

**METHOD FOR DETERMINING AND/OR MONITORING AT LEAST ONE PHYSICAL,
PROCESS VARIABLE OF A MEDIUM**

The present invention relates to a method for determining and/or monitoring at least one physical, process variable of a medium with an oscillatable unit, wherein the oscillatable unit is excited by means of a frequency search sweep within a predetermined frequency band in the working range of the oscillatable unit in the form of transmitted signals successively to oscillate with discrete exciter frequencies following one after the other, wherein the corresponding oscillations of the oscillatable unit are received in the form of received signals, wherein, via the frequency search sweep, that exciter frequency is ascertained, in the case of which the oscillatable unit oscillates with an oscillation frequency, which has a predetermined phase shift between the transmitted signal and the received signal, and wherein a transmitting/receiving unit excites the oscillatable unit to oscillate with the ascertained oscillation frequency or wherein the following frequency search sweep is started. The process variable is, for example, a predetermined fill level of the medium, the phase boundary, the density or the viscosity of the medium.

With vibronic measuring devices, a large number of physical variables can be detected or monitored, such as, for example, the fill level, the phase boundary, the density or the viscosity of a medium in a container or in a pipeline. The assignee provides such measuring devices in a large variety under the marks, Liquiphant and Soliphant.

Vibronic measuring devices have an oscillatable unit, which, most often, includes a membrane and a thereon secured oscillatory rod or an oscillatory fork having two tines. There are, however, also vibronic measuring devices known, whose oscillatable unit is only the membrane.

The exciting of the oscillatable unit to oscillate with the resonance frequency occurs usually via a piezoelectric stack- or bimorph drive or via electrodynamic drive elements, wherein the drive unit, most often, is embodied as a combined transmitting/receiving unit. The transmitted signal and the received signal have a phase shift, which usually lies in a defined range around 90° .

For fill level measurement, the effect is utilized that the oscillation frequency and oscillation amplitude change, when the degree of covering of the oscillatable unit changes. In air, undamped oscillation occurs, while oscillation is damped in the case of oscillatable unit covered with medium. This change in the oscillation amplitude or oscillation frequency is utilized to detect the reaching of a predetermined fill level, usually a maximum fill level, for overflow protection or a minimum fill level for protection against running empty,.

The oscillation amplitude of an oscillatory fork or of an oscillatory rod depends furthermore on how much mass is being dragged. If the density or the phase of a medium changes, then this influences the oscillation of the oscillatable unit, so that a transition between different phases as well as also density changes can be detected with the vibronic measuring device. In similar manner, the oscillation is damped when the viscosity of the medium increases.

In order to so set the exciter frequency that the oscillatable unit oscillates with a predetermined phase shift between transmitted signal and received signal, the assignee has developed a method utilizing a frequency search sweep. A corresponding patent application (Application No. DE 102009026685) has been filed but has not yet been published. The method will be described briefly here.

In the frequency search sweep, the oscillatable unit is excited successively to oscillate with discrete, closely neighboring frequencies and the frequency corresponding to the predetermined phase shift is ascertained. The ascertaining of the frequency occurs, in such case, via phase selective rectification and following low-pass filtering. A rectangular signal delayed by the predetermined phase shift relative to received signal is multiplied with the received signal. If the phase shift between the transmitted signal and the received signal corresponds to the predetermined phase shift, then this product contains only positive portions, while in the opposite case, it also negative has portions. The described evaluation methods can be implemented analogly or digitally. The embodiment with analog components has, in such case, two disadvantages. On the one hand, the circuit complexity is high and, on the other hand, the determining of the oscillation frequency at the predetermined phase shift is relatively inaccurate. The advantages in the case of the digital practice of the method include that the high circuit complexity is absent and, additionally, the oscillation frequency can be determined with high accuracy. The disadvantage of the digital method is, however that it is very calculation intensive, which makes a high computing power necessary.

An object of the invention, consequently, is to provide a method for the simple evaluation of frequency search sweep.

The object is achieved by the features including that the oscillation frequency at the predetermined phase shift is ascertained by sampling the received signal discretely at selected points in time, wherein the selected time points depend on the predetermined phase shift between transmitted signal and received signal, and that the voltage values U_i of the received signal sampled at the discrete exciter frequencies are evaluated with reference to amplitude.

Since the received signal is sampled discretely only at selected points in time, the number of measurement points, which are stored and further processed, is reduced compared to methods, in the case of which the entire received signal is further processed. In this way, the computing power required is reduced. A further advantage is that the evaluation occurs essentially digitally, which saves time and manufacturing costs compared with analog practice. The used components can have high tolerances, since, for example, noise is filtered out, so that exact results are achieved nevertheless.

In a first embodiment of the solution of the invention, for evaluating sampled voltage values U_i of the received signal, negative portions of the received signal are converted, by rectification or by adding an offset voltage, into positive voltage values. The received signal is an alternating voltage. Before digitizing for evaluating the received signal the therein contained, negative portions are preferably converted into positive portions, in order to make the received signal useful for an analog-digital converter, which can only process positive

input voltages. If an analog-digital converter is used, which can process both negative as well as also positive input voltages, then the changing into positive signals is not required. The changing into positive voltage values is accomplished either by rectification, i.e. through inverting the negative voltage values, or by adding a direct voltage to the alternating voltage, so that the entire voltage curve is shifted by a certain value (offset) into the positive region. The offset is selected, in such case, in order, on the one hand, that all negative voltage values are shifted into the positive region, and, on the other hand, the value of the maximum arising voltage does not exceed the allowable maximum input voltage of the analog-digital converter.

In a further development of the method of the invention, the received signal is always sampled at points in time, when it, in the case of presence of the predetermined phase shift between transmitted signal and received signal, passes through an extreme. Thus, per oscillation period, always two voltage values of the received signal are sampled.

In the case of an additional further development of the invention, for the case, in which the predetermined phase shift amounts to 90° , the received signal is always sampled at points in time, when the transmitted signal, in the case of presence of the predetermined phase shift, passes through zero.

A further development of the method of the invention provides that the sampled voltage values U_i of the received signal are evaluated by determining the frequency, at which the magnitude $|U_i|$ of the voltage value is maximum. If the received signal at a frequency f_k corresponds to an oscillation with the

predetermined phase shift, then the voltage value detected at the sampling points in time corresponds to the maximum oscillation amplitude. If the received signal at a frequency f_1 does not correspond to the oscillation with the predetermined phase shift, then the maximum amplitude is not detected at the sampling points in time, but, instead a lesser voltage value. If one plots the voltage values at different frequencies determined at the sampling points in time, then there results a curve with a maximum at the frequency f_k , where the transmitted signal and the received signal have the predetermined phase shift.

A further development of the method of the invention provides that the sampled voltage values U_i of the received signal are evaluated by adding the magnitudes of the voltage values $|U_i|$ sampled over a number of oscillation periods of equal frequency to a value $\Sigma |U_i|$, and the frequency is determined, at which the associated value $\Sigma |U_i|$ is maximum.

A further development of the solution of the invention is provides that the received signal is sampled always at points in time, at which, in the presence of the predetermined phase shift between transmitted signal and received signal, it passes through zeros and extrema. Per oscillation period, there are thus four voltage values sampled.

In the case of a further development of the method of the invention, for the case, in which the predetermined phase shift amounts to 90° , the received signal is always sampled at points in time when the transmitted signal, in the case of presence of the predetermined phase shift, passes through zero and at points in time, at which the transmitted signal, in the case of

presence of the predetermined phase shift, passes through an extreme.

In a further development of the method of the invention, the sampled voltage values U_{ii} , U_{ij} of the received signal are evaluated by subtracting from one another the magnitudes, in each case, of two sequential voltage values $|U_{ii}|$, $|U_{ij}|$, which correspond, at the predetermined phase shift, to the voltage value at a zero traverse and the magnitude of the voltage value at an extreme of the received signal, and the frequency is determined to be that at which the difference $\Delta U = |U_{ii}| - |U_{ij}|$ has maximum magnitude. If the measured voltage values $|U_{ii}|$ of the maximum voltage values, which occur at the respective frequency, by a magnitude dU_{ii} and the measured voltage values $|U_{ij}|$ differ from zero by a magnitude dU_{ij} , then the difference ΔU differs by $dU_{ii} + dU_{ij}$ from the maximum voltage value at the respective frequency. If one considers only the voltage values, which, in the case of predetermined phase shift, correspond to extrema, then these differ by a smaller value, namely dU_{ii} , from the maximum voltage value, which occurs at the respective frequency. If the predetermined phase shift is present, then there results in the case of the difference forming between the value, in the case of the maximum and the value, in the case of the zero traverse, the same (maximum) voltage value, which results only through consideration of the maximum. Therefore, is the maximum around the frequency corresponding to the desired phase shift in the case of consideration of the differences ΔU more marked than in the case of the method, in the case of which only the voltage values are sampled and evaluated, which, at predetermined phase relationship, correspond to the maximum,.

In a further development of the solution of the invention, the voltage values U_{ii} , U_{ij} of the received signal sampled over a number of oscillation periods of equal frequency are so evaluated that the magnitudes of the sampled voltage values $|U_{ii}|$, which were sampled at points in time, which, at the predetermined phase shift, correspond to the position of an extreme, are added to a value U_{max} , that the magnitudes of the sampled voltage values $|U_{ij}|$, which were sampled at points in time, which, at the predetermined phase shift, correspond to the position of a zero traverse, are added to a value U_{zero} , that the values U_{max} and U_{zero} are subtracted from one another and that the frequency is determined, at which the difference $\Delta U = U_{max} - U_{zero}$ has maximum magnitude. For each frequency, thus, in each case, only one voltage value is taken into consideration for determining the frequency at the predetermined phase shift.

A further development of the method of the invention provides that a phase shift between transmitted signal and received signal is set, which depends on the quality of the oscillatable unit

In an additional further development of the solution of the invention, a phase shift between transmitted signal and received signal is set, which lies preferably in the range between 70° and 120° . The predetermined phase shift amounts, most often, to 90° or lies preferably in the stated range. It is, however, equally possible that it assumes a value outside of the stated range, to the extent that the quality of the oscillatable unit permits this.

Another further development of the invention provides that the physical measured variable is a predetermined fill level of the

medium, the density, the viscosity, or the phase boundary of the medium. If a predetermined fill level of the medium in a container is to be detected, then the oscillatable unit is placed at the height of the predetermined fill level.

The invention will now be explained in greater detail based on the appended drawing, the figures of which show as follows:

Fig. 1a an example of the positioning of the sampling points in the case of a received signal with the frequency f_k corresponding to the predetermined phase shift;

Fig. 1b an example of the positioning of the sampling points in the case of a received signal with the frequency f_l lying outside the predetermined phase shift;

Fig. 1c the received signal of Fig. 1a after rectification;

Fig. 1d the received signal of Fig. 1a after adding a direct voltage;

Fig. 2 a flow diagram of the method of the invention;

Fig. 3 the histogram recorded for determining the frequency at the predetermined phase shift.

Fig. 1a shows the received signal R at an exciter frequency f_k over one and one half periods. For comparison, the transmitted signal T is likewise plotted. In Fig. 1a, the exciter frequency f_k corresponds to the predetermined phase shift $\Delta\phi$ between transmitted signal T and received signal R. At the sampling points in time, the received signal R is located in zero

traverses or extrema. The sampled voltage values U_{ii} correspond, consequently, to the maximum arising voltage value A_k , thus the amplitude, at this exciter frequency f_k and the sampled voltage values U_{ij} are zero. In this example, only the sampling points in time lying within a period are presented. Of course, samples at an exciter frequency f_k over a number of periods can occur, in order to achieve better statistics.

For the case shown here, in which the predetermined phase shift $\Delta\phi$ between transmitted signal T and received signal R amounts to 90° , the zero traverses of the transmitted signal T coincide with the extrema of the received signal R and the extrema of the transmitted signal T with the zero traverses of the received signal R. Relative to the transmitted signal T, the received signal R is thus always sampled at points in time, when the transmitted signal T passes through a zero or an extreme.

Fig. 1b shows a received signal R with an exciter frequency f_1 , which is located outside the predetermined phase shift $\Delta\phi$ for the transmitted signal T. The sampling points in time, consequently, do not coincide with the points in time, at which the received signal R passes through a zero or an extreme. The sampled voltage values U_{ii} differ from the maximum voltage value A_1 by a value dU_{ii} and the sampled voltage values U_{ij} differ from zero by a value dU_{ij} .

The received signals R illustrated in Figs. 1a and 1b are alternating voltages and the voltage values U_{ii} , U_{ij} at the sampling points in time are partially negative. In a preferred embodiment of the method, the received signal R is so modified before the sampling that only positive voltage values remain. This is accomplished, for example, by inverting, or rectifying,

the negative voltage portions. Fig. 1c shows the received signal R of Fig. 1a after rectification. Another opportunity for changing the negative voltage portions is to add a direct voltage to the received signal R. In this way, the entire voltage curve forming the received signal is shifted by a certain value, the so-called offset, into the positive region. The received signal R modified in this way is shown in Fig. 1d. Since this offset is the same for all exciter frequencies f_k contained in the frequency search sweep, all sampled voltage values U_{1i} , U_{1j} are shifted by the same value. If an offset is added to the received signal, then this value must be taken into consideration in the evaluation of the sampled voltage values U_{1i} , U_{1j} , since, for example, the voltage value U_{1j} in the case of a zero and presence of the predetermined phase shift $\Delta\varphi$ is not zero, but, instead, corresponds to the value of the offset voltage.

Fig. 2 discloses a flow diagram of an example of an embodiment of the method of the invention. In the following, it is assumed that the received signal R contains only positive portions because of rectifying or addition of a direct voltage. Application of a sign was therefore omitted. It should, however, be noted that in the case, in which no such modification of the received signal R has taken place, the magnitudes, or absolute values, of negative voltage values are formed.

During the frequency search sweep, the oscillatable unit is excited with discrete exciter frequencies f_k ($k=0\dots N$) within the total working range. The goal is to filter out that exciter frequency f_k , in the case of which the transmitted signal T and the received signal R have a predetermined phase shift $\Delta\varphi$, for

example, 90° . For this, a transmission signal T with a first exciter frequency f_0 is produced. The received signal R is sampled at selected points in time. The points in time are, in such case, then selected such that, in the case of predetermined phase shift $\Delta\phi$, the extrema and the zero traverses of the received signal R are detected. In the case of a predetermined phase shift $\Delta\phi = 90^\circ$, these are the points in time, at which the transmitted signal T traverses zero and extrema.

The voltage values U_{ii} sampled at expected extrema and voltage values U_{ij} sampled at expected zero traverses are stored. The sampled and stored voltage values U_{ii} , U_{ij} are processed, by subtracting, in each case, a voltage value U_{ii} , which corresponds to an expected extreme, from a thereon following voltage value U_{ij} , which corresponds to an expected zero-point,. After an established number of oscillation periods, the next exciter frequency f_k is set.

If the exciter frequency f_k is that, in the case of which the phase shift $\Delta\phi$ corresponds to the predetermined phase shift $\Delta\phi$, then the voltage values U_{ii} sampled at expected extrema correspond to the maximum voltage value, which occurs for the particular exciter frequency f_k , thus the amplitude A_k of the oscillation. The voltage values U_{ij} sampled at expected zero traverses are zero. If, however, the exciter frequency f_k differs from the exciter frequency f_k , in the case of which the predetermined phase shift $\Delta\phi$ is present, then the voltage values U_{ii} , U_{ij} detected at the sampling points in time are smaller than the associated amplitude A_k or greater than zero. The voltage value U_{ii} , which is detected, is thus not the maximum voltage value A_k , which occurs in the case of the respective exciter frequency f_k . If one forms the difference, in each case, of the

two voltage values U_{ii} and U_{ij} , which were sampled in the case of the expected zero traverse and in the case of the expected extreme, then this difference ΔU is smaller than the difference ΔU at the predetermined phase shift $\Delta\phi$. At the predetermined phase shift $\Delta\phi$, the difference ΔU equals the amplitude A_k of the received signal and, thus, is maximum. If to the received signal an offset is added, in order to obtain purely positive voltage values, then this value must be appropriately taken into consideration in the case of evaluating the sampled voltage values U_{ii} , U_{ij} .

An alternative embodiment of processing the voltage values U_{ii} , U_{ij} sampled at an exciter frequency f_k provides that all voltage values U_{ii} sampled in the case of an expected extreme are added to a value U_{max} , that all voltage values U_{ij} sampled in the case of an expected zero traverse are added to a value U_{zero} , and that then the difference $\Delta U = |U_{max} - U_{zero}|$ is formed. In this way, one obtains an averaged voltage value for each exciter frequency f_k .

In an additional method step, the formed voltage differences ΔU are plotted versus the respective exciter frequencies f_k . The resulting histogram has a maximum at the exciter frequency f_k corresponding to the predetermined phase shift $\Delta\phi$.

In this example of an embodiment, both expected zero traverses as well as also expected extrema are sampled and then the difference ΔU between the voltage values U_{ii} , U_{ij} is formed. In an alternative embodiment of the method, the received signal R is sampled only at points in time of expected extrema. If the received signal R in the case of the exciter frequency f_k corresponds to an oscillation with the predetermined phase shift

$\Delta\phi$, then the oscillation amplitude A_k is detected. If the received signal R in the case of the exciter frequency f_k does not correspond to the oscillation with the predetermined phase shift $\Delta\phi$, then not the amplitude A_k is detected, but, instead, a lesser value. If one plots the voltage values U_{ii} determined at different exciter frequencies f_k , then there results a curve with a maximum at that exciter frequency f_k , in the case of which the transmitted signal T and the received signal R have the predetermined phase shift $\Delta\phi$. Analogously to the case described for the difference forming, the sampled voltage values U_{ii} over a number of oscillation periods can be added up, so that in the histogram per exciter frequency f_k only a voltage value ΣU_{ii} is stated. Alternatively, an option is to list all sampled voltage values U_{ii} separately.

It is provided that as soon as a frequency search sweep is ended, a renewed frequency search sweep is started, the frequency search sweeps thus are performed continuously. In this way, changed process conditions can be rapidly reacted to and the oscillation frequency of the oscillatable unit can be immediately adjusted. Alternatively, for this, the oscillatable unit is excited with the exciter frequency f_k determined in the frequency search sweep. Renewed frequency search sweeps occur then, for example, instead, at determined intervals or are started on request.

Fig. 3 shows a histogram for determining that exciter frequency f_k , in the case of which the transmitted signal T and the received signal R have the predetermined phase shift $\Delta\phi$. Besides the received signal R sampled according to the method described in Fig 2, also shown is the received signal R before the sampling. The maximum at the exciter frequency f_k

corresponding to the predetermined phase shift $\Delta\phi$ is clearly evident in both curves. The sampled received signal R is, however, more sharply defined and has a higher ratio of maximum to baseline. The received signal R shown in this histogram is for a membrane oscillator.

List of Reference Characters

R	received signal
T	transmitted signal
$\Delta\varphi$	phase shift between transmitted signal and received signal
f_k	exciter frequency contained in the frequency search sweep
A_k	amplitude of the received signal with frequency f_k / maximum voltage value
U_{ii}	voltage values of the received signal sampled at points in time, at which an extreme of the received signal is expected
U_{ij}	voltage values of the received signal sampled at points in time, at which a zero of the received signal is expected,
dU_{ii}	difference between U_{ii} and A_k
dU_{ij}	difference between U_{ij} and zero

Patent Claims

1. Method for determining and/or monitoring at least one physical, process variable of a medium with an oscillatable unit, wherein the oscillatable unit is excited by means of a frequency search sweep within a predetermined frequency band in the working range of the oscillatable unit in the form of transmitted signals (T) successively to oscillate with discrete exciter frequencies (f_k) following one after the other, wherein the corresponding oscillations of the oscillatable unit are received in the form of received signals (R), wherein, via the frequency search sweep, the exciter frequency (f_k) is ascertained, in the case of which the oscillatable unit oscillates with an oscillation frequency, which has a predetermined phase shift ($\Delta\phi$) between the transmitted signal (T) and the received signal (R), and wherein a transmitting/receiving unit excites the oscillatable unit to oscillate with the ascertained oscillation frequency or wherein the following frequency search sweep is started,

characterized in that

the oscillation frequency at the predetermined phase shift ($\Delta\phi$) is ascertained by sampling the received signal (R) discretely at selected points in time, wherein the selected points in time depend on the predetermined phase shift ($\Delta\phi$) between transmitted signal (T) and received signal (R), and the voltage values U_i of the received signal (R) sampled at the discrete exciter frequencies (f_k) are evaluated with reference to their amplitude.

2. Method as claimed in claim 1,
characterized in that,

for evaluating sampled voltage values U_i of the received signal (R), negative portions of the received signal (R) are converted, by rectification or by adding an offset voltage, into positive voltage values $|U_i|$.

3. Method as claimed in claim 1 or 2,

characterized in that

the received signal (R) is always sampled at points in time, when it, in the case of presence of the predetermined phase shift ($\Delta\phi$) between transmitted signal (T) and received signal (R), passes through an extreme.

4. Method as claimed in at least one of claims 1-3,

characterized in that,

for the case, in which the predetermined phase shift ($\Delta\phi$) amounts to 90° , the received signal (R) is always sampled at points in time, when the transmitted signal (T), in the case of presence of the predetermined phase shift ($\Delta\phi$), passes through zero.

5. Method as claimed in claim 3 or 4,

characterized in that

the sampled voltage values U_i of the received signal (R) are evaluated by determining the exciter frequency (f_k) at which the magnitude of the voltage value $|U_i|$ is maximum.

6. Method as claimed in claim 3 or 4,

characterized in that

the sampled voltage values U_i of the received signal (R) are evaluated by adding the magnitudes of the voltage values $|U_i|$ sampled over a number of oscillation periods of equal frequency (f_k) to a value $\Sigma |U_i|$, and the exciter frequency

(f_k) is determined, at which the associated value $\sum |U_i|$ is maximum.

7. Method as claimed in claim 1 or 2,

characterized in that,

the received signal (R) is sampled always at points in time, at which, in presence of the predetermined phase shift ($\Delta\phi$) between transmitted signal (T) and received signal (R), it passes through zeros and extrema.

8. Method as claimed in claim 1,2 or 7,

characterized in that,

for the case, in which the predetermined phase shift ($\Delta\phi$) amounts to 90° , the received signal (R) is always sampled at points in time when the transmitted signal (T), in the case of presence of the predetermined phase shift ($\Delta\phi$), passes through zero and at points in time, at which the transmitted signal (T) passes through an extreme.

9. Method as claimed in claim 7 or 8,

characterized in that

the sampled voltage values U_{ii} , U_{ij} of the received signal are evaluated by subtracting from one another the magnitudes, in each case, of two sequential voltage values $|U_{ii}|$, $|U_{ij}|$, which correspond, at the predetermined phase shift ($\Delta\phi$), to the magnitude of the voltage value at a zero traverse and the magnitude of the voltage value on an extreme of the received signal (R), and the exciter frequency is determined to be that at which the difference $\Delta U = |U_{ii}| - |U_{ij}|$ has maximum magnitude.

10. Method as claimed in claim 7 or 8,

characterized in that

voltage values U_{ii} , U_{ij} of the received signal (R) sampled over a number of oscillation periods of equal frequency (f_k) are so evaluated that the magnitudes of the sampled voltage values $|U_{ii}|$, which were sampled at points in time, which, at the predetermined phase shift ($\Delta\phi$), correspond to the position of an extreme, are added to a value $U_{\max}$, the magnitudes of the sampled voltage values $|U_{ij}|$, which were sampled at points in time, which, at the predetermined phase shift ($\Delta\phi$), correspond to the position of a zero traverse, are added to a value U_{zero} , the values $U_{\max}$ and U_{zero} are subtracted from one another and the exciter frequency is determined, at which the difference $\Delta U = U_{\max} - U_{\text{zero}}$ has maximum magnitude.

11. Method as claimed in at least one of preceding claims,

characterized in that

a phase shift ($\Delta\phi$) between transmitted signal (T) and received signal (R) is set, which depends on the quality of the oscillatable unit.

12. Method as claimed in at least one of preceding claims,

characterized in that

a phase shift ($\Delta\phi$) between transmitted signal (T) and received signal (R) is set, which lies preferably in the range between 70° and 120° .

13. Method as claimed in at least one of preceding claims,

characterized in that

the physical measured variable is a predetermined fill level of the medium in a container, density, viscosity, or a phase boundary of the medium.