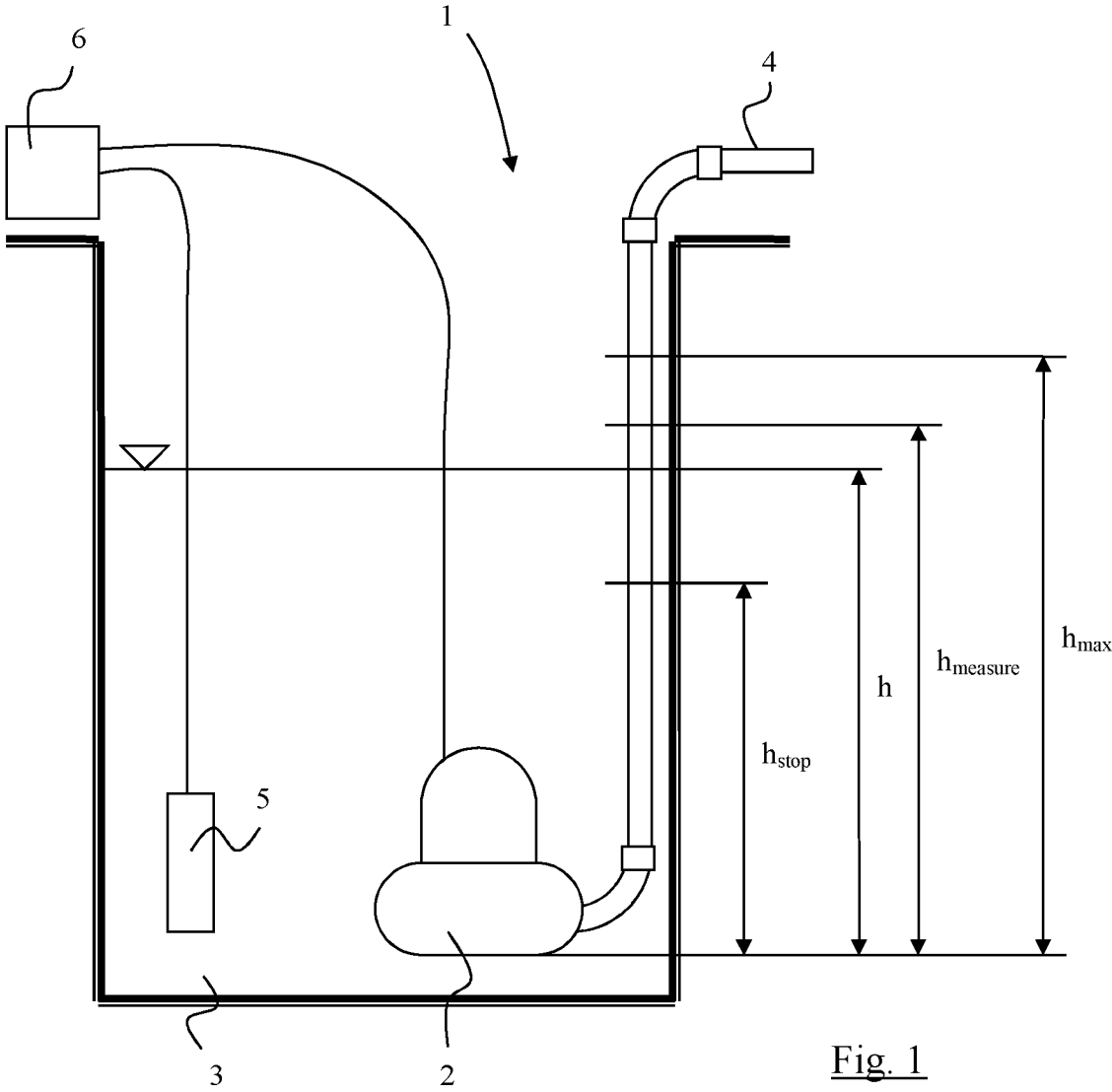
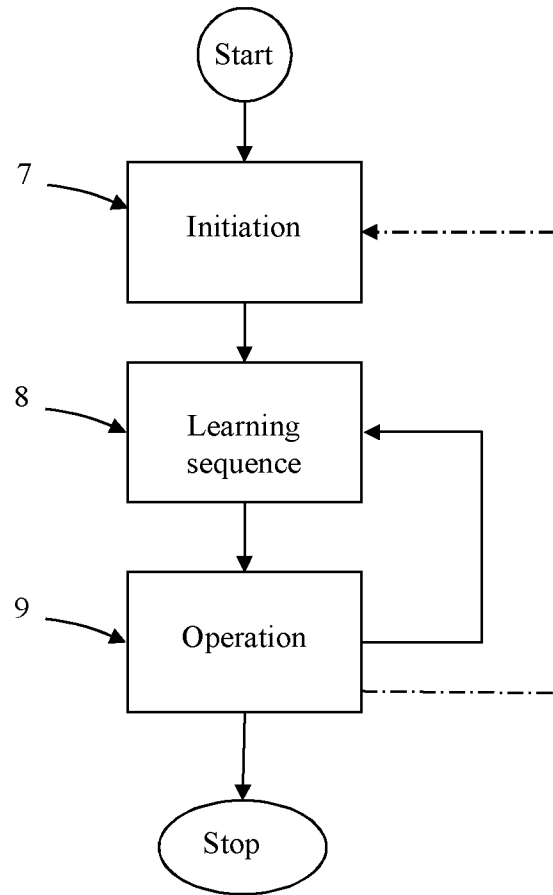
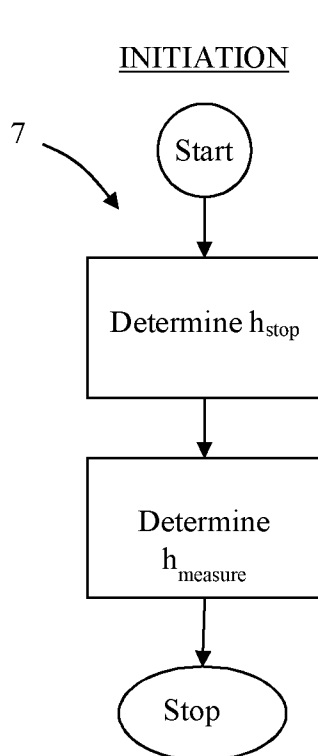
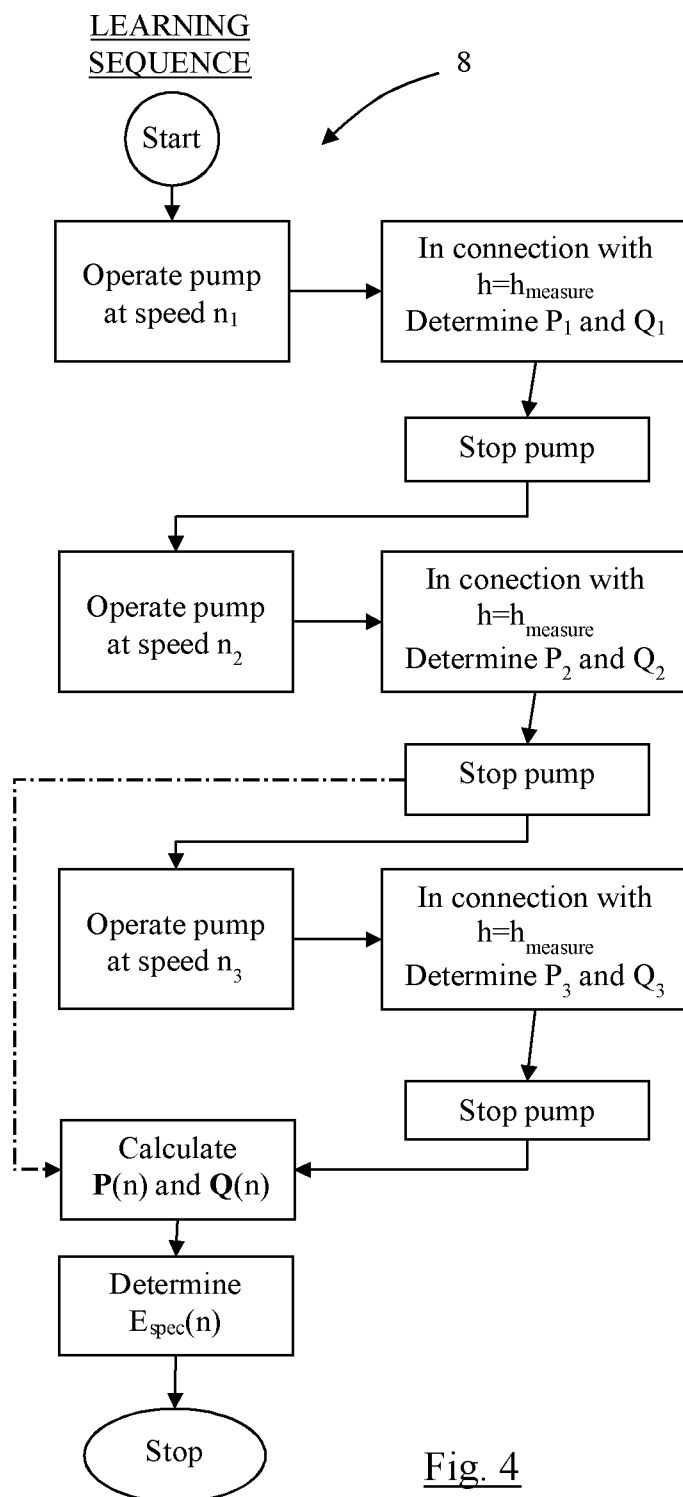


Fig. 1

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OPERATION OF PUMP STATIONFig. 2

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Fig. 3Fig. 4

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2014/061209

A. CLASSIFICATION OF SUBJECT MATTER

INV. F04D13/08 F04D15/00 F04B49/06 F04B49/20
 ADD. F04D13/16

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F04D F04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal , WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	wo 2006/019352 AI (ITT MFG ENTERPRISES INC [US]; HALLGREN GERT [SE]) 23 February 2006 (2006-02-23) page 1, line 4 - line 5 page 4, line 12 - line 29 page 7, line 12 - line 23 page 10, line 24 - page 11, line 33 page 16, line 8 - line 11 figure 2 figure 3 figure 4 figure 5a ----- -/- .	1-15



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"P" document published prior to the international filing date but later than the priority date claimed

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Date of the actual completion of the international search

22 August 2014

Date of mailing of the international search report

01/09/2014

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INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2014/061209

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011/081255 A1 (STEGE PERRY C [US] ET AL) 7 April 2011 (2011-04-07) paragraph [0003] paragraph [0005] paragraph [0024] - paragraph [0025] paragraph [0041] paragraph [0044] paragraph [0051] paragraph [0061] paragraph [0065] figure 4 figure 5 -----	1-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2014/061209

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2006019352 A1	23-02-2006	SE 0402043 A WO 2006019352 A1	20-02-2006 23-02-2006
US 2011081255 A1	07-04-2011	NONE	