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(54) Benævnelse: **FREMGANGSMÅDE TIL SVINGNINGSDÆMPNING AF EN DRIVTOGSINDRETNING**

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METHOD FOR VIBRATION DAMPING OF A DRIVE TRAIN ARRANGEMENT

[0001] The present invention relates to a method for vibration damping of a drive train arrangement with at least one active vibration damper arrangement and at least one vibration recording arrangement.

[0002] Furthermore, the present invention relates to a device for vibration damping of drive train arrangements having at least one active vibration damping arrangement, at least one vibration recording arrangement and a processing unit.

[0003] In the following description, a drive train arrangement is understood to mean, for example, a stationary drive train arrangement such as is used in wind power converters or the like. Vibrations of such drive train arrangements are transmitted to the outside via structural components of the wind power converters, for example, and can be perceived from the outside as sounds, so-called tonalities. The audible tones are, for example, humming or whistling and emerge as individual tones from the basic noise of the wind power converter. Such tonalities generally increase the potential disruptive effect of a noise considerably.

[0004] EP 2 479 427 A1 describes a method for damping the vibration of a drive train in a wind power converter using a braking device. In the process, parameter values are determined which represent a vibration of the drive train. Based on the determined parameter values, damping forces are exerted on a drive train using a braking device, which act against the vibrations of the drive train. Target values are determined from parameter values such as rotational speeds, torques, position and concentricity of the brake disk as a function of a current damping control command. A curve of vibration torques to be damped can be determined from the parameter values so that damping forces can be exerted that are opposite to the determined curve.

[0005] US 2018/017042 A1 describes a control system for damping structural vibrations of a wind power converter with multiple rotor blades. The system has an arrangement that picks up vibrations of the structure and is configured to determine damping commands. Each of the wind power converters has a damping controller that receives the damping commands and transmits the damping commands to an adjustment device of the turbine blades. This counteracts vibrations in the structure.

[0006] The object of the present invention is therefore to propose a method which reduces the noise emissions of a drive train arrangement.

[0007] The object is solved by the features of claim 1.

[0008] The vibration recording arrangement records vibrations of the drive train arrangement and transmits the recorded vibrations to the processing unit in the form of measurement signals. The processing unit converts the measurement signals into virtual degrees of freedom. The degree of freedom refers in the narrow, mechanical sense to any independent movement option or any combination of any movement option. There are six different degrees of freedom, such as rolling around the main axis of the drive train, pitching around the transverse direction, yawing around the vertical axis, an x- translatory movement, a y-translatory movement and a z- translatory movement. These degrees of freedom can be used to represent the rigid body vibrations or other elastic vibration modes of the drive train arrangement. If vibrations are only present in individual degrees of freedom, only the individual degrees of freedom concerned can be considered. The conversion of the measurement signals into virtual degrees of freedom is also referred to as a transformation. The determination of a virtual degree of freedom can be based on different measurement signals from different vibration recording arrangements.

[0009] Based on the calculated virtual degrees of freedom, at least one control signal is determined. In order to obtain at least one control signal, a reverse transformation is performed based on the virtual degrees of freedom. This control signal is output or transmitted to at least one vibration damper arrangement. The vibration damper arrangement damps the drive train arrangement based on the at least one control signal.

[0010] By converting the measurement signals into virtual degrees of freedom, vibrations of the drive train arrangement can be specifically evaluated. This allows targeted damping of the vibrations based on different measurement signals from different vibration recording arrangements.

[0011] Preferably, step b) uses at least one bandpass filter. The bandpass filter allows only signals of a certain frequency band to pass. Frequency ranges above and below this passband are blocked or significantly attenuated. This is a simple means of filtering measurement signals and assigning them to corresponding virtual degrees of freedom and/or frequency ranges. Several different bandpass filters can be used per measurement signal, so that several different frequency ranges can be determined based on one measurement signal, which in turn are assigned to different virtual degrees of freedom. This allows different frequency ranges to be considered based on one measurement signal.

[0012] Preferably, rotational speed measurement signals of at least one rotational speed sensor of the drive train arrangement are included in step c). By including speed measurement signals, rotational speed-dependent vibrations of the drive train arrangement can be damped in a targeted manner.

[0013] Preferably, the measurement signals are provided in at least a first coordinate system, wherein the virtual degrees of freedom are represented in at least a second coordinate system. For example, the measurement signals can be represented in a Cartesian coordinate system, with the measurement signals within the virtual degrees of freedom being represented in a polar coordinate system, for example. This allows simple assessment of the virtual degrees of freedom, so that the at least one control signal can be easily determined based on the virtual degrees of freedom.

[0014] The virtual degrees of freedom represent vibration components that are decisive for at least one tonality. As described above, a tonality, also known as a sonorousness, of a sound is present when individual tones can be heard within this sound. By mapping the vibration components, that are decisive for at least one tonality, in the virtual degrees of freedom, corresponding control signals can be determined so that the tonalities can be specifically damped.

[0015] Preferably, each virtual degree of freedom to be damped is damped by at least one vibration damper arrangement. The degrees of freedom of the drive train arrangement can therefore be damped by six vibration damper arrangements, for example. If fewer degrees of freedom are to be damped, the corresponding degrees of freedom are each damped by at least one vibration damper arrangement. This allows good damping of the drive train arrangement.

[0016] Preferably, for at least one degree of freedom, a primary excitation frequency and at least one secondary excitation frequency are damped simultaneously by the vibration damper arrangement. Due to the different transmission ratios within a drive train arrangement, for example, a primary excitation frequency and a secondary excitation frequency are caused or are caused by a further harmonic of an excitation frequency. The harmonic refers to further excitation frequencies that are in harmony with the primary or secondary excitation frequency. Efficient damping of the drive train arrangement is achieved by simultaneously damping the two excitation frequencies in relation to a degree of freedom.

[0017] Preferably, the processing unit uses methods of artificial intelligence or machine learning to determine the at least one control signal. The methods of artificial intelligence also include, for example, the field of machine learning. This makes it possible, for example, to observe the vibrations of the drive train arrangement over a long period of time so that possible signs of wear, which can cause vibrations, can also be included in the determination of the control signals. Furthermore, operating influences such as temperature, torque or power dependency or other environmental influences can be included in the determination of the control signals. Accordingly, manual readjustment of the vibration damping is avoided, which results in low personnel costs, a good damping effect and good efficiency.

[0018] Furthermore, the above-mentioned object is solved by the features of claim 9. The device is configured to perform a method according to any one of claims 1 to 8. By using the device in conjunction with the method described above, good damping of the drive train arrangement is achieved.

[0019] Preferably, the at least one vibration recording arrangement and the at least one vibration damping arrangement are arranged on a gearbox housing, a bearing point of the drive train and/or a machine carrier. The drive train refers to a unit comprising a rotor, input shaft, gearbox, output shaft and generator. In the present description, a bearing point of the drive train is understood to mean, for example, an elastic torque support or rigid connection that connects the drive train to the machine carrier. The machine carrier describes an arrangement that is designed to hold the drive train arrangement. Accordingly, the positioning of the vibration recording arrangement and the vibration damping arrangement can be freely chosen. This results in good flexibility of the arrangement.

[0020] Preferably, the vibration recording arrangement is arranged in an area subject to vibration. This allows good recording of measurement signals by the vibration recording arrangement, so that good control signals can be determined based on the good measurement signals, so that the drive train arrangement can be well damped.

[0021] Preferably, each a vibration recording arrangement and each a vibration damper arrangement form a unit. This allows a simple arrangement of the unit at corresponding areas of the drive train arrangement. Furthermore, the single unit comprising the vibration recording arrangement and the vibration damper arrangement allows for simple assembly.

[0022] Preferably, the at least one vibration recording arrangement and the at least one vibration damper arrangement are in data connection with the processing unit. This allows a simple exchange of the measurement signals and the control signals between the processing unit and the vibration recording arrangement or the vibration damper arrangement.

[0023] Preferably, the processing unit comprises at least one bandpass filter. The bandpass filter allows individual frequency ranges to be specifically filtered out of the measurement signals, so that virtual degrees of freedom can be determined from these frequency ranges. As a result, the virtual degrees of freedom are easy to calculate or determine, which leads to good efficiency.

[0024] Preferably, the processing unit is connected to at least one rotational speed sensor of the drive train arrangement. The term "connected" here refers to a data connection, so that rotational speed signals can be transmitted from the rotational speed sensor to the processing unit. Consequently, the processing unit can include the rotational speed signals in the calculation and determination of the control signal. This allows rotational speed-dependent determination of the control signal.

[0025] Furthermore, the vibration damping arrangement as indicated in Fig. 5 can damp the six rigid body movements or the elastic vibration modes of at least one component of the drive train arrangement. The rigid body movements are: Rolling (rotation about x-axis, pitching (rotation about y-axis), yawing (rotation about z-axis), x-translatory movement, y- translatory movement and z- translatory movement. The vibration damping arrangement allows all vibrations to be damped or reduced until full vibration reduction is achieved.

[0026] The invention is described below with reference to a preferred embodiment in conjunction with a drawing. Herein show:

Fig. 1	a schematic representation of a method according to the invention;
Fig. 2	a schematic representation of a determination of control signals based on processed measurement signals.
Fig. 3	a schematic representation of a first embodiment of a drive train arrangement;
Fig. 4	a schematic representation of a second embodiment of a drive train arrangement;
Fig. 5	a schematic representation of a third embodiment of a drive train arrangement;
Fig. 6	a schematic representation of a fourth embodiment of a drive train arrangement;
Fig. 7	a schematic representation of a fifth embodiment of a drive train arrangement;
Fig. 8	a schematic representation of a sixth embodiment of a drive train arrangement;
Fig. 9	a schematic representation of a seventh embodiment of a drive train arrangement;

[0027] In the following, identical elements are provided with the same reference signs.

[0028] Figs. 1 and 2 show a schematic diagram of the method for determining a control signal based on measurement signals by the at least one vibration recording arrangement 6 (only shown in Figs. 3 to 9).

[0029] Fig. 1 shows a method according to the invention for generating a control signal, which is transmitted to vibration damper arrangements 5, based on a measurement signal determined by the at least one vibration recording arrangement 6 (Figs. 3 to 9). For this purpose, the measurement signal, also known as the raw measurement signal, is filtered through two bandpass filters 9, 10 and assigned to a respective frequency range. The signal that emerges from the bandpass filters 9, 10 is also referred to as the processed measurement signal. Based on the processed measurement signal, each processed measurement signal is assigned to a virtual degree of freedom within a frequency range. For example, the processed measurement signals of the first bandpass filter 9 are assigned to the first frequency range, while the processed measurement signals of the second bandpass filter 10 are assigned to the second frequency range. Within the first or second frequency range, the processed measurement signals are converted into virtual degrees of freedom. Based on the virtual degrees of freedom of the respective frequency range, control signals for a respective vibration damper arrangement 5 are determined. Based on these control signals, the respective vibration damper arrangement 5 damps vibrations of the drive train arrangement. The transition from the processed measurement signal to a virtual degree of freedom is also called transformation. The transition from the virtual degree of freedom to a control signal is called a reverse transformation.

[0030] In Fig. 2, the method is explained starting from the processed measurement signal to a control signal. The processed measurement signal is transformed into a virtual sensor degree of freedom. The virtual sensor degree of freedom is processed by control algorithms that also include information from a rotational speed sensor 11, for example, so that one result of the control algorithm is a virtual actuator degree of freedom. The virtual actuator degree of freedom is transformed back in order to obtain a control signal. Artificial intelligence methods, for example, can also be used as part of the control algorithm.

[0031] Virtual degrees of freedom are movements or oscillations of the drive train arrangement represented in a virtual or digital environment. In this regard, the virtual degrees of freedom can be viewed and processed separately from the actual real degrees of freedom of the drive train arrangement. Furthermore, measurement signals from different vibration recording arrangements can be assigned to corresponding degrees of freedom.

[0032] The measurement signals can, for example, be transmitted in a first coordinate system, such as a cathartic coordinate system. The virtual degrees of freedom, on the other hand, can be represented in a second coordinate system, for example. The second coordinate system can, for example, be a polar coordinate system.

[0033] The virtual degrees of freedom should represent vibration components of the drive train or drive train arrangement, wherein the vibration components should be decisive for the tonality. This allows vibrations of the drive train arrangement to be effectively counteracted.

[0034] In order to map the relevant vibration components, the vibration recording arrangements 6 are arranged, for example, in corresponding areas subjected to vibrations of the drive train arrangement.

[0035] A vibration damper arrangement 5 and a vibration recording arrangement 6 can be formed as a single unit which is arranged to a corresponding point of the drive train arrangement.

[0036] The method for determining the control signal can also use artificial intelligence methods. This allows precise evaluation of the input values (measured values) and thus allows good damping of the drive train arrangement.

[0037] Fig. 3 shows a drive train arrangement of a wind power converter or wind engery converter with a gearbox/drive train housing 1, a torque support 2, a machine carrier 3, two bearing points 4, three vibration damper arrangements 5, two vibration recording arrangements 6, as well as a slow shaft 7 and a fast shaft 8. The fast shaft is arranged on the generator side, and the slowly rotating shaft 7 is arranged, for example, on a rotor of the wind engery converter, which is not shown. The vibration recording arrangements 6 are arranged on the torque supports 2 of the drive train arrangement. The vibration damper arrangement 5 is arranged on the gearbox/drive train housing 1.

[0038] Fig. 4 shows a second embodiment of the drive train arrangement. The gearbox/drive train housing 1 is connected to the machine carrier 3 by two torque supports 2 and two bearing points 4. A vibration recording arrangement 6 is provided on each torque support 2. Two vibration damper arrangements 5 and two vibration recording arrangements 6 are provided on the gearbox/drive train housing 1.

[0039] Fig. 5 shows a third embodiment of the drive train arrangement. Three units, each with a vibration recording arrangement 6 and vibration damper arrangement 5, are arranged on the gearbox/drive train housing 1. The drive train is connected to the machine carrier 3 via two torque supports 2 and two bearing points 4.

[0040] Fig. 6 shows a fourth embodiment of the drive train arrangement. Here, the vibration damper arrangements 5 are each arranged on the torque support 2 of the gearbox/drive train housing 1. Two vibration recording arrangements 6 are arranged on the gearbox/drive train housing 1. A vibration recording arrangement 6 is also arranged in the area of the torque support 2, the bearing point.

[0041] Fig. 7 shows a fifth embodiment of the drive train arrangement. Here, vibration damper arrangements 5 are arranged on a machine carrier 3, which is connected to the gearbox/drive train housing 1 via bearing points 4. The bearing points 4 are connected to torque supports 2 of the gearbox/drive train housing 1. A vibration recording arrangement 6 is provided on each of the two torque supports 2 shown.

[0042] Fig. 8 shows a sixth embodiment of the drive train arrangement. Vibration damper arrangements 5 are provided on the gearbox/drive train housing 1. Vibration recording arrangements 6 are provided on each of the two torque supports 2 of the drive train arrangement shown. Furthermore, two vibration damper arrangements 6 are provided on the drive train housing 1.

[0043] Fig. 9 shows a seventh embodiment example of the drive train arrangement, in which a vibration damper arrangement 5 and a vibration recording arrangement 6 are each formed as an element, which are arranged on the gearbox/drive train housing 1.

[0044] In the depicted Figs. 3 to 9, the respective vibration recording arrangements 6 and vibration damper arrangements 5 are connected to a processing unit not shown. The processing unit can furthermore be connected to at least one rotational speed sensor of the drive train arrangement, which is not shown, so that rotational speed signals can be communicated to the processing unit. Based on the measured values received from the vibration recording arrangements and the at least one rotational speed sensor, the processing unit, which is not shown, determines at least one control signal, which is transmitted to at least one vibration damper arrangement 5. Based on this control signal, the vibration damper arrangement 5 dampens vibrations of the drive train arrangement. The vibration damper arrangement 5 is an active vibration damper arrangement 5, also known as a damper or actuator. The vibration recording arrangement 6 is also referred to as a sensor or the like.

List of reference symbols

[0045]

1	gearbox/drive train housing
2	torque support (bearing point)
3	machine carrier
4	bearing point
5	vibration damper arrangement
6	vibration recording arrangement
7	slow shaft
8	fast shaft
9	first bandpass filter
10	second bandpass filter

Patentkrav

1. Fremgangsmåde til svingningsdæmpning af en drivtogsindretning med mindst en aktiv svingningsdæmperindretning (5) og mindst en svingningsoptagelsesindretning (6), omfattende følgende trin:

   a. tilvejebringelse af målesignaler fra den mindst ene svingningsoptagelsesindretning (6) til en forarbejdningsenhed; kendetegnet ved, at fremgangsmåden desuden indeholder følgende trin:

      b. overførsel af målesignalerne til virtuelle frihedsgrader, hvor de virtuelle frihedsgrader er svingninger af drivtogsindretningen præsenteret i et virtuelt miljø og viser drivtogets svingningskomponenter, som er afgørende for mindst en tonalitet;
      c. bestemmelse af mindst et aktiveringssignal baseret på de virtuelle frihedsgrader;
      d. udsendelse af det mindst ene aktiveringssignal til den mindst ene svingningsdæmperindretning (5);
      e. dæmpning af drivtogsindretningen via svingningsdæmperindretningen (5) baseret på det mindst ene aktiveringssignal.

2. Fremgangsmåde ifølge krav 1, kendetegnet ved, at trin b anvender mindst et båndpasfilter (9, 10).

3. Fremgangsmåde ifølge krav 1 eller 2, kendetegnet ved, at der i trin c inddrages omløbstalsmålesignaler fra mindst en omløbstalssensor i drivtogsindretningen.

4. Fremgangsmåde ifølge et af kravene 1 til 3, kendetegnet ved, at målesignalerne tilvejebringes i mindst et første koordinatsystem, og at de virtuelle frihedsgrader præsenteres i mindst et andet koordinatsystem.

5. Fremgangsmåde ifølge et af kravene 1 til 4, kendetegnet ved, at hver virtuelle frihedsgrad, der skal dæmpes, dæmpes af mindst en svingningsdæmperindretning (5).

6. Fremgangsmåde ifølge et af kravene 1 til 5, kendetegnet ved, at ved mindst en frihedsgrad en primær påvirkningsfrekvens og mindst en sekundær påvirkningsfrekvens dæmpes samtidig af svingningsdæmperindretningen (5).

7. Fremgangsmåde ifølge et af kravene 1 til 6, kendetegnet ved, at forarbejdningsenheden anvender metoder inden for kunstig intelligens eller maskinlæring til bestemmelse af det mindst ene aktiveringssignal.

8. Fremgangsmåde ifølge et af kravene 1 til 7, kendetegnet ved, at der foreligger op til seks forskellige virtuelle frihedsgrader, nærmere bestemt rulning om en hovedakse af drivtoget, tipning om en tværretning, krøjning om en lodret akse, en x-translatorisk bevægelse, en y-translatorisk bevægelse og en z-translatorisk bevægelse.

9. Anordning til svingningsdæmpning af drivtogsindretninger med mindst en aktiv svingningsdæmperindretning (5), mindst en svingningsoptagelsesindretning (6) og en forarbejdningsenhed, kendetegnet ved, at anordningen er udformet til at udføre en fremgangsmåde ifølge et af kravene 1 til 8.

10. Anordning ifølge krav 9, kendetegnet ved, at den mindst ene svingningsoptagelsesindretning (6) og den mindst ene svingningsdæmperindretning (5) er anbragt på et drivtog (1), et lejepunkt (2) af drivtoget (1) og/eller en bærende konstruktion (3).

11. Anordning ifølge krav 9 eller 10, kendetegnet ved, at svingningsoptagelsesindretningen (6) er anbragt i et svingningsbelastet område.

12. Anordning ifølge et af kravene 9 til 11, kendetegnet ved, at en respektiv svingningsoptagelsesindretning (6) og en respektiv svingningsdæmperindretning (5) udgør en enhed.

13. Anordning ifølge et af kravene 9 til 12, kendetegnet ved, at den respektive svingningsoptagelsesindretning (6) og den respektive svingningsdæmperindretning (5) står i dataforbindelse med forarbejdningsenheden.

14. Anordning ifølge et af kravene 9 til 13, kendetegnet ved, at forarbejdningsenheden har mindst et båndpasfilter (9, 10).

15. Anordning ifølge et af kravene 9 til 14, kendetegnet ved, at forarbejdningsenheden er forbundet med mindst en omløbstalssensor i drivtogsindretningen.

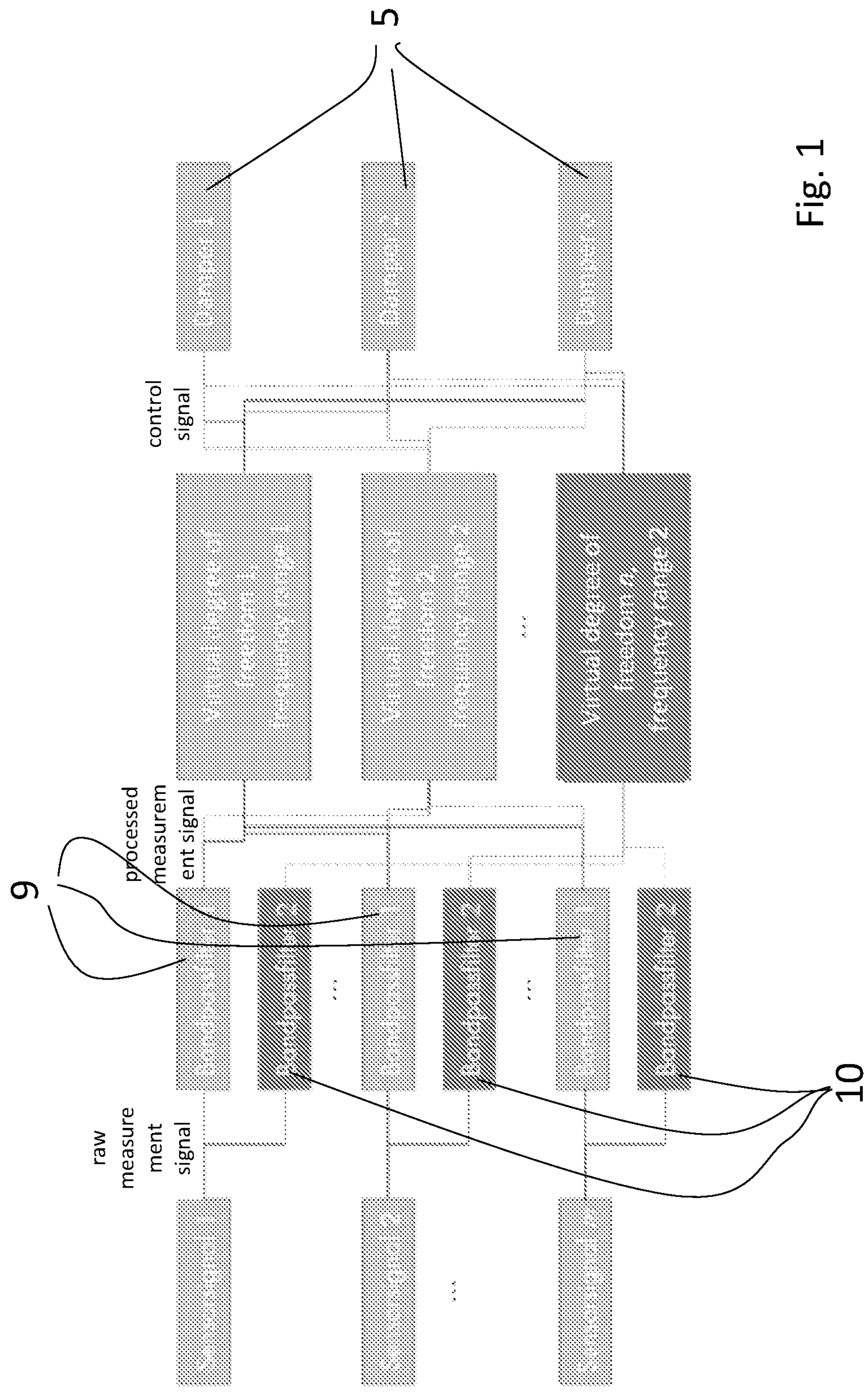
5
control signal
Virtual degree of freedom n, frequency range 2
processed measurem ent signal
9
raw measure ment signal
10

Fig. 1

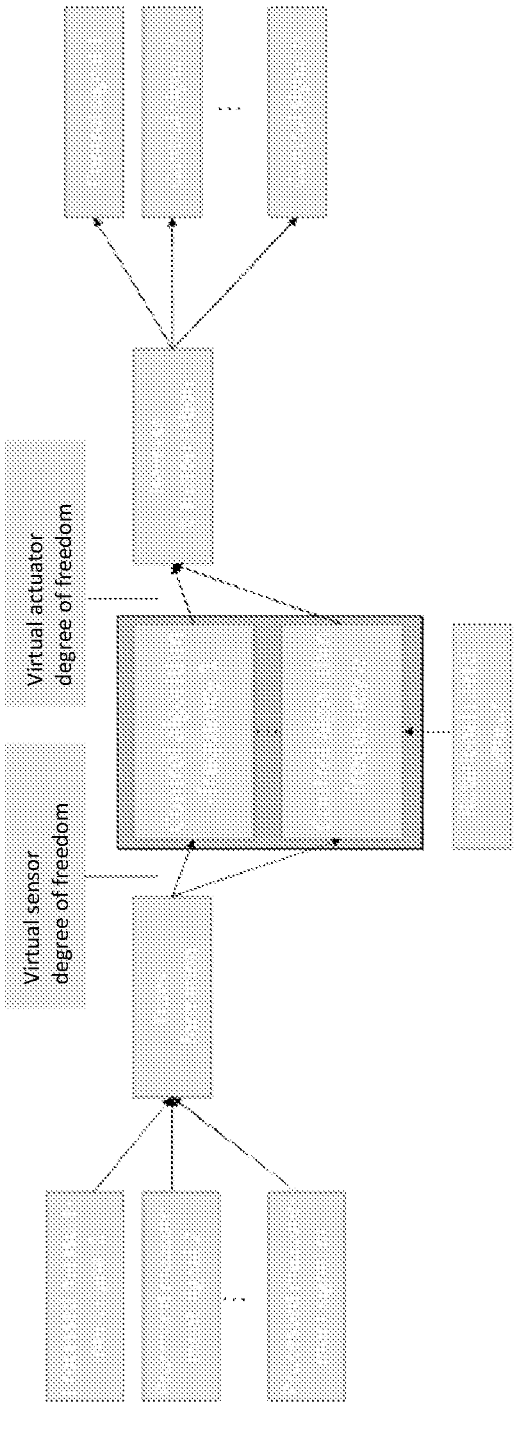
Virtual actuator
degree of freedom
Virtual sensor
degree of freedom

Fig. 2

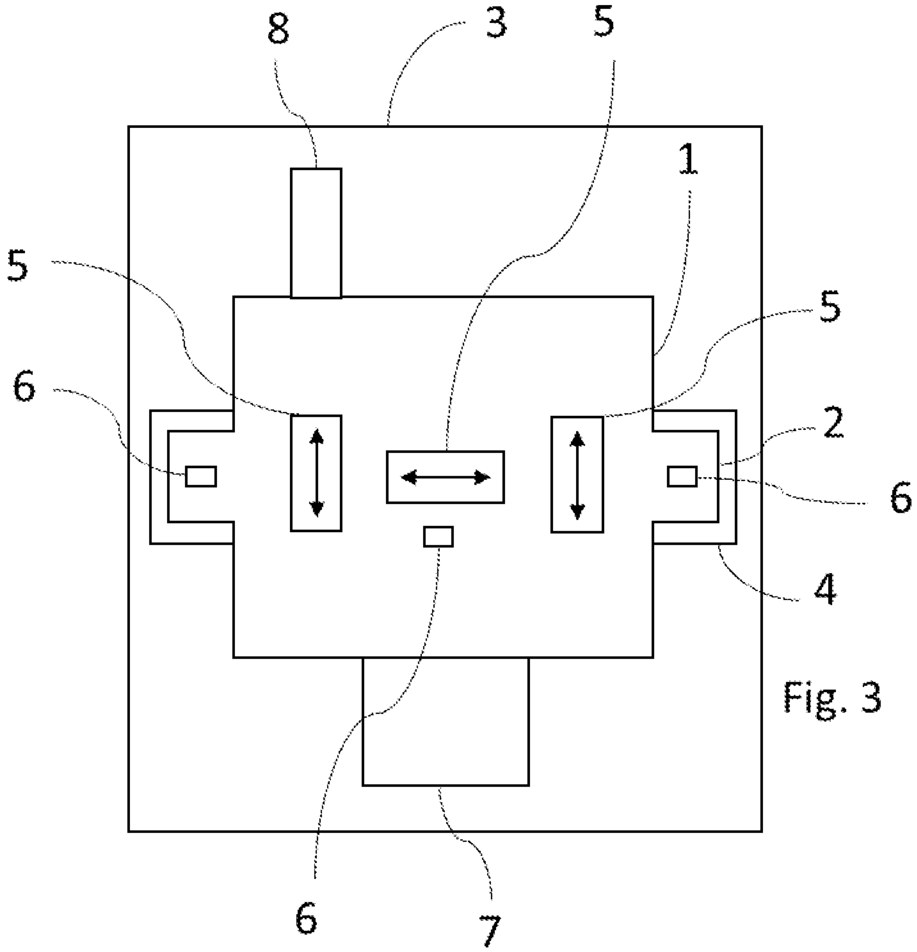

Fig. 3

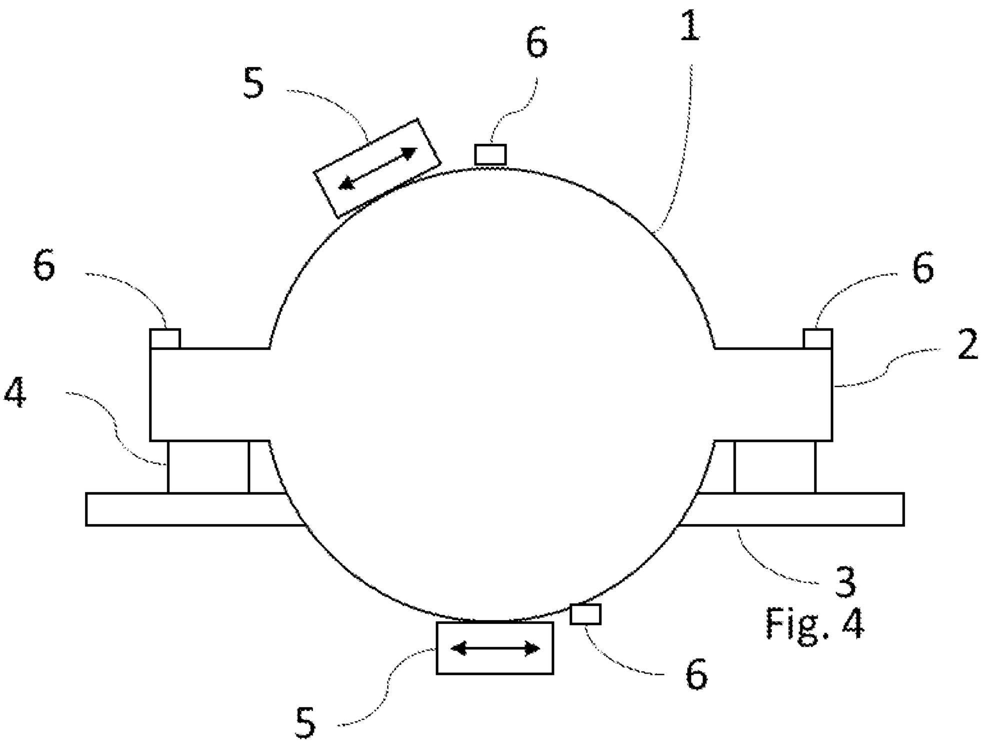

Fig. 4

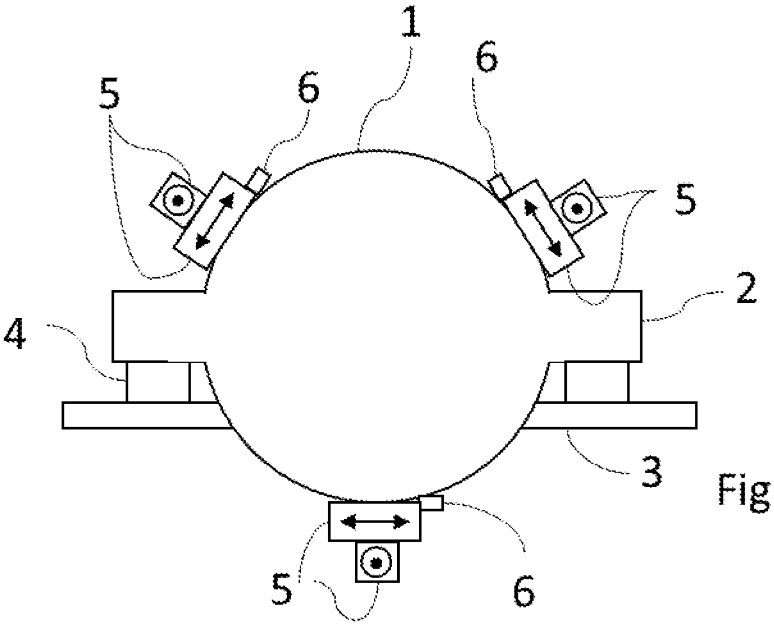

Fig. 5

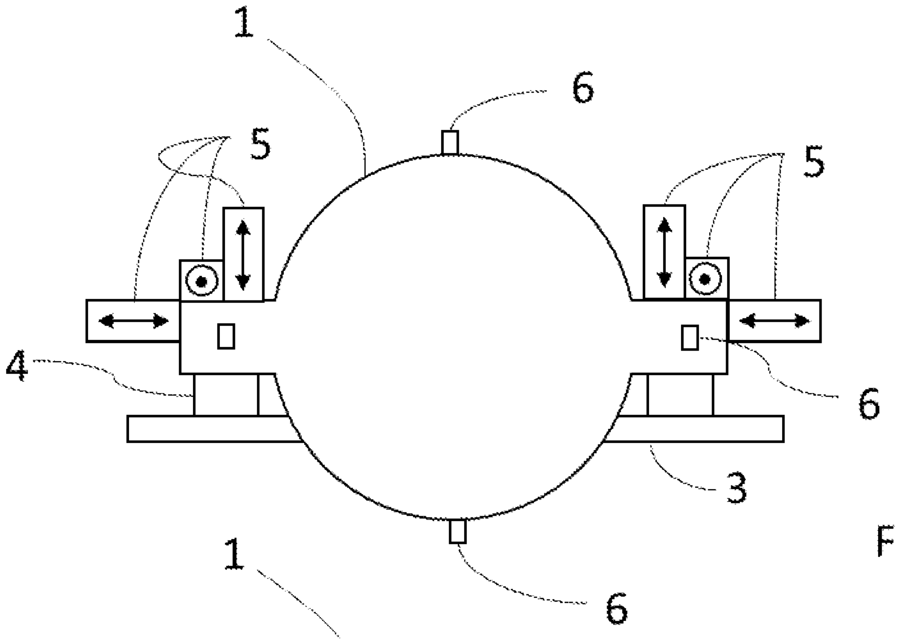

Fig. 6

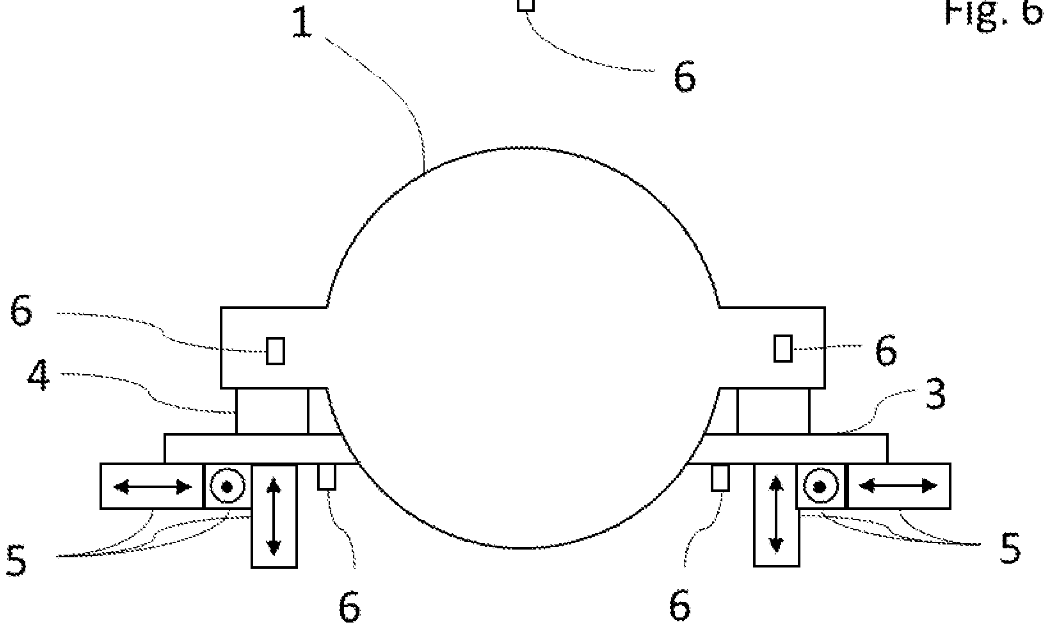

Fig. 7

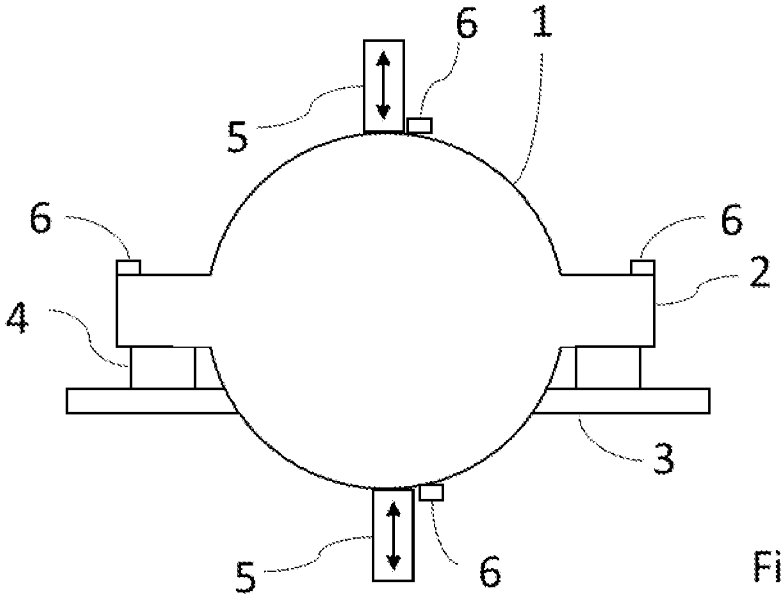

Fig. 8

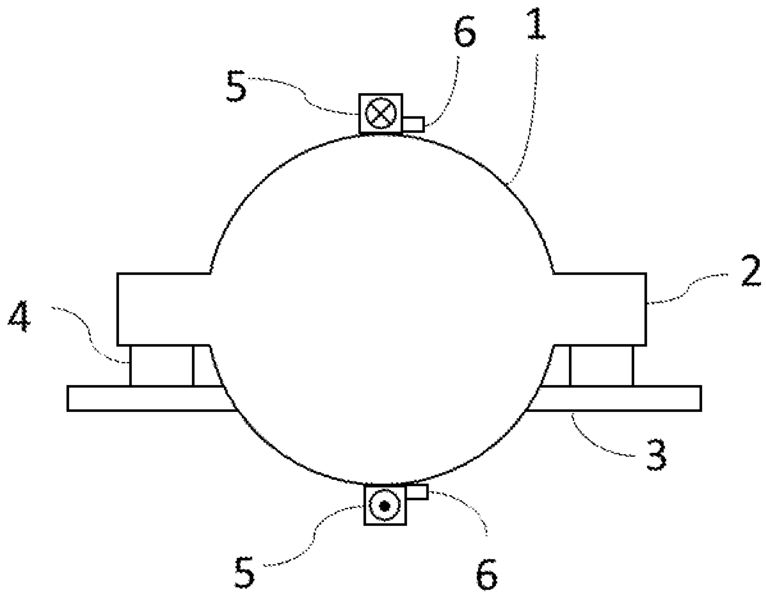

Fig. 9