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• **Ahola, Jero**
53850 Lappeenranta (FI)

(74) Representative: **Valkeiskangas, Tapio Lassi**
Paavali et al
Kolster Oy Ab
Iso Roobertinkatu 23
P.O. Box 148
00121 Helsinki (FI)

(71) Applicant: **ABB Oy**
00380 Helsinki (FI)

(72) Inventors:
• **Ahonen, Tero**
53810 Lappeenranta (FI)

(54) **Method and system for detecting cavitation of pump and frequency converter**

(57) A method and a system in accordance with a pump controlled with a frequency converter. The method comprising the steps of controlling the pump (4) with a frequency converter (2), the frequency converter (2) feeding a motor (3) connected to drive the pump, providing a torque estimate (T_{est}) and/or a rotational speed estimate (n_{est}) of the motor from the frequency converter,

forming one or more features (Feature1, Feature2, Feature3, Feature4) indicating cavitation or likelihood of cavitation of the pump (4) and/or reverse flow of the pump (4) using the provided estimates (T_{est} , n_{est}) and detecting cavitation or likelihood of the cavitation of the pump and/or reverse flow of the pump from one or more of the formed features (Feature1, Feature2, Feature3, Feature4).

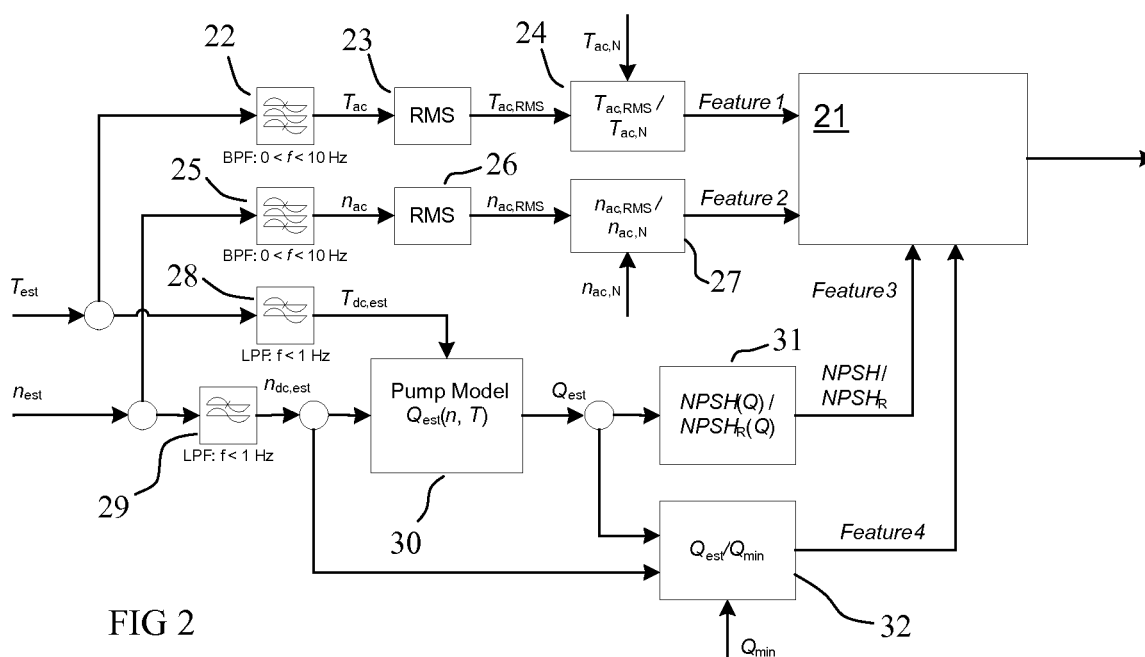


FIG 2

Description

FIELD OF THE INVENTION

[0001] The present invention relates to a method and system of detecting cavitation of a pump, and more particularly to a method and system, with which the cavitation of a pump controlled with a frequency converter can be detected without additional measurements.

BACKGROUND OF THE INVENTION

[0002] A known problem relating to pumps is their tendency for cavitation. Cavitation refers to a situation, in which suction pressure into the pump drops below a value in which the liquid to be pumped starts to boil, i.e. below vapour pressure of the liquid. This phenomenon generates vapour bubbles which collapse abruptly once the bubbles enter the higher pressure area in the pump. The abrupt change from gas phase back to liquid phase causes sudden pressure changes which cause audible noise and may damage the mechanical parts of the pump.

[0003] The detection of cavitation or the possibility of cavitation is an important aspect relating to pumping processes. If the cavitation or risk of cavitation can be detected, the mechanical wearing of the pumps is greatly reduced and the pump may be operated safely in a larger operating area.

[0004] Pumps, such as centrifugal pumps, are often controlled using a variable speed drive having a frequency converter which provides controlled voltage to a motor. The shaft of the motor is connected to the pump thereby providing mechanical power for the pumping action.

[0005] Known publications for detecting cavitation include US patent 6,757,665, in which it is suggested to observe the frequency spectrum of stator current of the motor rotating the pump using a separate current transducer. This method is based on measured values to which some known features appear when the pump is near cavitation or is cavitating.

The method does not take into consideration the operating point or the pumping process itself.

[0006] Another approach for detecting cavitation is a model-based solution. In this approach a system model is formed for the system starting from electrical or mechanical parameters of the motor and pump. The inputs for the model are, for example, motor currents, voltages and frequency. As proposed in US patent 6,918,307, the pump model estimates the produced volumetric flow rate and head it can deliver. If the volumetric flow rate and the pressure difference (head) are measured simultaneously, error variables can be determined for both quantities. Based on the error variables, the abnormalities in the pump behaviour can be determined and possible malfunctions can be diagnosed. This method suffers from the additional measurements, which are required for producing the error variables. The measurements require additional transducers, which cause further expenses due to costs for installation, maintenance and cabling. The transducers are also a potential risk as to reliability of the whole system, since the transducers are mechanical components which are subjected to possibly harsh conditions. A failure of one transducer makes the detection of cavitation impossible. Further the transducers are difficult to change, which causes possibly long downtimes in the pumping process.

[0007] US patent 6,663,349 discloses a method for detecting cavitation or likelihood of the pump cavitation. In this method the net positive suction head required ($NPSH_R$) and the net positive suction head available ($NPSH_A$) are determined from values obtained from sensors. The net positive suction head required and the net positive suction head available are compared and the likelihood of cavitation is determined on the basis of the comparison. A problem relating to this method is also the requirement for additional measurement sensors or transducers.

BRIEF DESCRIPTION OF THE INVENTION

[0008] An object of the present invention is to provide a method and a system for implementing the method so as to solve the above problems. The objects of the invention are achieved by a method and a system which are characterized by what is stated in the independent claims. The preferred embodiments of the invention are disclosed in the dependent claims.

[0009] The invention is based on the idea of forming one or more indicators relating to likelihood of pump cavitation or reverse flow in a pump based on estimated values obtained directly from a frequency converter which drives the pump. In particular these indicators are formed from estimated torque produced by the motor and from estimated rotational speed of the motor. The detection of cavitation also requires some parameters relating to the pump process and to the pump used.

[0010] An advantage of the method and apparatus of the invention is that cavitation, near cavitation or reverse flow situations can be detected reliably without any additional measurements. The present invention thus eliminates the need of sensors measuring the process variables.

[0011] According to the preferred embodiments of the invention, the detection of cavitation or the likelihood of cavitation is performed using multiple indicators simultaneously, which indicators are all based on the estimated values from the

frequency converter. The use of more than one indicator makes the detection even more reliable basically without any extra costs.

[0012] The invention also relates to a frequency converter that is adapted to carry out the method of the invention.

5 BRIEF DESCRIPTION OF THE DRAWINGS

[0013] In the following the invention will be described in greater detail by means of preferred embodiments with reference to the accompanying drawings, in which

- 10 Figure 1 shows a frequency converter driven pump system,
- Figure 2 is a block diagram of the present invention,
- Figures 3a and 3b are graphs relating to determination of an operation point of a pump,
- Figures 4 and 5 show measurement results relating to the present invention,
- Figure 6 shows a pump in connection with process variables,
- 15 Figure 7 shows AC RMS levels of torque and rotational speed estimates as a function of volumetric flow, and
- Figure 8 shows measured and estimated pressure ratio as a function of volumetric flow.

DETAILED DESCRIPTION OF THE INVENTION

20 **[0014]** Figure 1 shows the basic structure of a pump driven by a frequency converter. The frequency converter 2 is connected to a supplying network 1 via three-phase cabling. The frequency converter is further connected to a motor 3, which in turn is mechanically connected to a pump 4. The frequency converter controls the rotation of the motor and the pump in a desired manner. The frequency converter is further connected to an automation system via interface 5. The automation system may be a higher-level controller controlling the process to which the pump is connected. Thus

25 the automation interface gives the instructions for the operation of the pump which the frequency converter tries to implement. In Figure 1, all measurements from the system are omitted and the motor and the pumping process are controlled in a sensorless manner.

[0015] Figure 2 is a block diagram representing the procedures carried out in the present invention. In the present invention the frequency converter provides estimates for torque T_{est} and for rotational speed n_{est} . Modern frequency

30 converters are equipped with control systems, which use electrical motor models. Among other values, these motor models use and produce estimated produced torque and rotational speed of the motor. Some control schemes also take torque as a reference value enabling thus direct torque control.

[0016] According to the present invention the frequency converter, which controls the pump, provides torque estimate T_{est} and rotational speed estimate n_{est} of the motor. Since the motor is mechanically connected to the pump, estimates

35 describe also the pump operation. As mentioned, these values are readily available in the control system of the frequency converter.

[0017] Further in the present method, one or more features, which indicate cavitation or likelihood of the cavitation of the pump and/or reverse flow of the pump, are formed from the provided estimates. The features, which are obtainable from the estimated values, are explained in detail below.

40 **[0018]** When one or more of the indicating features have been formed, cavitation or likelihood of the cavitation of the pump controlled with the frequency converter is detected. Reverse flow may also be detected with or without detection of the cavitation. The detection is carried out in Figure 2 in a decision making block 21. The decision making block 21 receives as inputs one or more features which are calculated on the basis of the estimated torque and rotational speed. In Figure 2 the number of inputted features is four.

45 **[0019]** According to an embodiment of the invention, a feature indicating cavitation or likelihood of cavitation and/or reverse flow is formed by comparing an RMS value of alternating component (AC) of the torque estimate with the normal RMS value of alternating component of the torque estimate. Figure 2 shows this indicating feature as Feature1. The calculation of this feature begins by band pass filtering the estimated torque T_{est} in block 22. The pass band of the band pass filter is, for example, as indicated in Figure 2 from 0 to 10 Hz. Thus the band pass filtered value T_{ac} comprises low

50 frequency alternating component content of the estimate, but not the DC component. The AC component T_{ac} is further fed to block 23, which calculates effective value or RMS value of the AC component T_{ac} , RMS.

[0020] The AC component of the estimated torque can be calculated as follows. Simultaneously, also the DC component is calculated, and its use in the method is explained in detail further below. The DC component can be removed from the sample data of x (x being general representation of any variable, such as torque) by, for example with a high pass filter having a very low cut-off frequency. Alternatively, an average can be calculated from the sample data $[x_0 \dots x_{n-1}]$,

55 which corresponds to the value of DC component at the time of sampling

$$x_{dc,est} = \frac{1}{n} \sum_{i=0}^{n-1} x_i$$

[0021] Then for the AC component of variable x

$$x_{ac} = [x_0 \dots x_{n-1}] - x_{dc,est}.$$

[0022] The effective value or RMS value of the AC component can be calculated with the general formula for the RMS value (Root Mean Square)

$$x_{ac,RMS} = \sqrt{\frac{1}{n} \sum_{i=0}^{n-1} x_{ac,i}^2} = \sqrt{\frac{x_{ac,0}^2 + x_{ac,1}^2 + \dots + x_{ac,n-1}^2}{n}}.$$

[0023] Once the RMS value of the AC component is calculated, it is compared with normal value of RMS value of the AC component $T_{ac, N}$. The normal or typical value of RMS of the AC component may be detected and stored before the use of the invention or it can be detected and stored during the use of the method in circumstances in which the pump is certainly operating in normal operation point.

[0024] The comparison between the normal RMS value and the calculated RMS value is carried out in block 24 in Figure 2 and the comparison is in the form of ratio between a measured RMS value and the normal RMS value. Figure 4 shows measurement results indicating this calculated ratio as a function of ratio of net positive suction head available and net positive suction head required ($NPSHA / NPSH_R$) which is referred to in this text as the pressure ratio.

[0025] To avoid cavitation the pressure ratio should be at least above one since $NPSH_R$ represents a situation, in which the head produced by the pump has dropped by 3%. As seen from Figure 4, the ratio $T_{ac, RMS} / T_{ac, N}$ starts growing exponentially as the pressure ratio decreases. The measured data points and the pressure ratio are measured using sensors to show the usability of the method to indicate the cavitation. The data points are measured using different volumetric flows as indicated in the legend of Figure 4. Further an exponential fit curve is drawn in Figure 4.

[0026] The ratio $T_{ac, RMS} / T_{ac, N}$ grows when the pump is near cavitation due to the fact that, when cavitation starts or reverse flow occurs, the operation of the pump becomes discontinuous. This is seen in the shaft of the pump as growth of torque ripple (AC component). In other words, the power required by the pump oscillates. Consequently, the RMS value of the low frequency AC component increases, when compared to the normal situation. Thus the cavitation or reverse flow can be determined on the basis of Feature1 presented in Figure 2.

[0027] According to another embodiment of the invention, an indicating feature is formed by comparing the RMS value of alternating component of the rotational speed estimate with the normal value of alternating component of the rotational speed estimate. The rotational speed estimate can be used in similar manner to estimate the cavitation or reverse flow as the torque estimate. With reference to Figure 2, the estimated speed nest is fed to a band-pass filter 25. The AC component of the estimate n_{ac} is further fed to RMS block 26, which calculates the RMS value of the alternating component $n_{ac,RMS}$. The RMS or effective value of the alternating component is compared with normal RMS value of the AC component of the rotational speed $n_{ac,N}$ in block 27. The result of this comparison is denoted in Figure 2 as Feature2, which can be used to detect cavitation of the pump or reverse flow in the pump.

[0028] As can be seen from Figure 2, the estimated rotational speed and estimated torque are treated similarly. As explained above, the torque fluctuates when operation of the pump is abnormal. Similarly the rotational speed fluctuates or oscillates, and this can be seen as higher values of RMS of the alternating component.

[0029] The mathematical calculations for estimated torque and estimated speed are similar for obtaining the features indicating abnormal pump operation, and therefore the calculations are omitted for estimated speed.

[0030] The normal operating point in which both normal value for alternating component of torque and rotational speed are determined, can be, for example a situation, in which the pressure ratio is over 1.5. In operation points where the pressure ratio is above 1.5, the AC component is considerably smaller than in near cavitation situations or reverse flow situations. The normal value has to be determined since the RMS levels depend largely on application, thus each pump and each installation has its own characteristics and the measured RMS values do not have any absolute limits for comparison.

[0031] Figure 5 shows measurement results of ratio between the RMS value of alternating component of estimated rotational speed and the normal value of alternating component of rotational speed as a function of pressure ratio. The measurement results are for the same pump as the results in Figure 4. As can be seen from Figure 5, the calculated ratio increases as the pressure ratio approaches one. This means that as the pump approaches cavitation or reverse flow situation, the rotational speed starts to oscillate. Thus Feature2, as indicated in Figure 2, can be used for detecting cavitation or likelihood of cavitation.

[0032] Figure 7 shows measurement results in which AC RMS levels of both the torque estimate and the rotational speed estimate are plotted as a function of volumetric flow. Figure 7 has also a vertical line showing the minimum volumetric flow as recommended by the pump manufacturer and a curve showing the efficiency of the pump as a function of volumetric flow. In tests resulting to Figure 7 the flow of the pump was reduced by a valve on a pressure side such that the process was led to a reverse flow situation. As can be seen, the AC levels of the estimates start to increase as the volumetric flow is reduced to the minimum flow. Simultaneously, the efficiency of the pump also drops. From Figure 7 it is evident that the AC levels of the produced estimates give clear indication of cavitation resulting from the reverse flow of the pumped liquid.

[0033] According to an embodiment of the invention, an indicating feature is formed by calculating estimated volumetric flow in the pump from the direct components of the torque estimate and rotational speed estimate using a pump model. After the estimated volumetric flow is calculated, it is compared with minimum allowable volumetric flow. The result of this comparison is used as an indicating feature for detecting the likelihood of cavitation or reverse flow of the pumped media. Especially, this comparison is used in determining the likelihood of reverse flow.

[0034] In Figure 2 the feature relating to the minimum flow is marked as Feature4. The torque estimate T_{est} and a rotational speed estimate nest produced by the frequency converter are low-pass filtered in blocks 28 and 29 to obtain a direct component of the torque estimate $T_{dc, est}$ and a direct component of the rotational speed estimate $n_{dc, est}$. Thus the direct components (DC) refer to low-pass filtered values i.e. to levels, in which the torque estimate and the rotational speed estimate are. Alternatively, DC values of the estimates can be calculated by determining their mean values.

[0035] After the DC values of the estimates are calculated, the DC values $T_{dc, est}$ and $n_{dc, est}$ are fed to a block 30 containing a pump model, which calculates from the inputted estimates the estimated volumetric flow Q_{est} . The pump model incorporates a database or similar to which data relating to the pump can be stored. The stored data includes Q-P graph of the pump or selected data points from the graph. An example of a Q-P graph is shown in Figure 3b in which power of the pump (P) and volumetric flow (Q) are plotted with different diameters of the pump. Once the power delivered to the pump is known, the graph included in the pump model can estimate the volumetric flow.

[0036] The estimated power $P_{dc, est}$ delivered to the pump is calculated from the estimated DC levels of the rotational speed and torque with

$$P_{dc, est} = 2\pi \frac{n_{dc, est}}{60} \cdot T_{dc, est} \cdot$$

[0037] Since the Q-P graph is usually known for only one rotational speed, it must be transformed using affinity laws to correspond with the current rotational speed

$$Q = \frac{n_{dc, est}}{n_{nom}} \cdot Q_{nom}$$

$$P = \left(\frac{n_{dc, est}}{n_{nom}} \right)^3 \cdot P_{nom}$$

where index $_{nom}$ refers to nominal speed at which the graphs are given. Alternatively affinity laws may be applied to the power consumed by the pump $P_{dc, est}$ so that number of mathematical calculations is reduced.

[0038] When the estimated volumetric flow Q_{est} is compared with the minimum allowable volumetric flow Q_{min} , which is provided by the pump manufacturer and stored in the pump model, it can be easily determined if the pump is operating

in its normal operating area. The minimum allowable flow Q_{min} depends on the rotational speed of the pump. Therefore the minimum allowable volumetric flow should be calculated using affinity laws at the time of comparison to take into account the operating speed. Commonly a reverse flow occur, if the volumetric flow is below 30 - 70 % of the nominal volumetric flow. Reverse flow causes similar sudden pressure changes and discontinuities in the flow as cavitation. Thus the estimated volumetric flow can be used as a feature indicating a possibility of cavitation or reverse flow situation in a pump.

[0039] Another feature indicating the likelihood of cavitation or reverse flow situation according to an embodiment of the invention is formed from the comparison of the net positive suction head required ($NPSH_R$) and the net positive suction head available ($NPSH_A$) which are calculated on the basis of estimated torque, estimated rotational speed and system parameters. The ratio between the two is called a pressure ratio.

[0040] As seen from Figure 2, the calculation of the pressure ratio is carried out on the basis of the estimated volumetric flow Q_{est} in block 31, and the procedure for determining the estimated volumetric flow is described above. When the estimated volumetric flow is determined, $NPSH_R$ can be read from a graph provided for the pump in question. Such a graph is shown in Figure 3a, in which $NPSH_R$ is plotted as a function of volumetric flow (Q-NPSH_R curve). As in Figure 3b, the curves are provided for different pump sizes.

[0041] Since the curves are provided only for the nominal rotational speed, affinity laws must again be used to gain the $NPSH_R$ for the rotational speed in question

$$NPSH_R = \left(\frac{n_{dc,est}}{n_{nom}} \right)^2 NPSH_{R,nom}.$$

[0042] When compared with other affinity transformations, the suction head required by the pump has a minimum value and the value obtained with affinity transformation cannot be lower than the minimum value. If the volumetric flow produced by the pump is so low that it does not appear on the manufacturers Q-NPSH_R curve, the situation must be considered to be a situation where the AC levels of the estimates may have increased due to cavitation which is formed of the reverse flow. Correspondingly, if the volumetric flow produced by the pump is so high that it does not appear on the manufacturers Q-NPSH_R curve, cavitation may occur increasing the AC levels of the estimates.

[0043] For the pressure ratio to be calculated, also the net positive suction head available is to be determined. $NPSH_A$ can be estimated with

$$NPSH_A = H_s + \frac{p_0 - p_f(Q) - p_v(Temp)}{\rho(Temp)g} + \frac{v_0}{2g}$$

where H_s is the suction head of the pump, p_0 is the pressure of the environment, p_v is the evaporating pressure of the pumped liquid, p_f is an estimate of the pressure losses on the suction side, v_0 is the flow rate in the top of the container, g is the gravitation constant, Temp is the temperature of the fluid and ρ is the density of the fluid.

[0044] Figure 6 shows a pump 61 and a container 62 having the liquid to be pumped, and the level of the liquid is at height H_s from the pump 61. It is possible to give all the data required by the above equation to the pump model. The data should be given also with possible variation ranges. Since the data required by the equation can not be very exact, the $NPSH_A$ can be reliably estimated with

$$NPSH_A = H_s + \frac{p_0 - kQ^2 - p_v}{\rho g}$$

where a constant k represents the flow resistances on the suction side and the variables are given according the worst case situation.

[0045] For the calculation of the pressure ratio it is therefore required

- Rotational speed and torque estimates from the frequency converter nest, Test
- Curves representing operation of the pump in question and pressure requirements (Q-P and Q-NPSH_R)

- The properties of the pumped fluid for determining the evaporating pressure P_v and density ρ
- Suction head of the pump H_s
- Pressure of the surroundings p_0 in case the liquid is in a pressurized container
- Estimate of the flow losses in the suction side k .

[0046] Of the listed parameters, the static head H_s is the most important one.

[0047] Once the pressure ratio is calculated, it can be used as a feature indicating likelihood of cavitation, cavitation or reverse flow of the pumped liquid. As mentioned above, the pressure ratio should be at least above one. The required pressure ratio, however, depends on the pump used. The required pressure ratio can be determined on the basis of the operation principle of the pump (radial or axial flow) or the variable reflecting the type of the pump called suction specific speed N_{ss} , which is defined as

$$N_{ss} = \frac{N \cdot \sqrt{Q}}{(NPSH_r)^{0.75}}$$

where N is the rotational speed of the pump [min^{-1}], Q is the volumetric flow [m^3/h] in the best efficiency point of the pump characteristics. If the nominal suction speed of the pump is small (usually a radial flow pump), pressure ratio of 1.5 can be used. In connection with suction specific speeds (usually an axial flow pump) the pressure ratio may have values up to four, meaning that the available suction head must be at least four times higher than the required suction head. Once the pump type is known, the estimated pressure ratio gives clear indication on the operation point of the pumping process. This estimated pressure ratio is shown as Feature3 in Figure 2.

[0048] Figure 8 shows measured and estimated pressure ratio as a function of volumetric flow. It can be seen that the estimated values of the pressure ratio correspond to the measured ones, although there is an error in the volumetric flow estimation.

[0049] In Figure 2 four indicating features are fed to a decision making block 21. However, the decision making block may receive any number of indicating features, including one, two, three or the illustrated four features. The block 21 comprises a set of rules, fuzzy logic or similar means for making a decision and outputting it. The decision may be in the form of a number, which indicates the likelihood or severity of cavitation or reverse flow of the liquid. For example, the output 33 of block 21 may be an integer from 1 to 10, where 1 in the output depicts that operation is in the normal operating area, i.e. all features inputted to the decision making block provide indicators of the operation in a normal state. When some indicators begin showing small indications of cavitation or likelihood of the cavitation, the output 33 from the block 21 starts growing, and as all the indicators show signs of cavitation or reverse flow, the block 21 gives 10 to its output.

[0050] It is clear for the skilled person that the decision making block may operate in different ways. The output 33 of the decision making block may be led to an upper control system for further operations, including for a change of the operation state and for giving alarms, for example. With reference to Figure 1, the output 33 of the decision making block may be led to the upper control system via interface 5.

[0051] The decision making block 21, the pump model 30 and the parameters stored for the operation are preferably implemented in the frequency converter controlling the pump. Thus the method of the invention is preferably carried completely out in a frequency converter, for example, by means of software. The required calculations and the stored data may also be situated in the upper control system, whereby the frequency converter provides only estimated rotational speed and torque, and possibly the pump head and flow rate to the upper control system.

[0052] It will be obvious to a person skilled in the art that, as technology advances, the inventive concept can be implemented in various ways. The invention and its embodiments are not limited to the examples described above but may vary within the scope of the claims.

Claims

1. A method in accordance with a pump controlled with a frequency converter, **characterized in that** the method comprises the steps of
controlling the pump (4) with a frequency converter (2), the frequency converter (2) feeding a motor (3) connected to drive the pump,
providing a torque estimate (T_{est}) and/or a rotational speed estimate (n_{est}) of the motor from the frequency converter, forming one or more features (Feature1, Feature2, Feature3, Feature4) indicating cavitation or likelihood of cavitation

of the pump (4) and/or reverse flow of the pump (4) using the provided estimates (T_{est} , n_{est}) and detecting cavitation or likelihood of cavitation of the pump and/or a reverse flow of the pump from one or more of the formed features (Feature1, Feature2, Feature3, Feature4).

- 5 **2.** A method according to claim 1, **characterized in that** an indicating feature (Feature1) is formed by comparing an RMS value of alternating component of the torque estimate ($T_{ac,RMS}$) with the normal RMS value of alternating component of the torque estimate ($T_{ac,N}$).
- 10 **3.** A method according to claim 1, **characterized in that** an indicating feature (Feature2) is formed by comparing an RMS value of alternating component of the rotational speed estimate ($n_{ac,RMS}$) with the normal RMS value of alternating component of the rotational speed estimate ($n_{ac,N}$).
- 15 **4.** A method according to claim 1, **characterized in that** an indicating feature (Feature4) is formed by calculating an estimated volumetric flow (Q_{est}) from the direct components of the torque estimate ($T_{dc,est}$) and the rotational speed estimate ($n_{dc,est}$) using a pump model and comparing the estimated volumetric flow (Q_{est}) with an allowable minimum volumetric flow (Q_{min}) that is transformed to the present rotational speed.
- 20 **5.** A method according to claim 1, **characterized in that** an indicating feature (Feature3) is formed by calculating net positive suction head required ($NPSH_R$) from the direct components of the torque estimate ($T_{dc,est}$) and the rotational speed estimate ($n_{dc,est}$) using a pump model, calculating net positive suction head available ($NPSH_A$) from the system parameters and comparing the net positive suction head available ($NPSH_A$) with the net positive suction head required ($NPSH_R$).
- 25 **6.** A method according to any one of claims 1 to 5, **characterized in that** the calculation of RMS value of alternating component of the torque estimate ($T_{ac,RMS}$) and of the rotational speed estimate ($n_{ac,RMS}$) comprises the steps of separating low-frequency alternating components from the estimate to obtain separated alternating component values (T_{ac} , n_{ac}), calculating RMS value from the separated alternating component values.
- 30 **7.** A method according to any one of claims 1 to 6, **characterized in that** the direct components of the torque and rotational speed estimates are determined by low-pass filtering or by calculating the mean values of the torque estimate and rotational speed estimate, respectively.
- 35 **8.** A method according to any one of claims 1 to 7, **characterized in that** the calculation of estimated volumetric flow (Q_{est}) comprises the steps of calculating estimated power consumption ($P_{est,dc}$) of the pump from the direct components of the torque estimate ($T_{dc,est}$) and rotational speed estimate ($n_{dc,est}$), and determining from the given pump parameters the estimated volumetric flow (Q_{est}) on the basis of the estimated power consumption ($P_{est,dc}$).
- 40 **9.** A method according to any one of claims 1 to 8, **characterized in that** the calculation of net positive suction head required ($NPSH_R$) comprises the steps of calculating estimated power consumption ($P_{est,dc}$) of the pump from the direct components of the torque estimate ($T_{dc,est}$) and rotational speed estimate ($n_{dc,est}$), determining from the given pump parameters the estimated volumetric flow (Q_{est}) on the basis of the estimated power consumption ($P_{est,dc}$), and determining from the given pump parameters the estimated positive suction head required ($NPSH_R$) on the basis of the estimated volumetric flow (Q_{est}).
- 50 **10.** A system in accordance with a pump controlled with a frequency converter, **characterized in that** the system comprises a frequency converter (2) controlling the pump (4), the frequency converter (2) feeding a motor (3) connected to drive the pump, means for providing a torque estimate (T_{est}) and/or a rotational speed estimate (n_{est}) of the motor from the frequency converter, means for forming one or more features (Feature1, Feature2, Feature3, Feature4) indicating cavitation or likelihood of cavitation of the pump (4) and/or reverse flow of the pump (4) using the provided estimates (T_{est} , n_{est}) and

EP 2 196 678 A1

means for detecting cavitation or likelihood of cavitation of the pump and/or reverse flow of the pump from one or more of the formed features (Feature1, Feature2, Feature3, Feature4).

5 11. The system according to claim 10, **characterized in that** the system is incorporated in a frequency converter.

12. A frequency converter, **characterized in that** the frequency converter is adapted to carry out the method according to claims 1 to 9.

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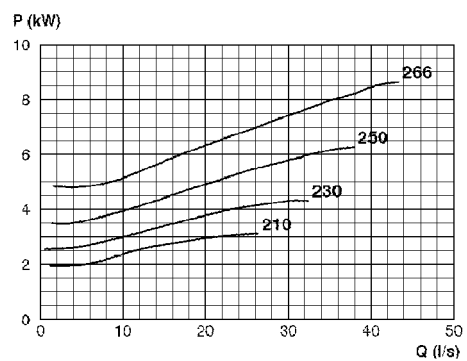
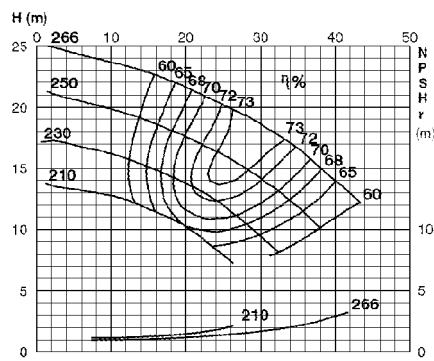
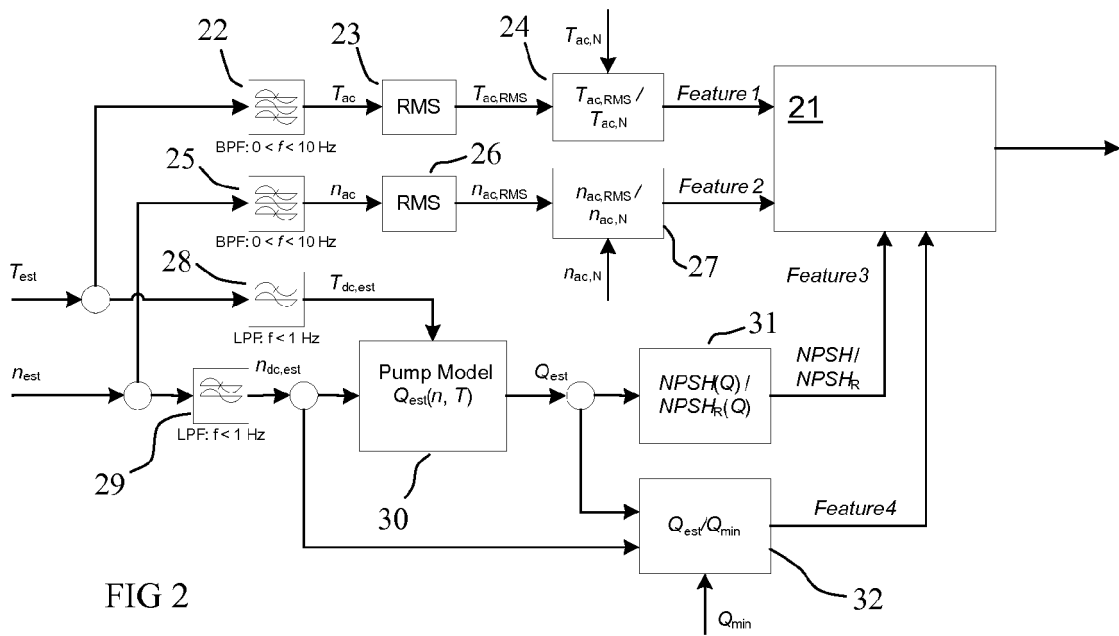
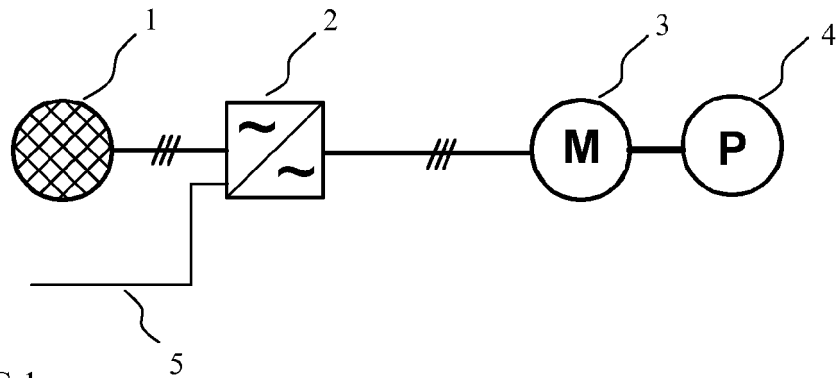
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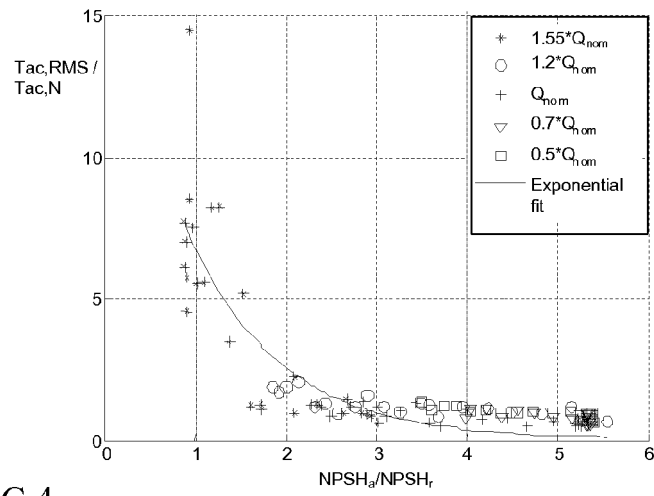


FIG 4

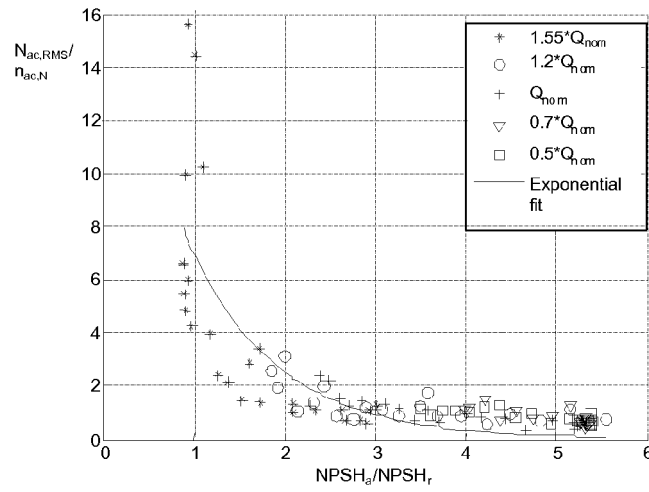


FIG 5

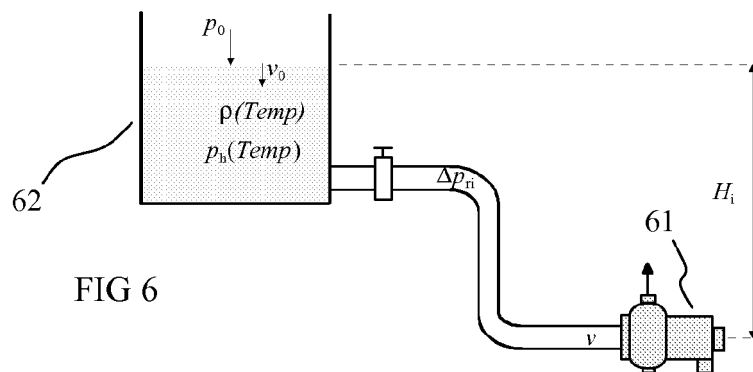


FIG 6

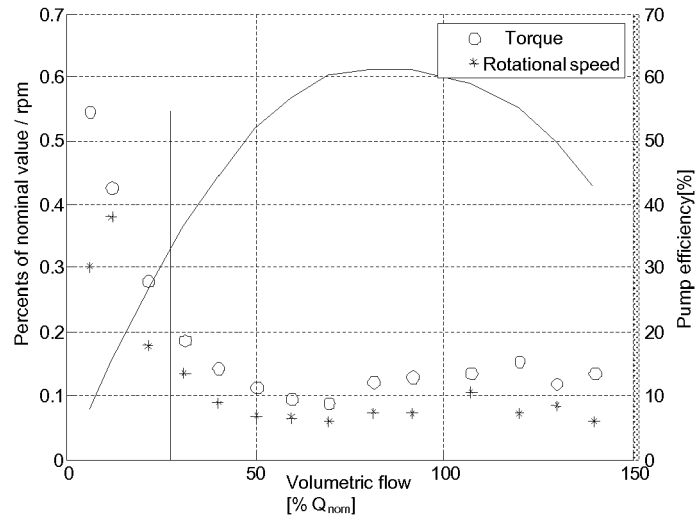


FIG 7

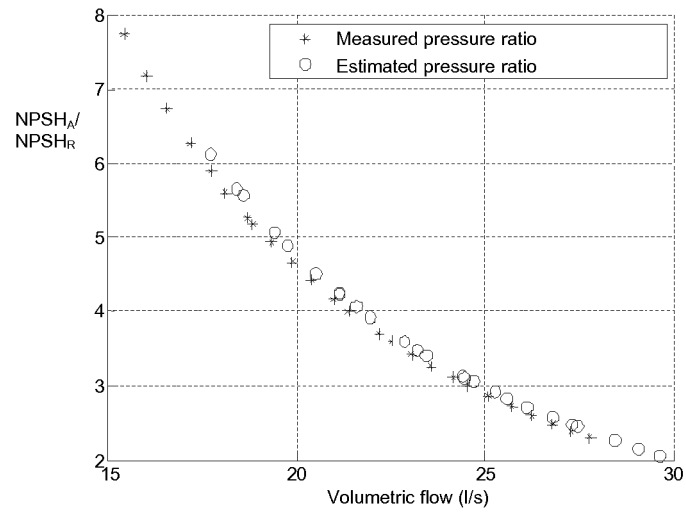


FIG 8



EUROPEAN SEARCH REPORT

Application Number
EP 08 17 1028

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			F04D
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 21 April 2009	Examiner Di Giorgio, F
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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21-04-2009

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