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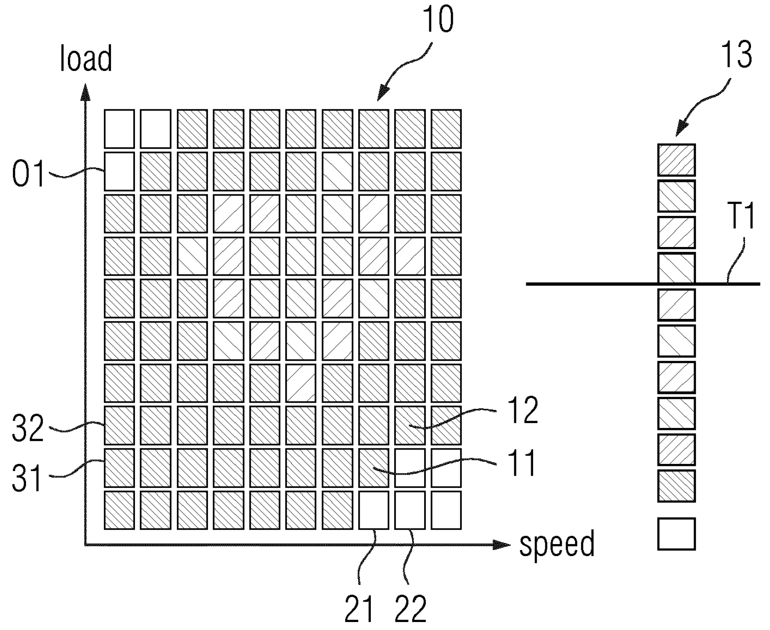
(54) METHOD FOR CONTROLLING AND/OR MONITORING AN OPERATION OF A PUMP SYSTEM

(57) A, preferably computer-implemented, method for controlling and/or monitoring an operation of a pump system (1), wherein the pump system (1) comprises a pump (2) and a motor (3) that is connected to drive the pump (2), the method comprising the steps of: determining a plurality of cavitation indicators (10), wherein each cavitation indicator (11, 12) indicates cavitation or a likelihood of cavitation of the pump (2) for different operating ranges (21, 22, 31, 32), wherein each operating range (21, 22, 31, 32) is given by a combination of values of a first and a second motor characteristic.

FIG 3



EP 4 361 445 A1

Description

TECHNICAL FIELD

[0001] The present disclosure relates to the field of pump systems and the control and/or monitoring of the same.

BACKGROUND

[0002] When operating pumps, the undesirable phenomenon of cavitation occurs when the suction pressure is too low and this leads to boiling bubbles in the pumped medium. At the very least, unplanned work operations will be needed to maintain the pump system, e.g., replace the impeller and/or housing of the pump.

[0003] From European patent application no. EP 21200024.4 it is known to measure the magnetic stray flux of an electric machine and to feed this magnetic stray flux into a simulation model of the electric machine. The simulation model determines operating parameters of the electric machine and analyses these operating parameters to identify faults in the electric machine.

[0004] From European patent application EP 2 196 678 A1 a method and a system in accordance with a pump controlled with a frequency converter has become known. Therein, one or more features indicating cavitation or likelihood of cavitation of the pump are determined in order to detect cavitation or likelihood of the cavitation of the pump from one or more of the formed features.

[0005] From US patent application US 2016/010639 A1 a sensorless technique for pump differential pressure and flow monitoring has become known.

[0006] From European patent application EP 1 198 871 A1 a malfunction detection of a machine driven with a variable rotational speed by an electric motor, whereby the motor is switched off when a malfunction occurs has become known. o this end, the machine and/or a unit actuated by the machine runs through all possible operating states in which the operating values of the motor recorded during the learning function are, in their association with the machine and/or the unit driven by the motor, stored, brought forward and used for monitoring malfunctions.

SUMMARY

[0007] Cavitation may lead to erosion of the impeller and/or housing and thus to the destruction of the pump. Prolonged operation of the pump during cavitation must be avoided at all costs.

[0008] It is thus desired to prevent interruptions (and therefore expensive downtimes) in a plant and ensure optimal motor load. It is also desired to prevent faults in the system and recognize impending failures before they happen.

[0009] It is thus an object to enable a more accurate assessment of the operating status, possible changes and the distance of the operating point to an unwanted operation with cavitation.

[0010] The object is achieved by the subject matter of the independent claims. Advantageous embodiments are provided in the dependent claims.

BRIEF DESCRITPTION OF THE DRAWINGS

[0011]

Figure 1	shows a pump system.
Figure 2	shows another pump system.
Figure 3	shows a visualization of cavitation indicators for different operating ranges.
Figure 4	shows a pump system and exemplary method steps.
Figure 5	shows visualizations of a first and a second operating point and a curve of transient operating points between the first and second operating point.
Figure 6	shows visualizations of cavitation indicators changing during the operation of the pump system.
Figures 7 to 15	show exemplary method steps.

DETAILED DESCRIPTION

[0012] In Figure 1 a pump system is shown. Pumps may be used in production plants within the process industries for conveying liquid fluids. A pump 2 may be combined with an electrical motor 3 driven by 3-phase alternating current (AC) from a converter 6. An actuator and/or sensor 4 in the pump system may together with the pump serve for generating and monitoring a defined (controlled) flow of a liquid. A control unit 5 may serve for the automation pump system. To that end, the control unit may comprise control functions. For example, in the case of centrifugal pump, a PI flow control takes place via a downstream, continuously adjustable proportional valve. The pump itself is controlled by the control unit (direct starter), e.g., SIMOCODE proffered by SIEMENS, controlled. A control device 7, such as an industrial PC, with a display may be coupled to the control unit 5. Motor characteristics, status values of the valve and/or measurement values form one or more sensors of the pump system, e.g., in the form of data, may be obtained by the operating device 7. The operating device 7 may then serve for further processing and/or visualizing the data obtained.

[0013] As shown in Figure 1, an actuator in the form of a valve may ensure that no liquid runs through the pump when it is switched off. The valve may also serve for controlling the pump load. The pump load is the back pressure and/or resistance to flow of fluids that the pump must overcome to force the fluid to flow through a pipeline, drill string, etc. Furthermore, in order to control the pump system, the flow rate, the inlet and outlet side pressures and/or the temperature of the liquid medium may be measured. A binary liquid detector is used to determine whether there is any liquid at all.

[0014] A plurality of characteristics of the pump system may be measured using one or more sensors. Hence, a plurality of sensor signals may be measured. For example, the electrical active power of the motor 3, the flow rate of the pumped medium, the input pressure (suction pressure) of the pump 2, the outlet pressure (delivery pressure) of the pump, and/or a binary signal whether the motor is running may be determined. Additionally for cavitation monitoring the temperature of the pumped medium may need to be determined. In addition, in case of speed-controlled pumps, the pump speed may be determined. And in case a converter 6 supplies the (shaft) power of the motor 3 the mechanical power may be determined. Further characteristics of the motor 3 may comprise nominal speed, nominal power, nominal efficiency. Characteristics of the pump 2 may comprise a minimum flow, a nominal flow, a delivery characteristic (H/Q characteristic), a power curve (P/Q curve), and/or an efficiency curve. Further characteristics may be determined, e.g., in case of a fluid other than water, a fluid specific vapor value may be determined.

[0015] A fault in the operation of a pump 2 may pose serious threats. Different monitoring and/or control functions may be relevant for the pump system dependent on the appropriate reaction and urgency. Diagnoses such as an acute blockage, dry running and/or cavitation may be reported immediately to the plant operator as an alert, e.g., an alarm, since such operating conditions can quickly damage the pump. An automatic emergency stop of the pump and/or closing of a valve may then be initiated. In particular operating states such cavitation may lead to damage to the pump after some time, but as a rule one still has to react relatively quickly. In this case, the diagnostic information may be reported to both the plant operator and the maintenance engineer.

[0016] For example, in case the conveyed liquid is flammable, an explosive atmosphere can be built up inside the pump by the gas/vapor phase together with oxygen (e.g. from air ingress). If cavitation occurs the material of propellers, valve discs or impellers is literally eaten away. In the case of machines at risk of cavitation, particularly hard and strong materials must therefore be used. Cavitation often results in a corrosive attack. Protective layers are removed and the roughened, porous surface offers optimal conditions for corrosion. Criteria for the occurrence of cavitation are mainly the cavitation number and the required net suction lift. The dimensionless cavitation number σ is a measure of when in a fluid cavitation occurs.

[0017] To avoid cavitation, the cavitation number σ should be chosen as large as possible. The following measures reduce the cavitation tendency: avoid low pressures, avoid temperatures close to the boiling point of fluids, use thin blade profiles, choose a small angle of attack for the blades, avoid abrupt deflections of the flow, round off the leading edge.

[0018] Another criterion is the NPSH value (Net Positive Suction heads). The NPSH value corresponds to the (pressure) energy of a liquid column under the existing operating conditions on connection flange. The value is always positive. A distinction is made between two NPSH values: NPSHA (Net Positive Suction Head Available): This is the present pressure of the plant at operating conditions as a head difference. NPSHR (Net Positive Suction Head Required): This is the pressure required to operate the pump as a height difference.

[0019] In Figure 2 another pump system is shown. Therein, a motor 3 drives the pump 2, wherein the motor is directly powered by a 3-phase alternating current (AC) mains line. For monitoring the operation of the pump system measurement values from one or more sensors, e.g., operatively coupled to the motor may be captured. Furthermore, motor characteristics may be determined. Said values may be read out from the motor or from a separate sensor, e.g., attached to the motor. For example, a control device 7, such as an industrial PC, may be communicatively couple to the motor and/or separate senor. A pump and pump system may have one or more operating ranges. As described herein a pump or pump system may thus be operated in one or more of these operating ranges. For example, the pump system may comprise one or more acceleration phase and/or deceleration phase of the pump and/or motor, e.g., during the ramp-up and/or ramp-down of the motor/pump. In general, the pump (system) may have an allowable operating range which comprises the operating ranges. The operating ranges may be given by given by a combination of values of a first and second motor characteristic.

[0020] Now turning to Figure 3, a plurality of cavitation indicators is shown. Therein each cavitation indicator indicates cavitation or a likelihood of cavitation of the pump for different operating ranges, wherein each operating range is given by a combination of values of a first and a second motor characteristic. A cavitation indicator may take on discrete values. As shown in Figure 3 the cavitation indicator may take on 10 values. In addition, a value of the cavitation indicator may be reserved for a case no motor characteristics are available or for other reasons no cavitation indicator could be determined. For example, the motor characteristics may be motor speed, e.g., speed values, and motor load, e.g., load values. Thus, speed intervals (comprising speed value ranges) and load intervals (comprising load value ranges) may be determined which together form operating ranges. Therein an operating range may be given by associating a speed interval 21, 22 with a load interval 31, 32. As shown in Figure 3 this may result in a cavitation indicator for 11 for a pairing of interval 11 with interval 31 and a second cavitation indicator 12 for the paring of interval 22 with interval 32. The allowable operating range may thus have cavitation indicators assigned to each or at least a plurality of the operating ranges. The resolution or width of the operating ranges may be chosen based on the frequency, update rate or sample rate of the speed values or load values available.

[0021] As shown in Figure 3 the cavitation indicators may be visualized, e.g., in the form of a heatmap. The visualization may be presented to a user, e.g., on a display of the control device 7. A heat map is created from the data at different operating points. This heatmap does not have to be completely filled.

[0022] Thereby, a more accurate assessment of the operating status, possible changes and the distance of the operating point to an unwanted operation with cavitation can be determined.

[0023] The cavitation indicator may be determined based on pump vibrations and/or magnetic flux. Hence, this may require a detection of pump vibrations and/or magnetic flux, e.g., in addition to the speed and load of the driving motor. The vibrations and/or magnetic flux (values) can be obtained, for example, via a sensor, such as the SIMOTICS Connect 400, attached to the pump and/or motor, using vibration and magnetic field sensors. Furthermore, the temperature of the conveyed medium may be measured or estimated by temperature measurement of the fluid or in the vicinity thereof. Characteristic values for the cavitation activity may then be determined from the vibration and/or magnetic flux signal.

[0024] Cavitation is the emergence and subsequent abrupt disappearance of vapor bubbles in the flow of a liquid. During the operation of pumps, such vapor bubbles can arise as a result of (locally) excessive flow speeds: the higher the speed, the lower the pressure in the liquid. If the pressure falls below the vapor pressure of the liquid, vapor bubbles form. If the pressure increases again in the direction of flow, the bubbles collapse: the gas in the bubble suddenly condenses. This implosion of the bubble results in so-called "jet impacts". Enormous pressure and temperature peaks occur, which are usually many times higher than the load limits of the material of the pump blade or pump wall. The surface of the blade or wall is permanently damaged and eventually destroyed. In addition, even a small amount of cavitation reduces the efficiency (head) of the pump. Full cavitation can even lead to a complete collapse of production.

[0025] The cavitation indicator(s) may be determined based on vibration signals. Alternatively, other signals such as motor current, stray magnetic field of the motor or acoustic signals of a microphone can also be used to determine the cavitation indicators.

[0026] As shown in Figure 3 the cavitation indicator may take on discrete values on a scale which at one end indicates high cavitation or likelihood thereof and at the other end indicates low or no cavitation or likelihood thereof. One or more thresholds T1 may be determined for the cavitation indicator.

[0027] Advantageously, the data comprising speed values, load values, and/or vibration and/or magnetic flux values is recorded during a start-up of the pump system or over a longer period of time with varying load and speed. Different acceleration trajectories can also be used in order to capture a large area of the operating ranges.

[0028] Figure 4 shows a pump system and exemplary method steps. A sensor 40 for detecting vibrations and/or magnetic flux of the motor may be attached to the motor or located in the vicinity of the motor 3. Hence, measurement values are obtained from the pump system. As described herein, the measurement values may be obtained by a control device which may further process the measurement values. Thus, based on the measurement values a cavitation indicator may be determined for each of the operating conditions present at the time the measurements were taken. For example, it may be necessary to obtain sufficient vibration and/or magnetic flux values in a certain operating range in order to determine a cavitation indictor for that operating range. A database with entries relating to the operating ranges and cavitation indicators associated with the respective operating ranges may then be created. To that end, the database may be stored in a memory of the control device or in the memory of another device. The cavitation indicator may then be visualized, e.g., in the from of a heatmap, in order to assist a user.

[0029] Figure 5 shows visualizations of a first and a second operating point O1, O2 and curves C1, C2 of transient operating points between the first and second operating point O1, O2. As before, the axes correspond to speed and load of the motor driving the pump. A first operating point O1, preferably corresponding to the present operating point of the pump, may have a first cavitation indicator assigned to it, which e.g., represents low or now cavitation or likelihood thereof. A second operating point, preferably operating point to be reached, may also have assigned a second indicator to it. Now according to the curve C1 the change of operating points requires the pump (system) to take on operating points at which cavitation and/or a high likelihood thereof occurs. Thus, a second curve C2 avoiding those operating points with high cavitation or likelihood thereof is determine. This second curve is determined such that it avoids operating points at which the cavitation indicator exceeds a threshold value. Hence, based on the operating ranges and the cavitation indicator assigned to (each of) the operating ranges it is possible to transitions between operating points that may cause cavitation to occur.

[0030] Figure 6 shows visualizations of cavitation indicators changing during the operation of the pump system. Again, cavitation indicators are determined for different operating ranges. During the operation of the pump system the behavior of the pump, i.e., its condition, may change. Hence, it may be necessary to update the cavitation indicators after a period of time, periodically or when an event occurs. As shown in Figure 6 at a first point in time t1, e.g., (directly) after commissioning the pump systema the cavitation indicators for a plurality of operating ranges are determined. After some prolonged operation of the pump system, at a second point in time t2 the cavitation indicators for at least part of the operating ranges are redetermined and/or updated. As shown in Figure 6, a comparison of the visualization of the cavitation indicators allows identifying that the cavitation behavior of the pump has changed. Based on the comparison the control settings of the pump system may be adapted. Furthermore, in addition to anomaly detection, the operating condition or rather error condition of the pump, e.g., a damage to the impeller or to the guide wheel, or deposits in pipes, may be determined. Furthermore, changes to the process can also be derived based on the comparison.

[0031] Figures 7 to 15 show exemplary method steps. In a step S1 a plurality of cavitation indicators may be determined. For example, the cavitation indicators may be calculated by a processor of an operating device. The cavitation indicators may be stored in a database. The database may be located in a memory of the operating device as well, i.e., the cavitation indicators are stored in the memory. In a step S2, it is determined whether a cavitation indicator (of the plurality of the cavitation indicators) exceeds a predetermined cavitation threshold. The cavitation threshold may be set, e.g., by a user and for example be based on experience, and/or the pump application, i.e., the usage of the pump system.

[0032] A cavitation indicator and thus each cavitation indicator of the plurality of cavitation indicators determined indicates cavitation or a likelihood of cavitation of the pump. The occurrence of cavitation can not be determined with absolute certainty since it is dependent on the specific circumstances the cavitation indicator may be interpreted as indicating a probability of cavitation.

[0033] Each cavitation indicator of the plurality of cavitation indicators may be determined for different operating ranges. Each operating range is given by a combination of values of a first and a second motor characteristic. For example, for an interval of values a representative value may be used, for example a median or mean value of the interval or range may be used as a basis for determining the cavitation indicator. Alternatively for all values of an interval or range the cavitation indicator may be determined and a mean or median value of the cavitation indicators may be used.

[0034] Each operating range may be given by a combination of values of a first and a second motor characteristic. The operating range may thus comprise individual values or may be an interval comprising multiple values. For example, an operating range may comprise a first value of the first motor characteristic and a first value of a second motor characteristic. Furthermore, an operating range may comprise multiple values of the first motor characteristic and multiple values of a second motor characteristic. The values of the first and second motor characteristic may be stored in a memory as described above and be associated with one another and/or with the cavitation indicator.

[0035] In a step S3, an alert may be initiated in case the cavitation threshold is exceeded by one or more cavitation threshold of the plurality of cavitation threshold. For example, the alert may be displayed. The alert may be a notification or an alarm and may comprise information about the one or more cavitation indicators exceeding the cavitation threshold.

[0036] Turning to Figure 8 further exemplary method steps are shown. In a step S0 a vibration and/or a magnetic flux may be measured. The vibration and/or the magnetic flux may be generated by the motor. The measurement may be taken at different operating ranges. In a step S1, as before, the cavitation indicator(s) for the respective operating range(s) may be determined based on the vibration and/or magnetic flux measured.

[0037] Turning to Figure 9, in a step S1 a plurality of cavitation indicators may be determined. Therein, the cavitation indicator may be a cavitation score, e.g., on cavitation scale. Hence in a step S4 a cavitation score may be determined. The cavitation scale may be a (discrete or continuous) cavitation scale, the cavitation scale indicating a first likelihood of cavitation at one end, e.g., cavitation present, and a second likelihood of cavitation, e.g., no cavitation present, on the other end.

[0038] Turning to Figure 10, in a step S5 a distance to one or more other operating ranges is determined. The distance may be between the one or more other operating ranges a first operating point. The first operating point may be associated with no or a low cavitation indicator (e.g., below the cavitation threshold). On the other hand, the first operating point may be associated with high/intermediate cavitation indicator

[0039] The distance may be determined in terms of the first and/or second motor characteristic, e.g., given in units of the first and /or second motor characteristic, respectively. The one or more other operating ranges may be associated or may possess a cavitation indicator that exceeds the predetermined cavitation threshold. Hence, the risk of the operating point of the pump system drifting towards a region of cavitation or likelihood thereof may be determined.

[0040] Thus, in a step S6, the control settings of the motor and/or the pump system may be adapted (automatically) based on the distance. The control settings of the motor and/or the pump system may relate to the first and/or second motor characteristic, preferably in order to arrive at an operating point with low/no cavitation indicator. The first motor characteristic may correspond to the motor speed and/or the second motor characteristic may correspond to the motor load (torque).

[0041] Turning to Figure 11, in a step S6, the control settings of the motor and/or the pump system may be adapted (automatically) based on the distance, as described herein. In a step S7, this may comprise adapting the motor speed setpoint of the motor and/or adapting a control valve setpoint of a control valve of the pump system. The pump system may thus comprise a valve that controls the motor load (torque).

[0042] Turning to Figure 12 further exemplary method steps are shown. In a step S8, a plurality of the cavitation indicators are determined during an acceleration phase and/or deceleration phase of the pump and/or motor. To that end, the corresponding measurements of the vibration and/or magnetic flux re also made during those phases, respectively. The acceleration phase(s) and/or deceleration phase(s) may correspond to the ramp-up and/or ramp-down of the motor/pump. This allows to capture the motor's and/or the pump's behavior over different and/or a plurality of operating ranges.

[0043] In a step S9, the cavitation indicators may be re-determined during the operation of the pump system. For example, for repeated acceleration phase(s) and/or deceleration phase(s) and/or after a predetermined period of operating time of the pump system. For example, at first point in time the cavitation indicator may be determined for one or more operating ranges and at later point in time the (and for the same or different operating ranges) the cavitation indicators may be redetermined.

[0044] Turning to Figure 13, as just described, in a step S9 the cavitation indicators may be redetermined during the operation of the pump system. In a step S10 the updated cavitation indicators may be compared with previously determined cavitation indicators, e.g., for the same or similar (e.g., overlapping) operating ranges. In a step S11, an operating condition of the pump/pump system may be determined based on the comparison, e.g., a damage of the pump and/or a deposition in a pipe of the pump inlet and/or pump out-let.

[0045] Turning to Figure 14, in a step S12 determining whether the cavitation indicator of one or more transient operating points between a first and a second operating point exceeds the cavitation threshold value. Therein, the one or more transient operating points may be located on a curve, given by the first and second motor characteristic. the curve connecting the first and second operating points. Now, in case the operating points exhibit cavitation, i.e., the cavitation indicators of those transient operating points exceed the cavitation threshold (set), such a curve may not be desired, since it is detrimental to the operating lifetime of the pump system. Thus, in a step S13, the curve may be adapted in case a cavitation indicator of the or more transient operating points exceeds the cavitation threshold value. In that case the curve may be adapted not to include (transient) operating points or (transient) operating ranges when the operation of the pump system is changed from the firs operating point to the second operating point.

[0046] Now turning to Figure 15, in a step S1 as previously described, a plurality of cavitation indicators may be determined. In a step S14 the plurality of cavitation indicators and the corresponding operating ranges may be visualized on a display, e.g., of an operating device, such as computer or a handheld.

[0047] A further embodiment comprises a computer program comprising program code that when executed performs the method steps of any one of the embodiments described herein. A further embodiment comprises a, preferably non-transitory, computer readable medium comprising the computer program.

Claims

1. A, preferably computer-implemented, method for controlling and/or monitoring an operation of a pump system (1), wherein the pump system (1) comprises a pump (2) and a motor (3) that is connected to drive the pump (2), the method comprising the steps of:

    determining a plurality of cavitation indicators (10),
    wherein each cavitation indicator (11, 12) indicates cavitation or a likelihood of cavitation of the pump (2) for different operating ranges (21, 22, 31, 32), wherein each operating range (21, 22, 31, 32) is given by a combination of values of a first and a second motor characteristic.

2. The method according to the preceding claim, further comprising:

    determining whether the cavitation indicator (11, 12) of one or more operating points (O1) of the motor (3), given by a combination of values of the first and the second motor characteristic within an operating range (21, 22, 31, 32), exceeds a predetermined cavitation threshold value (T1),
    initiating an alert in case the cavitation threshold value (T1) is exceeded.

3. The method according to any one of the preceding claims, further comprising:
    wherein each operating range (21, 22, 31, 32) is given by a combination of a first range of values of the first motor characteristic and a second range of values of the second motor characteristic.

4. The method according to any one of the preceding claims, further comprising:

    measuring a vibration generated by the motor (3) and/or a magnetic flux generated by the motor (3) at different operating ranges, and
    determining the cavitation indicator (21, 22, 31, 32) for that operating range based on the vibration and/or magnetic flux measured.

5. The method according to any one of the preceding claims, further comprising:

wherein the step of determining the cavitation indicator (21 ,22, 31, 32) at the different operating ranges comprises,
determining a cavitation score on a (discrete or continuous) cavitation scale, the cavitation scale indicating a first likelihood of cavitation at one end, e.g., cavitation present, and a second likelihood of cavitation, e.g., no cavitation present, on the other end.

6. The method according to any one of the preceding claims, further comprising:
determining for a first operating point within a first operating range, e.g., the first operating point associated with no/low cavitation indicator, a distance, e.g., in terms of the first and/or second motor characteristic, to one or more other operating ranges at which the cavitation indicator exceeds the predetermined cavitation threshold.

7. The method according to any one of the preceding claims, further comprising:
determining for a first operating point within a first operating range, e.g., the first operating point associated with high/intermediate cavitation indicator, a distance, e.g., in terms of the first and/or second motor characteristic, to one or more other operating ranges at which the cavitation indicator does not exceed the predetermined cavitation threshold.

8. The method according to any one of the preceding claims, further comprising:
adapting, based on the distance, the control settings of the motor and/or the pump system relating to the first and/or second motor characteristic, preferably in order to arrive at an operating point with low/no cavitation indicator.

9. The method according to any one of the preceding claims, further comprising:
wherein the first motor characteristic corresponding to the motor speed and/or the second motor characteristic corresponding to the motor load (torque).

10. The method according to any one of the preceding claims, further comprising:

adapting the motor speed setpoint of the motor and/or
adapting a control valve setpoint of a control valve of the pump system, wherein the control valve controls the motor load (torque).

11. The method according to any one of the preceding claims, further comprising:
wherein the plurality of the cavitation indicators is determined during an acceleration phase and/or deceleration phase of the pump and/or motor, e.g., during the ramp-up and/or ramp-down of the motor/pump.

12. The method according to any one of the preceding claims, further comprising:
re-determining, i.e., updating, the cavitation indicators during the operation of the pump system.

13. The method according to any one of the preceding claims, further comprising:

comparing the updated cavitation indicators with previously determined cavitation indicators, and
determining an operating condition of the pump/pump system based on the comparison, e.g., a damage of the pump and/or a deposition in a pipe of the pump inlet and/or pump outlet.

14. The method according to any one of the preceding claims, further comprising:

determining whether the cavitation indicator of one or
more transient operating points between a first and a second operating point exceeds the cavitation threshold value, wherein the one or more transient operating points are located on a curve, given by the first and second motor characteristic, connecting the first and second operating points.

15. The method according to any one of the preceding claims, further comprising:
adapting the curve in case a cavitation indicator of the or more transient operating points exceeds the cavitation threshold value.

16. The method according to the preceding claim,
visualizing the plurality of cavitation indicators and the corresponding operating ranges on a display.

17. A pump system operative to perform the method steps according to any one of the preceding claims.

FIG 1

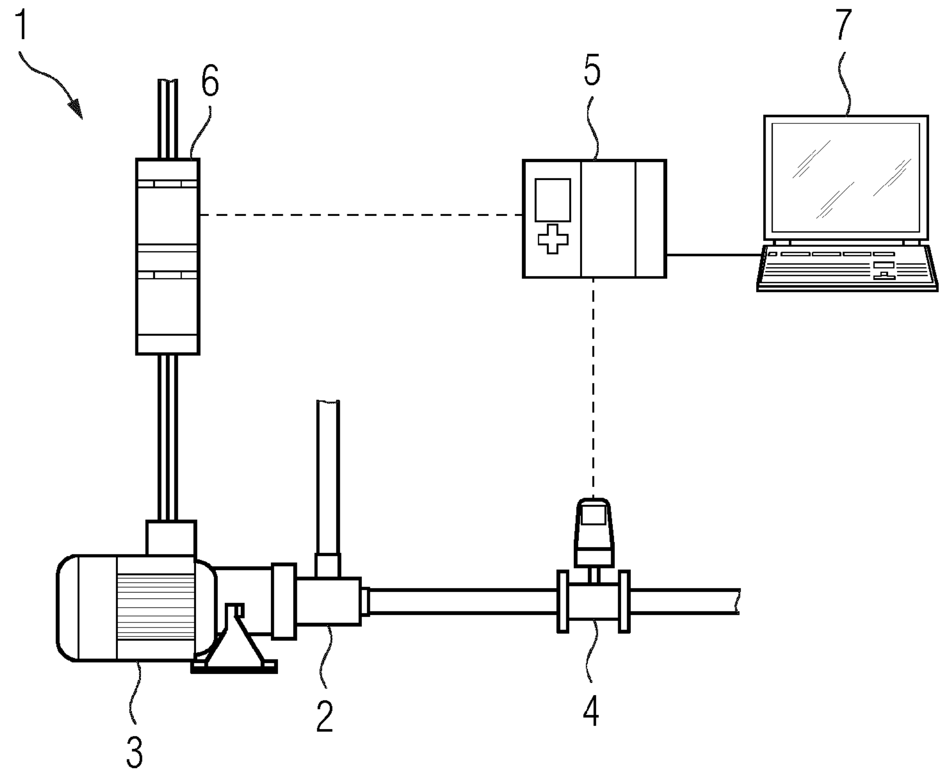


FIG 2

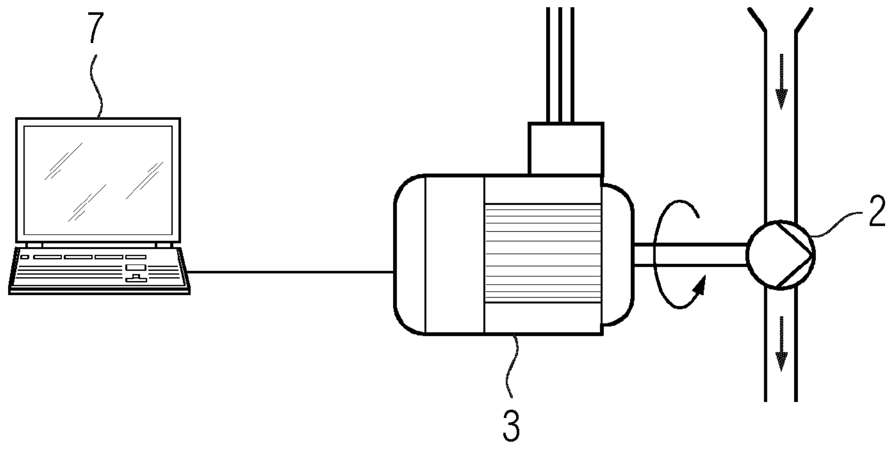
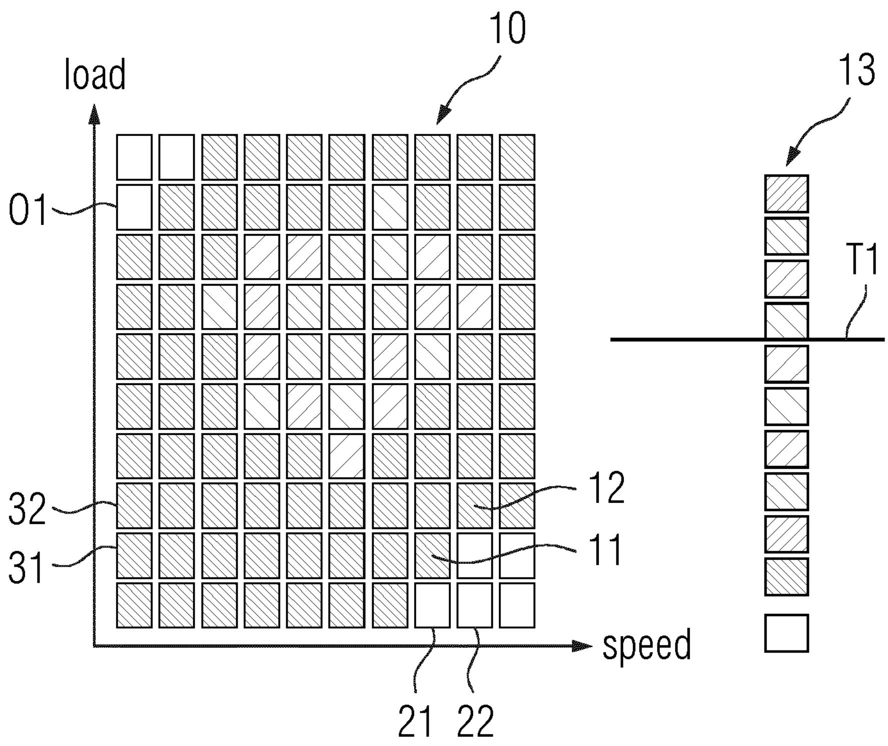


FIG 3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13
load
01
T1
32
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31
11
speed
21
22

FIG 4

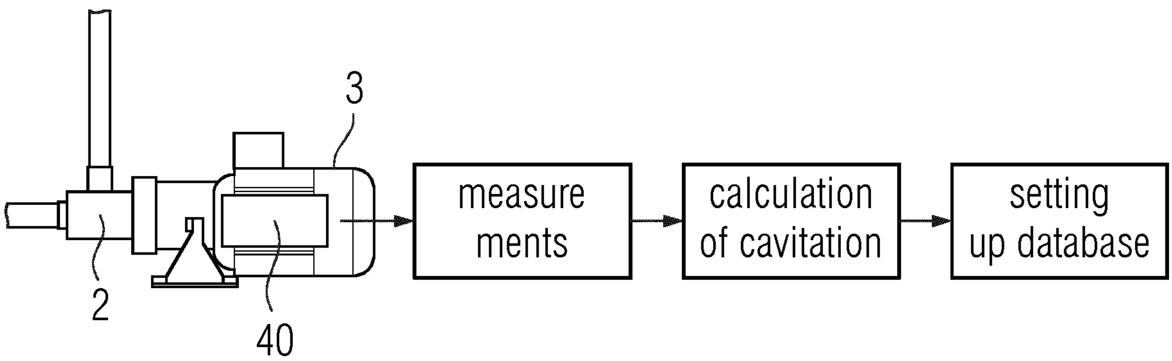

3
measure
ments
calculation
of cavitation
setting
up database
2
40

FIG 5

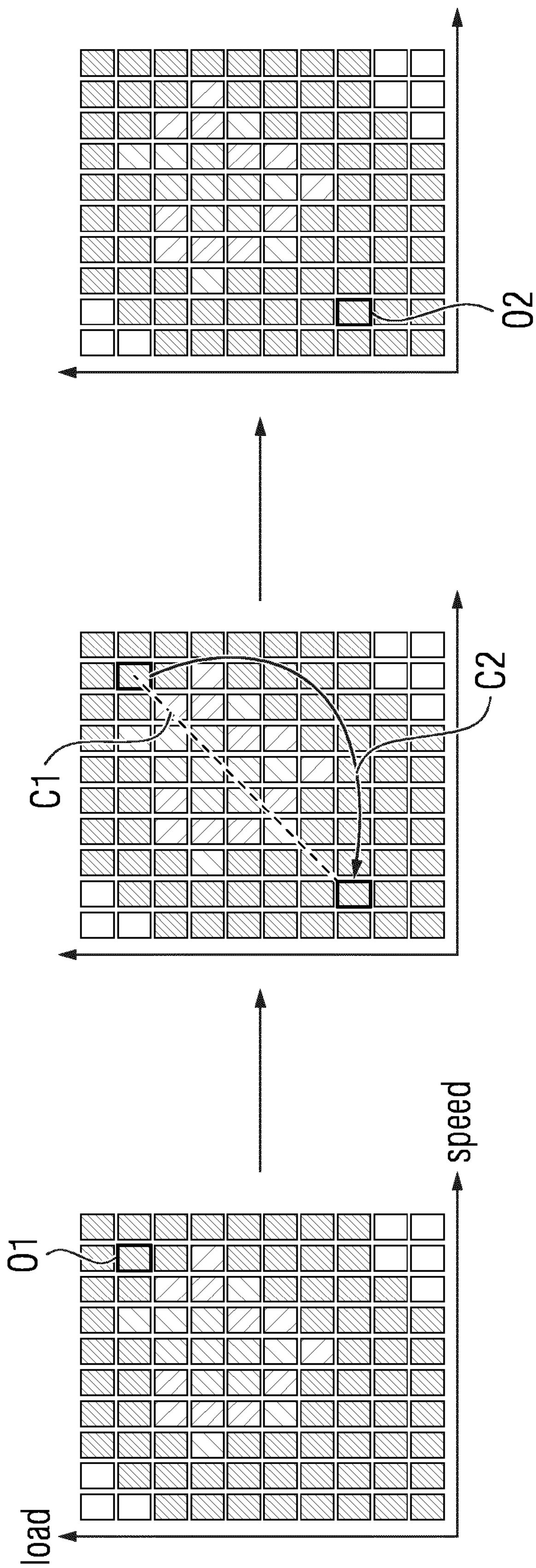


FIG 6

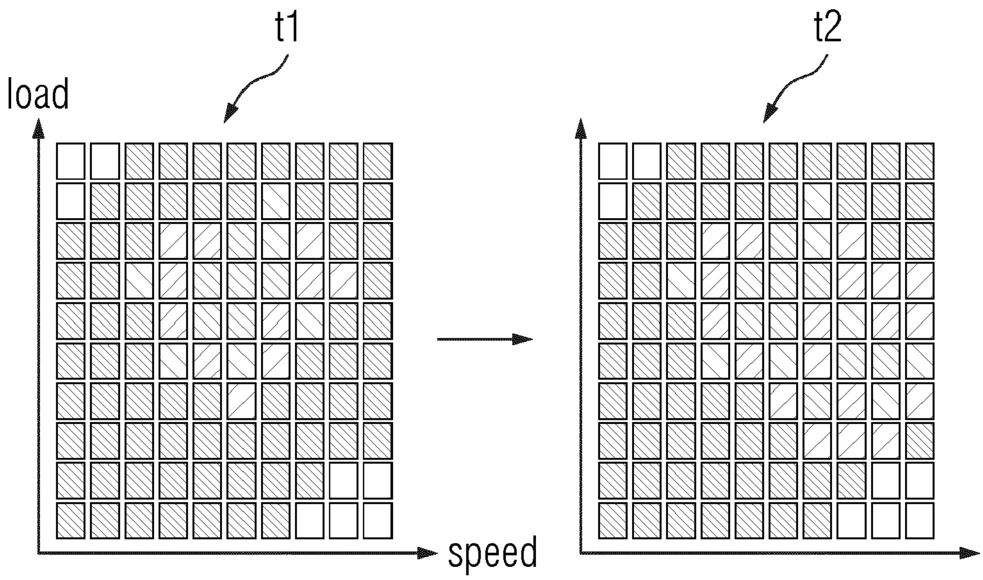

t1
t2
load
speed

FIG 7

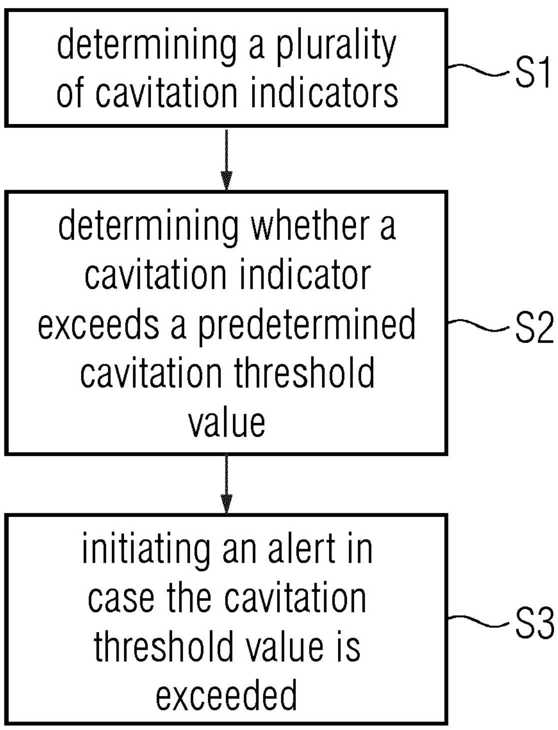

determining a plurality of cavitation indicators
S1
determining whether a cavitation indicator exceeds a predetermined cavitation threshold value
S2
initiating an alert in case the cavitation threshold value is exceeded
S3

FIG 8

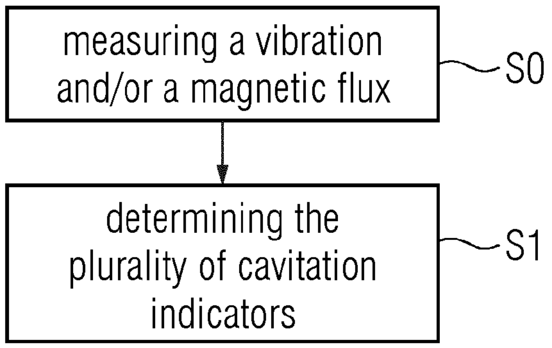


FIG 9

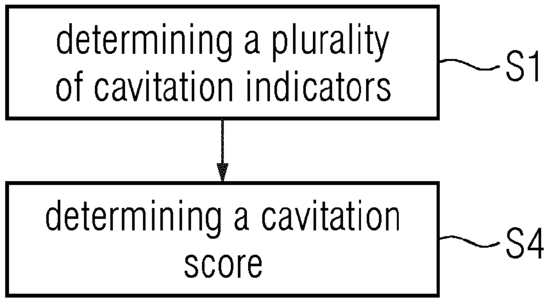


FIG 10

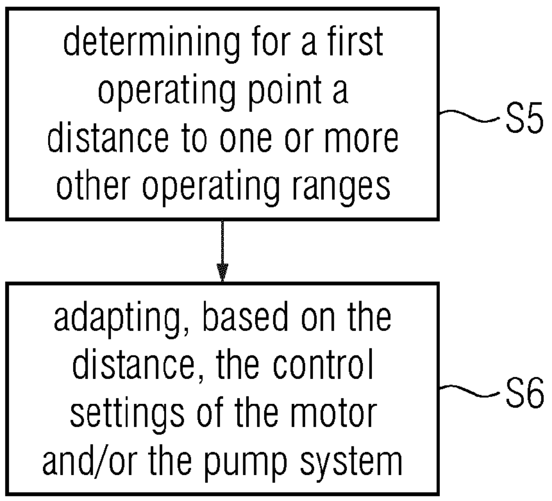


FIG 11

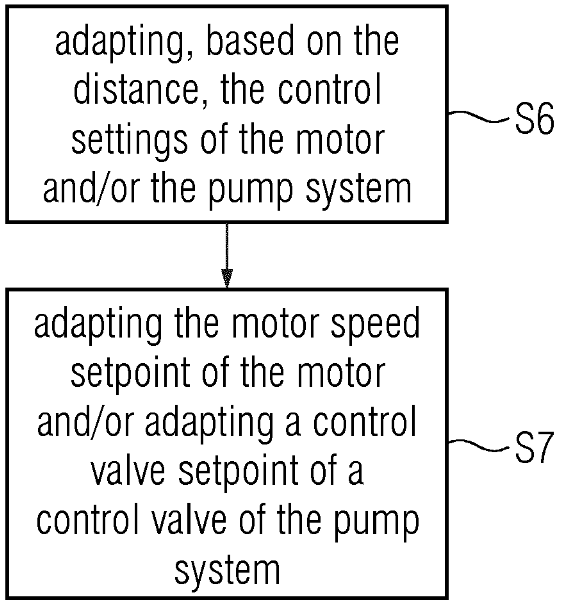

adapting, based on the distance, the control settings of the motor and/or the pump system
S6
adapting the motor speed setpoint of the motor and/or adapting a control valve setpoint of a control valve of the pump system
S7

FIG 12

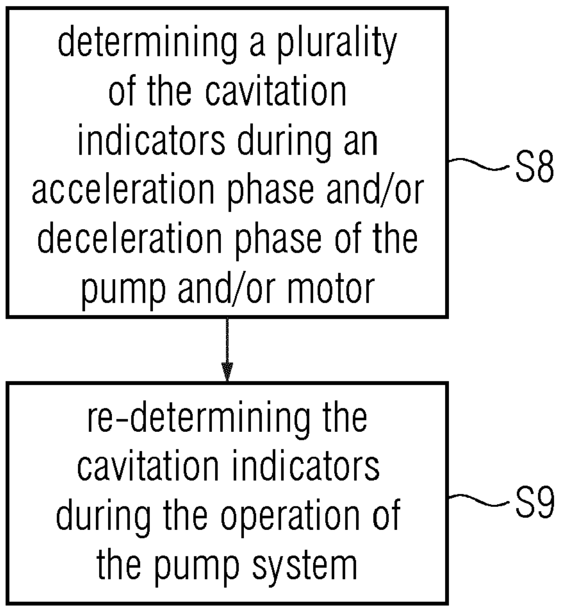

determining a plurality of the cavitation indicators during an acceleration phase and/or deceleration phase of the pump and/or motor
S8
re-determining the cavitation indicators during the operation of the pump system
S9

FIG 13

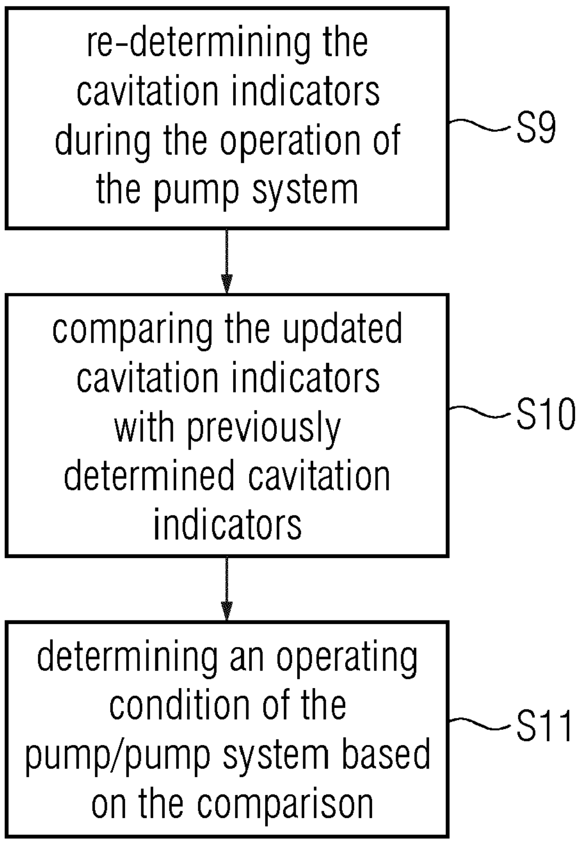

re-determining the cavitation indicators during the operation of the pump system
S9
comparing the updated cavitation indicators with previously determined cavitation indicators
S10
determining an operating condition of the pump/pump system based on the comparison
S11

FIG 14

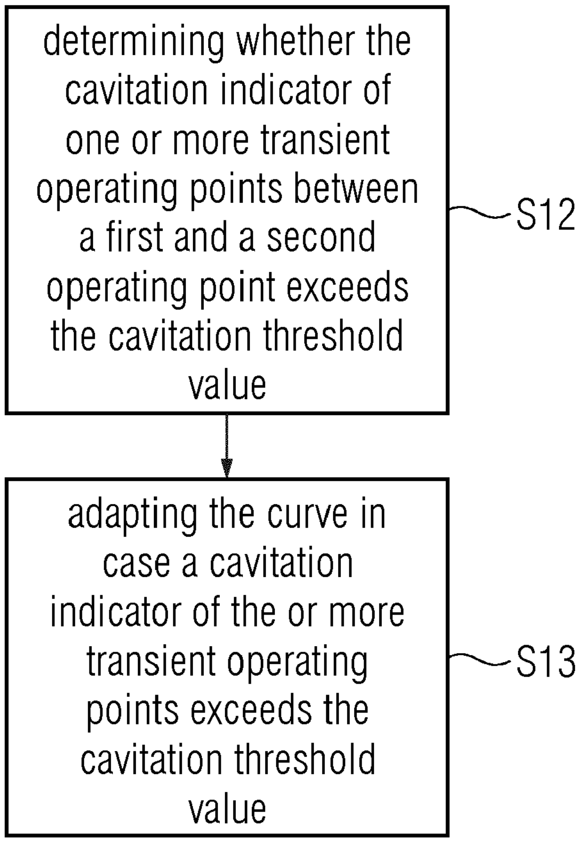
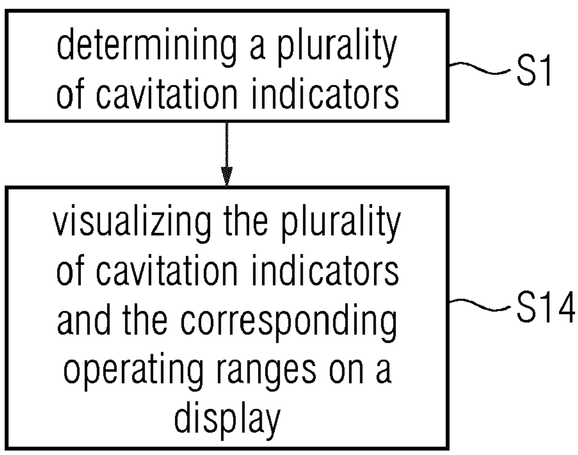

determining whether the cavitation indicator of one or more transient operating points between a first and a second operating point exceeds the cavitation threshold value
S12
adapting the curve in case a cavitation indicator of the or more transient operating points exceeds the cavitation threshold value
S13

FIG 15


determining a plurality of cavitation indicators
S1
visualizing the plurality of cavitation indicators and the corresponding operating ranges on a display
S14

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EUROPEAN SEARCH REPORT

Application Number
EP 22 20 4352

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X A	US 11 078 766 B2 (WEATHERFORD TECH HOLDINGS LLC [US]) 3 August 2021 (2021-08-03) * column 9, line 38 - column 11, line 51 * * figures 3,4a,4b * -----	1-12 13-15	INV. F04D1/00 F04D13/06 F04D15/00 F04D29/66 F04B49/02 F04C14/28
X A	US 10 247 182 B2 (CATERPILLAR INC [US]) 2 April 2019 (2019-04-02) * column 5, line 41 - column 6, line 14 * * figures 4-5 * -----	1-11 12-15	
X	EP 2 196 678 A1 (ABB OY [FI]) 16 June 2010 (2010-06-16) * paragraph [0014] - paragraph [0031] * * figures 1-5 * -----	1,3,9,17	
X	EP 1 286 056 A1 (RELIANCE ELECTRIC TECH [US]) 26 February 2003 (2003-02-26) * paragraph [0014] - paragraph [0029] * * figures 1-7 * -----	1,3,9,17	

TECHNICAL FIELDS SEARCHED (IPC)

F04D
F04B
F04C

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	23 March 2023	Lovergine, A

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23-03-2023

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 11078766 B2	03-08-2021	NONE	
US 10247182 B2	02-04-2019	NONE	
EP 2196678 A1	16-06-2010	CN 101750258 A	23-06-2010
		DK 2196678 T3	06-08-2012
		EP 2196678 A1	16-06-2010
		US 2010143157 A1	10-06-2010
EP 1286056 A1	26-02-2003	DE 60206711 T2	18-05-2006
		EP 1286056 A1	26-02-2003
		US 6655922 B1	02-12-2003

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Patent documents cited in the description

- EP 21200024 **[0003]**
- EP 2196678 A1 **[0004]**
- US 2016010639 A1 **[0005]**
- EP 1198871 A1 **[0006]**