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(54) METHOD FOR SURVEILLANCE OF AIR OPERATED DIAPHRAGM PUMP AND SURVEILLANCE DEVICE

(57) A method for surveillance of an air operated diaphragm pump is provided whereby initially an accelerometer with at least 3 orthogonal accelerometer measuring directions is attached to an air operated diaphragm pump or to a structure directly connected with an air operated diaphragm pump; agitation level of the accelerometer at a frequency rate above a predefined pulse rate of the air operated diaphragm pump is registered, and a base line noise level of the accelerometer agitation level during a period of no pump action is measured and stored, and a pulse rate of the air operated diaphragm pump is determined as the most significant frequency of pulses out of an entire power spectrum calculated from the accelerometer readings, and lastly the most significant frequency of pulses and the duration of registered pulse signals is determined and stored.

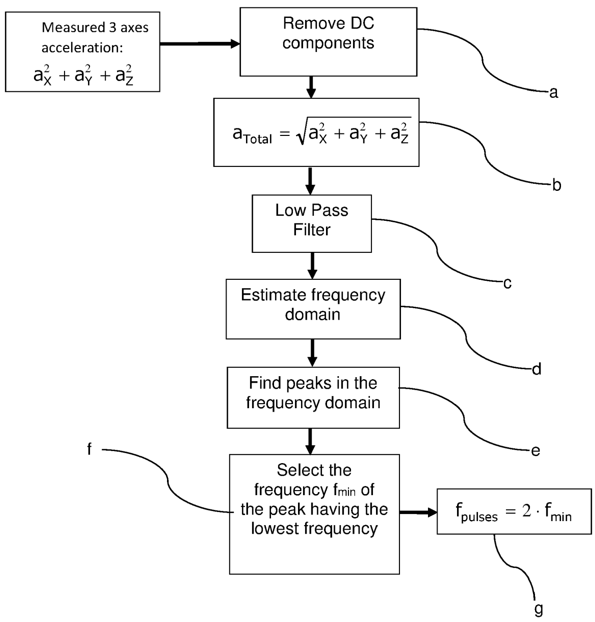

Fig. 6

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Description

Field of endeavor

[0001] The monitoring and surveillance of air operated diaphragm pumps to determine the number of pulses which has been conducted with a given pump is challenging, however important as an air operated diaphragm pump shall only survive a predefined number of pulses in a given environment due to diaphragm wear during pumping action. In order to avoid brake down during operation it is thus required, that a precise measure of pump strokes is obtained, such that the membrane may be changed in a planned maintenance operation, which does not adversely affect the operation of a plant comprising the pump.

Brief Description of the related are

[0002] It is known to add stroke counters fitted to the air exhaust system; however, such elements are prone to be unreliable and are not necessarily capable of detecting erratic pump action due to different kinds of mal function.

[0003] Thus, there is a need for a method and an apparatus which enables reliable and fail-safe detection of pump strokes and which eliminates the above- mentioned disadvantages of the prior art.

Summary

[0004] A method for surveillance of an air operated diaphragm pump is provided whereby initially an accelerometer with at least 3 orthogonal accelerometer measuring directions is attached to an air operated diaphragm pump or to a structure directly connected with an air operated diaphragm pump; agitation level of the accelerometer at a frequency rate above a predefined pulse rate of the air operated diaphragm pump is registered, and a base line noise level of the accelerometer agitation level during a period of no pump action is measured and stored, and a pulse rate of the air operated diaphragm pump is determined as the most significant frequency of pulses out of an entire power spectrum calculated from the accelerometer readings, and lastly the most significant frequency of pulses and the duration of registered pulse signals is determined and stored.

[0005] Based on the pulse frequency which is determined as the most significant frequency in the power spectrum and the duration of pulse or stroke action of the air operated pump, it is now easy to determine the number of stroke actions provided within a given time frame, and to also store this value.

[0006] By this method, a total number of stroke actions of a given pump may continually be surveilled, and the surveillance date may be used for the generation of alerts, in case the pump action is not according to plan, or an end of life for the membrane is approaching. Maintenance, such as the exchange of a pump membrane may be initiated timely and in a controlled manner, which does not negatively affect the operation of the plant in which the pump serves.

[0007] In an aspect of the invention the frequency spectrum for the accelerometer readings is determined from calculated values: aRMS(i) based on sampled accelerometer readings at a sampling rate whereby,

$$\mathrm{aRMS(i)} = \sqrt{\frac{1}{M}\sum_{k=i}^{i+M} a^2(i)}$$

and where i is the sample number, and M is the number of samples used to calculate the value aRMS_i, at sample number i, and further

$$a = a_{Total}(i) = \sqrt{X^2(i) + Y^2(i) + Z^2(i)}$$

where X_i, Y_i and Z_i are normalized accelerometer output values in orthogonal directions x, y and z respectively in each sample. It is the $a_{total}(i)$ values which are used in the calculation of the aRMS(i) values. Normalization if the X_i, Y_i and Z_i values are performed in a usual manner in order to exclude bias from gravitation so that only accelerations due to the movements of the pump are included in the calculations.

[0008] The aRMS(i) time dependent values are indicative of the energy levels contained in the accelerometer signal and thus indicative of the agitation level of the pump at a particular sample. The M value, which counts the number of samples going into calculating each aRMS(i) value determines, together with the sampling rate for the accelerometer signal, the frequency resolution of the calculated power spectrum.

[0009] In an aspect of the invention, M is chosen such that at a given sampling rate, the duration of the M samples spans a time of no more than half the time of a pulse duration during normal operation of the pump being monitored. In this way it is ensured, that the pump stroke signal is sure to show up in the power spectrum as a frequency with a significant energy content.

[0010] In an aspect of the invention an externally threaded part of an accelerometer housing is rotated into a threaded connection pipe or threaded pipe bracket located on a suction or pressure pipe leading to/from the air operated diaphragm pump whereby the distance between the connection pipe or bracket and the pump is adapted to be no more than 6 times the pipe diameter of suction or pressure pipe respectively, or preferably no more than 4 times the pipe diameter og most preferred no more than 2 times the pipe diameter. The working medium which the pump is to pressurize, shall also flow to/from the pump in accordance with the stroke rate of the pump, and thus the pipes leading to and from the pump and feeding the medium to the volume changing cavities in front of the membranes, shall vibrate in accordance with the stroke rate, at least close to the pump itself. Thus, it is preferred that the housing and accelerometer is provided close to the pump.

[0011] In this way it is assured, that the accelerometer shall be intimately connected to the vibrating part of the pump to be followed. Also, these pumps are usually connected with pipes, such as water pipes, and here, it is easy to connect the threaded stub to a connection pipe, such as an open pipe-end having internal threads. The threaded connection ensures a play-free connection between the accelerometer housing and the pump or pipe connection. Such a play free connection is important in ensuring that resonance frequencies of pipes and accelerometer housing are not energized by the sometimes-fierce vibrations of these pumps. It further allows the accelerometer housing to be added to the pump or pipes at the pump without use of specialized tools, and in fact the mounting of the accelerometer housing may be done by hand. The threads on the exterior of the stub shall be chosen according to the threading standard, which is most prominent in the country or region, where the pump is installed. The use of a simple treaded stub is also instrumental in ensuring, that the pump rate may be calculated fail safe with the relatively simple calculations given above.

[0012] In an aspect of the invention the following steps are performed:

- determine the pulse rate of the air operated diaphragm pump at regular intervals and store the determined pulse rates at a data repository within the housing,
- feed pulse rate data through a wireless connection channel to a remote data repository at regular intervals.

[0013] The determined pulse rates which have been collected at regular intervals allows for the pump to be monitored or surveilled, such that any un-foreseen events may be observed centrally for any number of pumps equipped with the surveillance means.

[0014] In an aspect of the invention an accelerometer housing houses a sub-giga radio which receives pulse rate data from one or more accelerometers at nearby pumps and feeds these pulse rate data through a cellular device via a cellular connection to a data repository located away from the cellular device. The data are wirelessly transmitted to a remote data repository and this will potentially create a digital version of a life story of the pump, which if compared to life stories of other pumps may provide valuable data concerning the reliability of a single pump, classes of pumps or populations of pumps working with similar media.

[0015] In a further aspect of the invention NFC signals are captured within the housing when an NFC enabled device such as a cell phone is placed in the vicinity of the housing. Such NFC signals are used to modify a content of a control device which control device facilitates the accelerometer measurements. In this way, an operator may change settings locally based on observed events and conditions around the pump in question.

[0016] In a further aspect the control device is adapted to monitor a pulse rate from a pump, and to provide an alert in case pulse rates are not within predetermined limits. This allows a close monitoring of a pump locally, such that immediate alerts may be provided to anyone in the vicinity of the pump.

[0017] The invention further relates to a surveillance device comprising a:

- housing and an accelerometer within the housing which accelerometer is adapted to capture acceleration data in 3 orthogonal directions in space, and a
- data repository adapted to temporarily store captured acceleration data,
- a calculation unit adapted to determine a pump stroke rate based on the accelerometer readings,
- a feed line adapted to wirelessly transmit stored accelerometer data which reflects the pump stroke rate,
- control device adapted to:
- control the capture of accelerometer data and to
- process the captured data, and
- to control the feed line and control the wireless transmission of the stored accelerometer data,

whereby the housing of the surveillance device comprises an externally threaded stub, which is adapted to threadedly connect to an internally threaded connection pipe or bracket at or associated with an air operated diaphragm pump.

[0018] In order to ensure, that accelerometer readings are sufficiently representative of motions of a given air operated diaphragm pump, the accelerometer housing shall have to be play-free and forcefully connected to the pump or piping connected to the pump. This is ensured by the externally treaded stub of the accelerometer housing and its being threadedly connected to an internally treaded connection pipe or bracket at or connected with an air operated diaphragm pump.

[0019] In an aspect of the invention the surveillance device is adapted to calculate an overall energy level measure based on registered accelerometer values in 3 orthogonal directions whereby a frequency spectrum for the overall energy level measure is determined from calculated values:

- aRMS(i) based on sampled accelerometer readings at a sampling rate whereby,

$$aRMS(i) = \sqrt{\frac{1}{M}\sum_{k=i}^{i+M} a^2(i)}$$

and where i is the sample number, and M is the number of samples used to calculate the value aRMS, at sample number i and further

$$a = a_{Total}(i) = \sqrt{X^2(i) + Y^2(i) + Z^2(i)}$$

where X_i, Y_i and Z_i are normalized accelerometer output values in orthogonal directions x, y and z respectively in each sample.

[0020] Hereby a secure and precise detection of the frequency spectrum for the energy level at the accelerometer is provided, such that pump stroke rate may be securely and precisely calculated when the frequency spectrum of the energy levels has been determined. A frequency spectrum based on the data here will display a dominant frequency line at the pulsation rate or pulsation frequency of the pump. And as these pulsations of the pumps are always periodic, they do not change significantly over time and further, the noise energy level is far below the energy level of the signal generated by the pulsations of the pump at the pulsation frequency.

[0021] In an aspect of the invention, the externally threaded part of the accelerometer housing is rotated into a threaded connection pipe or threaded pipe bracket located on a suction or pressure pipe to/from the air operated diaphragm pump whereby the distance between the connection pipe or bracket and the pump is adapted to be no more than 6 times the pipe diameter of suction or pressure pipe respectively, or preferably no more than 4 times the pipe diameter og most preferred no more than 2 times the pipe diameter.

[0022] Hereby it is ensured, that the obtained measurement data may be used in the calculation of the pump rate without the possibility of resonance frequencies of other parts of the system being energized to levels, where they might disturb the measurements.

[0023] In an aspect of the invention the device further comprises a PCB (printed circuit board) which PCB is mounted with the control device, a radio transmitter adapted to transmit captured accelerometer data and the accelerometer. The accelerometer may be a micromechanical device such as a MEMS device and thus adapted to be mounted onto a PCB. PCB parts may be screwed onto and thus secured unmovably to any inside part of the accelerometer housing.

[0024] In a further aspect of the invention an NFC enabled communication device and a sub-giga radio are provided at the PCB. This allows communication to and from the housing in various wireless formats, such as through the short-range NFC channel, which is part of many telephones and similar devices, and through a sub-giga radio transmission, which is used for standardized communication and data exchange in many industries.

[0025] In a further aspect of the invention, a battery is housed in the housing and connected to the PCB in order to energize the electric parts mounted thereon. This allows the device a stand-alone capability which is most important in places where electric power cables are not easily provided.

[0026] In yet a further aspect of the invention, the control device is adapted to provide an alarm in case the calculated pump rate is not according to expectation. In this way, the surveillance device also shall work as a stand-alone device, and still provide important benefits even if not in connection with a remote data repository.

[0027] In a further aspect, the surveillance device has a visual display which is mounted on the housing.

Brief Description of the Drawings

[0028] The invention will become more fully understood from the detailed description given herein below. The accompanying drawings are given by way of illustration only, and thus, they are not limitative of the present invention. In the accompanying drawings:

Fig. 1 shows a schematic 3d representation of a housing;
Fig. 2 shows an exploded view of the housing;
Fig. 3 shows a sectional view of a lowermost part of the housing;
Fig. 4 shows a bundle of wires adapted to feed signal in and out of the housing;
Fig. 5 is a schematic representation of the most important parts of the surveillance device according to the invention;
Fig. 6 is a route diagram with the main steps in the signal processing algorithm used to detect the pump stroke rate;
Fig. 7 shows three graphs with X, Y and Z direction values of the accelerometer readings displayed;
Fig. 8 shows the combined energy in the signal from the three axial direction calculated according to a norm;
Fig. 9 displays the same digital values after low pass filtration according to a digital filtering regime;
Fig. 10 is the data after an FFT conversion;
Fig. 11 is a pump and surveillance device disclosed with the surveillance device screwed into a pipe end connecting the two working membranes of a pump;
Fig. 12 is a bracket with a surveillance device mounted therein with its threaded stub an

Detailed description exemplary embodiments

[0029] Referring now in detail to the drawings for the purpose of illustrating preferred embodiments of the present invention, a housing 1 of the present invention is illustrated in Fig. 1.

[0030] Fig. 2 illustrates the various parts of the housing, whereby a cradle part 2, a lid part 3 and an elastomeric safety band 4 are shown one above the other. A battery pack 5 is also disclosed.

[0031] The cradle comprises a PCB element 8, which is mounted therein, and is equipped with a range of components.

[0032] In Fig. 3 the cradle part 2 is shown in a sectional view. Here, an externally threaded, but hollow stub 6 is clearly visible. The external threads 7 of the stub 6 shall be made according to a suitable standard, such as ISO metric pipe threads, NPT thread, or other standardized pipe thread. The pipe tread 7 on an exterior surface of the stub 6 allows the stub 6 to be threaded into a connection pipe or possibly a bracket with an internally threaded hole. In connection with the air operated membrane pumps it is mandatory to have a feed pipe and a delivery pipe for a fluid to be moved by the pump, and it is also required to have a feed line for compressed air. The stub 6 shall thus be easy to fix to any well-known internally threaded connection pipe or bracket with an internally threaded connection hole where such a bracket is adapted to fit onto a standardized pipe connection to the pump. Thus, the threaded stub allows the cradle part 2 to be connected to any one of a range of different membrane pumps.

[0033] When the stub 6 is connected to an internally threaded connection pipe at or near an air operated membrane pump, the vibrations generated by the pump shall be transmitted to the stub through the pipes, whether they be feed pipes to the pump or delivery pipes from the pump.

[0034] In Fig. 3 the cross-sectional view of the cradle 2 shows that it comprises raised screw stubs 11 added to the lower portion of the cradle 2. The screw stubs 11 allow items such as a PCB board 8 to be fastened to the cradle 2 by threaded screws (not shown).

[0035] The lid 3 has internally arranged threads on the skirt thereof, and these are adapted to engage externally arranged corresponding threads on the cradle 2 on a raised portion thereof.

[0036] The elastomeric safety band 4 is adapted to be preyed onto the assembly of cradle 2 and lid 3 to assume the position disclosed in Fig. 1. Here the band 4 shall cover the intersection between the cradle 2 and the lid 3. Hereby it is ensured, that no foreign substances shall enter into the enclosure formed by the cradle 2 and lid. It is also ensured through locking engagement between a lover rim of the safety band and the external side of the cradle 2, combined with a rotationally fixed connection between the safety band 4 and the lid 3, that lid and cradle shall not come apart in-advertently. This is of some importance, as the pumps in question often serve at rugged places, where various kinds of commotions may interfere with installed delicate equipment and cause distortions thereof. Such elements as intense vibrational levels at varying frequencies could cause a loosening between the lid and the cradle were it not for measures such as the safety band. Thus, the safety band 4 is important in keeping the contents of the housing safe, protected against shocks and dry.

[0037] In Fig. 4, a wire feed line 9 is disclosed, which comprises a moulded-on connector 10. The connector 10 is adapted to fit inside the cavity of the hollow stub 7. In order for the connector 10 to be installed inside the hollow stub, the bottom 12 thereof must be removed. This is done by drilling the bottom out, and a drill bit indent 13 is provided to ensure that this operation may be performed safely. When the connector 10 with its wire feed 9 is installed in a drilled hole in the stub 6, the upper and lower flanges of the connector shall secure the feed lines from being in-advertently pulled out, and they also ensure against penetration into the enclosure 1 of gasses or liquids. The feed line 9 may comprise a number of electric leads and thus allow the PCB a wired connection to surroundings, such as a power line, wired connection to one or more sensors, or allow a digital in/out wired connection to be facilitated at the PCB board. The feed line 9, running through the stub is used when the cradle part is installed into a wiring panel at a pump location and not directly onto a pump or pump related structure.

[0038] In Fig. 5 there is a schematic representation of the key components associated with the PCB. A sub-giga radio 14 is indicated, along with: an NFC-chip 15, a vibration sensor 16, a battery pack, analog input connectors 17, a digital input connector and a microcontroller 19. To make the different mentioned elements work together, they are interconnected in the usual manner through leads in the PCB and solder connections between PCB and parts mounted thereon. The battery pack may have a wire connection with a connector, in order to facilitate battery change.

[0039] The digital input port 18 may be connected through a digital input line 22 to external devices such as a high-speed counter in order to register strokes or flowmeter data.

[0040] The two analog input connectors 7 may be connected to external sensors, and also these input channels may be programmed to receive current or voltage signals according to need.

[0041] Further, a pressure/leek sensor 21 may be provided in the housing along with current/voltage sensors 20.

[0042] With reference to Fig. 6, the algorithm used to calculate the pulse rate of a pump based on a_x, a_y, a_z measured accelerometer data in 3-dimensional space comprise the following steps:

a. The DC offset of each measured axis is removed. This offset is mainly due to gravitation and may be removed according to usual practice.
b. The three axes are combined to calculate a measure for the total acceleration.
c. A low pass filter is applied to reduce the high frequency noise and emphasize temporal power elevation (the measured pulses power).
d. The filtered data is transformed to the frequency domain. An analogue or digital implementation of this step are (FFT) are both possible.
e. Periodic pulses in the time domain are transformed into spectral peaks in the frequency domain and due to the repetitive nature of the pump action, evenly spaced spectral peaks along the frequency axis is to be expected. The frequencies of the spectral peaks are registered.
f. The spectral peak having the lowest frequency is related to the frequency of the pulses.
g. The pump rate is now estimated as half the determined lower one of the frequency spectral peaks since in each pump period there are two pulses.

[0043] The algorithm provided in the block diagram may be implemented by an analog circuits or digital logic or by software or any combinations of these (Processor, FPGA, ASIC etc.).

[0044] It is generally assumed that:

(1) The source of the strongest force detected by the accelerometer is the stroke action of the pump.
(2) Stroke count is between 0 to 5 strokes per second (0 to 300 strokes per minute).
(3) The stroke count does not significantly change over a period of 30 seconds.

[0045] In a digital embodiment of the invention with a medium size air operated diaphragm pump, the following parameters are chosen:

Sampling frequency	Fs	52	Hz
Sampling Period	Δt=1/fs	19.23	msec
Data length	N	1560±100	Samples
Power estimation period	M	5	Samples
Power level threshold	PULSE_THRESHOLD		Normalized

[0046] The accelerometer measures the acceleration x, y and z in all 3 axes. The accelerometer measurements include acceleration related to the strokes and surrounding vibrations as well as the constant acceleration of gravity. The gravity acceleration does not contribute to the pulses vibrations and is eliminated in the usual manner as mentioned.

[0047] Calculating the constant component from gravity is provided by:

$$\mu_x = \frac{1}{N}\sum_{i=0}^{M} x(i),\ \mu_x = \frac{1}{N}\sum_{i=0}^{M} y(i),\ \mu_x = \frac{1}{N}\sum_{i=0}^{M} z(i)$$

[0048] The zero offset acceleration becomes:

$$X = x - \mu_x$$

$$Y = y - \mu_y$$

$$Z = z - \mu_z$$

[0049] The total magnitude of acceleration of each sample i, is

$$a_{Total}(i) = \sqrt{X^2(i) + Y^2(i) + Z^2(i)}$$

[0050] The measured acceleration is composed from the power of the vibrations induced by the pump, the power of other sources of vibrations in the vicinity and from additive noise. It is desired to reduce the effect of the additive noise. For this purpose, a Low Pass Filter (LPF) is applied.

[0051] An RMS filter is selected for its additional property of emphasizing temporal elevation in the power. The temporal power of the total acceleration magnitude is estimated by local RMS calculation. The RMS is calculated by a moving filter of length M:

$$aRMS(i) = \sqrt{\frac{1}{M}\sum_{k=i}^{i+M} a^2(i)}$$

M is selected to be 5 which reflects a cut-off frequency of ~10Hz and an estimation of the power over a period of $\frac{5}{52}[sec] = 0.096[sec]$ in time. The periodic pulses are detected based on the spectral topology (frequency domain) of the calculated RMS signal. Periodic pulses in the time domain are transformed into evenly spaced pulses or spectral lines in the frequency domain as well. Whereas the lowest frequency pulse is the based pulse, having the frequency corresponding to pump stroke rate.

[0052] Since the aRMS data still contains some random noise, the frequency domain is estimated by Power Spectral Density (PSD).

[0053] In the frequency domain, only periodic pulses are transformed into distinguished spectral peaks. Finding the frequency in which the first spectral peak is detected obtains the frequency of the pulses.

[0054] Since a cycle of the pump contains two pulses (both sides) the actual rate of the pump is slower by factor of 2 from the measured pulse rate.

[0055] Based on assumption (1), pulses having power weaker than the pump stroke power are not related to a pump stroke action. The level of power that indicates the power of a pump stroke depends on the pump interface to the surrounding frame and on the environment.

[0056] This must be calibrated on each individual pump. In the case of zero pulse rate (pump is off), the accelerometer sensors may still detect pulse rates due to periodic noise pulses, stemming from sources such as other pumps drawing air from the same air supply line, or feeding liquid into the same pump line or transmitting vibrations to the accelerometer through fixed construction parts. The classification of such noise as noise is based on the power level of the detected real pump pulse. The value of a parameter PULSE_THRESHOLD must be calibrated for each further pump to ensure fail-safe detection of a no-stroke situation.

[0057] Accelerometers are sensitive to any force applied to the subject. Thus, the measurements are noisy. The algorithm avoids the detection of noise as pump induced pulses. Random noise in general has low power compared to the power of pump stroke pulses and therefore random noise is not detected. A single erratic high-power pulse might be detected but since it is not periodic, the frequency domain analysis filters it out.

[0058] In Fig. 7, the digital values from a live measurement on a pump are shown. Each of directions X, Y and Z are represented with graphical display of the digital read out values, and the time counter is given along the x-axis of the graph. Thus, measurements over 60 seconds are presented.

[0059] In Fig. 8, the data from the X, Y and Z directions are provided at each sample according to the measure: $a_{Total}(i) = \sqrt{X^2(i) + Y^2(i) + Z^2(i)}$, and the same 60 seconds digital data represented in the X, Y and Z directions have now been consolidated to one scalar value at each sample. The y axis thus represents an energy measure, but the digital read out values have not been translated into physical values.

[0060] In Fig. 9, a_total is now represented after being subject to a filtering calculation with the digital filter having the predefined filter window length. The window length or number of samples in the filter calculation, and the sampling frequency for obtaining the accelerometer data should be chosen according to the stroke rate of the pump, such that a reasonable number of datapoints are obtained over a pump stroke action.

[0061] Fig. 10 discloses the results of an FFT or similar conversion into a frequency domain of the data represented in Fig. 9. As can be seen, there is a basic frequency of around 3 Hz which translates into a pump stroke or full cycle rate of 1.5 Hz. Here the x axis is in Hz, and the y axis, that is the vertical axis represents acceleration^2/Hz, or Power Spectral Density, again the values are not converted to the physical units, but the digital values are presented.

[0062] Fig. 11 shows an air operated diaphragm pump 24 mounted with a housing 1, comprising cradle part 2, lid part 3 and safety band 4. Inside the housing the PCB element 8 and battery pack 5 is provided. On a front side of the lid part 3, the visual display 30 may be provided in order to allow users to gain insight into internal conditions or registered parameters of the pump 24. A suction side pipe 26 is provided below the pump 24, and a pressure side pipe 25 is provided above the pump. A pipe end 28 is connected with the pressure side pipe 25. The housing 1 is screwed into the end pipe 28 grace to the treads 7 on pipe stub 6 (see Fig. 1, 2 or 3).

[0063] In Fig. 12 the suction side pipe 26 is seen with a pipe stub leading away from the suction side pipe 26, similar to the pressure side pipe end 28. The housing 1 may be mounted into any of pressure side pipe or suction side pipe in case suitable pipe ends are provided for the receipt of the stub 6 through the threads 7 thereon. To this purpose the pipe ends adapted to this purpose may be provided with internal threads.

[0064] Fig. 13 shows the housing 1 mounted at a bracket 27. The bracket 27 is adapted to be tightly connected to a pipe, such as a suction or pressure pipe 25,26 connected directly to an air operated diaphragm pump 24.

[0065] The housing 1 in Figs. 11, 12 and 13 shall be mounted quite close to the air operated diaphragm pump 24, and preferably the distance between the pump 24 and the housing 1 shall be no more than 6 times the diameter of suction or pressure side pipes 25,26 and preferably no more than 4 times this diameter. Ideally the distance shall not exceed 2 times the diameter of either pressure side or suction side pipe 25, 26. Hereby it is further ensured, that the vibrations which are transmitted through the housing and the PCB and to the accelerometer on the PCB originates from the pumping action or stroke action of the pump 24.

List of reference numerals

[0066]

1	- housing
2	- cradle part
3	- lid part
4	- safety band
5	- battery pack
6	- stub
7	- threads
8	- PCB element
9	- wire feed line
10	- connector
12	- bottom
13	- drill bit indent
14	- sub-giga radio
15	- NFC chip
16	- vibration sensor or accelerometer
17	- analog input connectors
18	- digital input port
19	- microcontroller
20	- sensor
21	- pressure and/or leak sensors
22	- digital input line
23	- analog input line
24	- air operated diaphragm pump
25	- suction side pipe
26	- pressure side pipe

27 - bracket
28 - pipe end
30 - display

[0067] While the invention has been described in detail with reference to exemplary embodiments thereof, it will be apparent to one skilled in the art that various changes can be made, and equivalents employed, without departing from the scope of the invention. The foregoing description of the preferred embodiments of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed, and modifications and variations are possible in light of the above teachings or may be acquired from practice of the invention. The embodiments were chosen and described in order to explain the principles of the invention and its practical application to enable one skilled in the art to utilize the invention in various embodiments as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the claims appended hereto, and their equivalents. The entirety of each of the aforementioned documents is incorporated by reference herein.

Claims

1. A method for surveillance of an air operated diaphragm pump, whereby the method comprises the following steps:

- attaching an accelerometer with at least 3 orthogonal accelerometer measuring directions to an air operated diaphragm pump or to a structure directly connected with an air operated diaphragm pump,
- register agitation level of the accelerometer at a frequency rate above a predefined pulse rate of the air operated diaphragm pump,
- determine a base line noise level of the accelerometer agitation level during a period of no pump action,
- determine the pulse rate of the air operated diaphragm pump as the most significant frequency of pulses out of an entire power spectrum calculated from the accelerometer readings,
- register the most significant frequency of pulses and the duration of registered pulse signals.

2. A method according to claim 1, wherein the frequency spectrum for accelerometer readings is determined from calculated values named $aRMS_i$ based on sampled accelerometer readings at a sampling rate whereby,

$$aRMS(i) = \sqrt{\frac{1}{M}\sum_{k=i}^{i+M} a^2(i)}$$

and where i is the sample number, and M is the number of samples used to calculate the value aRMS, at sample number i, and further

$$a_{Total}(i) = \sqrt{X^2(i) + Y^2(i) + Z^2(i)}$$

where X(i), Y(i) and Z(i) are normalized accelerometer output values in orthogonal directions x, y and z respectively in each sample.

3. A method according to claim 3, wherein a sampling rate is selected and a number of samples M is chosen, which reflects the pulse rate of the pump, such that the number of samples M spans a time fraction of a pump pulse duration of no more than half the time of a pulse duration.

4. A method according to claim 1, wherein an externally threaded part of an accelerometer housing is rotated into a threaded connection pipe or threaded pipe bracket located on a suction or pressure pipe to/from the air operated diaphragm pump whereby the distance between the connection pipe or bracket and the pump is adapted to be no more than 6 times the pipe diameter of suction or pressure pipe respectively, or preferably no more than 4 times the pipe diameter og most preferred no more than 2 times the pipe diameter.

5. A method according to claim 1, wherein the method comprises the following steps

- determine the pulse rate of the air operated diaphragm pump at regular intervals and store the determined pulse rates at a data repository within the housing,

- feed pulse rate data through a wireless connection channel to a remote data repository at regular intervals.

6. A method according to claim 3, wherein a sub-giga radio in the accelerometer housing receives pulse rate data from one or more accelerometers it nearby pumps and feeds these pulse rate data through a cellular device via cellular connection to a data repository located away from the cellular device.

7. A method according to claim 1, wherein NFC signals are captured within the housing when a NFC enabled device such as a cell phone is placed in the vicinity of the housing, and that the NFC signals are used to modify the contents of a control device which control device facilitates the accelerometer measurements.

8. A method according to claim 1, wherein the control device is adapted to monitor a pulse rate from a pump, and to provide an alert in case pulse rates are not within predetermined limits.

9. A surveillance device comprising a:

- housing and an accelerometer within the housing which accelerometer is adapted to capture acceleration data in 3 orthogonal directions in space, and a
- data repository adapted to temporarily store captured acceleration data,
- calculation unit adapted to determine a pump stroke rate based on the accelerometer readings,
- feed line adapted to wirelessly transmit stored accelerometer data which reflects the pump stroke rate,
- control device adapted to:
  - control the capture of accelerometer data and to
  - process the captured data, and
  - to control the feed line and control the wireless transmission of the stored accelerometer data,

whereby the housing of the surveillance device comprises an externally threaded stub, which is adapted to threadedly connect to an internally threaded connection pipe or bracket at or associated with an air operated diaphragm pump.

10. A surveillance device according to claim 9, wherein the control device is adapted to calculate an overall energy level measure based on registered accelerometer values in 3 orthogonal directions whereby a frequency spectrum for the overall energy level measure is determined from calculated values:

- aRMS(i) based on sampled accelerometer readings at a sampling rate whereby,

$$aRMS(i) = \sqrt{\frac{1}{M}\sum_{k=i}^{i+M} a^2(i)}$$

and where i is the sample number, and M is the number of samples used to calculate the value aRMS, at sample number i and further

$$a_{Total}(i) = \sqrt{X^2(i) + Y^2(i) + Z^2(i)}$$

where X(i), Y(i) and Z(i) are normalized accelerometer output values in orthogonal directions x, y and z respectively in each sample.

11. A surveillance device according to claim 10, wherein the externally threaded part of the accelerometer housing is rotated into a threaded connection pipe or threaded pipe bracket located on a suction or pressure pipe to/from the air operated diaphragm pump whereby the distance between the connection pipe or bracket and the pump is adapted to be no more than 6 times the pipe diameter of suction or pressure pipe respectively, or preferably no more than 4 times the pipe diameter og most preferred no more than 2 times the pipe diameter.

12. A surveillance device according to claim 10, wherein the device further comprises a PCB which PCB is mounted with the control device, a radio transmitter adapted to transmit captured accelerometer data and the accelerometer.

13. A surveillance device according to claim 10, wherein an NFC enabled communication device and a sub-giga radio is provided at the PCB.

14. A surveillance device according to claim 10, wherein a battery is housed in the housing and connected to the PCB in order to energize the electric parts mounted thereon.

15. A surveillance device according to claim 12, wherein the control device is adapted to provide an alarm in case the calculated pump rate is not according to expectation.

16. A surveillance device according to claim 9, wherein a visual display is mounted on the housing.

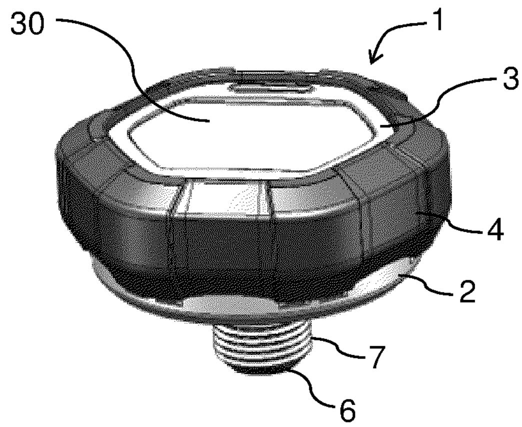


Fig. 1

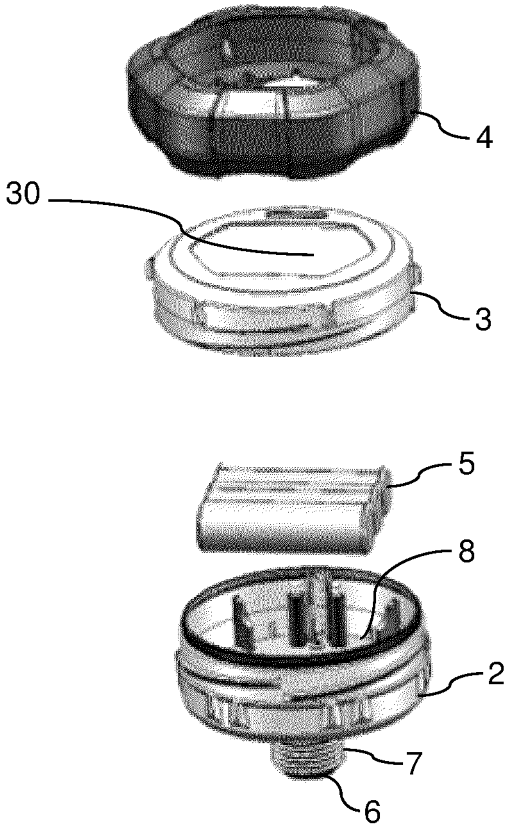


Fig. 2

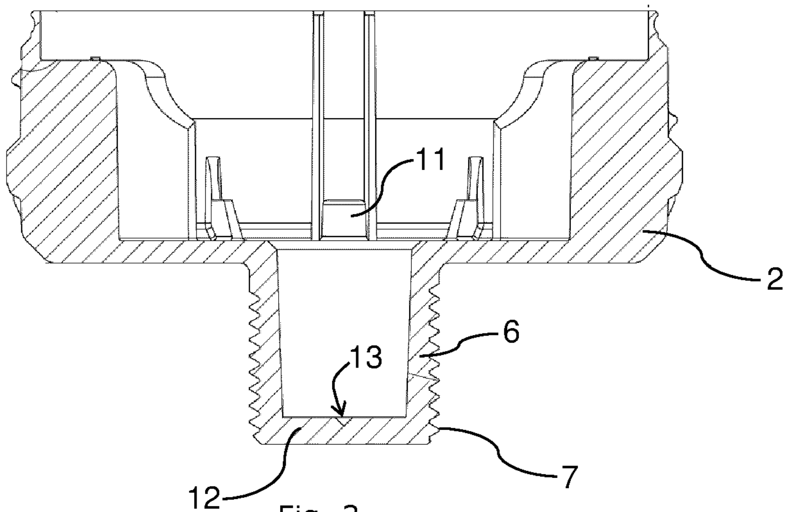


Fig. 3

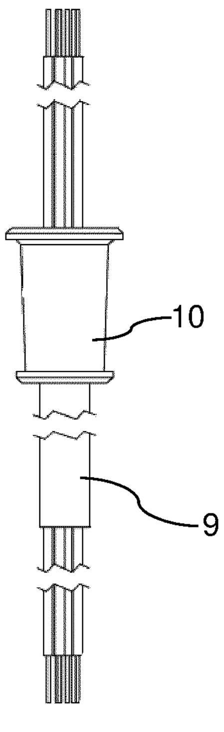


Fig. 4

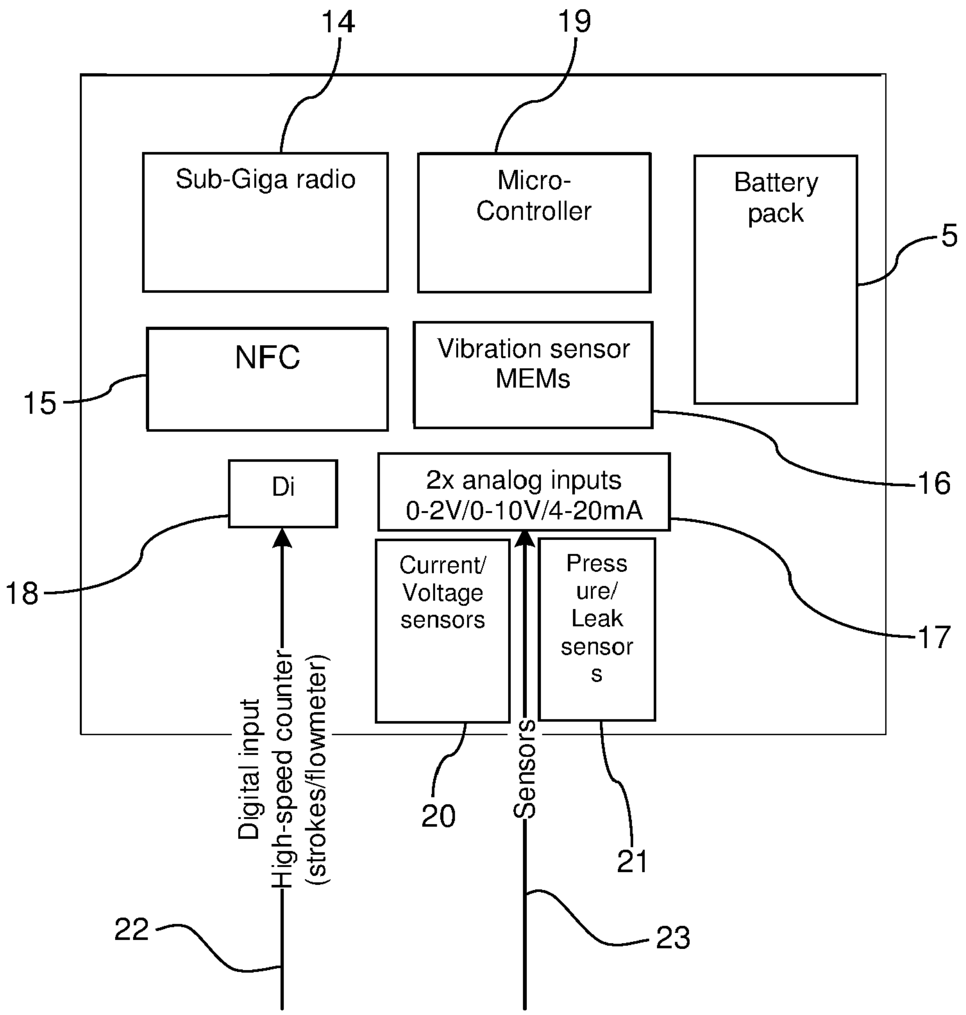

14
19
Sub-Giga radio
Micro-
Controller
Battery
pack
5
NFC
15
Vibration sensor
MEMs
16
Di
2x analog inputs
0-2V/0-10V/4-20mA
18
Current/
Voltage
sensors
Press
ure/
Leak
sensor
s
17
Digital input
High-speed counter
(strokes/flowmeter)
Sensors
20
21
22
23

Fig. 5

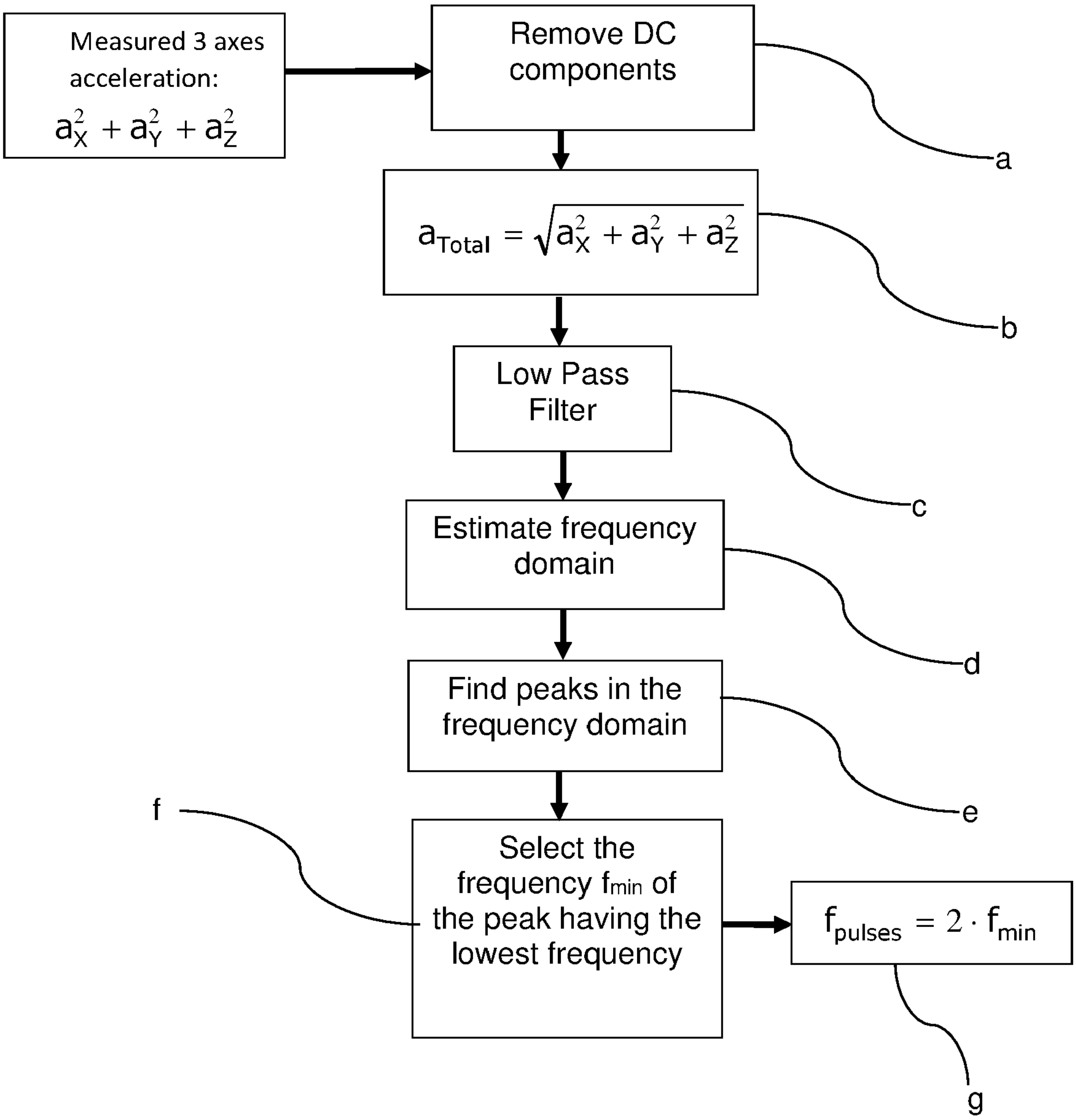

Measured 3 axes acceleration:
$a_X^2 + a_Y^2 + a_Z^2$
Remove DC components
$a_{Total} = \sqrt{a_X^2 + a_Y^2 + a_Z^2}$
Low Pass Filter
Estimate frequency domain
Find peaks in the frequency domain
Select the frequency f_{min} of the peak having the lowest frequency
$f_{pulses} = 2 \cdot f_{min}$
a
b
c
d
e
f
g

Fig. 6

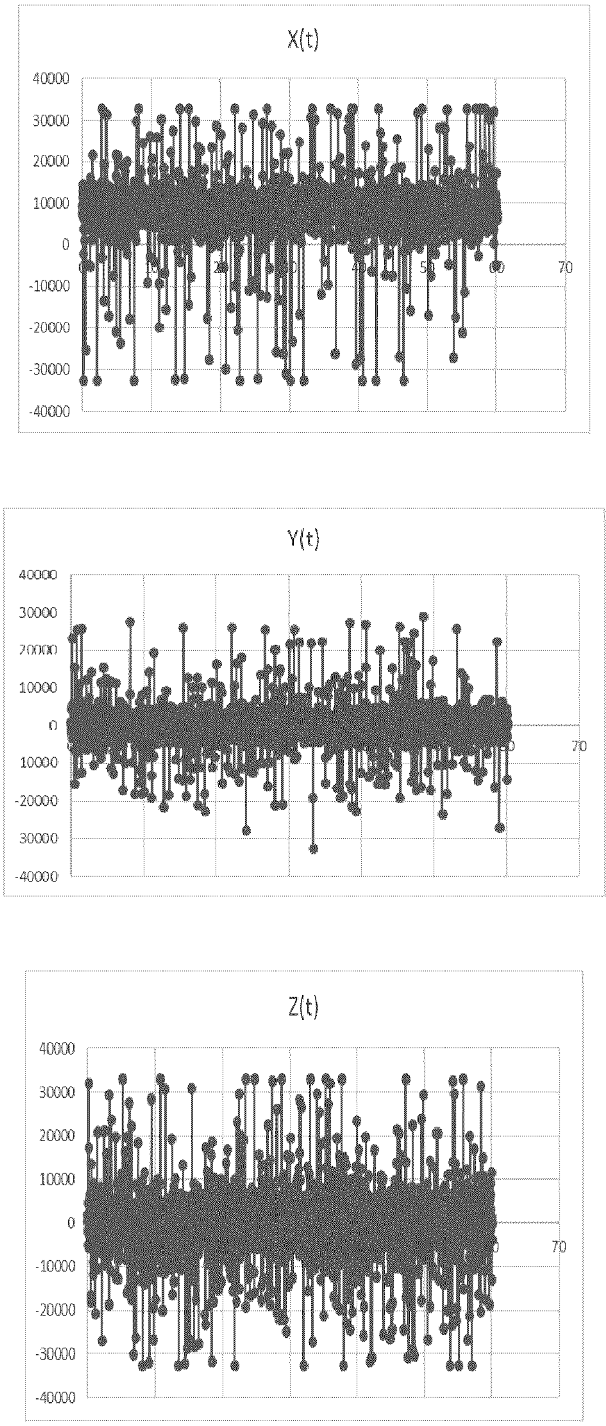

X(t)
40000
30000
20000
10000
0
-10000
-20000
-30000
-40000
70
Y(t)
40000
30000
20000
10000
0
-20000
-40000
70
Z(t)
40000
30000
20000
10000
0
-10000
-20000
-30000
-40000
70

Fig. 7

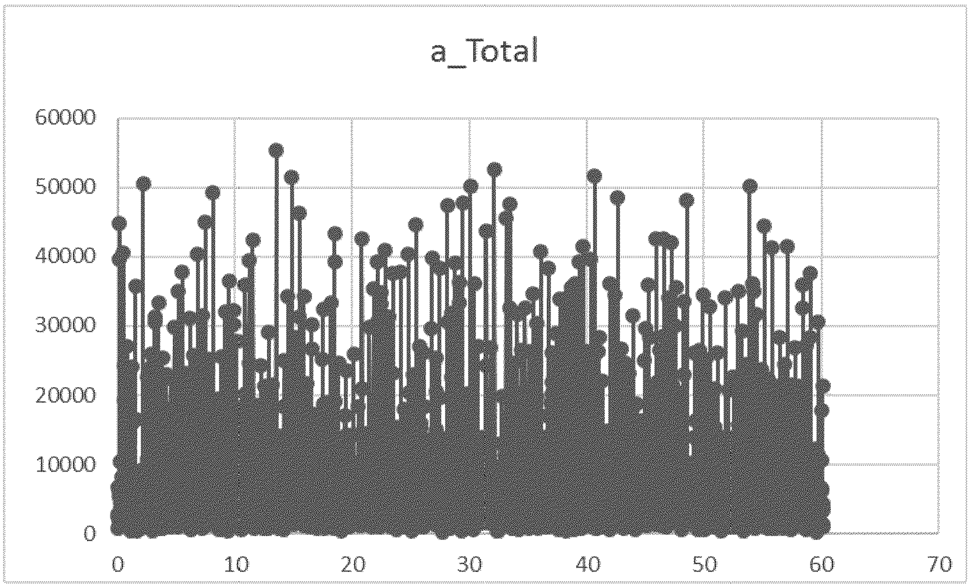

a_Total
60000
50000
40000
30000
20000
10000
0
0
10
20
30
40
50
60
70

Fig. 8

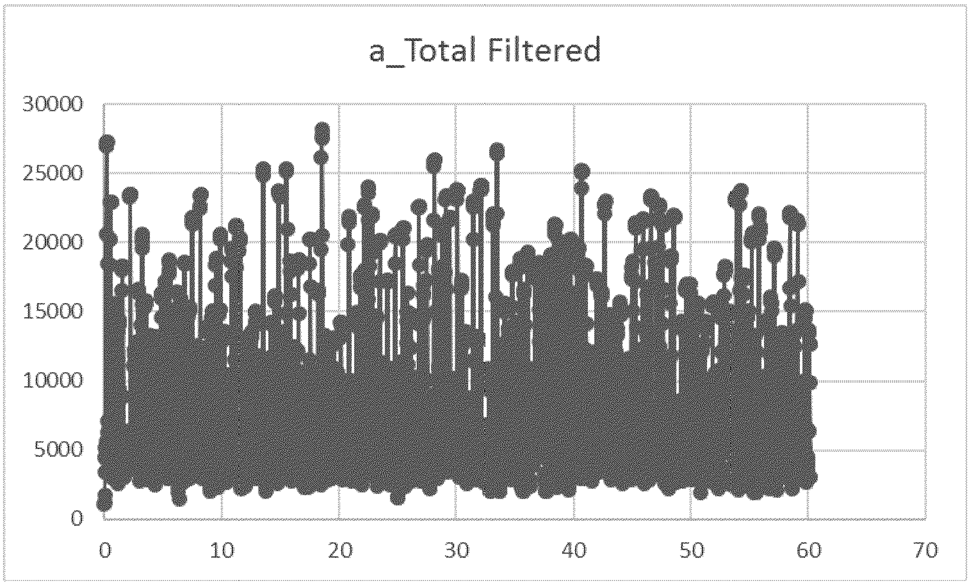
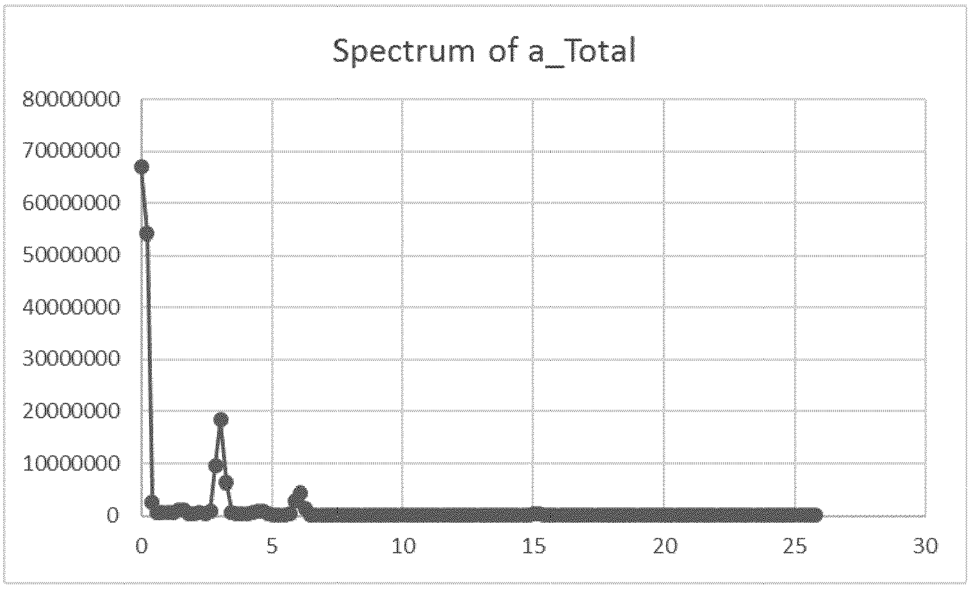
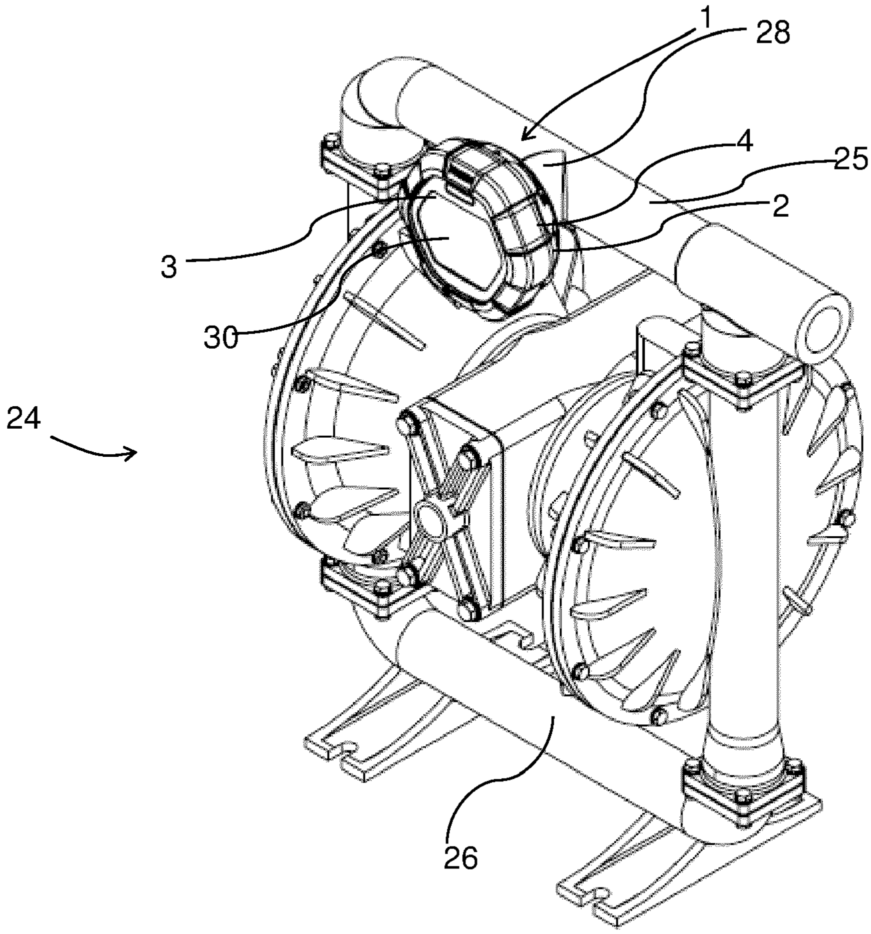

a_Total Filtered
30000
25000
20000
15000
10000
5000
0
0
10
20
30
40
50
60
70

Fig. 9



Spectrum of a_Total
80000000
70000000
60000000
50000000
40000000
30000000
20000000
10000000
0
0
5
10
15
20
25
30

Fig. 10



1
28
4
25
2
3
30
24
26

Fig. 11

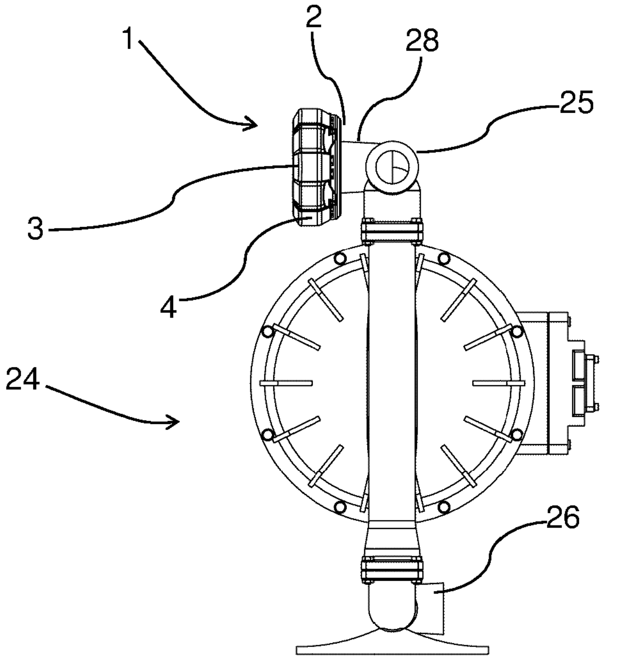


Fig. 12

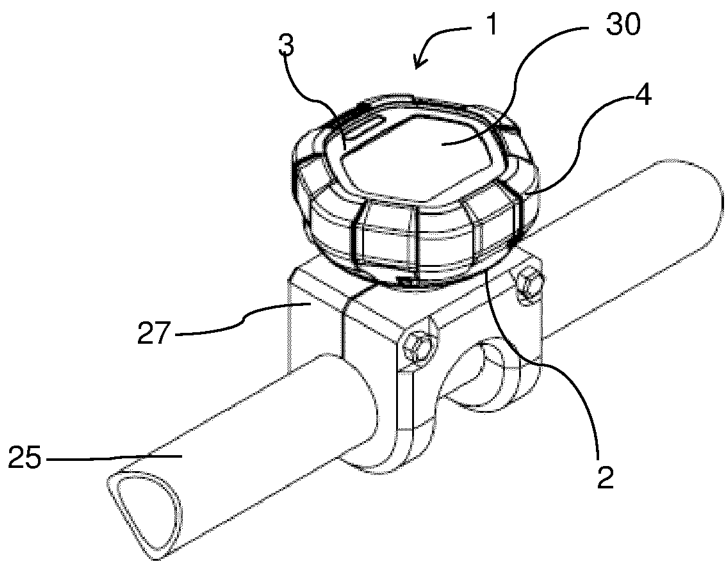


Fig. 13

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European Patent Office
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EUROPEAN SEARCH REPORT

Application Number
EP 20 20 4251

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X Y A	WO 2019/111190 A1 (SOILMEC SPA [IT]) 13 June 2019 (2019-06-13) * abstract *; figures * * page 14, line 3 - page 23, line 25 * -----	9,16 4-9 2,3, 10-15	INV. F04B43/00 F04B43/06 F04B49/06
Y	US 2012/051945 A1 (ORNDORFF MICHAEL [US] ET AL) 1 March 2012 (2012-03-01) * abstract *paragraph 50-51; figures 1-3 * -----	1,4-9,16	
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TECHNICAL FIELDS SEARCHED (IPC)

F04B

The present search report has been drawn up for all claims

3

Place of search	Date of completion of the search	Examiner
Munich	14 December 2020	Pinna, Stefano

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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L : document cited for other reasons
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EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

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14-12-2020

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82