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(54) **The present invention relates to a seismic shaker, i.e. an apparatus configured to generate vibrations on the soil or the ground.**

(57) A seismic shaker is described, the seismic shaker comprising:
- a base plate;
- an electromagnetic motor comprising a mover and a stator, the stator being mounted to the base plate, and
- a guiding mechanism comprising a plurality of discrete elements connecting the stator to the mover, the guiding mechanism being configured to enable a displacement of the mover relative to the stator in a first direction and restrict a displacement in a plane substantially perpendicular to the first direction.

Technical field:

The present invention relates to a seismic shaker, i.e. an apparatus configured to generate vibrations on the soil or the ground.

Background:

Seismic shaker can e.g. be used in the monitoring and exploration of oil and gas reserves. Such a seismic shaker typically includes an actuator such as an hydraulic actuator which is configured to exert a force, typically a time-varying force, onto a base plate that is arranged on the soil or the ground. Such a seismic shaker may further comprise a reaction mass that is suspended or substantially isolated from the base plate, whereby the reaction mass is configured to receive a reaction force of the time-varying force. The time-varying force as applied may e.g. be a sinusoidal varying force having a frequency that varies over time, e.g. changing from 5 Hz to 200 Hz over a period of e.g. 10 to 20 sec.
It has further been proposed to apply electromagnetic actuators for generating the time-varying force. Such actuators enable an improved performance with respect to the frequency range, controllability of the generated time-varying force, and reduce self-induced noise .
When such seismic shakers are scaled up to larger forces, e.g. > 20 kN, the robustness and/or reliability of known solutions may be insufficient.

Summary of the invention:

It is an object of the present invention to provide a seismic shaker comprising an electromagnetic actuator for generating a time-varying force, which enables a more reliable and/or robust operation.
According to an aspect of the present invention, there is provided a seismic shaker comprising:

- a base plate;
- an electromagnetic motor comprising a mover and a stator, the stator being mounted to the base plate, and
- a guiding mechanism comprising a plurality of discrete elements connecting the stator to the mover, the guiding mechanism being configured to enable a displacement of the mover relative to the stator in a first direction and restrict a displacement in a plane substantially perpendicular to the first direction.

The seismic shaker according to the present invention comprises a base plate. Such a base plate can e.g. be a rigid structure that is either solid or hollow, and is configured to be arranged on the ground at a location were a force is to be applied to the ground.

The seismic shaker according to the present invention further comprises an electromagnetic motor comprising a mover and a stator, whereby the stator is mounted to the base plate. In an embodiment, the electromagnetic motor as applied may e.g. be a synchronous motor, e.g. a permanent magnet motor. An electromagnetic motor typically comprises one or more coils, e.g. made from an electrical conductor such as Copper (Cu) or Aluminium (Al) which can cause a force to be generated between the mover and the stator, said force causing a relative displacement between the stator and the mover. In an embodiment of the present invention, the mover of the electromagnetic actuator serves as reaction mass or part of a reaction mass to receive a reaction force of the generated force. In an embodiment, the mover or reaction mass is supported on the base plate, e.g. via a vibration isolator such as a gas mount or air mount or other spring-like system. In an embodiment, multiple vibration isolators can be applied to support the mover or reaction mass onto the base plate.

In accordance with the present invention, the seismic shaker further comprises a guiding mechanism that is configured to enable a displacement of the mover relative to the stator in a first direction, e.g. a vertical direction and restrict or limit a displacement of the mover relative to the stator in a plane substantially perpendicular to the first direction. It can be pointed out that, in an embodiment, a small rotation of the mover relative to the stator may occur.

In accordance with the present invention, the guiding mechanism thus serves a similar purpose as a bearing such as a ball bearing or sliding bearing.

The guiding mechanism as applied in the present invention comprises a plurality of discrete members that connect the stator to the mover.

In an embodiment, such members can e.g. be or comprise rods that are rotatable connected to both stator and mover.

In an alternative embodiment, the members can be or comprise leaf springs, e.g. folded leaf springs.

In yet another embodiment, the members can comprise one or more spherical bearings. Such spherical bearings can e.g. be spherical plain bearings or elastic bearings comprising vulcanised rubber, or hole hinges, or spring hinges.

In an embodiment, the guiding mechanism comprises five or more discrete members connecting the stator to the mover. In an embodiment, the applied discrete members are configured to enable or allow a displacement of the mover relative to the stator in 1 degree of freedom, e.g. 1 translational degree of freedom, and limit a displacement of the mover relative to the stator in the remaining 5 degrees of freedom.

Brief description of the drawings:

Figure 1 schematically shows a first embodiment of a seismic shaker according to the present invention.

Figure 2 schematically shows a second embodiment of a seismic shaker according the present invention.

Figure 3a schematically shows a plan view of a third embodiment of a seismic shaker according to the present invention.

Figure 3b schematically shows a cross-sectional view of a seismic shaker according to the present invention.

Figures 4a and 4b schematically show cross-sectional views of electromagnetic motors as can be applied in a seismic shaker according to the present invention.

Figures 5a and 5b schematically show frequency sweeps as can be applied by a seismic shaker according to the present invention.

Figure 6 schematically shows a first discrete element as can be applied in a seismic shaker according to the present invention.

Figure 7 schematically shows a second discrete element as can be applied in a seismic shaker according to the present invention.

Figure 8 schematically shows two cross-sectional views of base plates as can be applied in a seismic shaker according to the present invention.

Detailed description:

Figure 1 schematically shows a cross-sectional view of a first embodiment of a seismic shaker 100 according to the present invention.

The seismic shaker 100 as schematically shown comprises a base plate 110 onto which a central column 120 is mounted. The seismic shaker 100 further comprises an electromagnetic motor 130. The electromagnetic motor 130 comprises a stator 130.1 mounted to the central column 120 and a mover 130.2. In an embodiment, the stator 130.1 can comprises a plurality of coils that are configured to co-operate with a plurality of permanent magnets of the mover 130.2, in order to generate a force in the vertical direction (Z-direction), as indicated by the arrow 140. In such embodiment, the stator 130.1 and mover 130.2 of the electromagnetic motor 130 may e.g. be axisymmetric about the axis 150 as shown. In such embodiment, the stator 130.1 may thus comprises a plurality of cylindrical coils arranged on the column 120 symmetrically about the axis 150. The column 120 may e.g. serve as back-iron for the magnetic flux generated by the permanent magnets and may thus be made of or comprise a ferromagnetic material The mover 130.2 of the electromagnetic motor 130 comprises an array of permanent magnets 130.21 that are mounted in a housing 130.22 of the motor 130. Said housing 130.22 may e.g. serve as back-iron for the magnetic flux generated by the permanent magnet and may thus be made of or comprise a ferromagnetic material. The array of permanent magnets 130.21 may comprises a cylinder shaped structure of permanent magnets. More details on such an electromagnetic motor 130 are provided below. In the embodiment as shown, the mover 130.2 of the electromagnetic motor 130 is mounted to a reaction mass structure 160. In an embodiment, the reaction mass structure 160 can be an integral part of the housing 130.22 of the electromagnetic motor 130, or , phrased differently, the mover 130.2 of the electromagnetic motor 130 may serve as the reaction mass structure 160 or reaction mass. As such, when the electromagnetic motor 130 is powered, it will exert a force on the base plate 110, while a reaction force of said force will be generated on the mover 130.2. As will be appreciated by the skilled person, in an embodiment of the present invention, the array of permanent magnets 130.21 may be arranged on the column 120 while the array of coils 130.1 is mounted to the housing or back-iron 130.2.

In accordance with the present invention, the seismic shaker 100 according to the present invention further comprises a guiding mechanism 170 that is to enable a displacement of the mover 130.2 relative to the stator 130.1 in a substantially vertical direction, i.e. in the Z-direction as indicated and substantially restrict movement in the other 5 degrees of freedom. In particular, the guiding mechanism may be configured to substantially restrict a displacement in a horizontal plane, i.e. a plane substantially perpendicular to the indicated Z-direction. Note that a small rotation, e.g. approx. 0.1 – 0.2 degrees about the axis 150, may occur.

In accordance with the present invention, the guiding mechanism 170 comprises a plurality of discrete elements 170.1, 170.2, 170.3, 170.4 that connect the stator 130.1 of the electromagnetic motor 130 to the mover 130.2 of the electromagnetic motor 130. In the embodiment as shown, the discrete elements 170.1-170.4 are rods that are rotatable connected to both the stator and the mover.

In an alternative embodiment, the discrete elements may be leaf springs or comprise leaf springs. As an example, the discrete elements can comprise folded leaf springs. As another example, the discrete elements can comprise 2 leaf springs, whereby the 2 leaf springs together are configured to restrict movement in 5 degrees of movement

In yet another embodiment, the discrete elements can comprise one or more spherical bearings.

Such spherical bearings can e.g. be spherical plain bearings or elastic bearings comprising vulcanised rubber, or hole hinges, or spring hinges.

In an embodiment of the present invention, the discrete elements 170.1-170.4 of the guiding mechanism 170 are configured to enable a displacement of the mover relative to the stator in only one degree of freedom, e.g. a translation in the vertical direction or Z-direction while disabling or restricting a displacement of the mover relative to the stator in the other 5 degrees of freedom, i.e. two translational degrees of freedom in the horizontal plane or XY-plane and rotational degrees of freedom about the Z-axis, X-axis or Y-axis. Note that a small rotation about the Z-axis may occur and may be allowed.

In the embodiment as shown, the discrete elements 170.1-170.4 are connected, on one side, to the reaction mass structure 160 and, on the other side, the column 120. By doing so, the discrete elements 170.1-170.4 of the guiding mechanism 170 are configured to connect the stator 130.1 to the mover 130.2.

In an embodiment, as mentioned, the reaction mass structure 160 can be an integral part of the mover 130.2, or the mover 130.2 may serve as reaction mass. In such embodiment, the discrete elements can be connected directly to the mover.

In an embodiment of the present invention, the column 120 further comprises one or more frames or structures mounted to it, to facilitate a connection of the discrete elements to the stator 130.1 or the column 120.

The seismic shaker 100 as schematically shown further comprises an enclosure 180 enclosing the electromagnetic actuator 130.

Figure 2 schematically shows a cross-sectional view of a second seismic shaker 200 according to the present invention.

The seismic shaker 200 as schematically shown comprises a base plate 210 onto which a central column 220 is mounted. The seismic shaker 200 further comprises an electromagnetic motor 230. The electromagnetic motor 230 comprises a stator 230.1 mounted to the central column 120 and a mover 230.2. In an embodiment, the stator 230.1 can comprises a plurality of coils that are configured to co-operate with a plurality of permanent magnets of the mover 230.2, in order to generate a force in the vertical direction (Z-direction), as indicated by the arrow 240. In such embodiment, the stator 230.1 and stator 230.2 of the electromagnetic motor 130 may e.g. be axisymmetric about the axis 150 as shown. In such embodiment, the stator 230.1 may thus comprises a plurality of cylindrical coils arranged on the column 220 symmetrically about the axis 250. The column 220 may e.g. serve as back-iron for the magnetic flux generated by the permanent magnet and may thus be made of or comprise a ferromagnetic material The mover 230.2 of the electromagnetic motor 230 comprises an array of permanent magnets 230.22 that are mounted in a housing 230.21 of the motor 230. Said housing 230.21 may e.g. serve as back-iron for the magnetic flux generated by the permanent magnet and may thus be made of or comprise a ferromagnetic material. The array of permanent magnets 230.22 may comprises a cylinder shaped structure of permanent magnets. In the embodiment as shown, the mover 230.2 of the electromagnetic motor 230 also serves as a reaction mass. As such, when the electromagnetic motor 230 is powered, it

will exert a force on the base plate 210, while a reaction force of said force will be generated on the mover 230.2. As will be appreciated by the skilled person, in an embodiment of the present invention, the array of permanent magnets 230.22 may be arranged on the column 220 while the array of coils 230.1 is mounted to the housing or back-iron 230.2.
In accordance with the present invention, the seismic shaker 200 according to the present invention further comprises a guiding mechanism 270 that is configured to enable a displacement of the mover 230.2 relative to the stator 230.1 in a substantially vertical direction, i.e. in the Z-direction as indicated and restrict a displacement in a horizontal plane, i.e. a plane substantially perpendicular to the indicated Z-direction, as also discussed above.
In accordance with the present invention, the guiding mechanism 270 comprises a plurality of discrete elements 270.1, 270.2, 270.3, 270.4 that connect the stator 230.1 of the electromagnetic motor 230 to the mover 230.2 of the electromagnetic motor 230. In the embodiment as shown, the discrete elements 270.1-270.4 are rods that are rotatable connected to both the stator and the mover. This can e.g. be realised by means of spherical bearings such as spherical elastic bearings or spherical plain bearings. In the embodiment as shown, the column 220 further comprises a top or upper frame or structure 220.1 and a bottom or lower frame or structure 220.2 to facilitate a connection of the discrete elements 270.1-270.4 to the column 220.
In an alternative embodiment, the discrete elements may be leaf springs or comprise leaf springs. As an example, the discrete elements can comprise folded leaf springs. In such embodiment, the restriction of the movement of the stator relative to the mover in 5 degrees of freedom may e.g. be realised using a pair of leaf springs as the plurality of discrete elements.

In an alternative embodiment the discrete elements may comprise one or more spherical bearings, e.g. elastic bearings or spherical plain bearings.
Similar to the first embodiment, the discrete elements 270.1-270.4 of the guiding mechanism 270 are configured to enable a displacement of the mover relative to the stator in only one degree of freedom, e.g. a translation in the vertical direction or Z-direction while prohibiting or restricting a displacement of the mover relative to the stator in the other 5 degrees of freedom, i.e. two translational degrees of freedom in the horizontal plane or XY-plane and rotational degrees of freedom about the Z-axis, X-axis or Y-axis.

In order to realise such guiding, the guiding mechanism, e.g. guiding mechanism 170 or 270, as applied in the present invention can comprise 5 or more discrete elements. By suitable application of 5 or more elements, a movement of the stator relative to the mover can be restricted or prohibited in 5 degrees of freedom, while allowing movement in a sixth degree of freedom, e.g. a translational degree of freedom.

In the embodiments as shown in Figures 1 and 2, the column 120 resp. 220 may correspond to the shaft of the electromagnetic motor as applied. Element 122, resp. 222 may e.g. be a flange or the like that serves as an interface to mount the shaft or column to the baseplate 110 resp. 210.

In the embodiments as shown in Figures 1 and 2, the reaction mass structure 160, resp. the housing 230.21 is mounted on the base frame via a low-stiffness support 190 resp. 290. Such a low-stiffness support may e.g. be a gas spring support, such as an air mount or the like. Preferably, the stiffness of such a low-stiffness support should be as low as possible, in particular in the direction of movement, i.e. the Z-direction in the embodiments of Figures 1 and 2. A low stiffness for the support provides that advantage that the required force for displacing the mover is minimised. It also results in a low eigenfrequency of the reaction mass reaction mass structure. Preferably, the eigenfrequency should be lower than the lowest frequency of a frequency sweep that is performed by the seismic shaker. More details on such a frequency sweep are provided below. In an embodiment, the eigenfrequency should e.g. be < 2 Hz. It is further preferred to have the stiffness of the low-stiffness support vary as little as possible over the required stroke of the mover. Preferably the stiffness variation is less than 10% over the entire stroke. In order to realise this, a gas spring having a comparatively large volume and/or comparatively large height can be applied for the support. With respect to the use of a gas spring support, it can further be pointed out that such a support will typically have no eigenfrequencies in the operating range of the frequency sweep, e.g. in the range from 1 – 250 Hz. A gas spring support can further be easily adjusted, by means of the gas pressure, and is comparatively compact.
Alternative supports such as mechanical springs may be applied as well. However, it can be pointed out that such supports may suffer from internal resonance frequencies adversely affecting the performance of the seismic shaker.

By applying a dedicated reaction mass structure and one or more frames or structures to the central column, an increased flexibility with respect to the shape, size, and position of the discrete elements can be obtained.
As an example, a cube-shaped or beam-shaped hollow structure may e.g. be used as a reaction mass structure that is connected to the housing of the electromagnetic motor, such housing typically having a cylindrical outer shape.

Figure 3a schematically shows a plan view of a third embodiment of a seismic shaker 300 according to the present invention where such a reaction mass structure is applied. The seismic shaker 300 comprises a tube-shaped reaction mass structure 310 which has a substantially square cross-section shaped such that it can receive an electromagnetic motor of which the shaft 320 protrudes a frame 330. In the embodiment as shown, a frame 330 is mounted to the shaft 320 of the electromagnetic motor of the shaker 300. The seismic shaker 330 further comprises a guiding mechanism which comprises a plurality of discrete element 340.1 – 340.6 connecting the frame 330 to the reaction mass structure 310. In the embodiment as shown, the mover of the electromagnetic motor is assumed to be connected to the reaction mass structure 310 such that the discrete elements 340.1-340.6 in fact provide a connection between the mover of the electromagnetic motor and the stator of the electromagnetic motor.
Figure 3b schematically shows a cross-sectional view of the seismic shaker 300 parallel to the XY-plane. Figure 3b schematically shows a cross-section of the tube-shaped reaction mass structure 310 which is connected to a housing 312, e.g. via interfaces 312.1 of the housing 312. Mounted inside the housing 312 is an array of permanent magnets 314 that is configured to generate a magnetic field to interact with a coil array 322 of the stator of the motor. Reference number 316 refers to a gap existing between the array of permanent magnets 314 and the coil array 322. The coil array 322 as shown is mounted to the shaft 320 of the motor.

The application of a guiding mechanism having a plurality of discrete elements connecting the stator to the mover provides, for the particular application of a seismic shaker, the advantage of being more robust. Compared to conventional solutions which e.g. apply a sliding bearing or a roller bearing, the application of the guiding mechanism of the present invention results in less friction or wear. Because of the comparatively small displacements during use of the mover relative to the stator, the lubrication of conventional solutions will become troublesome. The conventional bearing arrangement may also become polluted.
Figure 4a schematically shows a more detailed view on an electromagnetic motor as can be applied in a seismic shaker according to the present invention. Figure 4a schematically shows a cross-sectional view of an axisymmetric electromagnetic motor 400, the motor comprising a first part 410 and a second part 420. When applied in a seismic shaker according to the invention, the first part 410 may be referred to as the mover, the second part 420 may be referred to as the stator. In the embodiment as shown, the first part of the electromagnetic motor comprises an array of permanent magnets 410.1, the permanent magnets 410.1 being configured to generate a spatially alternating magnet field along the Z-direction. The arrows in

the permanent magnets 410.1 indicate the direction of magnetisation. In the embodiment as shown, the magnets 410.1 as applied have a width W, resulting a magnetic pitch P = 2*W. In an embodiment of the present invention, the array of permanent magnets 410.1 may comprise a Hallbach array, in order to increase the magnetic field that interacts with the second part 420.

In the embodiment as shown, the array of permanent magnets 410.1 is mounted inside a cylinder 410.2 that is e.g. made or comprises a ferromagnetic material and thus serves as a back-iron for guiding the magnetic flux as generated by the permanent magnets 410.1. In the embodiment as shown, the cylinder 410.2 is mounted inside a housing 410.3 of the electromagnetic motor 400. The housing 410.3 may e.g. be provided with mounting elements or structures, for mounting the first part 410 of the motor to a reaction mass structure. It can be pointed out that, as also mentioned above, that the cylinder 410.2, serving as back-iron, and the housing 410.3 may be integral parts.

In the embodiment as shown, the second part 420 comprises an array of coils 420.1, e.g. cylindrical coils that are arranged about a cylindrical shaft 420.2. The cylindrical shaft 420.2 can e.g. be made or comprise a ferromagnetic material and thus serves as a back-iron for guiding the magnetic flux as generated by the permanent magnets 410.1 of the first part 410 and the magnetic flux generated by the array of coils 420.1. In an embodiment of the present invention, the array of coils 420.1 may e.g. be a multi-phase array of coils, e.g. a three-phase coil array, configured to be powered by a three-phase power supply. By suitable powering of the coil array, forces can be generated on the first part 410, resulting in a displacement of the first part 410 relative to the second part 420.

In the embodiment as shown, the second part 420 of the electromagnetic motor further comprises cooling channels 420.3 through which a cooling fluid can be arranged, in order to cool the coil array 420.1. A suitable coolant may e.g. be water. As will be appreciated, alternative means of cooling the coil array, when required, can be implemented as well as for example air or forced air cooling or 2-phase cryogenic cooling systems.

In the embodiment as shown, the shaft 420.2 is further provided with a flange or interface 420.4 which can be used to mount the motor 400 to a base frame such as base frame 110 or 210 shown above.

In the embodiment as shown in Figure 4a, the permanent magnets 410.1 are magnetised in a direction perpendicular to the axial direction of the motor. It can be pointed out that an alternative motor can be designed having permanent magnets magnetized in the axial direction. Such an embodiment is schematically shown in Figure 4b. Figure 4b schematically shows a cross-sectional view of an axisymmetric electromagnetic motor 500, the motor comprising a first part 510 and a second part 420, the second part 420 e.g. corresponding to the second part 420 in Figure 4a. When applied in a seismic shaker according to the invention, the first part 510 may be referred to as the mover, the second part 420 may be referred to as the stator. In the embodiment as shown, the first part of the electromagnetic motor comprises an array of permanent magnets 510.1, the permanent magnets 510.1 being configured to generate a spatially alternating magnet field along the Z-direction. The arrows in the permanent magnets 510.1 indicate the direction of magnetisation. In the embodiment as shown, the permanent magnets 510.1 are magnetized in the axial direction 450. In between adjacent magnets, ferromagnetic members 510.2 are provided for guiding the magnetic flux generated by the permanent magnets 510.1. These members 510.2 further guide the magnetic flux as generated towards the cylindrical shaft 420.2 serving as back-iron. The members 510.2 may also be referred to as pole-shoes.

In the embodiment as shown, the array of permanent magnets 410.1 is mounted inside a housing 510.3 of the electromagnetic motor 400. The housing 510.3 may e.g. be provided with mounting elements or structures, for mounting the first part 510 of the motor to a reaction mass structure. In order to avoid or mitigate leakage of magnetic flux, the housing 510.3 should preferably be made from a non-magnetic material, e.g. stainless steel or the like.

With respect to the type of electromagnetic motor that is applied, the following is worth mentioning:

It can be pointed out that in principle, a seismic shaker may be equipped with other types of electromagnetic motors for generating the required force. It can also be pointed out that a seismic shaker may in principle comprise multiple electromagnetic motors for generating said force, the multiple motors acting in series or in parallel onto the base plate. The electromagnetic motor as schematically shown in Figure 4 may be referred to as a tubular permanent magnet actuator or motor. It can be pointed out that this type of motor can be easily scaled to generate comparatively large force onto the base plate of the shaker. In particular, the type of motor as depicted in Figure 4 can e.g. be designed to generate a force of 50 kN or more.

As an alternative to the tubular motor as described, iron core, core-less or iron-less electromagnetic motors such as U-channel type of motors or Lorentz type of motors or actuators can be mentioned as well. It may however be pointed out that such motors or actuators may be more difficult to scale to comparatively large forces or to scale them to accommodate for the required displacement range. When such motors are considered, it may thus be required to apply multiple motors rather than only one motor, as in the present invention. The application of multiple motors, rather than only one, to generate the required force on the base plate, may however complicate the operation of the shaker in that a synchronisation of the motors may be required. The application of multiple motors may further increase the number of parts of the shaker, adversely affecting the robustness.

When applied in a seismic shaker, the power supply of the electromagnetic motor as applied can be configured to perform a so-called frequency sweep. During such a frequency sweep, the mover of the motor is displaced relative to the stator according to a time-varying displacement, e.g. a substantially sinusoidal displacement, with a varying frequency. Such a frequency sweep may e.g. start at a comparatively low frequency, e.g. in a range between 2 Hz and 5 Hz and end at a comparatively high frequency, e.g. 200 Hz – 250 Hz. In order to realise such a frequency sweep, the power supply as applied in the seismic shaker according to the invention may e.g. comprise a control unit for controlling the power supply, whereby the control unit is configured to control the power supply to perform the frequency sweep. In such embodiment, performing the frequency sweep may thus comprise generating a force by the electromagnetic motor, the force having a variable frequency in accordance with the frequency sweep.

Figure 5a schematically shows a relative displacement of the mover of an electromagnetic motor during such a frequency sweep, as a function of time t. As can be seen, a frequency sweep typically starts with a comparatively low frequency which increases over time. For the frequency sweep as shown, the displacement has a maximum amplitude of approx. 25 mm. In general, the amplitude of the displacement during the frequency sweep may e.g. be in a range between 2 – 6 cm, e.g. in a range between 4-5 cm.

In an embodiment of the present invention, the magnetic pitch P of the electromagnetic motor as applied is selected to be substantially equal or smaller than the nominal displacement of the mover relative to the stator. By doing so, the thermal load or thermal dissipation of the coil array of the electromagnetic motor can be substantially evenly distributed over the different coils of the electromagnetic motor.

As can be seen from the typical frequency sweep, the displacement of the mover of the motor relative to the stator becomes very small at high frequencies. Operating the motor in such operating point, i.e. whereby the relative displacement of the mover vs. the stator is small, may result in an unbalanced thermal load of the motor, i.e. a thermal load whereby certain coils dissipate more than others. In order to avoid or mitigate this, it is proposed to superimpose a low-frequent displacement on the frequency sweep, in particular in the region where the amplitude of the frequency sweep is low. Figure 5b schematically shows a relative displacement of the mover of an electromagnetic motor during such a frequency sweep which includes a low-frequency displacement, as a function of time t. The corresponding low frequent movement of the mover with respect to the stator will more evenly distribute the average currents in the 3 phases of the power supply powering the motor, and the 3 phases of the motor.

In order to generate such a low-frequency displacement, superimposed on the frequency sweep, the control unit is configured to control the power supply to generate a low-frequency force by the electromagnetic motor, the low-frequency force causing a low-frequency displacement of the mover relative to the stator, during at least part of the frequency sweep. In an embodiment, the low-frequency displacement has a frequency that is significantly smaller than the lowest frequency or eigenfrequency of the frequency sweep. In an embodiment, the low-frequency displacement has a frequency smaller than 2 Hz. In an embodiment, the frequency of the low-frequency displacement can e.g. be 1/10 Hz, or 1/20 Hz or 1/30 Hz. In an embodiment, the low-frequency displacement has an amplitude that is correlated to the magnetic pitch P of the electromagnetic motor as applied.

The seismic shaker according to the present invention comprises a guiding mechanism that includes a plurality of discrete elements such as rods or leaf springs that are configured to constrain a movement of the mover of the electromagnetic motor of the seismic shaker relative to the stator of the electromagnetic motor.
In an embodiment of the present invention, the guiding mechanism comprises a first set of discrete elements that is arranged to connect a top part of the stator of the electromagnetic motor to a top part of the mover of the electromagnetic motor and a second set of discrete elements that is arranged to connect a bottom part of the stator of the electromagnetic motor to a bottom part of the mover of the electromagnetic motor.
In this respect, it can be pointed out that the electromagnetic motor, when implemented in seismic shaker is assumed to be arranged with the longitudinal axis in the vertical direction. The lower or bottom part of the motor would then correspond to the motor part that is closest to the base plate of the seismic shaker, the top part of the motor would be most remote from the base plate. Referring to Figure 2, the lower or bottom part of the motor may e.g. include the flange or structure 220.2 whereas the top part of the motor includes the flange or structure 220.1.
In an embodiment of the present invention, the first set of discrete elements can comprises a plurality of rods that connect a top flange or structure of the stator of the motor to the mover of the motor. An example of such an arrangement can e.g. be seen in Figure 3a, whereby 4 rods are arranged to connect a top flange of the motor to the mover of the motor, via the reaction mass structure. In such embodiment, the second set of discrete element may also comprises a plurality of rods that connect a bottom flange or structure of the stator of the motor to the mover of the motor.
In an embodiment, each set of discrete elements comprises 3 or more elements, e.g. 3 or 4 elements. In order to restrict the movement of the mover relative to the stator to only one degree of freedom, e.g. a translational degree of freedom in the vertical direction, a first set of 3 elements combined with a second set of 2 elements would be sufficient. However, it may be advantageous to have some redundancy in the set of discrete elements that is applied in the

guiding mechanism of the seismic shaker according to the invention to anticipate on a failure or malfunctioning of one or more of the elements.

Figure 6 schematically shows a discrete element 600, in particular a rod-shaped element, as can be applied in a guiding mechanism for a seismic shaker according to the present invention. The discrete element 600 as schematically shown comprises a substantially rigid bar or rod 610 having an elongate shape and provided with through holes or apertures or eyes 620 at both ends. The through holes 620 are configured to receive bar or rod-shaped members that are connected or part of the mover and the stator of the motor. In the embodiment as shown, the through holes 620 are provided with ring-shaped or cylindrical-shaped members 630 that provide an interface between the rod 610 and the mover or stator. In an embodiment, the interface members 630 can e.g. be made or comprise a ductile material such as rubber or the like. In another embodiment the interface members could comprise Plain Spherical Bearings. When the through hole on the right is connected to the stator of the electromagnetic motor as applied, and the through hole on the left is connected to the mover, the discrete element 600 enables a displacement of the mover relative to the stator in the indicated vertical direction Z by allowing a rotation as indicated by the arrow 640. When the mover is displaced relative to the mover, e.g. in accordance with the frequency sweep as shown in Figure 5, the discrete element 600 will rotate about the bar or rod that is inserted in the right through hole. It can be pointed out that the angle of rotation will be comparatively small, considering a nominal displacement of the mover relative to the stator of a few cm in the vertical direction.

As an alternative to the use of a rod-shaped discrete element as shown in Figure 6, the discrete elements as applied in the guiding mechanism of the seismic shaker according to the invention may also have a different shape. As an example, the elements may e.g. include leaf springs such as folded leaf springs. An example of such a folded leaf spring is schematically shown in Figure 7. Figure 7 schematically shows a folded leaf spring 700 comprising a leaf spring 710 that is bend at an angle, e.g. in the middle 720 of the leaf spring. The folded leaf spring 700 is further provided with interfaces 730 for mounting the leaf spring 700 to the mover and the stator of the electromagnetic motor as applied. As will appreciated by the skilled person, the application of a plurality of such leaf springs 700 connecting a mover to a stator enables to constrain the possible directions of displacement of the mover relative to the stator. In the example as shown in Figure 7, the leaf spring 700 e.g. allows a displacement along direction X, but prohibits a displacement along the direction Y. by suitable connection and orientation of a plurality of such leaf springs between a mover and a stator, one can thus enable or allow a displacement in the vertical direction while prohibiting or restricting movement in the other degrees of freedom.

In accordance with the present invention, the seismic shaker comprise a base plate onto which the electromagnetic motor is mounted. It is desirably that the base plate is light and rigid. In order to realise this, the base plate as applied in a seismic shaker according to the present invention may have a hollow structure and may include one or more ribs or reinforcement ribs.

Figure 8 schematically shows some exemplary cross-sectional views of base plates that can be applied in the present invention. On the left side of Figure 8, a cross-section view of a first base plate 800 is schematically shown, the base plate 800 having a circular cross-section and is provided with ribs 810.

On the right side of Figure 8, a cross-section view of a second base plate 850 is schematically shown, the base plate 850 having an octagonal cross-section and is provided with ribs 860.

As will be appreciated, various other shapes such as square or hexagonal cross-sections can be devised as well. It can be pointed out that for the application of a seismic shaker, it is preferred to exert a force on the soil as if the force would originate from a point source. It is further desirable to avoid or limit the excitation of sub-harmonics or higher harmonic frequencies. As such, it is preferred that the base plate is both light and rigid.

In an embodiment, the seismic shaker according to the present invention further comprises a power supply for powering the electromagnetic motor and a control unit for controlling the power supply.

In such embodiment, the control unit can be configured to control the power supply to perform a frequency sweep. The power supply as applied in the seismic shaker according to the present invention may e.g. comprise a power converter configured to provide a suitable voltage or current to the electromagnetic motor, in order for the motor to perform the required frequency sweep or, in general, generate the required force characteristic. Such a power converter can e.g. convert an AC supply power, e.g. generated by a diesel-generator, to a variable frequency supply power. In an embodiment, the seismic shaker according to the invention can thus include an AC generator and a power converter. Alternatively, or in addition, the AC power supply may be provided by one or more batteries, e.g. rechargeable or chargeable batteries.

In an embodiment, the seismic shaker according to the present invention is equipped with one or more sensors or measurement devices. As an example, the seismic shaker may be equipped with one or more motion sensors such as accelerometers e.g. mounted to the base frame, the stator of the motor or the mover of the electromagnetic motor. An acceleration signal as obtained from such a sensor may e.g. be applied as feedback to the power supply that is powering the electromagnetic motor. The acceleration signal may e.g. be used to determine a position of the mover relative to the stator, e.g. by integration of the signal twice or may be used to determine a velocity of the mover relative to the stator, e.g. by integration of the signal once.

In an embodiment, the seismic shaker according to the invention comprises at least one acceleration sensor mounted to the base plate and at least one acceleration sensor mounted to the movable reaction mass or mover. Such an arrangement enables to estimate the force exerted on the soil and enables to estimate the quality of the force signal. Such an embodiment further enables the application of feedforward or feedback control of the motor.

In an embodiment, the seismic shaker according to the embodiment, comprises a position sensor to measure a relative position between the base plate and the reaction mass or mover. Such a position sensor can be an absolute position sensor. Such a sensor can e.g. be an encoder based position sensor. Such encoders may e.g. be magnetic or magneto-strictive encoders. Optical sensors may however be considered as well, as well as LVDTs (Linear Variable Differential Transformer).The measurement signal of such a position sensor can e.g. be applied to control the commutation of the electromagnetic motor. It may also be applied for feedback control, e.g. low-frequency feedback control.

In the embodiments of the seismic shaker according to the present invention as shown in Figures 1 to 4b, the seismic shaker is oriented so as to generate a substantially vertical force onto the soil. As will be appreciated by the skilled person, the seismic shaker may also be oriented in such manner as to generate substantially horizontal forces onto the soil.

As required, detailed embodiments of the present invention are disclosed herein; however, it is to be understood that the disclosed embodiments are merely exemplary of the invention, which can be embodied in various forms. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a basis for the claims and as a representative basis for teaching one skilled in the art to variously employ the present invention in virtually any appropriately detailed structure. Further, the terms and phrases used herein are not intended to be limiting, but rather, to provide an understandable description of the invention.

The terms "a" or "an", as used herein, are defined as one or more than one. The term plurality, as used herein, is defined as two or more than two. The term another, as used herein, is defined as at least a second or more. The terms including and/or having, as used herein, are defined as comprising (i.e., open language, not excluding other elements or steps). Any reference signs in the claims should not be construed as limiting the scope of the claims or the invention.

The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

The term coupled, as used herein, is defined as connected, although not necessarily directly, and not necessarily mechanically.

A single processor or other unit may fulfil the functions of several items recited in the claims.

CONCLUSIES

1. Seismisch schudapparaat bestaande uit:

- een basisplaat;
- een elektromagnetische motor omvattende uit een beweger en een stator, waarbij de stator op de basisplaat is gemonteerd, en
- een geleidingsmechanisme dat een aantal discrete elementen omvat die de stator met de beweger verbinden, waarbij het geleidingsmechanisme is geconfigureerd om een verplaatsing van de beweger ten opzichte van de stator in een eerste richting mogelijk te maken en een verplaatsing in een vlak in hoofdzaak loodrecht op de eerste richting te beperken.

2. Seismisch schudapparaat volgens conclusie 1, waarbij de discrete elementen staven of bladveren zijn.

3. Seismisch schudapparaat volgens conclusie 2, waarbij de bladveren gevouwen bladveren zijn.

4. Seismisch schudapparaat volgens conclusie 1, waarbij het aantal discrete elementen een of meer sferische lagers omvat.

5. Seismisch schudapparaat volgens conclusie 4, waarbij de sferische lagers sferische glijlagers zijn.

6. Seismisch schudapparaat volgens conclusie 1, waarbij de stator vast op de basisplaat is gemonteerd.

7. Seismisch schudapparaat volgens conclusie 2, waarbij de stator een onderflens en een bovenflens omvat, waarbij het geleidingsmechanisme een eerste veelvoud van staven omvat die de bovenflens met de beweger verbinden en een tweede veelvoud van staven die de onderflens met de beweger verbinden.

8. Seismisch schudapparaat volgens een van de voorgaande conclusies, waarbij de basisplaat een in hoofdzaak holle geribde structuur omvat.

9. Seismisch schudapparaat volgens een van de voorgaande conclusies, waarbij de elektromagnetische motor een elektromagnetische motor met permanente magneet omvat,

waarbij de stator een reeks spoelen omvat die in de eerste richting zijn gerangschikt en de beweger een reeks permanente magneten omvat die in de eerste richting zijn gerangschikt.

10. Seismisch schudapparaat volgens conclusie 9, waarbij de reeks spoelen is geconfigureerd om te worden gevoed door een driefasige voeding.

11. Seismisch schudapparaat volgens een van de voorgaande conclusies, waarbij de beweger als reactiemassa dient en via een trillingsisolator door het basisframe wordt ondersteund.

12. Seismisch schudapparaat volgens conclusie 11, waarbij de trillingsisolator een gassteun omvat.

13. Seismisch schudapparaat volgens conclusie 11 of 12, waarbij de trillingsisolator een aantal trillingsisolatoren omvat die op de basisplaat zijn aangebracht.

14. Seismisch schudapparaat volgens een van de voorgaande conclusies, verder omvattende een stroombron voor het voeden van de elektromagnetische motor en een besturingseenheid voor het regelen van de stroombron.

15. Seismisch schudapparaat volgens conclusie 14, waarbij de besturingseenheid is geconfigureerd om de stroombron te sturen om een frequentiezwaai uit te voeren.

16. Seismisch schudapparaat volgens conclusie 15, waarbij het uitvoeren van een frequentiezwaai het genereren van een kracht door de elektromagnetische motor omvat, waarbij de kracht een variabele frequentie heeft in overeenstemming met de frequentiezwaai.

17. Seismische schudapparaat volgens conclusie 15 of 16, waarbij de besturingseenheid is geconfigureerd om de stroombron te regelen om een laagfrequente kracht te genereren door de elektromagnetische motor, waarbij de laagfrequente kracht een laagfrequente verplaatsing veroorzaakt van de beweger ten opzichte van de stator, gedurende ten minste een deel van de frequentiezwaai.

18. Seismisch schudapparaat volgens een van de conclusies 14 tot 17, verder omvattende een eerste bewegingssensor die op de beweger is gemonteerd.

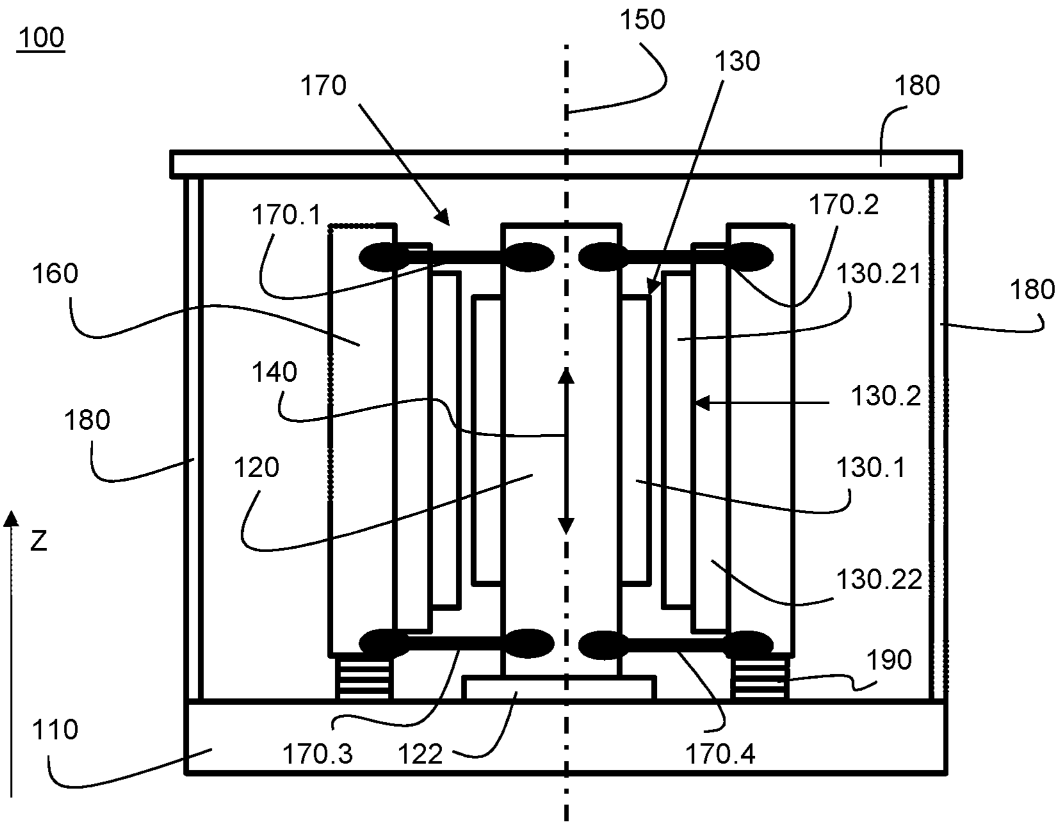
19. Seismische schudapparaat volgens conclusie 18, verder omvattende een tweede bewegingssensor die op de stator is gemonteerd.

20. Seismisch schudapparaat volgens een van de voorgaande conclusies, verder omvattende een positiemeetsysteem dat is geconfigureerd om een positiesignaal te genereren dat een positie van de beweger ten opzichte van de stator in verticale richting representeert.

21. Seismische schudapparaat volgens een van de conclusies 15 tot 16, waarbij de besturingseenheid is geconfigureerd om de stroombron te sturen op basis van een bewegingssensorsignaal ontvangen van de eerste bewegingssensor en / of de tweede bewegingssensor.

22. Seismisch schudapparaat volgens conclusie 20, waarbij de besturingseenheid is geconfigureerd om de stroombron te regelen op basis van het positiesignaal.

23. Seismisch schudapparaat volgens een van de voorgaande conclusies, waarbij de eerste richting een in hoofdzaak verticale richting is.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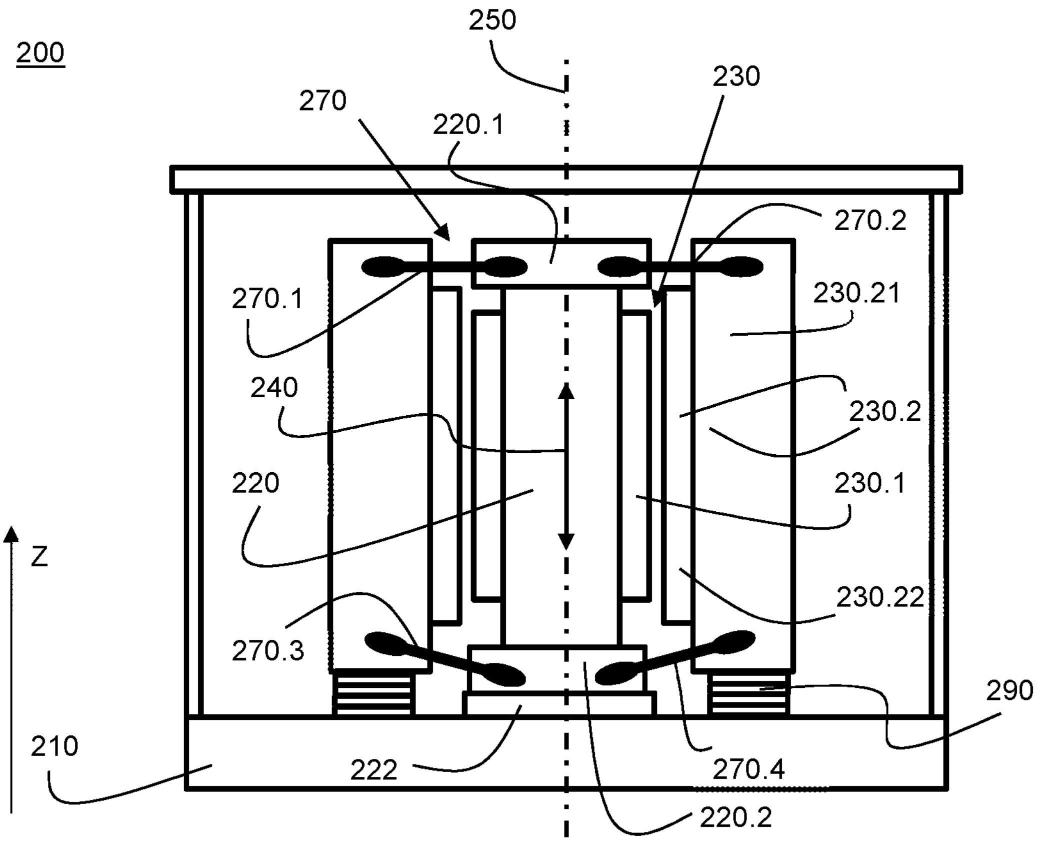
150
130
170
180
170.1
170.2
160
130.21
180
140
130.2
180
120
130.1
Z
130.22
190
110
170.3
122
170.4

Fig. 1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270
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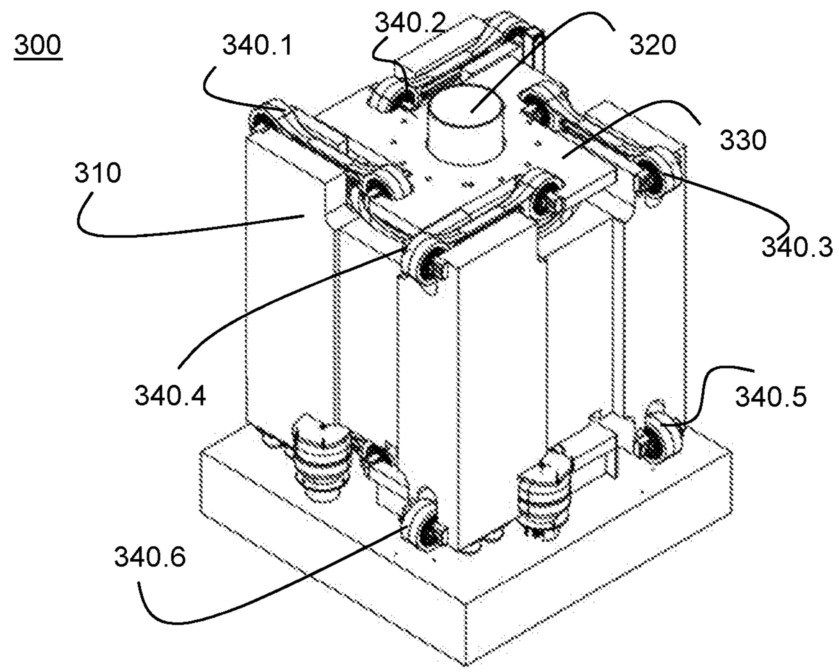
230
270.2
270.1
230.21
240
230.2
220
230.1
Z
230.22
270.3
290
210
222
270.4
220.2

Fig. 2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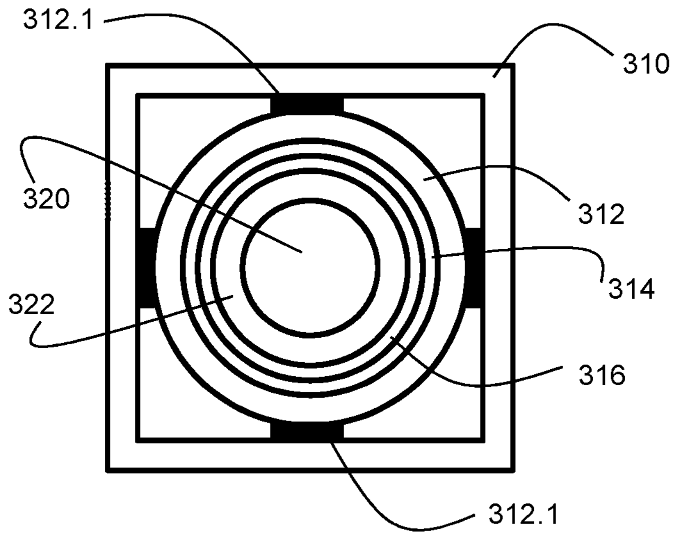
340.2
320
330
310
340.3
340.4
340.5
340.6

Fig. 3a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310
320
312
314
322
316
312.1

Fig. 3b

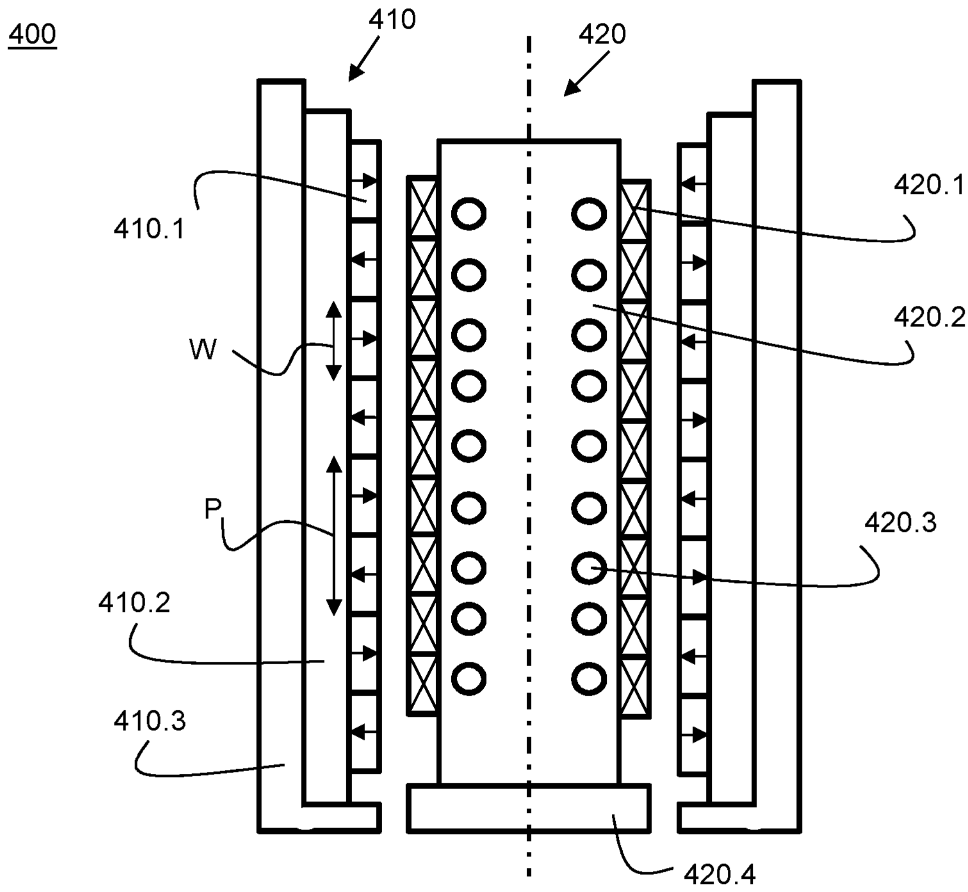


Fig. 4a

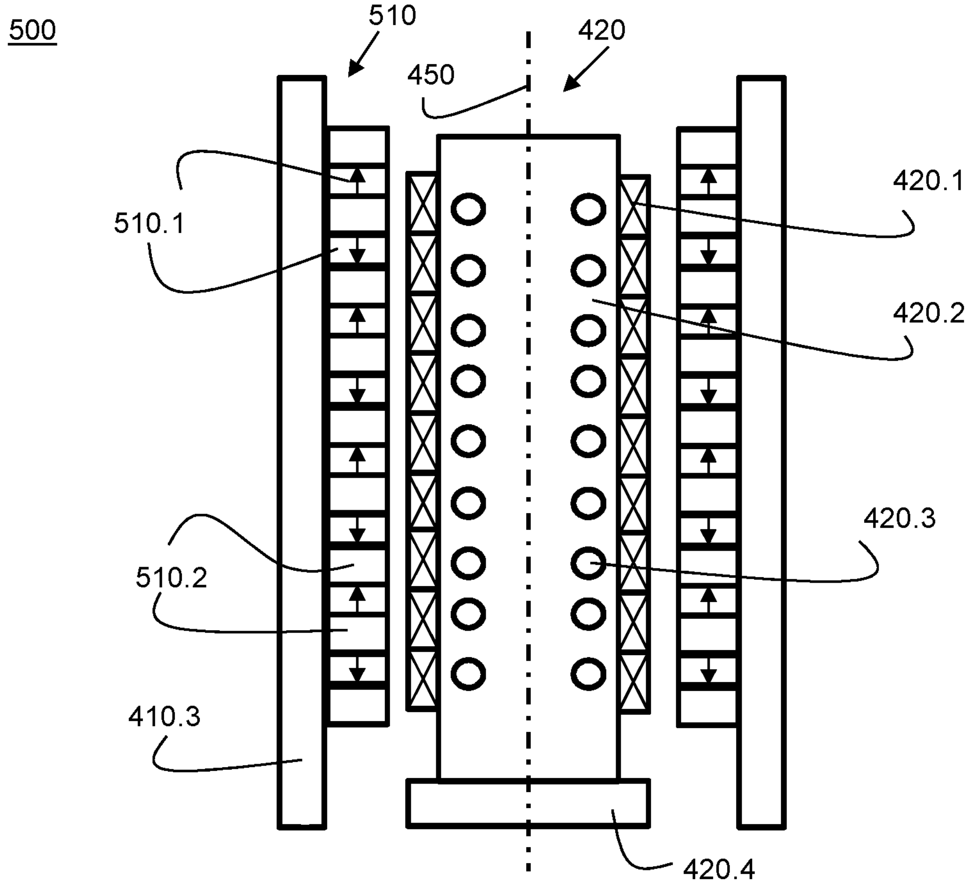


Fig. 4b

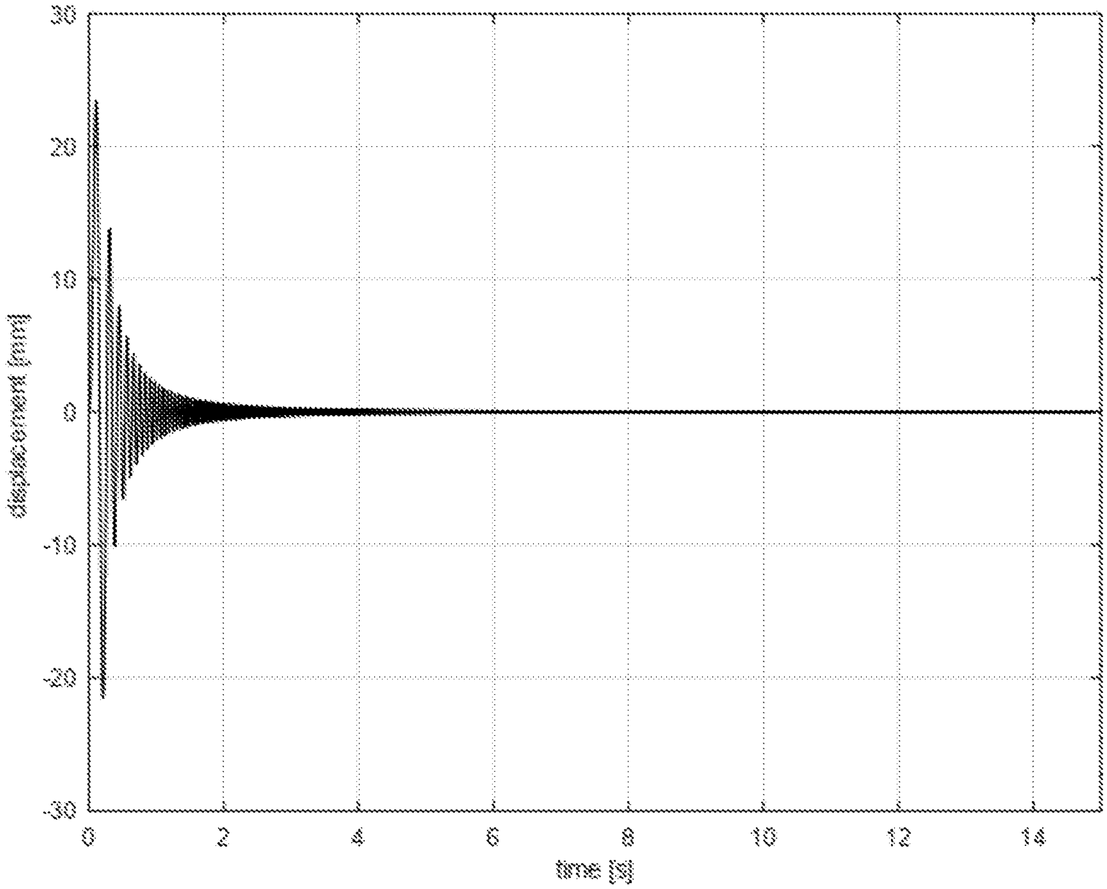


Fig. 5a

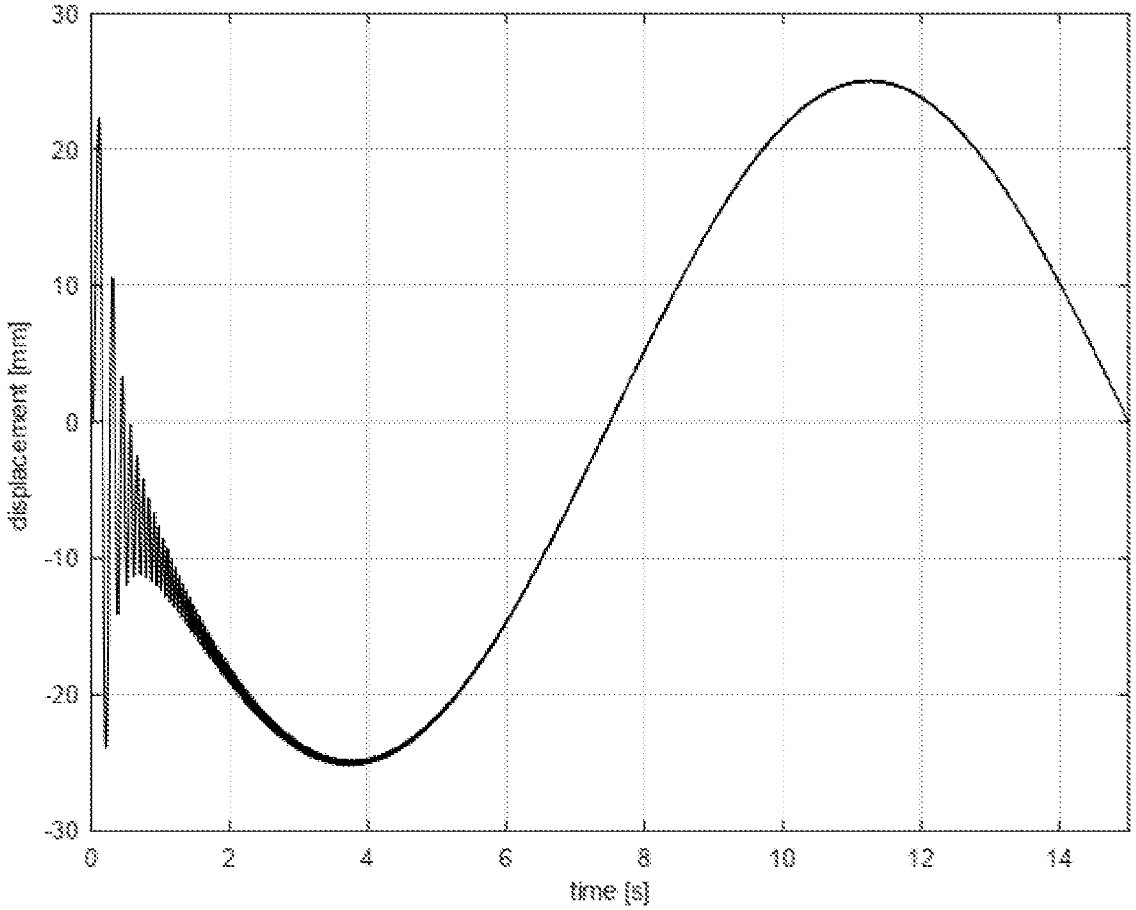

30
20
10
0
-10
-20
-30
displacement [mm]
0
2
4
6
8
10
12
14
time [s]

Fig. 5b

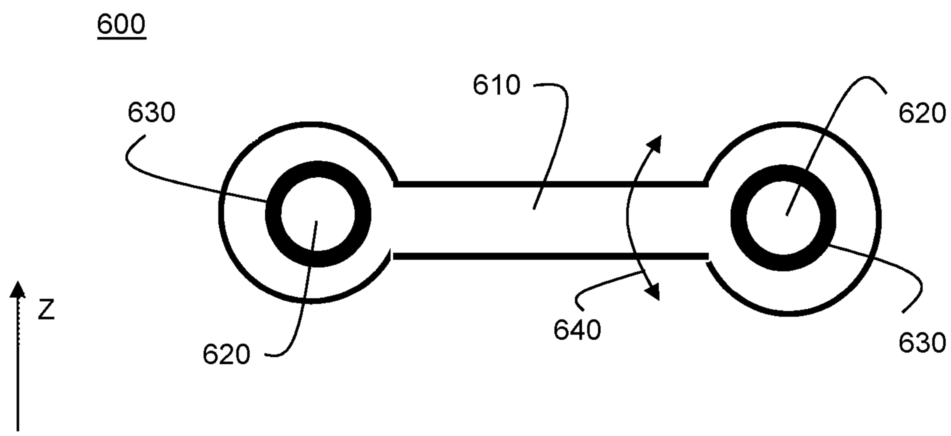

600
610
630
620
620
630
640
Z

Fig. 6

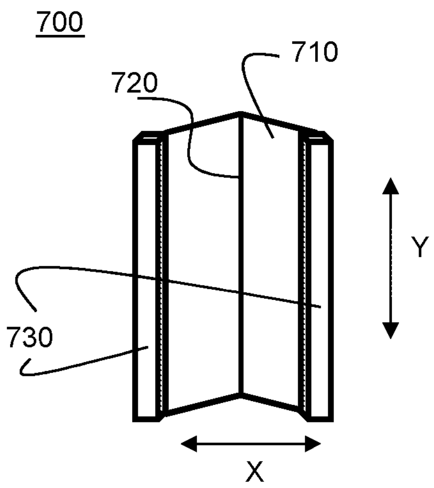


Fig. 7

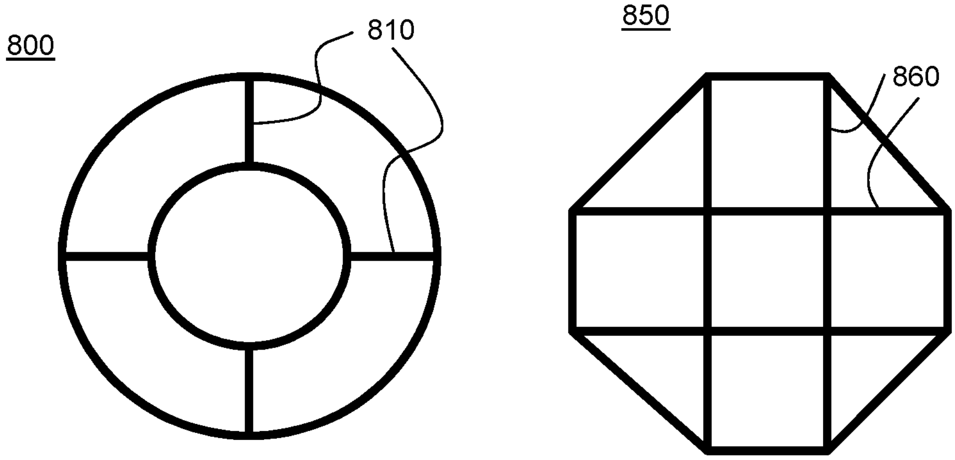


Fig. 8

Rijksdienst voor Ondernemend Nederland

RAPPORT BETREFFENDE HET ONDERZOEK NAAR DE STAND VAN DE TECHNIEK

Octrooiaanvrage 2026908

Classificatie van het onderwerp[1]: G01V1/155	Onderzochte gebieden van de techniek[1]: G01V
Computerbestanden: EPODOC, WPI	Omvang van het onderzoek: Volledig
Datum van de onderzochte conclusies: 28 december 2020	Niet onderzochte conclusies: -

Van belang zijnde literatuur

Categorie[2]	Vermelding van literatuur met aanduiding, voor zover nodig, van speciaal van belang zijnde tekstgedeelten of figuren	Van belang voor conclusie(s)
X Y	NL 2006429 C (MAGNETIC INNOVATIONS B V) 19 september 2012 * gehele document * – – –	1–3, 6–23 4, 5
X Y	WO 2014/196858 A (MI PARTNERS BV) 11 december 2014 * gehele document * – – –	1, 6–23 2–5
Y	US 2013/0286790 A (CONOCOPHILLIPS CO) 31 oktober 2013 * samenvatting; figuren 1 en 2 * – – – – –	2–5

Datum waarop het onderzoek werd voltooid: 13 augustus 2021	De bevoegde ambtenaar: dr.mr.ir. M.W.D. van der Burg **Octrooicentrum Nederland** **onderdeel van Rijksdienst voor Ondernemend Nederland**

1, 2 Zie toelichting volgend blad.

Toelichting:

[1] Classificatie gebieden van de techniek:
gedefinieerd volgens International Patent Classification (IPC).

[2] Categorie van de vermelde literatuur:

X: op zichzelf van bijzonder belang zijnde stand van de techniek

Y: in samenhang met andere geciteerde literatuur van bijzonder belang zijnde stand van de techniek

A: niet tot de categorie X of Y behorende van belang zijnde stand van de techniek

O: verwijzend naar niet op schrift gestelde stand van de techniek

P: literatuur gepubliceerd tussen voorrangs- en indieningsdatum

T: niet tijdig gepubliceerde literatuur over theorie of principe ten grondslag liggend aan de uitvinding

E: octrooiliteratuur gepubliceerd op of na de indieningsdatum van de onderhavige aanvrage en waarvan de indieningsdatum of de voorrangsdatum ligt voor de indieningsdatum van de onderhavige aanvrage

D: in de aanvrage genoemd

L: om andere redenen vermelde literatuur

&: lid van dezelfde octrooifamilie; corresponderende literatuur

Rijksdienst voor Ondernemend Nederland

AANHANGSEL

Behorende bij het Rapport betreffende het Onderzoek naar de Stand van de Techniek

Octrooiaanvrage 2026908

Het aanhangsel bevat een opgave van elders gepubliceerde octrooiaanvragen of octrooien (zogenaamde leden van dezelfde octrooifamilie), die overeenkomen met octrooigeschriften genoemd in het rapport. De opgave is samengesteld aan de hand van gegevens uit het computerbestand van het Europees Octrooibureau per 13 augustus 2021. De juistheid en volledigheid van deze opgave wordt noch door het Europees Octrooibureau, noch door Octrooicentrum Nederland gegarandeerd; de gegevens worden verstrekt voor informatiedoeleinden.

In het rapport genoemd octrooigeschrift		Datum van publicatie	Overeenkomende octrooigeschriften		Datum van publicatie
NL 2006429	C2	19-09-2012	DK 2549300	T3	21-09-2020
			EP 2549300	A1	23-01-2013
			PL 2549300	T3	08-02-2021
WO 2014196858	A1	11-12-2014	EP 3004936	A1	13-04-2016
			US 10222495	B2	05-03-2019
			US 2016124097	A1	05-05-2016
US 2013286790	A1	31-10-2013	AU 2013256431	A1	13-11-2014
			CA 2871649	A1	07-11-2013
			EP 2845032	A1	11-03-2015
			US 2013286780	A1	31-10-2013
			US 9217796	B2	22-12-2015
			US 9217799	B2	22-12-2015
			WO 2013166058	A1	07-11-2013

Rijksdienst voor Ondernemend
Nederland

SCHRIFTELIJKE OPINIE

Octrooiaanvrage 2026908

Indieningsdatum: 17 november 2020	Voorrangsdatum:
Classificatie van het onderwerp [1]: G01V1/155	Aanvrager: Seismic Mechatronics B.V.

Deze schriftelijke opinie bevat een toelichting op de volgende onderdelen:

☒	Onderdeel I	Basis van de schriftelijke opinie
☐	Onderdeel II	Voorrang
☐	Onderdeel III	Vaststelling nieuwheid, inventiviteit en industriële toepasbaarheid niet mogelijk
☐	Onderdeel IV	De aanvrage heeft betrekking op meer dan één uitvinding
☒	Onderdeel V	Gemotiveerde verklaring ten aanzien van nieuwheid, inventiviteit en industriële toepasbaarheid
☐	Onderdeel VI	Andere geciteerde documenten
☐	Onderdeel VII	Overige gebreken
☐	Onderdeel VIII	Overige opmerkingen

De bevoegde ambtenaar:
dr.mr.ir. M.W.D. van der Burg

Octrooicentrum Nederland
onderdeel van Rijksdienst voor Ondernemend Nederland

1 Gedefinieerd volgens International Patent Classification (IPC).

Schriftelijke Opinie

Octrooiaanvrage 2026908

Onderdeel I	**Basis van de schriftelijke opinie**

Deze schriftelijke opinie is opgesteld op basis van de op 28 december 2020 ingediende conclusies.

Onderdeel V	**Gemotiveerde verklaring ten aanzien van nieuwheid, inventiviteit en industriële toepasbaarheid**

1. Verklaring

Nieuwheid	Ja: conclusie(s)	4, 5, 7, 8, 10, 12, 13, 16
	Nee: conclusie(s)	1–3, 6, 9, 11, 14, 15, 17–23
Inventiviteit	Ja: conclusie(s)	-
	Nee: conclusie(s)	4, 5, 7, 8, 10, 12, 13, 16
Industriële toepasbaarheid	Ja: conclusie(s)	1–23
	Nee: conclusie(s)	-

2. Literatuur en toelichting

In het rapport betreffende het onderzoek naar de stand van de techniek worden de volgende publicaties genoemd:

D1: NL 2006429 C (MAGNETIC INNOVATIONS B V) 19 september 2012
D2: WO 2014/196858 A (MI PARTNERS BV) 11 december 2014
D3: US 2013/0286790 A (CONOCOPHILLIPS CO) 31 oktober 2013

<u>Nieuwheid</u>
Uit D1 (zie in het bijzonder figuur 2) is een seismisch schudapparaat overeenkomstig conclusie 1 bekend. De discrete elementen van het geleidingsmechanisme bestaan uit een aantal gevouwen bladveren (verwijzingscijfer 11 in figuur 2 van D1). Een gemiddelde vakman zal op basis van zijn vakkennis in figuur 2 direct en ondubbelzinnig meelezen dat de stator vast op de basisplaat is gemonteerd. Uit de draad die in figuur 2 loopt tussen de processor unit (17) en de lineaire elektromagnetische motor (7) zal de vakman direct en ondubbelzinnig opmaken dat de stator een reeks spoelen omvat en de beweger een reeks permanente magneten. De elektromagnetische motor van het schudapparaat uit D1 is geschikt om een laagfrequente kracht te genereren (zie blz. 1, regel 31: 'lage frequenties'). Zowel op de stator als op de beweger zijn bewegingssensoren gemonteerd (zie in figuur 2 en blz. 4, regels 23–24, de versnellingssensoren 13 en 15) waarbij de vakman direct en ondubbelzinnig meeleest dat deze sensoren met de besturingseenheid zijn verbonden (zie blz. 4, regel 23–24). De gevouwen bladveren zorgen ervoor dat de beweger in hoofdzaak verticale richting beweegt (zie blz. 4, regels 16–18, van D1). Gezien het bekende uit D1 zijn de conclusies 1–3, 6, 9, 11, 14, 15, 17–19, 21 en 23 niet nieuw.

Schriftelijke Opinie

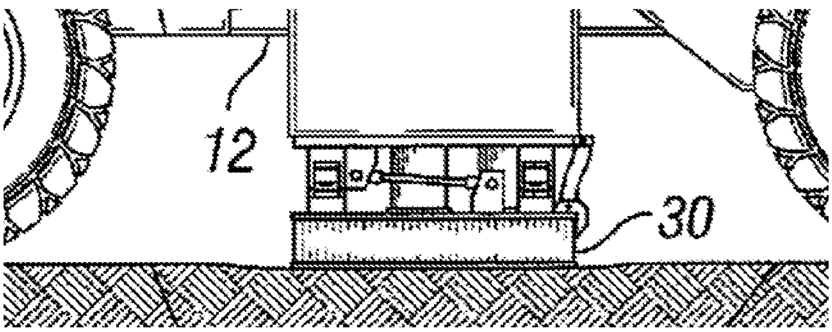
Octrooiaanvrage 2026908

Uit D2 (zie in het bijzonder figuur 2) is een seismisch schudapparaat overeenkomstig conclusie 1 bekend. Het geleidingsmechanisme is zichtbaar in figuur 2. De elektromagnetische motor van het schudapparaat uit D2 is geschikt om een laagfrequente kracht te genereren (zie blz. 2, regels 21–22: 'from 1 to 200 Hz'). Zowel op de stator als op de beweger zijn bewegingssensoren gemonteerd (zie figuur 2 en blz. 5, regel 6, de versnellingssensoren 11 en 13) die met de besturingseenheid zijn verbonden (zie figuur 2). Het schudapparaat omvat voorts een positiemeetsysteem dat is geconfigureerd om de positie van de beweger ten opzichte van de stator in verticale richting te meten (zie blz. 5, regel 8: 'displacement sensor 17, measuring the movement of the reaction mass 5'). Gezien het bekende uit D2 zijn de conclusies 1, 6, 11, 14, 15, 17–22 niet nieuw.

De maatregelen van de overige conclusies, de conclusies 4, 5, 7, 8, 10, 12, 13 en 16, zijn niet bekend uit D1 of D2 en daarmee nieuw.

<u>Inventiviteit</u>
De meest nabije stand van de techniek wordt gevormd door het seismische schudapparaat bekend uit D1. In tegenstelling tot D2 worden in D1 gevouwen bladveren (zie blz. 4, regels 17–18, en verwijzingscijfer 11 in figuur 2 van D1) als discrete elementen van het geleidingsmechanisme geopenbaard.

Conclusies 4 en 5
Het effect van de maatregel uit conclusie 4, dat de discrete elementen sferische lagers omvatten, is dat door toepassing ervan minder hysterese-verliezen in de gevouwen bladveren optreden, hetgeen bevorderlijk is voor een nauwkeurige controle van de opgewekte trilling. De vakman gesteld voor de opgave om dit effect te bereiken zal zich oriënteren op geleidingsmechanismen van andere seismische schudapparaten. Daarbij zal hij stuiten op document D3. Hieruit is een seismisch schudapparaat ('seismic vibrator source') met een elektromagnetische motor (zie figuur 2 van D3) bekend. In figuur 1 van D3, zie ook onderstaand fragment uit de figuur, staan een aantal discrete elementen van het geleidingsmechanisme afgebeeld:



De gemiddelde vakman zal op basis van zijn algemene vakkennis hierin direct meelezen dat de staaf aan beide uiteinden draaibaar is gelagerd.
Conclusie 4, een seismisch schudapparaat met de maatregel dat de discrete elementen van het geleidingsmechanisme een of meer sferische lagers omvat, is daarmee niet inventief ten opzichte van

D1 gecombineerd met D3. De maatregel van conclusie 5, dat de betreffende lagers sferische glijlagers zijn, is evident voor de vakman en kan het seismische schudapparaat geen inventiviteit verlenen. Conclusie 5 is daarmee niet inventief ten opzichte van D1 gecombineerd met D3 en de algemene kennis van de vakman.

Overige conclusies

De maatregelen van de resterende conclusies, zijnde de conclusies 7, 8, 10, 12, 13 en 16, zijn voor de vakman triviaal en kunnen het schudapparaat geen inventiviteit verlenen. Conclusies 7, 8, 10, 12, 13 en 16 zijn daarmee niet inventief ten opzichte van D1 en de algemene vakkennis van de vakman.