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GB 2222279 A **GB 1601096 A**

(58) Field of Search
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INT CL^5 **F16F**
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(54) Vibration cancellation device

(57) A vibration cancellation device for rigidly mounting to or forming part of an apparatus subject to vibration comprises a mass 14 supported by magnetic levitation but which is magnetically driven to provide vibration-cancelling relative movement, movement sensors 26 controlling the application of power, in a relative motion cancellation direction.

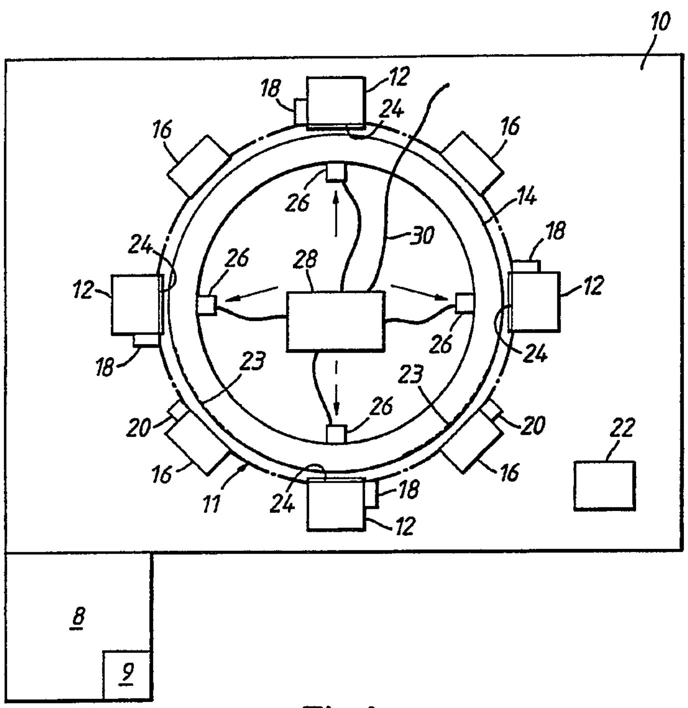

Fig.1

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

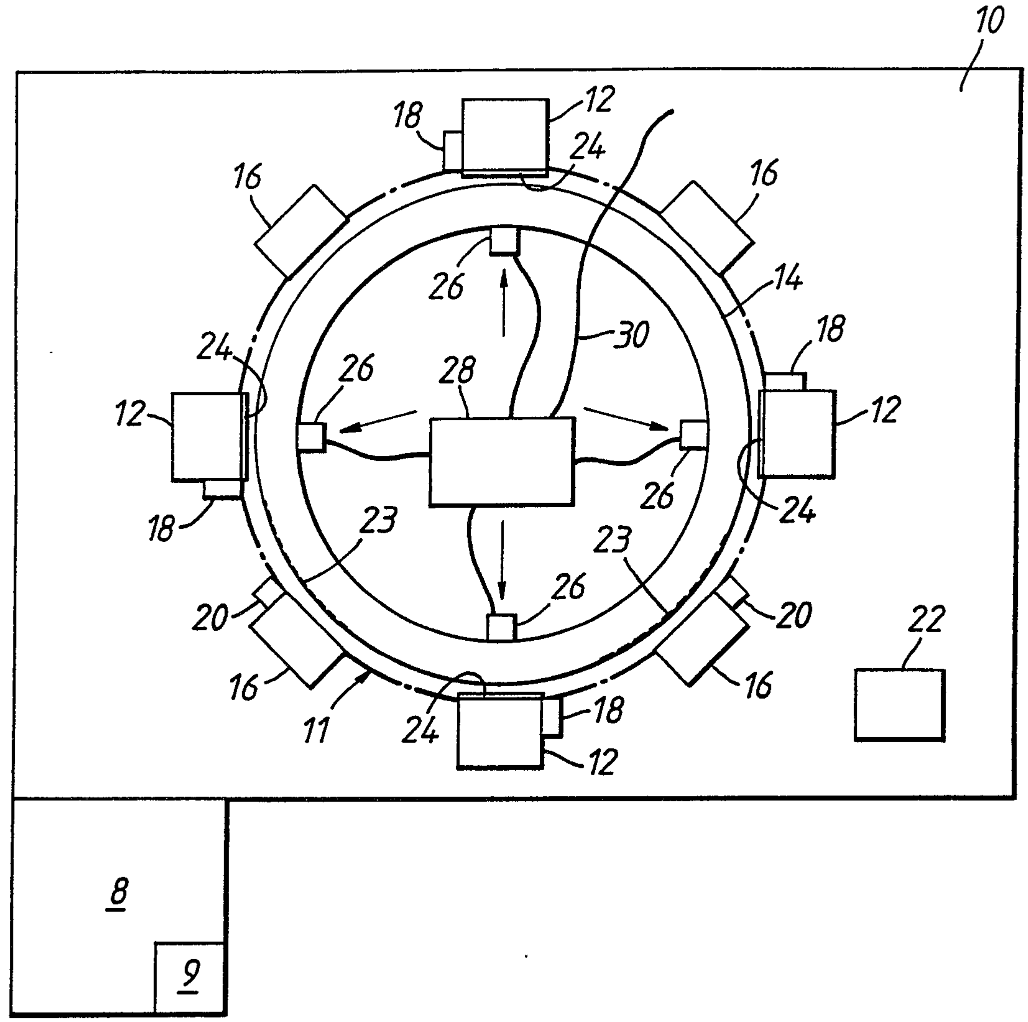
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Fig.1

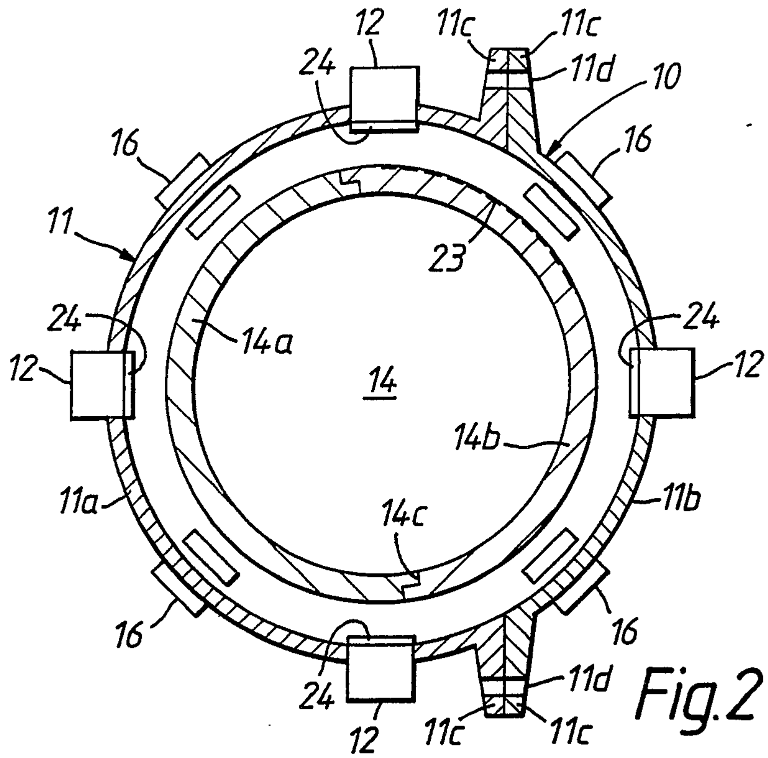
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Fig.2

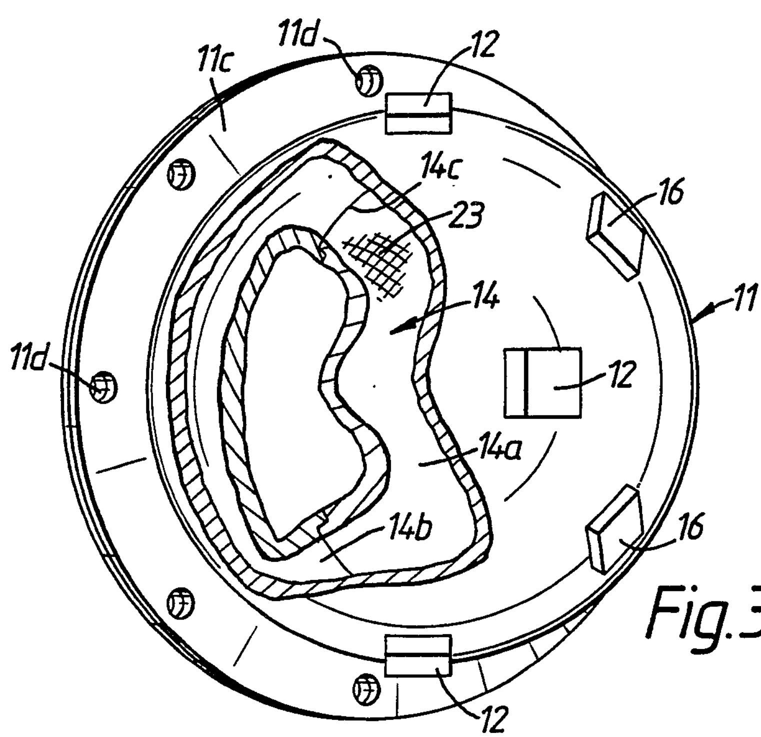
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Fig.3

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VIBRATION CANCELLATION DEVICE

This invention concerns a vibration cancellation device. There is a considerable potential for an active vibration cancellation device able to reduce overall vibration of mechanical structures. Such devices could be attached to or embedded in struts, pipes or masts that are subject to vibration forces in order to eliminate these by active cancellation techniques. In addition, machinery is conventionally mounted on some type of passive mounting arrangement to reduce the severity of transmitted vibration to a supporting structure therefor. The use of an active vibration cancellation device, mounted near the base of such passive mounts can be used substantially to improve overall performance by cancelling vibrations which would otherwise be transmitted into the supporting structure.

Active vibration cancellation has been experimented with in the past particularly in the case of engines running at a steady speed where the vibration energy spectrum has a significant content in only a few harmonics of the engine rotation rate. This allows one to use narrow-band active cancellation techniques only, which techniques are the simplest to implement. The cancellation technique tried was to use oscillating masses to suppress the resultant narrow band mechanical vibrations. However, heretofore, to generate an anti-phase momentum in a required direction, the oscillating mass had to be mechanically supported. A linear oscillating mass of an active vibration canceller is described in, for example, the journal of the Chartered Mechanical Engineer, January 1983, pages 41 to 47 (particularly page 44 and Fig. 13) in a paper by G.B.B. Chaplin. Alternatively, some form of diaphragm or spider support was provided to limit motion of the mass to the correct axis. In practise, such linear supports, spiders or diaphragms proved to be unreliable, through wear and fatigue. There was also a more significant objection: they could not easily withstand shock loading. This, along with their demonstrated unreliability, resulted in the idea largely being dropped.

Accordingly, it is an object of the present invention to provide an active vibration cancellation device having a very high reliability and resistance to shock, which device is able to minimise or cancel linear and/or angular momentum (mechanical vibrations, in general, contain both types of motion), in a structure.

According to the present invention, there is provided a device, for reducing vibration of a structure, comprising a mass having a rest position motionlessly supported from the structure by a magnetic field, means for sensing the vibration, and means for controlling the magnetic field to vibrate the mass and, by reaction, to apply an antiphase vibration to the structure.

The invention also provides a device, for reducing vibration of a structure, comprising an auxiliary mass supported by the structure by a magnetic field, sensing means for sensing the vibration, and means for vibrating the auxiliary mass by varying the magnetic field, in accordance with the sensed vibration whereby to apply, by reaction, antiphase vibration to the structure.

The invention further provides a vibration cancellation device for rigidly mounting to or forming part of a structure subject to vibration in at least one plane and/or about at least one axis, the device comprising an auxiliary mass supported by magnetic levitation for movement relative to the structure in the at least one plane and/or about the at least one axis, sensing means for sensing the vibration-induced relative movement, force applying means, and control means for receiving the output of the sensing means and for causing the force applying means to apply force to vibrate the mass and, by reaction, to provide antiphase forces to reduce vibration of the structure.

The invention will be described further, by way of example, with reference to the accompanying drawings, in which:-

Figure 1 is a diagrammatic representation of a vibration cancellation device in accordance with the present invention;

Figure 2 is a cross-section of a vibration cancellation device according to the present invention; and

Figure 3 is a perspective view, part broken away, of the device of Figure 2.

As shown in the drawings, a vibration cancellation device comprises a frame 10 forming part of or for rigidly mounting to an apparatus (not shown) subject to vibration. The frame 10 is in the form of a flanged hollow non-ferro-magnetic spherical shell or cage having a major hemisphere 11a and a minor hemisphere 11b each having flanges 11c enabling the hemispheres to be secured together, and to an apparatus subject to vibration, by bolts (not shown) extending through holes 11d in the flanges 11c. The frame 10 supports three pairs (of which only two pairs are shown) of radial drive electromagnets 12, each pair being located one at each end of a respective one of three orthogonal diameters of the spherical interior of the shell 11. An anti-vibration body in the form of a hollow steel sphere 14 is located in the spherical space defined interiorly of the shell 11. The sphere 14 is in the form of two hemispheres 14a and 14b, which are secured together along a join line 14c. The magnets 12 serve to support, by magnetic levitation, the sphere 14, when the sphere is at rest, substantially concentrically of the spherical space. It will be appreciated that that pair of the magnets which is not shown are provided on a diameter orthogonally of the plane of Figure 1.

Similarly, equi-spaced upon the surface of the spherical shell 11 are three pairs (of which again only two pairs are shown) of tangential drive magnets 16.

At least one of each pair of radial drive magnets 12 is provided with a proximity sensor 18 (not shown in Figures 2 and 3) and at least one of one pair of tangential drive magnets 16 is provided with photo sensing means 20 (not shown in Figures 2 and 3).

The proximity sensors 18 serve to control, via control means 22 (Figure 1), the magnetically levitated state of the sphere 14, by causing the radial drive magnets 12 to produce magnetic fields contactlessly supporting and holding the sphere 14 substantially concentrically of the spherical space i.e. motionless in any direction, in its rest state. Similarly, the sensing means 20, in conjunction with markings 23 on the surface of the sphere 14, provide an output to the control means 22 which then drives the tangential drive magnets 16 to ensure, in its rest state, non-rotation of the sphere 14 about any axis.

The proximity sensors 18 and photosensing means 20 constitute first and second sensing means. When vibration in at least one plane of the frame 10 is imparted thereto by the apparatus or structure to which it is rigidly mounted, the first sensing means, one or more of the proximity sensors 18, senses a change in the proximity of the sphere 14 thereto. Via a feedback loop, the sensed change in proximity is used to cause one or more of the radial drive magnets 12 to apply magnetic forces to the sphere 14 in a direction such as to move the sphere and cancel the change in proximity. Similarly, when vibration occurs about at least one axis of the frame 10, the second sensing means, one or more of the photosensing means 20, senses a change in the orientation of the sphere 14. Via a feedback loop, the sensed change in orientation is used to cause one or more of the tangential drive magnets 16 to apply magnetic forces to move the sphere 14 in a direction such as to cancel the change in orientation, i.e. to vibrate the sphere in directions and/or orientations matching those of the sensed vibrations of the structure. The reactions to the applied magnetic forces give to the structure an anti-phase momentum in a direction cancelling vibration.

At least the radial drive magnets 12 have shock absorbent surfaces 24 e.g. of synthetic rubber (see Figures 1 and 2), to prevent damage should a shock, applied to the device, cause the sphere 14 to impact one or more of the magnets 12 before the proximity sensors 18 and radial drive magnets 12 could cause corrective movement of the sphere 14.

In use, the shell 11 is mounted by means of bolts through the holes 11d in the flanges 11c to an apparatus subject to vibration. The vibration may be in any direction and/or angular about any axis. In order to cause corrective movement of the sphere 14 in the spherical space, the proximity sensors 18 and/or the photosensors 20, through the control means 22, cause current to be fed to the radial drive magnets 12 and/or the tangential drive magnets 16, to cause the sphere to vibrate in a manner tending initially to eliminate (or minimise) relative movement between the sphere 14 and the frame 10 (and the magnets). The reaction of the forces applied to the sphere 14, in this way, serve to reduce or cancel the vibration of the frame 10 (and the apparatus whereto it is mounted). Thus, in cancelling vibration, the ultimate aim is for the frame 10 (and the structure whereto it is rigidly mounted) to remain stationary and for the sphere 14 to vibrate under the action of the drive magnets 12 and 16

The first and second sensing means are sufficient to enable relatively low frequency cancellation (or minimisation) of vibration. At higher frequencies of vibration, it is preferable to use additional or alternative sensing means. These additional or alternative sensing means may be mounted on the frame 10, to sense the vibration thereof directly, and/or on the sphere 14, to measure the vibration imparted thereto by the magnets 12 and 16. Accelerometers, for example, piezoelectric devices may provide the alternative or additional sensing means.

If the additional or alternative sensing means are mounted on the shell 11 or the vibrating apparatus, and measure directly vibration of the apparatus to which the frame is secured, predictive drive may be applied to the magnets 12 and/or 16 to cause the sphere 14 to vibrate and thus minimise or prevent movement of the frame 10. Predictive drive is feasible because most vibrations are of a cyclical nature and repeat at discernible frequencies.

As shown in Figure 1, accelerometers 26 are provided, internally of the sphere 14, to measure the vibration imparted to the sphere 14. The accelerometers feed an output box 28 located in the sphere 14. The box 28 contains electronic circuitry for example, A/D convertors, multiplexors and electro-optic transducers whereby the signals from the accelerometers 26 may be fed, from the sphere 14, for example, via a single optical fibre 30 (not shown in Figures 2 and 3). The fibre 30 provides no support for the sphere 14 and is sufficiently flexible to minimise or eliminate any damping effect on the movement of the sphere. Instead of a fibre optic cable 30, thin electrical conductors may be used. However, any damping effect must be minimised and support for the sphere 14, must not be provided.

The output of the accelerometers 26, via the cable 30, may be analysed to indicate the vibration of the sphere 14. In theory, the vibration of the sphere 14 is directly indicative of the vibration of the device and of the apparatus to which the device is rigidly mounted. Thus, if additional or alternative sensing means are mounted on the frame 10 as suggested above, the accelerometers 26 provide a comparative means for applying corrective drive to the magnets 12, 16. If the output of the proximity sensors 18 and of the photosensors 20 is also monitored, for example in the control means 22, the outputs could also be compared with that of the accelerometers 26 and a feedback loop established in the control of the magnets 12 and 16 to tune the device and to minimise hysteresis in the cancellation of vibration.

Alternatively, the device could be tuned to provide fixed frequency or broad band vibration cancellation or minimisation.

The two important features of the device of the present invention are (i) that there are no moving parts that can wear out so the system should be very reliable indeed and (ii) that the system can survive very considerable linear shocks - these, at worst, cause the sphere to impact the electromagnets - and the impact can be softened by the use of the thin synthetic rubber covering.

In order to sense the motion of the steel sphere accurately over the full frequency band, for example 0 to 500 Hz or greater, the accelerometers 26 are mounted, as shown in Figure 1, near the surface of the sphere 14 and are placed at opposite ends of three mutually orthogonal axes. If these axes are numbered 1, 2 and 3 then the accelerometers at the ends of axis 1, 2 and 3 respectively, are orientated parallel to axes 2, 3 and 1 respectively. By integrating the outputs of these accelerometers, all the components of the instantaneous linear and angular velocities of the sphere 14 can be determined. This arrangement would give accurate measurements at higher frequencies. To avoid error build up at the lower frequencies, the external position and orientation sensors 18 and 20 are necessary. This would ensure that the control could accurately keep the mean position of the centre of and the mean orientation of the sphere 14 correctly positioned. Further, by suitable digital signal processing, one could use the proximity sensors 18, the orientation sensors 20 and the accelerometers 26, along with suitable complementary cross-over filters, to give the most precise measurement of linear and angular acceleration over the full frequency band.

The external position sensors 18 can take any of a number of forms all of which are known in the prior art. Orientation sensing by the sensors 20 is more difficult but could be achieved by an optical coding technique whereby the movement of a pattern 23 on the sphere 14 is observed passing fixed locations whereby the direction and total angular movement can be tracked. Alternatively, if the surface of the sphere 14 were ferro-magnetically non uniform, Hall effect devices or linear differential transformers could be used to sense rotation of the sphere. For low frequency control, these sensors 18 and 20 could provide all the information necessary but, for higher frequency control, the accelerometers, mounted in the sphere 14 and/or on the frame 10, are far more accurate.

Extraction of the accelerometer outputs from the moving sphere need not be effected by the cable 30. There are several non-contacting techniques for transmitting such accelerometer information to the external control means 22. These techniques all require some power to be available within the sphere 14. This power may be made available by non-contacting transfer provided by a suitable electromagnetic coupling technique.

A simpler, but more restrictive, alternative to the above described device, is to limit the maximum angular excursions of the sphere 14 by including several lugs (not shown) on the sphere 14 to impact stops (also not shown) for example, the sides of the electromagnets 12, 16. In this arrangement, the outputs from the accelerometers could again be multiplexed onto a single optical fibre which very loosely couples the sphere 14 to the external control means 22. Electric power to the sphere 14 if necessary, may be provided via two thin and flexible wires coupling the sphere to a power source on the device. Considerable care would be needed to minimise the possibility that these couplings to the sphere could become the least reliable part of the complete vibration cancelling device.

In theory, only three radial drive magnets 12 and only three tangential drive magnets 16 are necessary. Three magnets (12 or 16) on the surface of the spherical space, with appropriate sensors can detect movement and apply corrective drive to the sphere 14. However, electromagnetic drives are non-linear drives and difficulties arise in the control exercised by the control means 22 in calculating the drive to be applied by the magnets.

Further, it is possible that combined radial and tangential drive magnets may be used so that each magnet may be energised in either or both of two ways to impart drive to the sphere.

In a simpler, more compact device, the sphere 14 is a solid ferro-magnetic body. Its size can then be much smaller for the same weight. External sensors 18, 20 and 26 are then used to determine vibration of the structure and/or frame 10 and the drive applied to the magnets 12, 16.

In another embodiment, the sphere 14, although symmetrical, has non-uniform ferro-magnetic surface properties caused by inserts or by internal ribs to a hollow sphere.

It is possible to use other forces to support and drive the sphere 14. For example, fluid jets may replace the magnets 12 and 16.

CLAIMS

1. A device, for reducing vibration of a structure, comprising a mass having a rest position motionlessly supported from the structure by a magnetic field, means for sensing the vibration, and means for controlling the magnetic field to vibrate the mass and, by reaction, to apply an antiphase vibration to the structure.

2. A device, for reducing vibration of a structure, comprising an auxiliary mass supported by the structure by a magnetic field, sensing means for sensing the vibration, and means for vibrating the auxiliary mass by varying the magnetic field, in accordance with the sensed vibration whereby to apply, by reaction, antiphase vibration to the structure.

3. Apparatus for reduction of vibration in a structure including a source of vibration, the apparatus comprising a plurality of devices each supporting, by a magnetic field, a respective inertial mass, means for sensing the vibration, and control means for controlling the magnetic field or fields to cause vibration of the respective inertial mass or masses thereby to apply to the structure, antiphase vibration to minimize or cancel the source induced vibration of the structure.

4. A vibration cancellation device for rigidly mounting to or forming part of a structure subject to vibration in at least one plane and/or about at least one axis, the device comprising an auxiliary mass supported by magnetic levitation for movement relative to the structure in the at least one plane and/or about the at least one axis, sensing means for sensing the vibration-induced relative movement, force applying

means, and control means for receiving the output of the sensing means and for causing the force applying means to apply force to vibrate the mass and, by reaction, to provide antiphase forces to reduce vibration of the structure.

5. A device as claimed in claim 4 wherein the auxiliary mass is contactlessly supported for movement relative to the structure in three orthogonal planes.

6. A device as claimed in claim 4 or 5 wherein the mass is contactlessly supported for movement relative to the structure about three orthogonal axes.

7. A device as claimed in any preceding claim wherein the sensing means comprises first sensing means for sensing relative movement of the mass in at least one plane.

8. A device as claimed in claim 7 wherein the first sensing means comprises one or more proximity sensors mounted on a frame.

9. A device as claimed in any preceding claim wherein the sensing means comprises second sensing means for sensing relative movement of the mass about at least one axis.

10. A device as claimed in claim 9 wherein the second sensing means comprises one or more photosensors for monitoring the surface of the mass upon movement thereof about at least one axis.

11. A device as claimed in any preceding claim including further sensing means for sensing relative movement of the mass at frequencies higher than those sensed by the sensing means.

12. A device as claimed in claim 11 wherein the further sensing means comprises accelerometers arranged to sense vibration of a structure and/or to sense relative movement of the mass.

13. A device as claimed in claim 11 or 12 wherein the further sensing means are mounted on the mass.

14. A device as claimed in any preceding claim wherein the mass is ferromagnetic.

15. A device as claimed in any preceding claim wherein the mass is spherical.

16. A device as claimed in any preceding claim wherein the mass comprises a hollow steel sphere having, as further sensing means, diametrically opposed accelerometers secured to the interior surface of the sphere at the ends of three orthogonal diameters, for sensing movement of the mass.

17. A device as claimed in any preceding claim comprising an electromagnet at each side of the mass orthogonal to the at least one plane, the control means serving to energise the electromagnets to apply forces to the mass orthogonal to the at least one plane to reduce vibration of the structure.

one plane to reduce vibration of the structure.

18. A device as claimed in any preceding claim further including means for applying rotational forces to the mass about at least one axis, in opposition to the relative movement thereabout.

19. A device as claimed in claim 18 wherein the means for applying rotational forces comprises at least one pair of opposed electromagnets producing forces tangential to rotation of the mass about the at least one axis.

20. A device as claimed in any preceding claim, wherein the surface of the mass is configured so as to indicate to photosensors of the sensing means, relative movement of the body about the at least one axis.

21. A device as claimed in any preceding claim further including a frame arranged for mounting to a structure subject to vibration, the frame defining a spherical space wherein the mass is contactlessly supported, the frame serving also to support the sensing means and the force applying means.

22. A device as claimed in claim 21 wherein the frame comprises a flanged spherical shell defining internally the spherical space wherein the mass is contactlessly supported and arranged for mounting to a structure subject to vibration by the flange.

23. A device as claimed in claim 21 or 22 wherein the frame is of a non-

ferromagnetic material.

24 A vibration cancellation device substantially as hereinbefore described with reference to the accompanying drawings.

25. A method of reducing vibration of a structure including a vibration source, the method comprising the steps of supporting, from the structure, by magnetic field, at least one inertial mass, sensing vibration of the structure, and controlling the magnetic field to drive the at least one inertial mass to vibrate, whereby, by reaction, an antiphase vibration is applied to the structure.

26. A method as claimed in claim 25 further including the step of sensing vibration of the mass, comparing the sensed vibrations of the structure and the mass, and applying a corrective drive to the mass.

27. A method as claimed in claim 25 or 26 wherein the vibration is a linear vibration and a linear drive is applied to the mass.

28. A method as claimed in claim 25 or 26 wherein the vibration is both linear and rotational and linear and rotational drives are applied to the mass.

29. A method of reducing vibration of a structure including a vibration source comprising the step of transferring the vibration to a contactlessly supported inertial mass by driving the mass in accordance with the vibrations and thereby applying, by

reaction, a vibration cancelling drive to the structure.

30. A method of reducing vibration of a structure as claimed in claim 29 and substantially as hereinbefore described.

Patents Act 1977
Examiner's report to the Comptroller under Section 17 (The Search Report) — 18 —

Application number: GB 9312021.0

Relevant Technical fields

(i) UK Cl (Edition L) F2S (SCK, SCL, SAX, SCN)

(ii) Int Cl (Edition 5) F16F

Search Examiner: D DODD

Databases (see over)

(i) UK Patent Office

(ii) ONLINE DATABASES: WPI

Date of Search: 30 SEPTEMBER 1993

Documents considered relevant following a search in respect of claims 1-30

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
X	GB 2222279 A (WESTINGHOUSE)	1,2,4,25, 29 at least
X	GB 1601096 (SOC.EUR.PROP) - Note page 5, lines 83-94	1,2,4,25, 29 at least

SF2(p) ms - doc99\fil002318

Category	Identity of document and relevant passages	Relevant to claim(s)

Categories of documents

X: Document indicating lack of novelty or of inventive step.

Y: Document indicating lack of inventive step if combined with one or more other documents of the same category.

A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family, corresponding document.

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