

Method and device for detecting a pulse-type mechanical
effect on a system part

The invention relates to a method and to a device for
5 detecting a pulse-type mechanical effect on a system
part.

There is a need in a multiplicity of applications to
monitor continuously the proper operation of a system
10 part for example a pipeline or a container in chemical
process engineering or a fluid-flow machine, in order
to detect disturbances in good time and to avoid
serious consequential damage. A multiplicity of methods
for such monitoring are known in the prior art.

15 EP 0 765 466 B1 proposes, for example, to undertake the
monitoring of the vibrations of turbine blades with the
aid of microwaves that are directed onto the turbine
blades. Conclusions may be drawn on the turbine's state
20 of vibration from the modulation of the microwaves
reflected at the turbine blades.

In the method known from DE 198 57 552 A1, the rupture
of the shaft of a turbine is detected by measuring the
25 rotational frequencies at the ends of the shaft.

It is proposed in DE 198 43 615 C2 to undertake the
diagnosis of the state of a combustion drive with the
aid of an analysis of the frequency spectrum of the
30 measurement signals that are picked up with the aid of
a sound pickup arranged in the air inlet region or
exhaust gas region.

In DE 197 27 114 C2, a machine is monitored by
35 detecting the signals of structure-borne sound striking
it, instead of the air noise. In this known method, as
well, there is an analysis of the respectively
determined frequency spectra of the measurement signals
detected by the structure-borne sound pickup.

In the case of the method disclosed in DE 195 45 008 C2, as well, the frequency spectrum of the measurement signal detected by a monitoring sensor, for example an acceleration pickup, is analyzed during the operation of the machine and compared with a reference frequency spectrum.

In order to be able to ascertain the intrusion of foreign parts into a gas turbine, in US 4,888,948 there is arranged at the inlet of the turbine a sensor with the aid of which an electric charge induced by the foreign bodies is detected.

In the method, disclosed in DD 224 934 A1, for determining a change in state of a machine having rotating parts, measured values of a signal describing the operating state are detected continuously and compared with adaptive threshold values. In order to determine these threshold values, quantile values of the probability distribution of the measured values are determined recursively and adaptively. Parameters for the state of the machine are determined from the number and level of the instances of overshooting of the threshold values.

A particular problem is represented by loose parts that are entrained by the flow and strike the system part and which cause only a pulse-type, short term effect that is correspondingly problematic to demonstrate reliably.

Problems of this kind can occur, for example, in the case of gas turbines whose combustion chambers are lined with ceramic tiles for protection against overheating. These ceramic tiles are subjected to high dynamic loads by alternating pressure fluctuations occurring in the combustion chamber. It can happen in this case that portions of the tiles on the respective

holders break away, are entrained by the flow of exhaust gas and strike the first guide-blade row of the gas turbine. This can lead to damage to the coating of the guide blades, and to destruction of the moving
5 blades arranged therebehind. Moreover, there is the risk of a tile already damaged by the breaking away of portions becoming completely detached from the holders and possibly causing correspondingly massive damage to the gas turbine. In this case, the occurrence of small
10 loose parts or an individual tile indicates an impending total breaking away of a tile or a number of tiles, and so switching off the gas turbine in good time and exchanging the damaged tiles prevent more extensive damage.

15 It is known in principle from WO 01/75272 A2 for the purpose of monitoring such impacts on a system part to make use of suitable sensors to detect the impact by means of structure-borne sound thereby produced.
20 However, particularly in the case of gas turbines, the problem arises here that the normal level of operating noise is so high that even the signal component generated by the impact of a whole tile on the guide blade of the gas turbine is smaller than the background
25 generated by the normal operating noises, and so, in particular, the occurrence of relatively small portions cannot be detected by simply monitoring the amplitudes of the signals of structure-borne sound. It is therefore proposed in this publication for the purpose
30 of improving the signal-to-noise ratio to subject the measurement signal picked up by a measuring sensor to bandpass or high-pass filtering in order in this way to eliminate the signals of structure-borne sound produced in normal operation of the turbine. These measures are
35 not, however, sufficient for reliably identifying a pulse-type event in the case of high background noises that vary temporally.

There is known from WO 03/071243 A1 a method for detecting a pulse-type mechanical effect on a system part in the case of which the detected structure-borne sound signal is subjected to a windowed Fourier transformation. The algorithms explained there in more detail are used to derive from a multiplicity of Fourier spectra determined in this way an evaluation function K that indicates the occurrence of a pulse-type mechanical effect on the system part. The algorithm, specified in this publication, for deriving the evaluation function K enables the precise detection of a signal component that is superposed on the noisy measurement signal and is to be ascribed to a pulse-type effect.

The essential step in this proposed evaluation algorithm is that for each time window and each of the prescribed frequencies the deviation of the magnitude A of the Fourier transform from a mean magnitude $\bar{A}$ is determined. In this case, a decisive significance attaches to the formation of the mean magnitude $\bar{A}$, since there can be random changes in state in system parts, particularly in the case of a turbine, in which the system part changes from one operating state into another, and the operating or background noise can rise very quickly to a significantly higher level. The start of a so-called hum is such a change in state, in the case of a turbine, for example. This is caused by the arrangement of the flames in an annular space, which can have the result that the entire combustion chamber is excited to sympathetic vibrations, the vibration modes in the circumferential direction being preferred, in particular. These resonance phenomena can in part break off abruptly and likewise start up again abruptly. If a sliding mean magnitude that is formed by a simple averaging as an arithmetic mean from a number of prior magnitudes is used as a basis for the method disclosed in WO 03/071243, with the content of WO 03/071243 being expressly a constituent part of the

present patent application, it has emerged that these noise fluctuations can lead to erroneous triggering. In order to avoid instances of such erroneous triggering, monitoring for pulse-type mechanical effects was
5 therefore suppressed in practice during the humming of the turbine, which is detected by analyzing the signal characteristic.

In other system parts, as well, for example in a
10 reactor pressure vessel of a nuclear power plant, operationally induced short-term operating noises are superposed on the continuous basic noises (fluid flow, pump noise), as caused, for example, by permissible changes in the operating conditions and intentional
15 interventions in the operating sequence (actuation of valves, movement of control rods).

It is the object of the invention to specify a method for detecting a pulse-type mechanical effect on a
20 system part that is further improved by comparison with the method disclosed in WO 03/071243. The object of the invention is also to specify a device for carrying out the method.

25 With regard to the method, said object is achieved in accordance with the invention with the aid of a method having the features of patent claim 1. In the case of the method for detecting a pulse-type mechanical effect on a system part, an operating noise present in the
30 system part is detected continuously by a sensor arranged on the system part, and is converted by said sensor into a measurement signal that is processed with the aid of the following method steps:

a) the magnitude ($A(f_i, t_j)$) of the transform of the
35 measurement signal (M) is determined with the aid of prescribed parameters of a mathematical transformation rule in time steps of temporally sequential time windows,

- b) the deviation of the magnitude ($A(f_i, t_j)$) from a mean magnitude ($\bar{A}(f_i, t)$) is determined for each time step (δt) and each of the prescribed parameters (f_i),
- c) an evaluation function ($K(t)$) is derived for each
5 time step (δt) from the deviations determined for each of the prescribed parameters (f_i),
- d) the evaluation function ($K(t)$) is compared with a threshold value (K_0), and the overshooting of the threshold value (K_0) is used as an index for the
10 presence of a pulse-type signal component indicating the mechanical effect,
- e) the mean magnitude ($\bar{A}(f_i, t_j)$) is determined in a sliding fashion as a function of time (t) from a data record ($\underline{A}(f_i, t)$) having M magnitudes ($A(f_i, t_m)$) with the
15 aid of the relationship

$$\bar{A}(f_i, t) = (Q_\alpha(f_i, t) + Q_{1-\alpha}(f_i, t))/2$$

Q_α and $Q_{1-\alpha}$ being respectively the α and $(1-\alpha)$ quantiles of the magnitudes ($A(f_i, t_m)$) respectively determined in a time segment (T), and $t_m = t + m\delta t$ and m being a whole
20 number.

The invention is based in this case on the finding that a simple numerical averaging of the magnitude A can have the consequence that a fast transition of the
25 operating state into a state having a higher noise level is erroneously interpreted as a burst signal, that is to say a signal resulting from a pulse-type effect on the system part. Such a signal is illustrated in the diagram in accordance with figure 2. In this
30 diagram, the measurement signal M picked up at a turbine by a structure-borne sound pickup is plotted against time t . It is to be seen in the figure that a humming that lasts respectively approximately 2 s sets in abruptly at the instants $t = 4$ s and $t = 8$ s.

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The evaluation function $K(t)$ derived from the measurement signal M in accordance with figure 2 on the basis of the in WO 03/071243 A1 is illustrated, likewise as a function of time, in a diagram in figure

3. It is to be gathered from this figure that the evaluation function $K(t)$ rises significantly at least during the time period of the humming of the turbine between $t = 4$ s and $t = 6$ s. This rise would then be
5 erroneously interpreted as a burst signal for the occurrence of a large system part. In this case, the calculation of the evaluation function $K(t)$ was based on an improved iterative calculating method in which the mean magnitude $\bar{A}$ and a mean quadratic deviation
10 (variance) are determined for each frequency f_i in a sliding fashion with the aid of the relationships
$$\bar{A}(f_i, t + \delta t) = k\bar{A}(f_i, t) + (1-k)A(f_i, t + \delta t)$$
 and
$$\text{var}A(f_i, t + \delta t) = k\text{var}A(f_i, t) + (1-k)(A(f_i, t + \delta t) - \bar{A}(f_i, t))^2,$$
 δt being the time step in which the
15 magnitude A is respectively determined for a time window Δt . By selecting the parameter k , it is now determined to what extent a magnitude $A(f_i, t + \delta t)$ being newly added thereto influences the newly calculated mean magnitude $\bar{A}(f_i, t + \delta t)$. This approach corresponds to
20 an exponentially weighted averaging, k determining the adaptation rate. In the event of a sudden change in the magnitude $A(f_i, t)$ from a constant initial value to a likewise constant new value, there would then be an approximately exponential adaptation of the new mean
25 magnitude $\bar{A}$ to the new, currently present magnitude A with a time constant $\tau = \delta t / (1-k)$. For $k = 0.999$ and $\delta t \approx 3.2$ ms, there is a time constant τ of 3.2 s.

As is to be gathered from figure 3, even an evaluation
30 algorithm improved in this way is not capable of adapting optimally to fast changes in the operating noise, that is to say of determining with sufficient accuracy the respectively valid mean magnitude $\bar{A}(f_i, t)$, and the standard deviation $A(f_i, t)$ thereof, of the
35 operating noise in the event of fast changes. Certainly, it is possible in principle to adapt the mean magnitude $\bar{A}(f_i, t)$ more quickly to the changed operating situation by reducing the time constant τ , that is to say by reducing the parameter k . However,

this has the disadvantage that a superposed burst signal can no longer be recorded with sufficient sensitivity. In order to be able to distinguish burst signals such as are caused by the striking of loose parts from these superposed background noises of the machine, it is necessary to determine a mean on which no burst signal is superposed, or for which a possibly superposed burst signal in any event has a negligible influence on the mean magnitude $\bar{A}(f_i, t)$ owing to a very large time constant.

The second-named object is achieved in accordance with the invention with the aid of a device having the features of patent claim 6, the advantages of which correspond to the advantages specified in relation to patent claim 1.

Advantageous refinements of the method and of the device are specified in the respective subclaims.

Reference is made to the drawing for the purpose of further explanation of the invention. In the drawing:

figure 1 shows an exemplary embodiment of a device in accordance with the invention, in a schematic diagram,

figure 2 shows a diagram in which the operating noise (measurement signal M) of a turbine that is detected by a measuring pickup is plotted against time t,

figure 3 shows a diagram in which the evaluation function K derived from the measurement signal M of figure 2 in accordance with an evaluation algorithm represented in WO 03/071243 is plotted against time,

figure 4 shows a simplified diagram in which the measurement signal M is plotted against time t with higher temporal resolution,

5 figure 5 shows a diagram in which the magnitude A of the frequency spectrum determined from the measurement signal M by fast Fourier transformation is plotted against time t for a prescribed frequency f_i ,

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figure 6 shows a diagram in which the sliding time mean $\bar{A}$ of the magnitudes A of the spectrum is likewise plotted against time t for a prescribed frequency f_i ,

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figure 7 shows a diagram in which the evaluation function K derived from the measurement signal of figure 2 with the aid of a method in accordance with the invention is plotted against time t ,

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figure 8 shows a diagram in which there is plotted against time t a measurement signal M picked up at a turbine and on which there is superposed a burst caused by an impact, and

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figure 9 shows a diagram in which the evaluation function K determined from this measurement signal is likewise plotted against time.

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In accordance with figure 1, there are arranged on a system part 2, for example, a gas turbine, a plurality of measuring pickups or sensors 4, in particular piezoelectric acceleration pickups, that continuously detect in a number of measuring channels the operating noise present in the system part 2 and propagating in the form of structure-borne sound. The sensors 4 respectively convert the structure-borne sound signals into an electric measurement signal that is amplified

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in a preamplifier 6 and is relayed to an analogue/digital converter 8 that is connected to a digital memory 10. The amplified measurement signal M respectively present is thus digitized, buffered and
5 relayed for further processing to an arithmetic unit 12 in which the evaluation algorithm according to the invention is implemented.

The arithmetic unit 12 includes for each measuring
10 channel a processor for a fast calculation of a transform of the data relayed by the analogue/digital converter 8, as well as a ring memory for storing a number L of the transforms determined by the transformation. This transformation can be, for
15 example, a fast windowed Fourier transformation FFT. Any mathematical operation with which it is possible to represent this mathematical function with the aid of a complete set of orthogonal base functions is to be understood as a transformation of said function (the
20 measurement signal $M(t)$) in the meaning of the present invention. As is the case with the Fourier transformation - these orthogonal base functions can be formed by the exponential function $e^{-i\omega t}$. However, it is also possible in principle to use other periodic
25 functions as orthogonal base system. These transformations are used to calculate discrete transforms with the aid of a predetermined set of discrete parameters. In the case of Fourier transformation, these are permanently prescribed
30 frequencies $f_i = \omega_i / 2\pi$ that are selected in accordance with the respective system part, as is explained in more detail for a turbine, for example, in WO 03/071243.

35 For each measuring channel, an algorithm implemented in the arithmetic unit 12 and explained in more detail below employs the discrete transforms determined in the arithmetic unit 12 to determine an evaluation function $K(t)$ dependent on time t that is compared in a

comparing device 14 with a prescribed threshold value K_0 . An overshooting of the threshold value K_0 (alarm threshold) serves as index for the presence of a pulse-type signal component caused by a transient mechanical effect, and generates a corresponding trigger signal S. The trigger signal S is fed to a transient recorder 16 in which the measured data (measurement signals M_s) for a time range of 10 s, for example, is recorded and relayed to an evaluation computer 18 in order that the latter can be used to carry out a subsequent analysis.

Figure 2 shows the measurement signal M respectively detected by a sensor 4 at a turbine for a time period of approximately 10 s. It is clearly to be seen that the turbine begins to hum abruptly at the instants $t = 4$ s and $t = 8$ s.

Figure 4 uses a schematic sketch to explain the first step of the mode of procedure implemented in the arithmetic unit 12 (figure 1). The measurement signal M digitized with a high clock rate (typically 80-100 kHz, associated time interval DT approximately 0.01 - 0.0125 ms, (drawn enlarged in the figure) (and illustrated in analogue fashion in the figure for reasons of clarity) is respectively stored for a time range TS (typically approximately 10 s), and updated in accordance with the clock rate. In a time window Δt within this time range TS , the digitized measurement signal M is subjected to a fast discrete Fourier transformation. Subsequently, the time window Δt is updated displaced by a time step δt , and a Fourier transformation is carried out anew in an overlapping time window Δt of the same length. In the exemplary embodiment, $\Delta t = 25.6$ ms and $\delta t = 3.2$ ms. In this way, time-dependent magnitudes $A(f_i, t)$ are determined for each time window Δt and for a finite number of discrete frequencies f_i .

In figure 5 the time profile of the magnitude A for a prescribed frequency f_i is illustrated. It may be gathered from this figure that the magnitude A varies with time for this prescribed frequency f_i . The time interval plotted in the figure is the time step δt in which the fast Fourier transformation is updated. In accordance with the invention, the associated value of the magnitude $A(f_i, t_j)$, where $t_j = t_0 + j\delta t$, j being a natural number, is determined for a multiplicity N of prescribed frequencies f_i or frequency ranges and in temporally sequential time steps δt for temporally overlapping time windows Δt .

A mean magnitude $\bar{A}(f_i, t)$ is now formed from the values of the magnitude $A(f_i, t)$. This mean magnitude $\bar{A}(f_i, t)$ is a temporally sliding mean which is determined in a sliding fashion in time steps δt as a function of the time t from a data record $\underline{A}(f_i, t)$, assembled from M magnitudes $A(f_i, t_m)$ of a time segment T , with the aid of the relationship

$$\bar{A}(f_i, t) = (Q_\alpha(f_i, t) + Q_{1-\alpha}(f_i, t))/2,$$

wherein Q_α and $Q_{1-\alpha}$ are the α and $(1-\alpha)$ quantiles of the magnitudes $A(f_i, t_m)$ relatively determined in a time segment T , where $t_m = t + m\delta t$ and m is a whole number. To this end, the magnitudes $A(f_i, t_m)$ associated with this time segment T , arranged by way of example symmetrically in relation to the instant t (it holding in this case that $-\frac{M-1}{2} \leq m \leq \frac{M-1}{2}$ and M is odd), and

respectively forming the data record $\underline{A}(f_i, t)$ assigned to the instant t are sorted in a sequence by value of the magnitude. The α or $(1-\alpha)$ quantile is then that value of the magnitude which is located at the position αM or $(1-\alpha)M$ of the sequence. In practice, values are set between $0.7 \leq \alpha \leq 0.8$, preferably $\alpha = 0.75$ for α . A mean magnitude $\bar{A}(f_i, t)$ obtained with the aid of this calculating method is illustrated in figure 6.

The α and $(1-\alpha)$ quantiles, Q_α and $Q_{1-\alpha}$, respectively, are now used to calculate a mean deviation $s(f_i, t)$ of the magnitudes $A(f_i, t_m)$ from the mean magnitude $\bar{A}(f_i, t)$,
5 by using the relationship

$$s(f_i, t) = \sqrt{\frac{Q_\alpha(f_i, t) - Q_{1-\alpha}(f_i, t)}{2q_{1-\alpha}}},$$

$q_{1-\alpha}$ being the $(1-\alpha)$ quantile of the normalized Gaussian
10 distribution or normal distribution.

This calculating method (quantile method) can therefore be used to calculate the mean and deviation of a data record without taking account of the values that are
15 located outside the ranges defined by α and $(1-\alpha)$. This means that substantially higher magnitudes such as can occur in an additionally amplified fashion from a superposed burst signal are not taken into account, and thus also cannot corrupt the result. This method can be
20 used in conjunction with the same quality of the result of calculation to select a substantially shorter time segment, for example a data record $\underline{A}(f_i, t)$ comprising $M = 100$ values of the magnitude $A(f_i, t_j)$ and having a length of $T = 320$ ms for the time segment for a time
25 step $\delta t = 3.2$ ms. Consequently, the mean magnitude $\bar{A}(f_i, t)$ is adapted to rapid changes in the operating background so that these are unable to lead to corruption of the normalized spectra or to appear as erroneous displays in the monitoring. It is possible in
30 the case of such a mode of procedure for the striking of loose parts to be detected even during the humming of a gas turbine, that is to say when sympathetic vibrations in the combustion chamber give rise to substantially higher background noises very abruptly,
35 for example with a time constant of approximately 0.5 s in association with an amplitude rise by a factor of 5 and more. The existing calculated mean magnitude

$\bar{A}(f_i, t)$ and the mean deviation $s(f_i, t)$ can now be used in a further computing step to determine on the basis of the quantile method an improved mean magnitude $\bar{A}_{opt}(f_i, t)$ by eliminating from the respectively present data record $\underline{A}(f_i, t)$ those magnitudes $A(f_i, t_m)$ that are significantly greater than the previously calculated mean magnitude $\bar{A}(f_i, t)$. In practice, it has proved to be advantageous in this case when calculating the mean to eliminate those magnitudes $A(f_i, t_m)$ that are greater than $\bar{A}(f_i, t) + 3s(f_i, t)$. With the complete data record $\underline{A}(f_i, t)$, a renewed calculation of mean is then carried out with the aid of a δ or $(1-\delta)$ quantile, in which case

$$\delta = \alpha (M - M_E) / M$$

holds, and M_E is the number of the magnitudes $A(f_i, t_m)$ that are greater than $\bar{A}(f_i, t) + 3s(f_i, t)$. As an alternative thereto, it is also possible and mathematically identical to determine the α and $(1-\alpha)$ quantile anew with the aid of a data record reduced by these magnitudes $A(f_i, t_m)$. With the aid of these δ and $(1-\delta)$ quantiles, or of the α and $(1-\alpha)$ quantiles obtained with the reduced data record, an improved mean $\bar{A}_{opt}(f_i, t)$ or an improved mean deviation $s_{opt}(f_i, t)$ is now calculated in accordance with the abovenamed formula.

With the aid of the mean magnitudes $\bar{A}(f_i, t)$ or $\bar{A}_{opt}(f_i, t)$ and of the mean deviation $s(f_i, t)$ or $s_{opt}(f_i, t)$, a normalized deviation $D(f_i, t)$ of the magnitude A from the mean magnitude $\bar{A}$ is now calculated for each frequency in accordance with the following equation:

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$$D(f_i, t_m) = (A(f_i, t_m) - \bar{A}(f_i, t)) / s(f_i, t) \text{ or}$$

$$D(f_i, t_m) = (A(f_i, t_m) - \bar{A}_{opt}(f_i, t)) / s_{opt}(f_i, t).$$

The magnitudes $A(f_i, t_m)$ of M spectra are evaluated in order to determine the mean magnitude $\bar{A}(f_i, t)$ valid at the instant t and the mean deviation $s(f_i, t)$ valid at this instant t . In other words: both the mean magnitude
5 $\bar{A}(f_i, t)$ or $\bar{A}_{opt}(f_i, t)$ and the mean deviation $s(f_i, t)$ or $s_{opt}(f_i, t)$ are constantly updated with the aid of M transformations. This updating is performed in time steps δt . The data record $\underline{A}(t+\delta t)$ forming the basis of the calculation of the new mean magnitude $\bar{A}(f_i, t+\delta t)$ or
10 $\bar{A}_{opt}(f_i, t+\delta t)$ and of the new mean deviation $s(f_i, t+\delta t)$ or $s_{opt}(f_i, t+\delta t)$ is formed in this case by deleting the first (oldest) magnitude and adding the newest magnitude. In the case of a time segment T arranged symmetrically relative to the instant t , these are the
15 magnitudes

$$A(f_i, t - \frac{M-1}{2} \delta t) \text{ and } A(f_i, t + \frac{M-1}{2} \delta t).$$

In an advantageous refinement, the normalized deviation
20 $D(t, f_i)$ is additionally averaged in a frequency range $f_{i-L}, f_{i-L+1}, \dots, f_{i+L}$ surrounding the frequency f_i and consisting of $2L+1$ frequencies, and a mean normalized deviation $\bar{D}(t, f_i)$ is determined by the equation

$$25 \quad \bar{D}(f_i, t) = \frac{1}{1+2L} \sum_{k=-L}^{k=+L} D(f_{i+k}, t).$$

This additional computing step leads to a reduction in the level and breadth of fluctuation of normalized deviation in the ranges in which only background
30 signals are present. The useful signal components are not markedly varied by the averaging in the frequency range, since they always occur in a fashion concentrated about neighboring frequency lines. This measure results once more in an improvement to the
35 signal/background ratio by a further 10 to 15 dB.

A further improvement in the signal/background ratio is achieved when a threshold value D_0 is additionally introduced, and a normalized deviation $\bar{D}_s(f_i, t)$ is determined with the aid of the relationship $\bar{D}_s = D_0$ for
5 $\bar{D} < D_0$ and $\bar{D}_s = \bar{D}$ for $\bar{D} \geq D_0$.

The normalized deviations $D(f_i, t)$, $\bar{D}(f_i, t)$ or $\bar{D}_s(f_i, t)$ determined in this way are squared and summed through all the discrete frequencies f_i :

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$$S(t) = \sum_{i=1}^N D(f_i, t)^2 / N \quad (a)$$

$$S(t) = \sum_{i=1}^N \bar{D}(f_i, t)^2 / N \quad (b)$$

15 or

$$S(t) = \sum_{i=1}^N \bar{D}_s(f_i, t)^2 / N \quad (c).$$

An evaluation function $K(t)$ is now derived from this
20 sum $S(t)$ by extracting the root:

$$K(t) = \sqrt{S(t)} \quad (1).$$

The latter serves as indicator for the occurrence of an impact. As an alternative to this, it is also possible
25 for the evaluation function to be formed from the difference between the root of the sum $S(t)$ and a sliding time mean of this root

$$\tilde{K}(t) = K(t) - \bar{K}(t) \quad (2),$$

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and for it to serve as characteristic for the occurrence of an impact. If $K(t)$ or $\tilde{K}(t)$ overshoots a threshold value K_0 (alarm threshold), which is between

1.5 and 2 for gas turbines, this constitutes an indication for the impact of a loose part.

5 The evaluation function $K(t)$ obtained in this way and with the aid of the mean normalized deviation $\bar{D}_s$ from the measurement signal M of figure 2 is illustrated in figure 7. It is now clearly to be seen that the humming of the turbine does not influence the evaluation function $K(t)$.

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Nevertheless, it remains possible with the aid of the inventive method to reliably detect the striking of a loose system part. Figure 8 shows a real measurement signal $M(t)$ obtained on a turbine and on which there is
15 superposed at an instant $t = 3.9$ s a burst that is caused by an impact and cannot be identified directly in the measurement signal M .

Figure 9 illustrates with an enlarged time scale the
20 evaluation function K derived from the measurement signal of figure 8. It is to be seen from the figure that the event (the burst) taking place is rendered noticeable by a clear rise in the evaluation function K .

Claims

1. A method for detecting a pulse-type mechanical effect on a system part (2), in the case of which an operating noise present in the system part (2) is detected continuously by a sensor (4) arranged on the system part (2), and is converted by said sensor into a measurement signal (M), characterized by the following method steps:
- 10 a) the magnitude ($A(f_i, t_j)$) of the transform of the measurement signal (M) is determined with the aid of prescribed parameters (f_i) of a mathematical transformation rule in time windows (Δt) that are temporally sequential in time steps (δt),
 - 15 b) the deviation of the magnitude ($A(f_i, t_j)$) from a mean magnitude ($\bar{A}(f_i, t)$) is determined for each time step (δt) and each of the prescribed parameters (f_i),
 - c) an evaluation function ($K(t)$) is derived for each time step (δt) from the deviations determined for each
 - 20 of the prescribed parameters (f_i),
 - d) the evaluation function ($K(t)$) is compared with a threshold value (K_0), and the overshooting of the threshold value (K_0) is used as an index for the presence of a pulse-type signal component indicating
 - 25 the mechanical effect,
- characterized in that
- e) the mean magnitude ($\bar{A}(f_i, t_j)$) is determined in a sliding fashion as a function of time t from a data record ($\underline{A}(f_i, t)$) having M magnitudes $A(f_i, t_m)$ with the
 - 30 aid of the relationship
$$\bar{A}(f_i, t) = (Q_\alpha(f_i, t) + Q_{1-\alpha}(f_i, t))/2$$
$$Q_\alpha \text{ and } Q_{1-\alpha} \text{ being respectively the } \alpha \text{ and } (1-\alpha) \text{ quantiles of the magnitudes } A(f_i, t_m) \text{ respectively determined in a time segment } (T), \text{ and } t_m = t + m\delta t \text{ and } m \text{ being a whole}$$
 - 35 number.
2. The method as claimed in claim 1, in which the time segment (T) is arranged symmetrically in relation to the instant t .

3. The method as claimed in claim 1 or 2, in which an improved mean magnitude ($\bar{A}_{opt}(f_i, t)$) is calculated from the mean magnitude ($\bar{A}(f_i, t)$), in that to determine the
5 quantiles those magnitudes ($A(f_i, t)$) that overshoot the mean magnitude ($\bar{A}$) by a prescribed difference value are eliminated from the data record.

4. The method as claimed in claim 1, 2 or 3, in which
10 for each of the prescribed parameters (f_i) a mean deviation ($s(f_i, t)$) of the magnitudes ($A(f_i, t_j)$) from the mean magnitude ($\bar{A}(f_i, t)$) is determined for a plurality of sequential time windows (Δt) with the aid of the relationship

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$$s(f_i, t) = \sqrt{\frac{Q_\alpha(f_i, t) - Q_{1-\alpha}(f_i, t)}{2q_{1-\alpha}}}$$

$q_{1-\alpha}$ being the $(1-\alpha)$ quantile of the normalized normal distribution, and the normalized deviation of the
20 magnitudes from the mean magnitude ($\bar{A}(f_i, t)$) being determined with the aid thereof and being used to calculate the evaluation function ($K(t)$).

5. The method as claimed in claim 4, in conjunction
25 with claim 3, in which the prescribed difference value is a threefold multiple of the mean deviation (s).

6. The method as claimed in either of claims 4 and 5,
in which for each time window (Δt) the sum of the
30 squares of each normalized deviation is formed over each of the prescribed parameters from which the evaluation function (K) is derived.

7. The method as claimed in one of the preceding
35 claims, in which the mathematical transformation rule is a windowed Fourier transformation, and the

parameters are frequencies (f_i) of the frequency spectrum of the measurement signal (M).

8. A device for detecting a pulse-type mechanical effect on a system part (2), having at least one sensor (4), arranged on the system part (2), for continuously detecting and measuring an operating noise present in the system part (2), and having an A/D converter (10), connected downstream of the sensor (4), for digitizing the measurement signals (M) detected by the sensor (4) and for relaying the digitized measurement signals to an arithmetic unit (12) for carrying out the following computational steps:

a) the magnitude ($A(f_i, t_j)$) of the transform of the measurement signal (M) is determined with the aid of prescribed parameters (f_i) of a mathematical transformation rule in time windows (Δt) that are temporally sequential in time steps (δt),

b) the deviation of the magnitude ($A(f_i, t_j)$) from a mean magnitude ($\bar{A}(f_i, t)$) is determined for each time step (δt) and each of the prescribed parameters (f_i),

c) an evaluation function ($K(t)$) is derived for each time step (δt) from the deviations determined for each of the prescribed parameters (f_i),

d) the evaluation function ($K(t)$) is compared with a threshold value (K_0), and the overshooting of the threshold value (K_0) is used as an index for the presence of a pulse-type signal component indicating the mechanical effect,

characterized in that

e) the mean magnitude ($\bar{A}(f_i, t_j)$) is determined in a sliding fashion as a function of time t from a data record ($\underline{A}(t)$) having M magnitudes $A(t_m)$ with the aid of the relationship

$$\bar{A}(f_i, t) = (Q_\alpha(f_i, t) + Q_{1-\alpha}(f_i, t))/2$$

Q_α and $Q_{1-\alpha}$ being respectively the α and $(1-\alpha)$ quantiles of the magnitudes $A(f_i, t_m)$ respectively determined in a time segment (T), with $t_m = t + m\delta t$ and m being a whole number.

9. The device as claimed in claim 8, in which the time segment (T) is arranged symmetrically in relation to the instant (t).

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10. The device as claimed in claim 8 or 9, having an algorithm, implemented in the arithmetic unit (12), for calculating an improved mean magnitude ($\bar{A}_{opt}(f_i, t)$) from the mean magnitude ($\bar{A}(f_i, t)$), in that to determine the
10 quantiles those magnitudes ($A(f_i, t_m)$) that overshoot the mean magnitude ($\bar{A}(f_i, t)$) by a prescribed difference value are eliminated from the data record ($\underline{A}(t)$).

11. The device as claimed in one of claims 8 to 10, in
15 which, in the arithmetic unit (12), for each of the prescribed parameters (f_i) the mean deviation ($s(f_i, t)$) of the magnitudes ($A(f_i, t_j)$) from the mean magnitude ($\bar{A}(f_i, t)$) is determined for a plurality of sequential time windows (Δt) with the aid of the relationship

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$$s(f_i, t) = \sqrt{\frac{Q_\alpha(f_i, t) - Q_{1-\alpha}(f_i, t)}{2q_{1-\alpha}}}$$

$q_{1-\alpha}$ being the $(1-\alpha)$ quantile of the normalized normal distribution, and the normalized deviation of the
25 magnitudes from the mean magnitude ($\bar{A}(f_i, t)$) being determined with the aid thereof and being used to calculate the evaluation function ($K(t)$).

12. The device as claimed in claim 11, in conjunction
30 with claim 10, in which the prescribed difference value is a threefold multiple of the mean deviation (s).

List of reference numerals

2	System part
4	Sensor
6	Pre-amplifier
8	Multiplexer
10	Analogue/digital converter
12	Arithmetic unit
14	Comparing device
16	Transient recorder
18	Evaluation computer
M	Measurement signal
K	Evaluation function
t	Time
Δt	Time window
δt	Time step
A	Magnitude
f_i	Frequency
$\bar{A}$	Mean magnitude
<u>A</u>	Data record
TS	Time range
DT	Time interval
T	Time segment