METHOD FOR DIAGNOSING OPERATING STATES OF A SYNCHRONOUS PUMP, AND DEVICE FOR CARRYING OUT SAID METHOD

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The invention relates to a method for diagnosing operating states (36, 38, 40, 42) of a synchronous pump in a liquid circuit, particularly in a washing machine or similar. According to the inventive method, the alternating voltage (U) applied to the pump motor and the alternating current (I) of the motor are measured in at least one measurement step (30), the extent of a phase shift (Δφ) between the alternating voltage (U) and the alternating current is measured at least at one point in time in a determination step (32), the phase shift (Δφ) or the progress thereof is determined from the recorded measured values and a characteristic of the phase shift (Δφ) or the progress thereof is determined, and the determined characteristic is assigned to a predetermined pump operating state (36, 38, 40, 42) in an assignment step (34).
Fig. 1
$U, J$

$\Delta \phi 1, \Delta \phi 2$

$t$

Fig. 2
Fig. 3
Fig. 6

Fig. 7
METHOD FOR DIAGNOSING OPERATING STATES OF A SYNCHRONOUS PUMP, AND DEVICE FOR CARRYING OUT SAID METHOD

[0001] This invention relates to a method for diagnosing operating states of a synchronous pump in a liquid circuit, particularly in a dishwasher or similar.

[0002] Dishwashers often make use of synchronous pumps, that is pumps driven by synchronous motors, to pump the water used for washing back from the bottom of the interior of the appliance to the spray arms, thereby creating a closed liquid circuit. This arrangement is widely used in order to save fresh water.

[0003] In an ideal case, the volume of circulating water remains constant, and the synchronous pump used to circulate the water works at a constant output. Problems can occur, however, if water becomes trapped at points inside the machine from which it cannot flow away, or be pumped away, and hence is no longer available to be recycled to the spray nozzles. Such liquid reservoirs are created, in particular, by saucepans or similar containers which tip over during washing so that they finish up with their open ends facing upwards and collect the water which is directed downwards onto the items to be cleaned. Another problem is caused when water is prevented from circulating due to clogging of the filter disposed in the floor on the inside of the appliance at the inlet of the feed line of the synchronous pump. If the volume of circulating water falls below a certain minimum, the incident-free functioning of the appliance can no longer be guaranteed. Irrespective of the fact that dirty objects are not cleaned as they should be, there is a risk in this case of damage to the synchronous pump.

[0004] Hence it is desirable to be able to determine the momentary operating state of the water circuit and, in particular, to ascertain that the pump is functioning correctly. Methods are known for measuring the volume of water fed into the circuit prior to the washing process. It is possible, for example, to convey the water via a wheel which will then rotate at a speed proportional to the volume of water conveyed across it. The advantage of this arrangement is that it is inexpensive, but the results are relatively inaccurate. There is no permanent monitoring of the volume of water in circulation whilst the machine is in operation.

[0005] Document DE 196 30 257.5 A1 discloses a device for controlling the volume of water in a dishwasher, whereby the torque of the synchronous motor driving the pump is monitored to determine the operating state of the synchronous pump. For this purpose the power uptake of the stator winding is measured and a dosing valve for supplying the water for washing is controlled as a function thereof, thereby guaranteeing permanent monitoring of the volume of water in circulation.

[0006] Document DE 24 15 171.1 A1 further discloses the measuring of the operating state of a synchronous motor by means of the phase shift between the alternating voltage applied to the motor and the alternating current. A momentary phase shift can then be assigned to a particular operating state.

[0007] The prior art solution is directed towards providing a means of monitoring the operating state of synchronous machines with asynchronous start-up, and of signalling asynchronous functioning. The intention is to economise the costly and generally used method of measuring the speed of rotation, replacing it with a less expensive means of monitoring. For the particular application on which this invention is based, however, this method is only suitable to a very limited degree as not all the operating states of a dishwasher can be unambiguously identified by this prior art method. This is particularly true of the above-described problems in connection with a liquid circuit.

[0008] The task of this invention is, therefore, to provide a method for diagnosing operating states of a synchronous pump of the type described above, the goal of said method being to ensure the easiest, most reliable and most cost-effective means possible of detecting and identifying a variety of operating states of the synchronous pump corresponding to malfunctions in the liquid circuit, in particular a fall in the volume of water in circulation below a minimum level and clogging of the filter.

[0009] This task is solved according to the invention by means of a method according to claim 1.

[0010] In the method according to the invention, an initial measurement step involves taking at least one measurement of the alternating voltage applied to, and the alternating current through, the motor. In a subsequent determination step, the extent of a phase shift occurring between the alternating voltage and the alternating current is measured. The phase shift ascertained is used in a subsequent assignment step to identify a pump’s operating state.

[0011] This diagnostic method is based on the knowledge that the phase shift between the voltage and the current of the synchronous pump can be used as an indicator of a pump malfunction. If, for example, a certain volume of water is withdrawn from the dishwasher water circuit, say by an upturned saucepan, there will be a change in the phase shift due to the occurrence of an air-water mix in the pump housing. Action can then be taken to correct the malfunction. The volume of water in the circuit can be topped up with fresh water, for example. It may also be possible to trigger a warning signal to alert an operator. All the steps in the method are relatively simple and inexpensive to execute, on top of which the phase shift measurement is reasonably accurate compared to conventional methods. Ongoing monitoring of the water level means that fresh water can be added exactly as required, thereby achieving a resources-saving water circuit. An additional energy-saving effect is achieved in that only the water in the circuit need be heated for the individual washing cycles.

[0012] In a preferred embodiment of the method according to the invention the extent of the phase shift in the assignment step is assigned to a predetermined phase shift value range linked to a certain pump operating state.

[0013] Furthermore, preferably in the determination step, the difference between the measured extent of the phase shift and a saved predetermined phase shift can be determined and in the subsequent assignment step this phase shift difference is assigned to a pump operating state. In this case, the state of the pump is identified not with reference to the measured extent of the phase shift, but to its deviation from a predetermined target value.

[0014] In a preferred embodiment of the method, the determination step involves measuring the extent of the phase shift at various intervals so that the chronological
progression of the phase shift can be determined from the recorded measured values. A characteristic of the chronological progression of the phase shift is ascertained for assignment to a predetermined pump operating state.

[0015] The ascertained feature is preferably assigned to a predetermined characteristic value range linked to a pump operating state.

[0016] The gradient of the slope of the chronological progression of the phase shift is preferably determined in the determination step and in the assignment step it is assigned to a predetermined slope value range linked to a pump operating state. Here, then, the gradient of the slope of the chronological progression of the phase shift is used to identify the pump operating state, e.g. a clogged filter.

[0017] In a further preferred embodiment, the determination step comprises a transformation step in which the chronological progression of the phase shift is submitted to a Fourier transform and the amplitude of the Fourier transform is determined in a predetermined frequency range is determined. In this case, the assignment step serves to assign the previously ascertained amplitude to a predetermined amplitude value range which is in turn linked to a pump operating state.

[0018] Hence in this case, the analysis is conducted in the frequency range. If, for example, the chronological progression of the phase shift exhibits high-frequency signal components this may indicate that there is an air-water mixture in the pump housing preventing the pump from operating at full capacity.

[0019] The Fourier transform may preferably be a discrete Fourier transform (DFT) or the special form of the DFT, the so-called fast Fourier transform (FFT).

[0020] The determination of the chronological progression of the phase shift in the determination step may preferably include a sliding averaging.

[0021] The measurement step may preferably include converting the measured alternating voltage signal and the measured alternating current signal into rectangular signals.

[0022] A device for carrying out the method according to the invention comprises a microcontroller with a timer comprising a voltage inlet for recording a start signal and a current inlet for recording a stop signal. These voltage and current inlets are configured to interpret the exceeding of a predetermined voltage or current level as a start or stop signal. The content of the timer is proportional to the chronological gap between the start and stop signals. The microcontroller further comprises a memory for recording the timer content.

[0023] The timer of the above-mentioned microcontroller can be used to measure the extent of the phase shift. The content of the memory, which is accessed by other analytical devices, is proportional to the phase shift so that the device according to the invention offers a simple means of analysing the pump operating state.

[0024] In one preferred embodiment the memory comprises a number of memory cells for saving a sequence of memory contents.

[0025] Furthermore, the microcontroller comprises an evaluation unit for averaging the memory contents.

[0026] An interface preferably serves to transmit operating state-related data from the microcontroller to a control unit to control the liquid circuit.

[0027] The invention can also be applied to suitably constructed washing machines or other machines that operate in circulating mode.

[0028] A preferred embodiment of the invention will be described in more detail below with reference to the drawings, in which

[0029] FIG. 1 is a diagrammatic illustration of the voltage and current signals to be measured and their transformation;

[0030] FIG. 2 is a diagrammatic illustration of the progression of the phase shift;

[0031] FIG. 3 is a diagram showing the function units of a device for carrying out the method according to the invention;

[0032] FIG. 4 to 7 show the chronological progression of the phase shift in line with various pump operating states and

[0033] FIG. 8 is a flow diagram explaining the method steps according to the invention.

[0034] FIG. 1 shows four diagrams, each illustrating the progression of voltage and current signals against time t. The top left diagram shows the sinus-shaped path of the voltage U applied to a synchronous pump of a liquid circuit, whilst the bottom left diagram shows the path, also sinus-shaped, of current I. Both sinus curves of voltage signal U and current signal I are out of phase in relation to each other by a phase shift \( \phi \), that is corresponds to a chronological shift between the zero crossing of current signal I with respect to voltage signal U. The extent of this phase shift can be used according to the invention to diagnose a pump operating state as will be explained below. For this purpose the voltage U and current I applied to the motor are measured in one measurement step and the extent of phase shift is then determined in a determination step. Before further evaluation the measured voltage and current signals U and I are first processed by means of conversion into rectangular signals U' and I'. These signals are shown in a top and bottom diagram on the right-hand side of FIG. 1. In detail, the voltage signal U is converted into rectangular signal U' by an optocoupler which converts the analogue sinus-voltage signal U into a digital rectangular signal. This produces a simultaneous potential separation between the motor voltage and a downstream microcontroller used for evaluation purposes. To convert the sinus current signal I into rectangular signal I', the motor current is conducted over a shunt as measuring resistance and the measuring voltage is converted into a rectangular signal by means of an operational amplifier. In this case, too, the potential separation is ensured by means of a downstream optocoupler.

[0035] FIG. 2 shows these processed signals U', I' together. Here, too, the abscissa corresponds to time t, whilst the ordinate corresponds to the amplitude of the signals. In the pump's normal operating mode in which it is completely filled with water, a certain phase shift \( \phi \) occurs. If water is removed from the water circuit in a dishwasher causing a decrease in the volume of water conveyed by the synchronous pump, the phase shift \( \phi \) between voltage and current signals U, I increases considerably as soon as the volume of
water falls below a certain level. This increase in the phase shift can be determined in a determination step which follows on from the previously described measurement step, and then used to determine the operating state of the pump. For this purpose the measured extent of the phase shift can be assigned in a subsequent assignment step to a value range which again corresponds to a predetermined operating state. One may elect to start by determination the difference between the measured extent of the phase shift and a predetermined phase shift value, corresponding, for example, to a measured extent 2 of the phase shift as per FIG. 2 and a value 1 in problem-free normal operating mode, and this difference in phase shift is assigned to a diagnostic operating state.

[0036] In a preferred embodiment of the method which will be considered in more detail below, the chronological progression of phase shift is determined by measurement at different points in time. This offers extensive possibilities in terms of analysing the progression of the phase shift and of examining it for characteristic features. A certain characteristic such as the extent of an ascertained parameter in the chronological progression of phase shift can be assigned to a predetermined pump operating state in an assignment step which follows on from the determination step. This assignment may also involve assigning, i.e. classifying, the characteristic to a predetermined characteristic value range linked to a pump operating state.

[0037] The block diagram in FIG. 3 shows functional components of a device for carrying out this method. A microcontroller 10 comprises a timer 12 with a voltage inlet 14 and a current inlet 16. The voltage inlet 14 serves to record the rectangular voltage signal U', whilst the current inlet 16 serves to record the rectangular current signal I'. For this purpose the rectangular signals are adjusted to the level of microcontroller 10. The rising slope of voltage signal U' serves as a start signal for timer 12 whilst the rising slope of current signal I' serves as a stop signal. The content of timer 12, which is saved in a memory 18 of microcontroller 10, is proportional to the chronological gap between start and stop signals, and hence proportional to the phase shift between these signals.

[0038] Memory 18 may comprise a number of memory cells which serve to store a succession of memory contents. This makes it possible to determine the chronological progression of phase shift over time t. Hence it is possible, within a certain timeframe t, to conduct a number of phase shift measurements, with each measurement corresponding to one memory content at one memory position of memory 18. These measured values are then subjected to sliding averaging with the help of a software module 20 of microcontroller 10. The result is a smoothed chronological progression of phase shift which can be examined for certain characteristics or parameters. The advantage of sliding averaging is that it dampens the impact of measurement errors. Furthermore, it is also possible in this manner to analyse the characteristics of the phase shift progression after each new measurement process.

[0039] The device may further comprise an interface for transmitting operating state-related data to a water circuit controlling or regulating unit, such as a hardware interface of microcontroller 10 for communicating with an external control module. If microcontroller 10 itself serves to regulate the water circuit the communication is accomplished internally by a software interface for exchanging data between the appropriate software modules.

[0040] FIGS. 4 to 7 show chronological progressions of phase shift over time t according to different operating states of the synchronous pump. The curves shown are derived from a large number of measured values corresponding to memory positions of memory 18, processed by software module 20 in the manner described above. FIG. 4 shows the start-up phase of the synchronous pump. In a first time range t1 there is a brief increase in the phase shift. The chronological progression in this range t1 also exhibits high-frequency signal components. In the subsequent time range t2, a relatively small, constant phase shift without high-frequency signal components is established. This corresponds to the normal operating state of the pump with a sufficient volume of water in the circuit, corresponding, for example, to a sufficiently high level of water in a dishwasher.

[0041] FIG. 5, on the other hand, shows the chronological progression of phase shift as the water is pumped away, whereupon air enters the pump housing. A first time range of the curve t2 corresponds to the normal operating state of the pump with a sufficiently high level of water as already shown in FIG. 4. The phase shift in this time range t2 is relatively small. But if additional air enters the pump housing causing an air-water mixture, the phase shift in time range t3 increases very rapidly and high-frequency signal components become established. The progression seen in time range t3 also occurs if a small amount of water is withdrawn from the water circuit (e.g. if a saucepan turns open-end upwards).

[0042] If the pump housing empties gradually during time range t4, the phase shift gradually increases from the almost constant value maintained in t3 until finally, in time range t5, a constant high phase shift value is reached which corresponds to the complete emptying of the pump housing. This occurs when all the water is completely drained out of the circuit.

[0043] As can be seen from FIG. 5, different operating states of the pump correspond to different chronological progressions of phase shift. This means it is possible to draw conclusions as to the current operating state by examining the phase shift. In particular, it is possible to investigate certain parameters of the chronological progression of phase shift and its extent at certain points, such as the gradient of the curve that is ascertained. If one looks, for example, at time range t4 in FIG. 5, one sees an approximately linear progression in the phase shift over time t. If one determines the slope S1 at a certain point in time, this slope S1 can be assigned to a certain pump operating state: in this case to a gradually emptying of the pump housing. In the assignment step the gradient of slope S1 is then assigned, i.e. classified, to a predetermined slope value range linked to a pump operating state.

[0044] A further possibility is to follow the determining of the chronological progression of the phase shift with a transformation step in which the chronological progression of the phase shift is subjected to a Fourier transform. This allows investigation of the frequencies contained in the progression of the signal, as these frequencies are indicators of certain operating states. In time range t3, for example, during which an air-water mixture occurs in the pump
housing, there are high-frequency signal components which do not occur in the normal operating state, so that the occurrence of such frequency components is a clear indicator of a system malfunction. Thus the amplitude of the Fourier transforms in a predetermined frequency range is determined and in the assignment step the amplitude ascertained is assigned to a predetermined amplitude value range linked to a pump operating state. In this case, for example, the high-frequency components caused by an air-water mixture in the pump housing will occur within a predetermined range of amplitude values, thereby allowing categorization of the previously ascertained amplitude of the Fourier transforms. The Fourier transform may be a discrete Fourier transform (DFT) or the special form of the DFT, the so-called fast Fourier transform (FFT), which can be calculated by software module 20 of microcontroller 10.

[0045] Other characteristic signal progressions will be described below.

[0046] FIG. 6 shows the chronological progression of phase shift in the event of filter clogging preventing a sufficient supply of water to the pump feed. Starting from the normal pump operating state in time range t2, the filter clogging builds up, leading to a gradual increase in phase shift until the filter is completely clogged (time range t7) and the phase shift attains a very high, constant value. The slope S2 in time range t6 is thus an indicator of the occurrence of continuous filter clogging. To diagnose this operating state one therefore determines, in the determination step in the manner described above, the gradient of slope S2 of the ascertained chronological progression of phase shift, and in the assignment step the ascertained gradient of slope S2 is assigned to a predetermined slope value range, which, in this case, corresponds to the operating state associated with continuous filter clogging.

[0047] Complete clogging of the filter (time range t7) can also occur all of a sudden if a foreign body enters the filter. This case is depicted in time ranges t8 and t9. Whilst the pump operates normally with a small phase shift during time t8, there is a sudden increase in the phase shift in the event that the foreign body enters the filter, so that a very high constant phase shift is attained in time range t9. Both operating states can be ascertained with the help of one of the above-described diagnostic methods.

[0048] Finally, FIG. 7 shows a case in which the synchronous motor of the pump is in one of its two dead points and fails to start up. This operating state is also diagnosable since in this case the phase shift signal attains a very high constant value without any high-frequency signal components occurring. For example, the lack of high-frequency signal components offers a possibility for diagnosis in that the above-described Fourier transform is performed and the progression of the amplitude of the Fourier transforms is examined.

[0049] The flow diagram in FIG. 8 summarises the individual steps of the method. In measurement step 30 the alternating voltage U applied to the motor and the motor alternating current I are measured and converted into rectangular signals U', I'. In the subsequent determination step 32 the extent of the phase shift between the alternating voltage U' and the alternating current I' is determined, the chronological progression is ascertained and sliding averaging is performed. In this determination step 32 one may also examine a parameter of the curve that is ascertained, e.g. the extent of the slope. The subsequent assignment step 34 then serves to classify the ascertained characteristic, e.g. the gradient of the curve, i.e. to assign it to a predetermined range of values linked to a pump operating state which may correspond to a malfunction of the synchronous pump. It is optionally possible that determination step 32 includes the above-mentioned transformation step for frequency analysis by means of Fourier transform, and the amplitude of the Fourier transforms is classified in assignment step 34. Four such-to-be-assigned operating states 36, 38, 40, 42 are shown on the right-hand side of FIG. 8, namely the successful start-up of the synchronous pump, the aspiration of air if the water level is low, the non-conveyance of the pump if the filter is clogged and the failure of the pump to start up.

[0050] The diagnostic method according to the invention and the corresponding device are particularly well suited to use in dishwashers, but are not limited to this. The invention can easily be used in connection with liquid circuits of other types requiring, during operation, ascertainment of certain operating states of the synchronous pump and diagnosis of malfunctions.

[0051] Merely ascertaining the phase shift between voltage and current in a single measuring point delivers information about the operating state of the motor with regard to a certain parameter such as the load moment. Other ascerteniments are rendered possible if the chronological progression of the phase shift between voltage and current is established by means of several successive measurements. The invention includes both variants of the measuring method. It is, however, also possible to carry out the method so that only one of the two measuring methods is used. Both methods therefore have independent importance.

What is claimed is:

1. Method for diagnosing operating states of a synchronous pump in a liquid circuit, comprising the following steps:

   at least one measurement step which measures an alternating voltage applied to a pump motor and an alternating current to provide recorded measured values,

   a determination step which:

   determines an extent of a phase shift between the alternating voltage and the alternating current at least one point in time from the recorded measured values, and

   determines a characteristic of the phase shift or of its chronological progression, and

   an assignment step which assigns the determined characteristic to a predetermined pump operating state in an assignment step.

2. The method of claim 1, wherein the assignment step includes the step of assigning the extent of the phase shift to a predetermined phase shift value range linked to a pump operating state.

3. The method of claim 1, wherein:

   the determination step, includes the step of determining the difference between the measured extent of the phase shift and a saved predetermined phase shift and
the assignment step, includes the step of assigning said difference in phase shift to a predetermined pump operating state.

4. The method of claim 1, wherein the determination step, includes the steps of:

determining the extent of the phase shift between the alternating voltage and the alternating current is at different times,

determining the chronological progression of the phase shift from the recorded measured values.

5. The method of claim 4, wherein the assignment step, includes the step of assigning the determined characteristic to a predetermined characteristic value range linked to a pump operating state.

6. The method of claim 5, wherein:

the determination step, includes the step of determining the extent of the slope of the chronological progression of the phase shift, and

the assignment step, includes the step of assigning the determined extent of slope to a predetermined slope value range linked to a pump operating state.

7. The method of claim 4, wherein

the determination step comprises a transformation step in which the chronological progression of the phase shift is subjected to a Fourier transform and the amplitude of the Fourier transform in a predetermined frequency range is determined, and

the following assignment step, includes the step of assigning the determined amplitude to a predetermined amplitude value range linked to a pump operating state.

8. The method of claim 7, wherein the Fourier transform is one of the following:

- a discrete Fourier transform (DFT) and
- a fast Fourier transform (FFT).

9. The method of claim 4, wherein the determination of the chronological progression of the phase shift in the determination step includes the step of sliding averaging.

10. The method of claim 1, wherein the measurement step includes a conversion of the measured alternating voltage signal and of the measured alternating current signal into rectangular signals.

11. Device for carrying out the method according to claim 1, said device comprising a microcontroller including:

- a timer,
- a voltage inlet for recording a start signal,
- a current inlet for recording a stop signal, said voltage and current inlets being constructed to interpret exceeding of a predetermined voltage or current signal level as a start or stop signal, with a content of the timer being proportional to a chronological gap between the start signal and stop signal, and
- a memory for saving the timer content.

12. The device of claim 11, wherein the memory comprises a number of memory cells to save a sequence of memory contents.

13. The device of claim 12, wherein the microcontroller comprises an evaluation unit for averaging the memory contents.

14. The device of claim 11, further comprising an interface for transmitting operating state-related data to a control unit for controlling the liquid circuit.

15. The method of claim 2, wherein the pump operating state is a low water level state.