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(54) Titre : PROCEDE DE DETECTION DE CAVITATION
(54) Title: METHOD FOR DETECTING CAVITATION

(57) Abrégé/Abstract:
Disclosed is a method for detecting cavitation during operation of a hydraulic machine which has at least one impeller, said method using at least one structure-borne noise sensor, wherein the following method steps are carried out: detecting the signal of the at least one sensor over a period of time which comprises at least one rotation of the impeller; band pass filtration of the signal; preparing the signal; temporally dividing the signal into suitable time intervals (the following three steps are carried out separately for the individual partial signals); spectral decomposition; applying an event counter in the frequency domain; weighting the events with respect to their extent in the frequency band; calculating at least one characteristic value from the weighted events of all the partial signals; comparing the at least one characteristic value with at least one limit value.

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(54) Title: METHOD FOR DETECTING CAVITATION

(54) Bezeichnung : VERFAHREN ZUR DETEKTION VON KAVITATION

(57) Abstract: Disclosed is a method for detecting cavitation during operation of a hydraulic machine which has at least one impeller, said method using at least one structure-borne noise sensor, wherein the following method steps are carried out: detecting the signal of the at least one sensor over a period of time which comprises at least one rotation of the impeller; band pass filtration of the signal; preparing the signal; temporally dividing the signal into suitable time intervals (the following three steps are carried out separately for the individual partial signals); spectral decomposition; applying an event counter in the frequency domain; weighting the events with respect to their extent in the frequency band; calculating at least one characteristic value from the weighted events of all the partial signals; comparing the at least one characteristic value with at least one limit value.

(57) Zusammenfassung: Verfahren zur Detektion von Kavitation beim Betrieb einer hydraulischen Maschine, welches wenigstens ein Laufrad aufweist, mit Hilfe von wenigsten einem Körperschallsensor, wobei folgende Verfahrensschritte durchgeführt werden: Erfassung des Signals des wenigstens einen Sensors über einen Zeitraum, der wenigstens eine Umdrehung des Laufrades umfasst; Bandpassfilterung des Signals; Aufbereitung des Signals; zeitliche Aufteilung des Signals in geeignete Zeitintervalle (die hierauf folgenden drei Schritte werden auf den einzelnen Teilsignalen separat durchgeführt); spektrale Zerlegung; Anwendung eines Ereigniszählers im Frequenzraum; Gewichtung der Ereignisse bzgl. ihrer Ausdehnung im Frequenzband; Berechnung wenigstens eines Kennwertes aus den gewichteten Ereignissen aller Teilsignale; Vergleich des wenigstens einen Kennwertes mit wenigstens einem Grenzwert.

Method for detecting cavitation

The present invention relates to the operation of a hydraulic machine with an impeller, in particular a turbine, pump or pump-turbine in a hydroelectric power plant.

Cavitation can occur during the operation of a hydraulic machine. Cavitation generally occurs in operating ranges that are outside the optimum operating range for which the hydraulic machine was primarily designed. Cavitation may lead to increased wear of the hydraulic machine. In certain operating states, the occurrence of cavitation cannot be reliably predicted, especially in the transitional areas of no cavitation - cavitation. Many circumstances influence cavitation behavior. Among the factors responsible for discrepancies in the prediction are the influence of air pressure, water temperature, sediment concentration in the water or the degree to which the hydraulic surfaces are worn down. At the same time, on the one hand the exact dependence of the cavitation on the parameters mentioned is often not sufficiently known, and on the other hand some of the parameters cannot be detected with sufficient accuracy. Therefore, in order to exclude cavitation reliably, certain operating ranges must be avoided. As a result, the usable operating range of a hydraulic machine is restricted.

Another strategy for reducing the harmful effects of cavitation is pursued in the case of some turbines, in that air is fed into the water at suitable locations. The feeding-in of the air generally requires compressors, which have a not inconsiderable energy consumption. Since, as described above, it cannot be accurately predicted in which operating ranges harmful cavitation will occur, in the case of these turbines the blowing-in of air is already activated as a

precaution in operating ranges in which still no cavitation or little cavitation actually occurs. This gives rise to an energy consumption that is greater than would be required on the basis of the cavitation behavior of the hydraulic machine.

The adverse effects mentioned could be avoided if incipient cavitation could be reliably measured.

The object of the present invention is therefore to provide a method for measuring cavitation that is reliable and can be easily applied and can be used during the operation of the hydraulic machine in order to detect incipient cavitation and to choose the operating state in such a way that cavitation is just avoided.

Various methods for detecting cavitation by means of measuring instruments are known. One possibility is for example the use of structure-borne sound sensors that are designed specifically for very high frequencies (100 kHz to 1 MHz) and are attached to the turbine casing. For further processing, it has proven to be beneficial to form two characteristic values (W. Knapp, C. Schneider, R. Schilling "Ein Monitor-System zur akustischen Kavitationsüberwachung von Wasserturbinen" [A monitoring system for the acoustic cavitation monitoring of water turbines], 8th international seminar on "Wasserkraftanlagen" [hydroelectric power plants], TU Wien [Vienna University of Technology], 1994). Characteristic value 1 represents the sum effective value of the highpass-filtered time signal. Characteristic value 2 is a counting signal. The evaluator in this case counts the peaks in a predefined time window.

The inventor has thoroughly investigated variants of the measuring and evaluation methods that are known and

described in the previous paragraph. In its investigations, it found that cavitation can be detected with these methods. However, limit values for this must be determined for each hydraulic machine in which cavitation is to be detected. If the characteristic values calculated from the measured values exceed the limit values, there is cavitation. Investigations that were carried out on 4 different hydraulic machines gave different limit values for each of these hydraulic machines. The limit values on these machines could only be determined because it was known for these machines, or was otherwise possible to observe, when cavitation occurs and when it does not.

During the operation of a randomly chosen hydraulic machine, it is neither known nor can be otherwise observed when cavitation occurs. Therefore, the measuring and evaluation methods that are known and described above cannot be applied in practice to a randomly chosen hydraulic machine, since the required limit values for the hydraulic machine are not known and cannot be determined without an extremely great effort (for example by fitting windows in the water-carrying channels through which the occurrence of cavitation could be visually observed).

The inventor has recognized that the stated object can be achieved by finding an alternative measuring and evaluation method which indicates cavitation by the measured variable exceeding a limit value, it being possible for the limit value to be chosen such that it is the same globally for any randomly chosen hydraulic machine. This global limit value can then be fixed on one or more hydraulic machines that are well known and/or accessible for viewing, and be used for the measuring method on a randomly chosen hydraulic machine.

The stated object is achieved by the features of claim 1.

The way in which this is achieved is based on a novel and inventive evaluation method, which is described below. The measuring and evaluation method according to the invention is likewise based on measurement with the aid of structure-borne sound sensors. The basis for the evaluation method that is used is the raw signal from one or more structure-borne sound sensors. The signal of the at least one sensor is detected over a time period which is of such a length that it comprises at least one rotation of the impeller. Proceeding from this raw signal, the following evaluation steps are carried out:

Choice of the frequency band to be considered: the detected structure-borne signal is filtered with a bandpass filter. Filtering limits that have proven to be practicable are f_min=100 kHz and f_max=300 kHz. The method also still works however with filtering limits that deviate from the values mentioned, for example with f_min=200 kHz and f_max=600 kHz.

Preparation of the signal: if appropriate, the filtered signal is scaled, in order to take into account the gain factor of the sensor used. Subsequently, the mean value of the signal is subtracted, in order to compensate for a possible offset of the signal. This is followed by denoising the signal with a suitable filtering function.

Division of the signal with respect to the position of the impeller of the hydraulic machine: during the measurement, the impeller of the hydraulic machine rotates. The known rotational speed can be used to calculate the time interval Delta_T_360, in which the impeller has turned once through 360°. The time

interval Delta_T_360 is then divided still further and the denoised signal is considered separately in these time intervals. The inventor has found that it is expedient to carry out the division of the signal into time intervals that correspond to an impeller rotation of 1°, i.e. that the corresponding time interval is Delta T 1 = Delta T 360 / 360. The method also works however if time intervals that are greater or smaller are taken, for example for an impeller rotation of 0.1° to 10°. With smaller time intervals, the computing effort required increases and, with greater time intervals, there is a deterioration in the resolution with respect to the impeller position and in the sensitivity of the measuring method because measuring is performed integrally over a greater rotational angle of the impeller. The subsequent evaluations up until the calculation of the characteristic value are carried out on the partial signals divided with respect to these time intervals.

Spectral decomposition of the prepared partial signals: the signal is spectrally decomposed for each time interval, and the spectrum obtained provides information on the spectral composition of the signal.

Application of an event counter: an event counter is applied to the respective spectrum. For this purpose, a threshold value must be fixed. This threshold value is global, i.e. not dependent on the hydraulic machine being measured. Details of fixing the threshold value are described further below. There is an event to be counted if at least one evaluation point comes to lie above the threshold value thus fixed. If a number of successive points lie above the threshold, there is likewise a single event, which however is given a higher weighting, as described below.

Calculation of the characteristic value: the calculation of the characteristic value is based on a weighting of the individual events with respect to their extent in the frequency band. The extent of the events in the frequency band is determined by the directly successive points in the frequency band that lie above the threshold value being counted. The falling of the amplitude below the threshold value consequently indicates the end of the event. Many metrics are conceivable for the weighting of the events with respect to their extent. The inventor has used the following metric: the counting values Z1 and Z2 are obtained for each spectrum: Z1 is the number of events and Z2 is the number of points in the frequency band that lie above the threshold value. The sum of Z1 and Z2 is formed over all the spectra considered. The two sums are multiplied. The characteristic value is the product of these sums, but normalized to one rotation of the hydraulic machine. As stated, other suitable metrics may also be used.

Comparison with the limit value: the characteristic value is compared with a limit value. The limit value is the same for all hydraulic machines. If the characteristic value exceeds the limit value, there is cavitation, and suitable means for avoiding damage can be taken (for example altering the operating state or blowing in air).

Global determination of the threshold value and the limit value: the threshold value and the limit value were fixed by the inventor on the basis of the 4 hydraulic machines investigated. The same threshold value and the same limit value were obtained for all 4 machines. The absolute value of the threshold value and the limit value only depends here on the gain factor or the sensitivity of the sensors used and the parameters of the evaluation method (for example on the frequency

band considered and the temporal scanning rate of the sensors). It is also directly evident from what has been said above that the absolute values of the threshold value and the limit value are dependent on one another. Thus, similar results are obtained if for example the threshold value is chosen to be somewhat lower and conversely the limit value is chosen to be correspondingly higher. Furthermore, moderate alterations in the choice of the limit value and the threshold value have only a slight effect on the information derived with respect to the state of cavitation of the machine, since the characteristic value increases extremely steeply at the beginning of cavitation. Therefore, the invention described here is not based on the absolute values of the threshold value and the limit value but on the evaluation steps described above. It is only possible by the sequence of evaluation steps according to the invention that have been described to fix globally valid pairs of values for the threshold value and the limit value. Therefore, only one possible pair of values for the threshold value and the limit value shall be given here: for the sensors used by the inventor, a possible threshold value of 0.01 V^2 (for the frequency band of 100 to 300 kHz) and a possible limit value of 100 were obtained.

It is also possible to work with a number of threshold values and limit values. If for example it is wished to indicate cavitation that is just beginning, a second, lower threshold value and a second corresponding limit value are chosen. For the occurrence of cavitation that is beginning, the inventor fixed a threshold value of 0.01 V^2 and a limit value of 10 (likewise under the conditions mentioned in the paragraph above).

Finally, it should also be mentioned that the sensor or sensors used must of course be attached at suitable locations of the hydraulic machine (for example on the

turbine cover or on the suction pipe wall in the direct vicinity of the impeller).

Patent claims

1. A method for detecting cavitation during the operation of a hydraulic machine, which has at least one impeller, with the aid of at least one structure-borne sound sensor, characterized in that the following method steps are carried out: detection of the signal of the at least one sensor over a time period which comprises at least one rotation of the impeller; bandpass filtering of the signal; preparation of the signal; temporal division of the signal into suitable time intervals (the three steps following this are carried out separately on the individual partial signals); spectral decomposition; application of an event counter in the frequency domain; weighting of the events with respect to their extent in the frequency band; calculation of at least one characteristic value from the weighted events of all the partial signals; comparison of the at least one characteristic value with at least one limit value.