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DESCRIPTION

The invention relates to a method for detecting leaks in closed fluid circuits in which the working fluid passes through a two-phase mixture. From a thermodynamic point of view, this primarily concerns the Clausius-Rankine process and its variants of the refrigeration process, heat pump process, compression heat pump process and steam turbine process, wherein however, this list is not exhaustive and these cyclic processes have also become known under a wide variety of names.

The difficulty is to keep the respective working fluid safely in the process and to prevent leaks as much as possible. The difficulties are explained in more detail below on the basis of the heat pump process or the analogously designed refrigeration process, but they also apply analogously to all other cycle processes mentioned above. In the past, safety refrigerants were mainly used as working fluids, in which occurring leaks and their avoidance were largely seen as contrary to economic concerns, since the working fluids were expensive. It is estimated that up to 70 percent of the production of such safety refrigerants came from the need to refill leaky installations. At that time, heat pumps, refrigerators and air conditioning installations were practically maintenance-free, except for this refill requirement.

This situation has changed since the safety refrigerants have been recognised as greenhouse gases and as depleting the ozone layer. In the meantime, all safety refrigerants that contain fluorinated hydrocarbons have been banned except in exceptional cases, and replaced with other refrigerants. These replacement refrigerants are expensive, corrosive, flammable or toxic, and they often require high working pressures. As a result, the demands on leak-tightness placed on the equipment have increased considerably. At the same time, the need for control and warning devices as well as the need for diagnosis and documentation have also increased. However, the desire for maintenance-free and inexpensive systems has remained.

The reasons for leakages or leaks and the associated losses of refrigerant are vibrations, temperature and pressure fluctuations that lead to expansion and contraction, and

connection points of various components. Leaks are mainly found at solder joints, most leaks are weak and can only occur temporarily, which impedes the locating of the leaks.

5 Various methods are known for locating, monitoring, and for preventing leaks. According to the prior art, a pressure test is usual, in which the system is pressurised with an inert gas without refrigerant and suspected parts are sprayed with a soap solution. Leaks then show up through foam formation. It is also possible to add fluorescent substances to the inert gas or the later refrigerating fluid, as leaks can then be detected with UV lighting. If the apparatus are enclosed or are located in closed spaces, gas sensors are used that can
10 work even at the smallest concentrations. Here infrared cells are used. However, these are quite expensive and may also have to be explosion-proof.

The finer such detectors are set, the more often false alarms can be observed, in the case of gas sensors, especially when the refrigerants are natural substances such as
15 hydrocarbons, carbon dioxide or ammonia. In addition, duct formation can occur in the event of leaks and there is no guarantee that the detectors are positioned in such a way that they can detect the leaks in all cases. If the installation has to be emptied for leak detection and filled with test gas, the leak may then no longer show up because it only occurs at certain temperatures, pressures or vibrations.

20 Another monitoring method is described by DE 10 2013 100 410 A1. Here, a filling-amount-sensitive measurement variable is detected over a predetermined period of time and thus an actual frequency distribution of the measurement values is created. This actual frequency within the specified period is compared with a reference frequency
25 distribution and the offset is determined and evaluated. Time series are not formed, but excluded. Such a filling-amount-sensitive measurement variable can be the fill level of a refrigerant reservoir, the outlet temperature at the condenser or the gas bubble frequency and its size spectrum. Small leaks appear to be difficult to detect with this method, and the method does not indicate the location of the leak.

30 The monitoring method described by US 5,174,125 A shows an extension arm which is attached to a refrigerant line which is located downstream of the expansion valve. The extension arm increases the vibrations of the refrigerant, if these decrease. An

acceleration sensor that sends a signal is attached to the extension arm. In this way, an early warning can be issued in advance of a significant loss of refrigerant to indicate that the cooling function is at risk. However, this method is not suitable for the detection of small leaks.

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The monitoring method described by DE 102 14 519 A1 uses the heat radiation on the side of the condenser and the difference between the calculated heat radiation and that measured by a temperature sensor. This difference serves as a signal.

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A number of technologies for avoiding leaks have also become known in terms of design. For example, EP 2 207 962 B1 describes a refrigerant compressor which has a hermetically sealed compressor housing. Since the vibrations caused by the operation of the piston-cylinder unit and its drive motor place a load on all parts of the refrigerant compressor and these vibrations occur on the pressure pipe, means are proposed to reduce or at least decouple these harmful vibrations, which are the cause of most leaks. The technical prejudice that vibrations are not useful and therefore have to be prevented has been consolidated.

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The present invention therefore has the object of reliably detecting even small leaks and limiting the location of the leak. In the event of critical leaks, the method should put the installation in a safe state and be able to issue an alarm. The method should also be able to detect other device errors.

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JP 2005 241 089 A, WO 2008/144864 A1 and EP 697 586 A2 have also become known. JP 2005 241 089 A describes a freezing installation with a cooling circuit, in which state variables are determined around a compressor, including sound pressure, vibrations and power requirements. A leak is concluded from abnormal behaviour by means of statistical analyses, especially by determining the Mahalanobis distance. WO 2008/144864 A1 describes a diagnostic system in freezing installations in which malfunctions are inferred by means of mechanical waves which are divided into two categories. The two categories differentiate between vibrations that are generated by the system, such as those generated by the compressor, and those that are not generated by the system. EP 697 586 A2 generally describes a leak detection system which is primarily suitable for nuclear

power generation plants, in which the vibration behaviour is recorded and analysed. A neural network and fuzzy logic are used to detect abnormal behavior.

The invention solves this problem for the detection of losses of working fluid in a closed thermodynamic cycle in which there is a two-phase state, in that

- vibrations are measured in at least two dimensions by means of a plurality of acceleration sensors, said vibrations being the vibrations of at least one component of the system in which the working fluid is present in two phases,
- said measured data are recorded,
- time series are formed from the latter,
- said time series are transformed into the frequency domain, wherein frequency spectra are generated,
- the frequency spectra are listed according to time and recorded in different operating states,
- the frequency spectra are correlated with one another according to different operating times,
- differences of the frequency spectra are detected with the same operating states,
- and with a shift of the frequency spectra a warning signal is output, and
- acceleration sensors detect the vibrations excited by the system and at least one oscillation generator dampens these vibrations stimulated by the system by opposite phase vibrations.

The usual thermodynamic cycle processes, in which two-phase system occur, require a compression step that is implemented in practical applications by a compressor. This compressor, sometimes referred to as a compressor, is also the main source of sound and vibrations in most cases. These are to be measured. The vibrational patterns of gas-flow apparatus and pipes differ significantly from those in which a liquid flows. This is especially true in two-phase areas. In the event of fluid losses that indicate leaks, less liquid will flow through the apparatus and pipes and the total mass of the system will also be reduced, as can be seen in the vibrational patterns.

Therefore, these vibrational patterns are detected by acceleration sensors, converted into electrical signals, collected as data, recorded and brought into an automatically evaluable

form. The automatic evaluation is carried out through a sample comparison, for which different methods are available. In all cases, time series are initially created, from which frequency spectra are generated. This can either be done in such a way that the temporal amplitude curves obtained are plotted against the frequencies and the time, and thus a curve profile is obtained which can be compared periodically by superimposing. It is also possible to perform a fast Fourier decomposition and to compare the numerical values obtained in each case. The natural frequencies of the system can also be determined here.

This process must be carried out for each operating state so that the target states are known. The respective measurement curves are compared with these target states. If, when correlating, the pattern reveals that the frequencies are shifting upwards, a loss of work medium can be assumed, which leads to the conclusion that there is a leak.

The frequency spectra can be shifted upwards or downwards. It is also possible for a part of the frequency spectra to shift upwards and another part to shift downwards. In embodiments of the inventions, it is therefore provided that a leak warning signal is output when there is a significant shift in the frequency spectra upwards, and a device warning signal is output when there is a significant shift in the frequency spectra downwards. A device warning signal means a suspected bearing damage or a suspected loosening of a connection, in both cases this can lead to a leakage loss or an impending leak.

It is also provided that oscillation generators excite the system with vibrational bands over a wide frequency range. As described in EP 2 207 962 B1, the normally installed compressor stimulates the installations via its pressure pipe. On the one hand, it may be desirable that these compressor vibrations are not transferred to subsequent heat exchangers, which would mean transfer to the connected heating circuit in the case of a heat pump, on the other hand, very fine shifts in the frequency spectrum are difficult to detect and one would run the risk of false alarms, if every very small change would immediately trigger an alarm.

Thus, instead of using the external excitation by the compressor and the harmonics for analysis, it can be provided that acceleration sensors detect the vibrations excited by the

system and at least one oscillation generator dampens these vibrations stimulated by the system by opposite phase vibrations. On the one hand, this has the advantage that the sound transmission to connected heat exchangers is less, on the other hand, the same oscillation generator can emit a vibration signal over a wide frequency range, such as an
5 increase in a tone from very low frequencies, for example 25 Hz, up to a high 4 kHz, within a period of, for example, a second, and then carry out similar high-resolution analyses in the vicinity of the detected natural vibrations. Of course, this can be done at several points, in special cases higher frequencies up to the ultrasonic level can be used.

10 In a further embodiment of the method it is therefore provided that each of the acceleration sensors measures the accelerations in three spatial axes, wherein these are preferably perpendicular to one another.

Further embodiments deal with the obtaining of reference values with which the
15 determined frequency spectra and natural frequencies are correlated. It is provided here that for obtaining natural frequency shift values due to fluid losses the device is filled with working fluid in stages, wherein after each filling step at least one operation procedure is determined by determining the respective natural frequencies for the respective part filling state and the measured frequency spectra are correlated with said measurement
20 values for part filling.

Alternatively, it is provided that for obtaining natural frequency displacement curves due to fluid losses the device is filled continually with working fluid. wherein after reaching a
25 minimum filling amount the installation is switched on and the respective natural frequencies are determined during the further filling process as a function of the filling amount, and the measured frequency spectra are correlated with said measurement values for partial filling. Both alternatives can also be combined, wherein the pauses between filling levels are used to ensure that actuators generate vibrations over a wide frequency range.

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The object of the invention is also achieved by a device for detecting a leak in an installation in which there is a fluid in a two-phase state, wherein the device has

- a closed circuit, in which said fluid circulates,

- at least one compressor and at least one stress-relieving device,
- at least one circulation pump,
- at least two heat exchangers, one of which introduces heat into the fluid and the other of which removes heat from the fluid, wherein

5 • in at least a part of the device, in which during the intended operation there is a two-phase system of the fluid, a plurality of acceleration sensors is attached,

- wherein said acceleration sensors can absorb vibrations in at least two spatial axes,

10 • the acceleration sensors are connected to a computer device for storage and evaluation, which forms time series data from the latter, and transforms said time series into the frequency domain,

- lists the frequency spectra obtained in a spectrographic representation according to time and recorded in different operating states,

15 • correlates with one another said frequency spectra according to different operating times,

- and with a shift of the frequency spectra outputs a warning signal, and

• at least one oscillation generator is attached which can excite the system with vibrational bands over a large frequency range and generates an opposite phase vibration to the separately excited vibrations.

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In embodiments of the device it is provided that the device outputs a leak warning signal when the frequency spectra are shifted upward and outputs a device warning signal when the frequency spectra are shifted downward.

25 In one embodiment of the device it is provided that at least one oscillation generator is attached in a part of the device, in which there is a two-phase system of the fluid during the intended operation, which can excite the system with vibrational bands over a large frequency range.

30 The invention will now be explained in detail with reference to the figures, wherein a heat pump is selected as an example. In the figures:

Fig. 1: an overview of a heat pump installation with acceleration sensors and oscillation generator,

- Fig. 2a: a measured signal curve over time for a specific frequency,
Fig. 2b: a frequency spectrum for a refrigerant mass 1,
Fig. 2c: a frequency spectrum for a refrigerant mass 2 after a refrigerant loss,
Fig. 3: a flow chart for leak detection.

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Fig. 1 shows a simple air/water heat pump system, which in this example comprises a cooling circuit 1 with a refrigeration compressor 2, a condenser 3, a pressure-relief valve 4 and an evaporator 5. Here, compressed refrigerant 6 flows to the condenser 3, where it gives off its heat to the heat transfer stream 7, which is conveyed by the circulating pump 8 as a heat flow 9 to the consumer. The refrigerant 10 thus cooled and condensed arrives at the pressure-relief valve 4, wherein it cools down further and is conducted into the evaporator 5 as a cooling stream 11. There it absorbs heat from the ambient air 12, which is drawn in by fan 13 through the evaporator 5. The heated refrigerant 14 is compressed again by the refrigeration compressor 2, whereby the refrigeration cycle 1 is closed.

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The two-phase area comprises the condenser 3, the condensed refrigerant 10, the pressure-relief valve 4 and the evaporator 5. A collection container 15 is arranged behind the condenser 3. Acceleration sensors 16, 17 and 18 are arranged in this connection branch, each of which records accelerations in 3 spatial axes. With the actuator 19 as an oscillation generator, vibrations can be fed to the system. This makes it possible, for example, to impose a frequency band of 0 to 4000 Hertz on the system within a short time interval and to determine the vibration characteristics as a function of the degree of filling. This can be carried out several times during the initial filling process, even while the installation is already running in test mode, in order to be able to assign a corresponding vibrational pattern to each filling state, which will serve for the correlation in later operation.

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The actuator 20 serves to compensate for vibrations of the refrigeration compressor 2 and is expediently arranged directly in front of the condenser 3 so that the condenser 3 cannot transmit the vibrations of the refrigeration compressor to the heating circuit. In this way, a significant reduction in noise is achieved. At the same time, this actuator 20, like the actuator 19, can introduce defined vibrations into the system for testing purposes.

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Commercial sensors such as are also found in smartphones serve as acceleration sensors 16, 17 and 18. These are much cheaper than the gas sensors previously used, and they also generate a constant flow of data, from which it is easy and quick to see if or that the sensors are continuing to function properly. They therefore do not need to be regularly
5 tested or serviced, rather this can be limited to situations in which the data indicate irregular operation.

The vibration excitation is carried out during regular operation predominantly by the refrigeration compressor 2. In addition to the fundamental vibration that is generated by
10 the piston operation, a plurality of harmonics also arise, which is characteristic. The actuators are only required when the machine is at a standstill, during filling or during more detailed examinations. They are otherwise optional. Even the smallest leaks can be detected with them. Commercially available piezo sound sources, such as those found in small loudspeakers or headphones, are used as actuators 19 and are also very
15 inexpensive.

Fig. 2a shows a vibration curve which one of the sensors outputs in one of the axes for a certain frequency, here 50 Hz, as amplitudes during a time slice, which here is 150 milliseconds. With three sensors, each with 3 axes, this results in 9 vibration curves. These
20 vibration curves are transformed into the frequency domain and a spectrum is obtained. This is usually done by fast Fourier transformation. The result is a typical, repeating pattern that depends on the filling condition. In the event of leaks, this pattern shifts to higher frequencies.

Fig. 2b shows a spectrum over a frequency band from 0 to 4000 Hz, recorded over a period of 30 seconds. This spectrum shows at which frequencies resonance occurs in the filled state. With regard to these resonance frequencies, there is a detectable shift to higher frequencies when refrigerant losses occur. Fig. 2c shows such a shifted spectrum after a loss of refrigerant, wherein the spectra shown in Figs. 2b and 2c are recorded at the same
30 operating point. For precision analyses, the actuators can be used here, with the help of which the resonance frequencies can be determined precisely.

Fig.3 shows a flowchart for signal processing. At the beginning, obtaining the reference data takes place in the initialisation 100. This relates to the various operating states and their tolerance fields. The reference data are then transferred in the adaptation 101 and adapted to the installation, so that installation data, temporal drift and other factors are defined and, if necessary, adapted later. Initialisation 100 and adaptation 101 are units that are carried out by service personnel or in the factory.

Then it is forwarded to the "signal acquisition and processing" 102, which is an integral part of the device. Two strands are provided in this unit: The first strand consists of the vibration signal acquisition 103, in which the vibration amplitude is recorded in multiple axes, the signal preprocessing 104, in which the frequency spectrum is calculated over all channels, and the signal analysis 105, in which the frequency spectrum is limited. Several alternatives are available for signal analysis 105. Either the peaks in the frequency spectrum are determined, wherein a search window is defined in the frequency range, or a pattern evaluation takes place. Possibly this is followed by standardisation. An evolving algorithm, fuzzy logic, neural networks and image processing (BV/IP) based algorithms for pattern recognition are used as methods. In summary, the first strand concerns the treatment of the incoming signals.

The second strand, on the other hand, concerns the data that are supplied by the heat pump. In the signal acquisition of HP system 106, the state variables are recorded as intrinsic measured values such as pressure, temperature, etc. of the heat pump. An interpolation or clustering of the reference operating states, which follow from the state variables, takes place in the signal processing 107. The spectral reference data are determined in the signal postprocessing 108.

Both strands converge in the data correlation 109, where, alternatively or cumulatively, a peak comparison between reference data and actual vibration data or a pattern comparison is carried out. A tolerance analysis is also carried out.

Normally, it is then decided in the "leak decision" unit 110 on the basis of a threshold value or a multidimensional threshold value table as a function of the operating state, whether there is a leak or not.

If there is no leak, the two strands with the vibration signal acquisition 103 and the signal acquisition of HP system 106 are run through again.

- 5 If there is a leak, appropriate security measures are activated in the leak warning 111.

From time to time, data from the signal acquisition and processing 102 are returned for an adaptation to the adaptation 101, for example as a data packet to the factory service, so that a learning system trains the pattern recognition, wherein data from several
10 structurally identical installations can also be included.

List of reference numerals

	1	Refrigerant circuit
	2	Refrigeration compressor
	3	Condenser
5	4	Pressure-relief valve
	5	Evaporator
	6	Compressed refrigerant
	7	Heat transfer flow
	8	Circulation pump
10	9	Heat flow
	10	Condensed refrigerant
	11	Cold flow
	12	Ambient air
	13	Fan
15	14	Heated refrigerant
	15	Refrigerant collection container
	16	Acceleration sensor A
	17	Acceleration sensor B
	18	Acceleration sensor C
20	19	Actuator
	20	Actuator with vibration compensation
	100	Initialisation
	101	Adaptation
	102	Signal acquisition and processing
25	103	Vibration signal acquisition
	104	Signal preprocessing
	105	Signal analysis
	106	Signal acquisition of HP system
	107	Signal processing
30	108	Signal postprocessing
	109	Data correlation
	110	Leak decision
	111	Leak warning

Patentkrav

1. Fremgangsmåde til at detektere tab af arbejdsfluid i en lukket termodynamisk cyklus (1), i hvilken der er en tofasetilstand, hvor

- 5 • vibrationer måles i mindst to dimensioner (103) ved hjælp af en flerhed af accelerationssensorer (16, 17, 18), vibrationerne af mindst en komponent af systemet i hvilket arbejdsfluiden er til stede i to faser,
- nævnte målte data registreres,
- tidsserier dannes fra sidstnævnte,
- 10 • nævnte tidsserier transformeres til frekvensdomænet, hvor frekvensspektre genereres (104),
- frekvensspektrene listes i henhold til tid og registreres i forskellige driftstilstande (105),
- frekvensspektrene korreleres med hinanden i henhold til forskellige driftstidspunkter (109),
- 15 • forskelle af frekvensspektrene detekteres med de samme driftstilstande,
- og med et skift af frekvensspektrene et advarselssignal udsendes,
- accelerationssensorer (16, 17, 18) detekterer vibrationer exciteret af systemet og **kendetegnet ved, at** mindst en svingningsgenerator (19, 20) dæmper nævnte vibrationer exciteret af systemet ved hjælp af modstående
- 20 fasevibrationer.

2. Fremgangsmåde ifølge krav 1, **kendetegnet ved, at** med et opad skift af frekvens et lækageadvarselssignal (111) udsendes.

25 **3.** Fremgangsmåde ifølge krav 1, **kendetegnet ved, at** med et nedad skift af frekvens et indretningsadvarselssignal udsendes.

4. Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 3, **kendetegnet ved, at** svingningsgeneratorer (19, 20) exciterer systemet med vibrationsbånd

30 over et stort frekvensområde.

5. Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 4, **kendetegnet ved, at** hver af accelerationssensorerne (16, 17, 18) måler accelerationerne i tre akser.
- 5 **6.** Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 5, **kendetegnet ved, at** for at opnå egenfrekvensskiftværdier på grund af fluidtab indretningen fyldes med arbejdsfluid i stadier, hvor efter hvert fyldningstrin mindst en driftsprocedure bestemmes ved at bestemme de respektive egenfrekvenser til den respektive delfyldningstilstand og de målte frekvensspektre korreleres med
- 10 nævnte måleværdier til delfyldning.
- 7.** Fremgangsmåde ifølge et hvilket som helst af kravene 1 til 5, **kendetegnet ved, at** til produktionen af egenfrekvensforskydningskurver på grund af fluidtab indretningen fyldes kontinuerligt med arbejdsfluid, hvor efter at have nået en
- 15 minimumfyldningsmængde installationen tændes og de respektive egenfrekvenser bestemmes under den yderligere fyldningsproces som en funktion af fyldningsmængden, og de målte frekvensspektre korreleres med nævnte måleværdier til delvis fyldning.
- 20 **8.** Indretning til at detektere en lækage i en installation i hvilken der er en fluid i en tofasetilstand, hvor indretningen har
- et lukket kredsløb (1), i hvilket nævnte fluid cirkulerer,
 - mindst en kompressor (2) og mindst en afspændingsindretning (4),
 - mindst to varmevekslere (3, 5), en af hvilke introducerer varme til fluiden
- 25 og den anden af hvilke fjerner varme fra fluiden,
- i mindst en del af indretningen, i hvilke under den beregnede drift der er et tofasesystem (10, 11) af fluiden, en flerhed af accelerationssensorer (16, 17, 18) er anbragt,
 - hvor nævnte accelerationssensorer (16, 17, 18) kan absorbere
- 30 vibrationer i mindst to rumakser,
- accelerationssensorerne (16, 17, 18) er forbundet til en computerindretning til lagring og evaluering,

- som danner tidsseriedata fra sidstnævnte,
 - transformerer nævnte tidsserier til frekvensdomænet,
 - lister frekvensspektrene opnået i en spektrografisk repræsentation i henhold til tid og registreret i forskellige driftstilstande,
- 5
- korrelerer med hinanden nævnte frekvensspektre i henhold til forskellige driftstidspunkter,
 - og med et skift af frekvensspektrene udsender et advarselssignal,

kendetegnet ved, at

mindst en svingningsgenerator (19, 20) er fastgjort, som kan excitere systemet
 10 med vibrationsbånd over et stort frekvensområde og generere en modstående fasevibration til de separat exciterede vibrationer.

9. Indretning ifølge krav 8, **kendetegnet ved, at** den udsender et lækageadvarselssignal (111) under et opad skift af frekvensspektrene.
 15

10. Indretning ifølge krav 8, **kendetegnet ved, at** under et nedad skift af frekvensspektrene den udsender et indretningsadvarselssignal.

11. Indretning ifølge et hvilket som helst af kravene 8 til 10, **kendetegnet ved, at** mindst en svingningsgenerator (19) er fastgjort i en del af indretningen, i hvilket der er et tofasesystem af fluiden under den beregnede drift, som kan excitere systemet med vibrationsbånd over et stort frekvensområde.
 20

12. Indretning ifølge et hvilket som helst af kravene 8 til 11, **kendetegnet ved, at** mindst en svingningsgenerator (20) er fastgjort mellem kompressoren (2) og den første følgende varmeveksler (3).
 25

Fig. 1

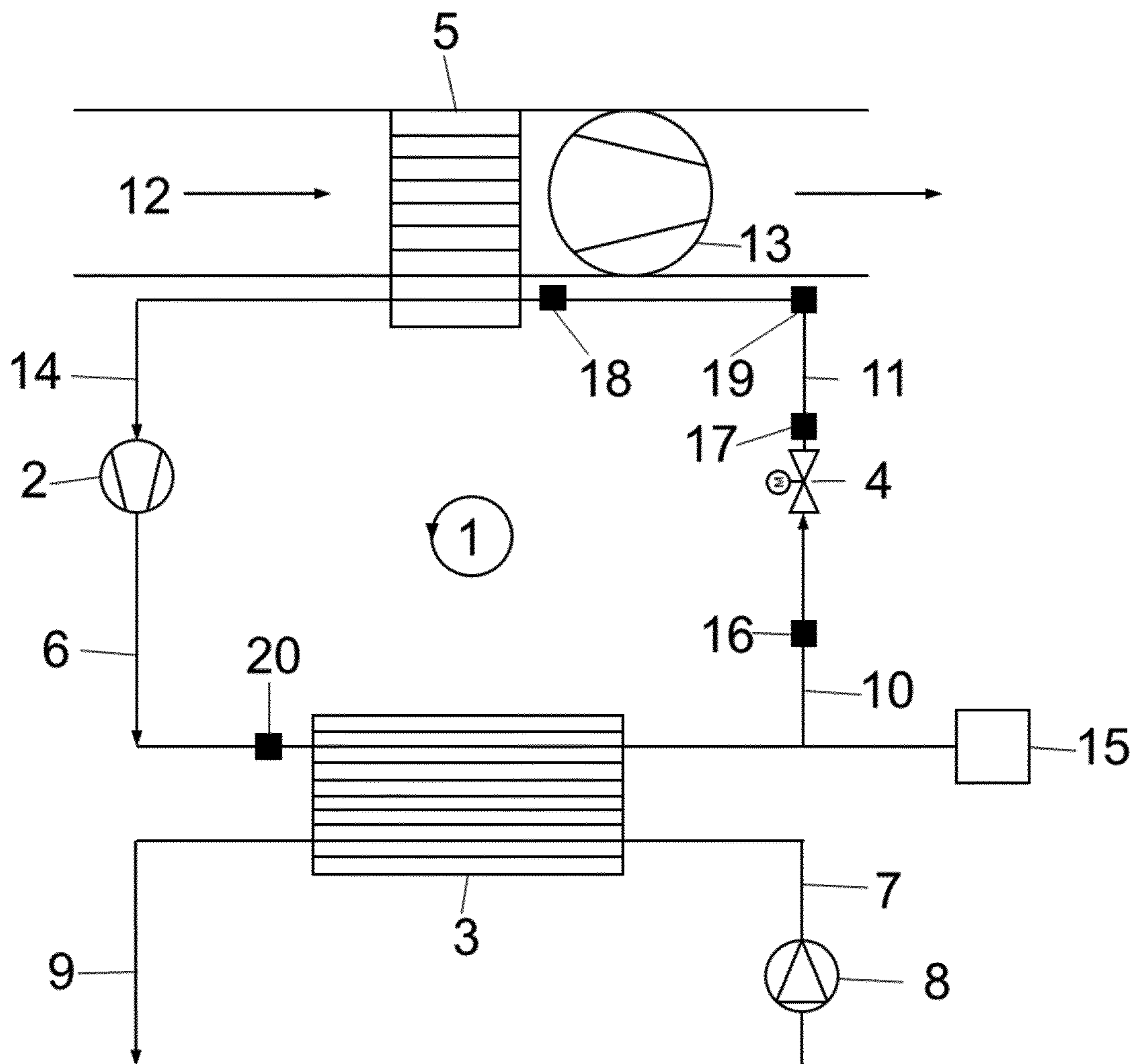


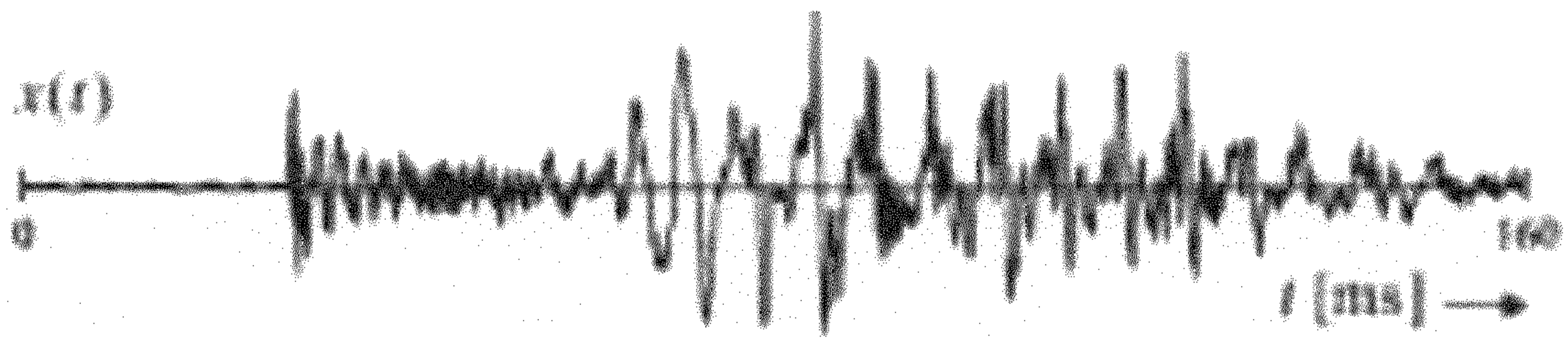
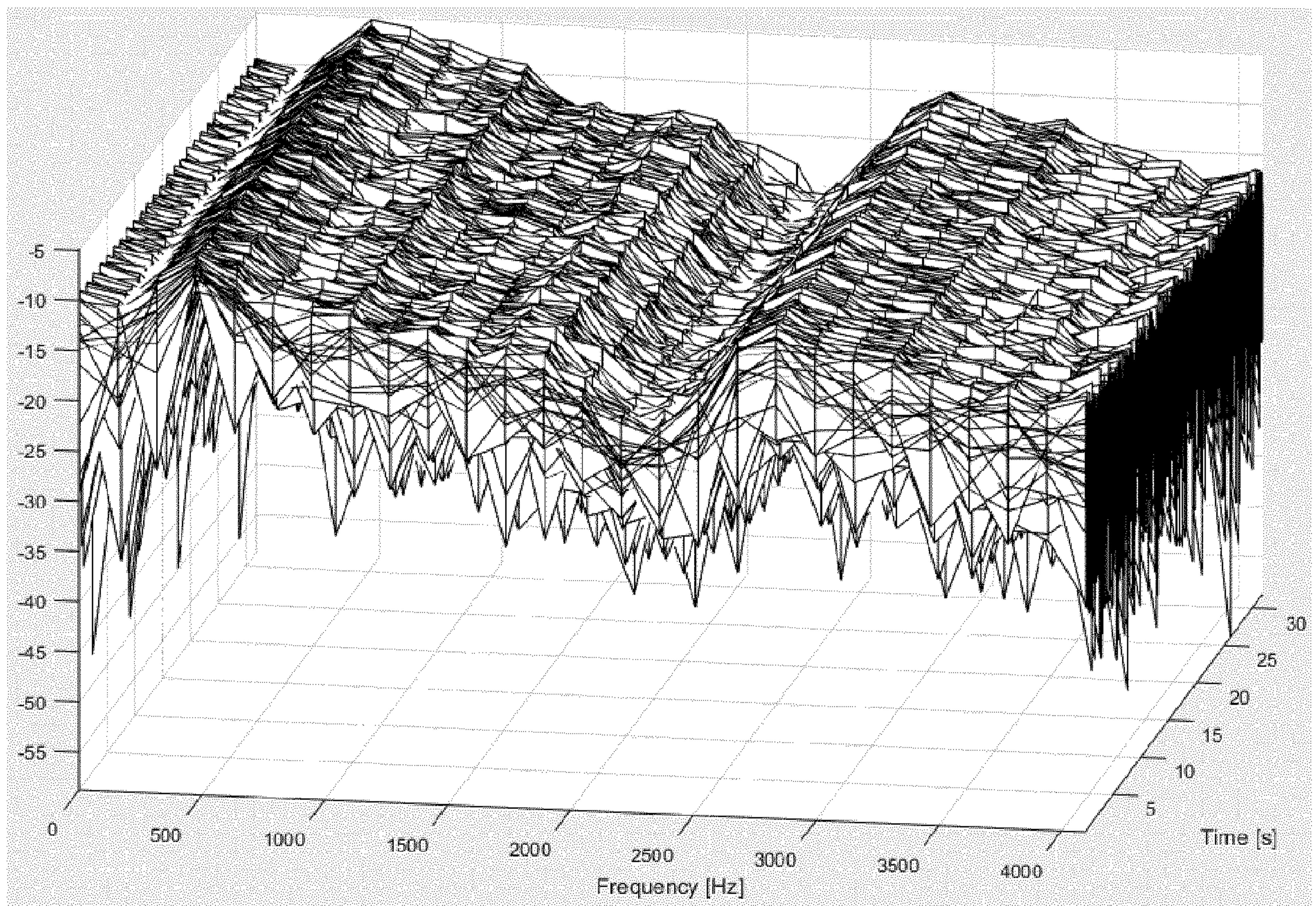
Fig. 2aFig. 2b

Fig. 2c

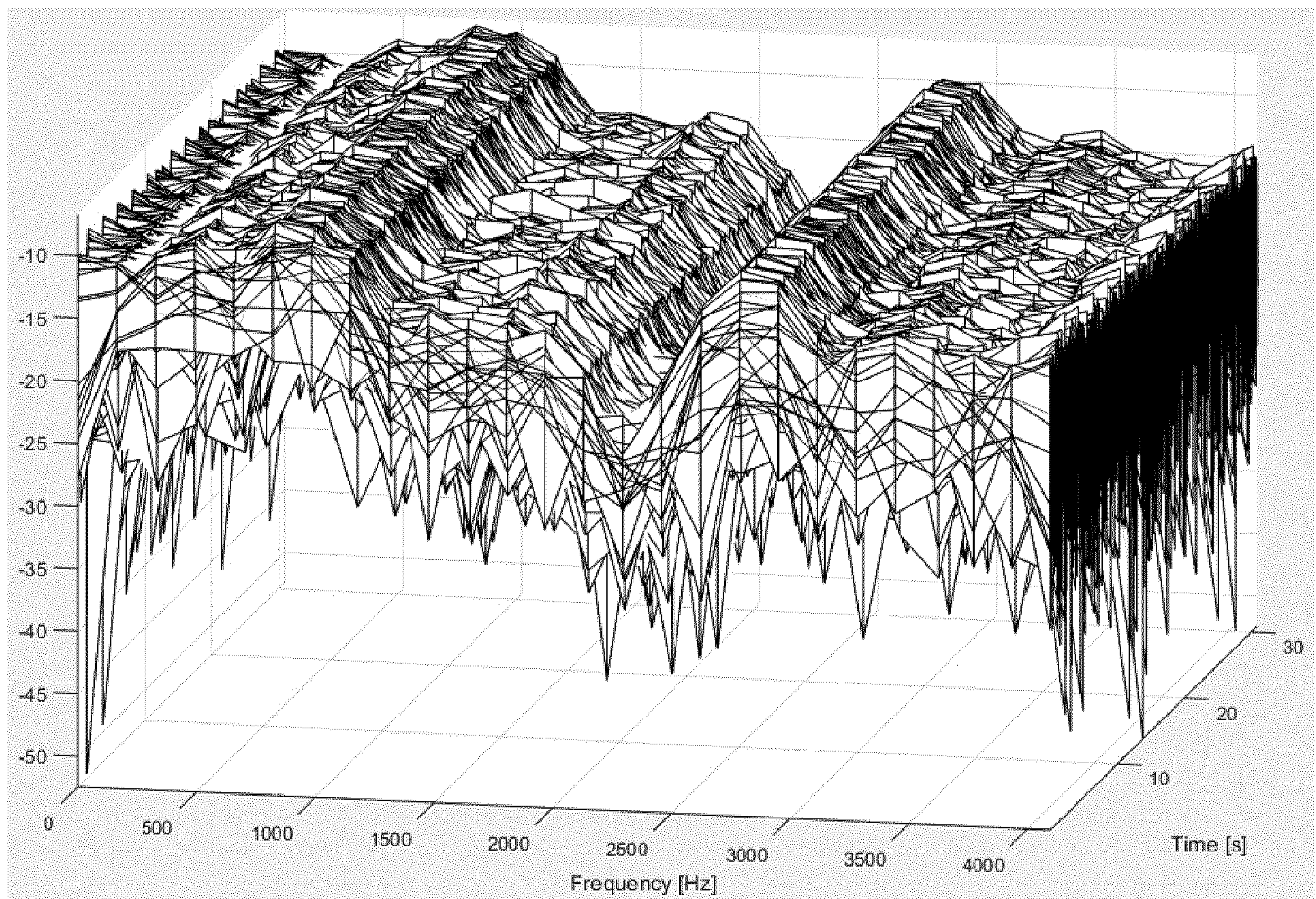


Fig. 3

