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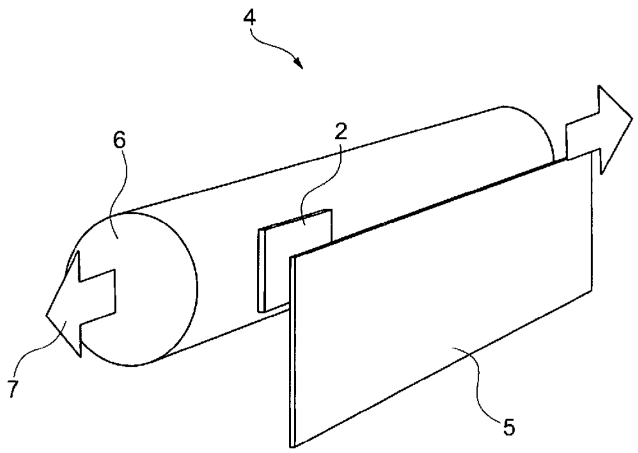

Fig. 2

(57) Abstract: A position sensor device comprising a magnetic element, a first magnetic field detector for detecting a magnetic field influenced by the magnetic element at a first position, a second magnetic field detector for detecting a magnetic field influenced by the magnetic element at a second position and a position determining unit, the magnetic element is fixable to a movable object, movable along a linear first path, the position determining unit is adapted to determine a position of the magnetic element along the linear first path based on detection signals detected by the first magnetic field detector and the second magnetic field detector, the position determining unit is adapted to determine a position of the magnetic element along a substantially linear second path, said second path being perpendicular to the first path.

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Device for and method of determining a position of a movable object

Reference to related application

This application claims the benefit of the filing date of United States Provisional Patent Application No. 60/917,462 filed May 11, 2007 and of European Patent Application No. 07 009 554.2, filed May 11, 2007, the disclosures of which are hereby incorporated herein by reference.

Field of the invention

The present invention relates to sensors in general. More particularly, it relates to a position sensor device, to a linear actuator position determining system and to a method of determining the position of a movable object.

Technological background of the invention

For many applications, it is desirable to measure a position with the utmost precision possible. For example, it is advantageous to know the position of a linearly moving, reciprocating object to accurately control its actual motion vs. the desired motion.

One-dimensional position determining systems are well known. However, since only one dimension is to be measured, the systems according to the state of the art also comprise only one single position determining device. This device is usually aligned with the axis of the reciprocation movement or in another embodiment is aligned perpendicular to the same axis. Thus, minor deviations from the intended path, which could be interpreted as perpendicular to this path, would mostly be not detectable since such movement would normally occur in the least sensitive part of a one-dimensional position determining system and so the overall accuracy of a system or device according to the state of the art would be diminished without being able to detect or even correct these inaccuracies.

Summary of the invention

It is an object of the present invention to provide a position sensor device, a linear actuator position determining system and a method of determining the position of a movable object with increased accuracy.

This object is achieved by providing a position sensor device, a linear actuator position determining system and a method of determining the position of a movable object according to the independent claims.

According to an exemplary embodiment of the present invention a position sensor device is provided, comprising a magnetic element, a first magnetic field detector for detecting a magnetic field influenced by the magnetic element at a first position, a second magnetic field detector for detecting a magnetic field influenced by the magnetic element at a second position and a position determining unit, wherein the magnetic element is fixable to a movable object, being substantially movable along a linear first path, wherein the position determining unit is adapted to determine a position of the magnetic element along the linear first path based on detection signals detected by the first magnetic field detector and the second magnetic field detector, wherein the position determining unit is adapted to determine a position of the magnetic element along a substantially linear second path, said second path being perpendicular to the first path, based on detection signals detected by the first magnetic field detector and the second magnetic field detector and wherein the position determining unit is adapted to correct the determination of the position along the first path by using information related to the second path.

According to an another exemplary embodiment of the present invention a linear actuator position determining system is provided, comprising a linear actuator with substantially linear, reciprocating movement, a position sensor device, a magnetic element attached to the linear actuator, a first magnetic field detector for detecting a magnetic field influenced by the magnetic element at a first position, a second magnetic field detector for detecting a magnetic field influenced by the magnetic element at a second position and a position determining unit, wherein the position determining unit is adapted to determine a position of the magnetic element along a substantially linear first path based on detection signals detected by the first magnetic field detector and the second magnetic field detector, wherein the position determining unit is adapted to determine a position of the magnetic element along a substantially linear second path, said second path being perpendicular to the first path, based on detection signals detected by the first magnetic field detector and the second magnetic field detector and wherein the position determining unit is adapted to correct the determination of the position along the first path by using the information related to the second path.

According to another exemplary embodiment of the present invention a method of determining the position of a movable object is provided, comprising the steps of receiving a first detection signal from a first magnetic field detector, receiving a second detection signal from a second magnetic field detector, determining the position of a magnetic element attached to the movable object along a substantially linear, reciprocating first path using the first detection signal and the second detection signal, determining the position of the magnetic element attached to the movable object along a substantially linear second path, said second path being perpendicular to the first path, using the first detection signal and the second detection signal and correcting the determination of the first path by using the information related to the second path.

In the context of the description, the following definitions will be used:

Magnetic element: A magnetic element is any magnetic active element, that is an element, which is changing/altering/influencing a least one magnetic (field) parameter in its vicinity. The magnetic element must not necessarily actively influence the magnetic field parameters, but can alter those parameters simply by its presence or simply with energy from the field. The magnetic field element may be something as simple as a permanent magnet or an actively magnetic encoded region. Alternatively, it may also be an active element, being powered by an energy source, subsequently influencing the magnetic field parameters. The influence may be predetermined, i.e. a calculated alteration, or may also be an undetermined, random, arbitrary alteration.

Magnetic field detector: A magnetic field detector is any device that is capable of detecting or perceiving an alteration, a change or another arbitrary influence on a magnetic field. The alteration may be either determined quantitatively or just qualitatively. The orientation of a magnetic field and a change thereof may also be detected.

According to an exemplary embodiment of the present invention, a position sensor device and a magnetic element is provided. The path of the magnetic element is to be determined.

The position sensor device may use a two-dimensional sensor arrangement for detecting movement of the magnetic element along two different paths, a first path and a second path using two magnetic field detectors. The detected first path and second path are perpendicular to each other. Thus, the movement of the magnetic element may be determined by the first magnetic field detector and the second magnetic field detector as to be within one plane.

However, it is an object of the present invention to not determine a movement of the magnetic element within a plane, but rather along a defined path. Said path may be identical or at least be parallel to the first path determined by the first magnetic field detector and second magnetic field detector, as described above. However, it is pointed out that this is not mandatory. The defined path of the magnetic element may also be different from said first path and may even be aligned arbitrarily in space.

For example, the magnetic element may be attached to a linearly moving, reciprocating object, like e.g. the piston of a hydraulic, pneumatic or otherwise operated linear actuator. Accordingly, the reciprocating movement of the piston and thus the magnetic element may be along a substantially linear path.

Since the movement now is not within a plane but rather along said linear path, one single sensor would be sufficient to determine the position of the magnetic element. However, minor deviations and irregularities in the path of the magnetic element and thus the exact position of the piston might not be detected.

The position sensor device of the present invention may improve and even correct the determined position of the magnetic element and thus the position of the piston by using the additional position information of the determined second path to correct and further render more precisely the position of the magnetic element.

Thus, by using the position sensor device according to the present invention, deviations, irregularities and errors in the position determination of the magnetic element may be corrected and the actual position may be rendered more precise as compared to a determination using only a single sensor.

Further exemplary embodiments can be derived from the dependent claims.

Below, further embodiments of the position sensor device according to the present invention will be described. However, it is denoted, that these preferred embodiments also apply to the linear actuator position determining system and the method of determining the position of a movable object.

According to a preferred embodiment, the position sensor device may further comprise a third magnetic field detector for detecting a magnetic field influenced by the magnetic element at a third position. To further increase the accuracy of the correction, a third magnetic field detector may be added. Thus, more individual information can be obtained.

According to a further preferred embodiment, the position determining unit of the position sensor device may be adapted to determine a position of the magnetic element along the linear first path based on detection signals detected by the first magnetic field detector, the second magnetic field detector and the third magnetic field detector, wherein the position determining unit is adapted to determine a position of the magnetic element along the substantially linear second path, said second path being perpendicular to the first path, based on detection signals detected by the first magnetic field detector, the second magnetic field detector and the third magnetic field detector and wherein the position determining unit is adapted to determine a position of the magnetic element along a substantially linear third path, said third path being perpendicular to the first path and second path, based on detection signals detected by the first magnetic field detector, the second magnetic field detector and the third magnetic field detector. Thus, the position sensor device is expanded to be able to actually acquire a three-dimensional movement, i.e. an arbitrary movement in space. Said three paths represent an arbitrary coordinate system.

According to a further preferred embodiment, the position determining unit is adapted to correct the determination of the position along the first path by using the information related to the second path and the third path. Since the path of the piston of the linear actuator and subsequently the path of the magnetic element is not altered, the additional information related to the determined third path may now be used to render the determined position of the magnetic element even more precisely.

According to another preferred embodiment of the present invention, the movable object may be movable along a substantially reciprocating linear path. The magnetic element may be attached to a linear actuator, e.g. to the piston of such an actuator. With an according reciprocating movement of the piston, the magnetic element is also moving in an according reciprocating manner. A reciprocating movement may be considered a, not necessarily uniformly, repeated movement along a substantial identical straight line.

According to a further preferred embodiment, the magnetic element may be adapted to respond to a magnetic field. Responding may be any kind of reaction process of the magnetic element when brought into the vicinity of a magnetic field or vice versa.

According to a preferred embodiment, the magnetic element may be adapted to alter a magnetic field. Here, magnetic field parameters of the magnetic field acting on the magnetic element may be altered and subsequently the magnetic field itself may be changed. Thus, the magnetic element may be retroacting on the magnetic field.

According to another preferred embodiment altering the magnetic field may be carried out by either changing, partly eliminating, entirely eliminating, absorbing, weakening, modifying, withdrawing energy from or dampening of the magnetic field. Also, this alteration may be an arbitrary combination of the aforementioned methods.

According to a further exemplary embodiment, the magnetic element may be a magnetic field sink. Generally speaking, a magnetic field sink may withdraw energy from the genetic field. Also, a magnetic field sink may comprise a magnet field negatively acting, thus counteracting, on another magnetic field, i.e. the magnetic field acting on the magnetic element.

According to another preferred embodiment, the magnetic element may be a magnetic field source. Thus, the magnetic element itself may be generating a magnetic field. This magnetic field may be the same acting on the magnetic element or may be an altogether different one.

According to a next preferred embodiment, the magnetic element may be an active element, a passive element, a RFID tag, a LC oscillating circuit, a LRC oscillation circuit or even an arbitrary combination of the aforementioned implementations.

According to a further exemplary embodiment, the first magnetic field detector, the second magnetic field detector and the third magnetic field detector are substantially identical magnetic field detectors. This may ensure easy compatibility between different measurements as well as substantially identical sensibility to alteration of the magnetic field. Furthermore, the ease of calibration, if required, and maintenance is improved.

According to another preferred embodiment, the first magnetic field detector, the second magnetic field detector and the third magnetic field detector each may comprise a coil. Coils may be considered to be best suited for having the highest sensitivity to magnetic fields. Thus, a magnetic field detector comprising a coil itself may have the highest sensitivity to magnetic fields. Said coils can either be built three-dimensional, like e.g. wound wire, or can also be for example printed on a printed circuit board (PCB).

According to a further exemplary embodiment, each of the respective coils may be adapted to generate a magnetic field. Thus, each coil may actively generate a magnetic field. The magnetic field originates at the respective coil and penetrates space in well-known manner.

According to another exemplary embodiment, the magnetic field generated by each of the coils may be generated by applying an electrical signal to the coil. Thus, by applying an electrical signal, for example a current, to the coil, the respective coil is actively generating the magnetic field.

According to a further exemplary embodiment, the electrical signal may be a constant electrical signal. A constant or continuous signal is a signal represented by a substantially constant value. This value may be at least one of a voltage, a current, a potential or an arbitrary combination of the aforementioned. Further or additional values may be considered, too.

According to another exemplary embodiment, the electrical signal may be an alternating or pulsed electrical signal. Here, the signal is not of a constant nature, but rather changing over time. This change may be a periodical change, like for example a sinusoidal function. The signal may be modulated or it may even be non-continuous, like for example a pulsed signal. A pulsed signal may be considered a constant signal in sections. Between sections the signal may rise or fall to a different value, may return to zero or even change its algebraic sign. The time intervals between changes may be substantially constant, may be a recurring pattern or may even be completely arbitrary. Again, this value may be at least one of a voltage, a current, a potential or an arbitrary combination of the aforementioned. Further or additional values may be considered, too.

According to a further exemplary embodiment, each of the coils may be adapted to respond to a magnetic field. Responding may be any kind of reaction triggered by a magnetic field. This may be a reaction due to the magnetic field being initiated, terminated or altered. The source of the magnetic field may execute this kind of change or the magnetic field may even be substantially constant but the source is affected or moved. Responding may also be considered detecting a measurable change in the magnetic field.

According to another exemplary embodiment, each of the coils may be adapted to perceive an alteration of the magnetic field, which magnetic field was generated by the same coil. The respective coil perceives a change within the field parameters of the magnetic field. Parameters like field strength, field intensity, field orientation, flux density, induction density, force, energy or the like may be affected. The change may result from an internal change of state, generation mode or procedure, like the change of field generating parameters or may also occur due to external influences like actively or passively interacting with and/or modifying of the magnetic field by introducing, moving or removing a device capable of changing or interacting a magnetic field. Since the coils are adapted to perceive an alteration of the magnetic field like mentioned above, the coils may even perceive an alteration of a self-generated magnetic field. Perceiving a change in the self-generated field may even enhance the sensitivity of robustness of the detection. Enhanced methods for error correction and improving signal-to-noise-ratio (SNR) may benefit from the magnetic field being generated and subsequently perceived by the same coil.

According to a further exemplary embodiment, the position determining unit may be adapted to determine the position of the magnetic element based on at least one out of the group comprising of a ratio of the generated magnetic field and received magnetic field, a difference of the generated magnetic field and received magnetic field and an amplitude of one of the generated and received the magnetic fields. In one instance, the position determining unit does not process the individual signals relating to generated and received magnetic field independently, buy may combine the signals or the pieces of information, so that spatial and signal amplitude information can be combined in a complementary manner. Particularly, not only the absolute values of the detection signals are used for calculation of the position of the magnetic element but rather a ratio between two signals may be used. Thus, the system is reducing background offset effects, improving the signal to noise ratio and so improving accuracy. Furthermore, it is for instance possible to arrange the magnetic element in an equilibrium state in the center of gravity of a triangle, wherein the magnetic field detectors are arranged on the corners of the triangle. By comparing the difference or the ratio between the signals relating to generated and received magnetic field of the magnetic field detector, the position of the magnetic element in the plane of the triangles can be determined. When the magnetic element moves outside the plane of the triangles, the signal amplitude of each of the magnet field detectors decreases, because the magnetic element is interacting in a reduced way due to the increased distance between magnetic element and the magnet field detectors. The difference, ratio or amplitude of each of the signals represents an individual distance of the magnetic element and the magnetic field detectors. Thus, a spatial detection, that is, determination of a position in three-dimensional space may be achieved by triangulation. This concept may be applied to other configurations of magnetic field detectors as well, arranged in a planar or non-planar manner. Particularly, when the magnetic field detectors are arranged in an three-dimensional manner, it is then possible to determine the position of the magnetic element by only comparing different magnetic field signals without using absolute values.

According to another exemplary embodiment, the position sensor device may further comprise a signal linearization unit adapted to generate a linear signal being characteristic for the position of the movable object based on the determined position of the magnetic element. Here, the signal linearization unit performs all the necessary measurements, comparisons and/or calculations related to determining the exact position of the magnetic element. The signal linearization unit may even include limitations of a given path of the magnetic element, like for example boundaries or known facts like an only substantially linear (i.e. one-dimensional) or in another embodiment two-dimensional movement. The signal delivered from or calculated by the signal linearization unit may represent the exact position of the magnetic element on a linear scale. Nonlinearities may also have been taken into account during processing or calculation of the value. The linear signal may or may not need to be adjusted to the proper scale of movement.

According to a further exemplary embodiment, the position sensor device may further comprise a driver unit adapted to provide the first, second and third magnetic field detectors with a driver signal for generating a magnetic field in accordance with the driver signal and being adapted to process, particularly to filter, the respective received magnetic fields in accordance with the driver signal. By using such a driver unit, the functionality of the magnetic element and the magnetic field detectors can be synchronized. For instance, knowing which activation signal scheme is applied to the magnetic field detectors for generating the magnetic field. This activation scheme can be used during processing the detection signals of the magnetic field detectors to clearly and reliably evaluate the signals and thus the position of the magnetic element.

According to another exemplary embodiment, the driver unit may be at least one out of the group comprising a printed circuit board, a microprocessor and a computer program element. The driver unit may be a discreetly built circuitry (PCB) or a microprocessor (CPU), in which the steps of operating the driver unit may be programmed software components. The system according to the invention can be realized or controlled by a computer program, that is by software, or by using one or more special electronic optimization circuits, that is in hardware, or in hybrid form, that is software components and hardware components.

According to a further exemplary embodiment, the position sensor device may be adapted to be implemented in at least one of the group consisting of a Gearbox Input Shaft, Gearbox Output Shaft, Rear Axle Drive Shaft, Wheel Hub, Combustion Engine Control, Transmission Control, Automatic Transmission, Power Assist Steering, Clutch Control, Bearing Forces, Cam Shaft Position, Crank Shaft Position, Injection Valve Control, F1 Gearbox System, F1 Power Steering, F1 Rear Axle Drive Shaft, Racing Bike Steering, Propulsion Control, Large Size Combustion

Engine, Tractor - Trailer Drive System, Rear Suspension Load, Clutch Control, Hydraulic Actuator, Helicopter, Construction Equipment, Fire Engine, Falk-Lifter, Concrete Mixer and Pumps, Crane Cabin Position, Dentist Drill, Operating Table, Stethoscope Control, Hammer Drill, Assembly Line Fastener Tool, Wheel Fastener, Sander, Washing Machine, Vacuum Cleaner, Sports Equipment, Garden Tools: Grass Trimmer, Bicycle Gear Change Control, Oil & Water Drilling, Tunnelling & Mining, Paint Pump, Paint Mixer, Electric Powered Actuator, Hydraulic Powered Actuator, Pneumatic Powered Actuator, Flow Meter, Gas Turbine Engine, Wind Power Plant, Paper Printing Equipment, Explosion Save Potentiometer, Maintenance Tools, Robotics Position Control, Robotics Force Control, Engine Test Bed, Calibration Tool, Vibration & Resonance Test, Drum Speed Detection, Drive Belt Friction Test. A multitude of applications can be considered valid and beneficial.

According to another exemplary embodiment, the linear actuator position determining system may comprise a third magnetic field detector for detecting a magnetic field influenced by the magnetic element at a third position, wherein the position determining unit may adapted to determine a position of the magnetic element along the substantially linear first path based on detection signals detected by the first magnetic field detector, the second magnetic field detector and the third magnetic field detector, wherein the position determining unit may be adapted to determine a position of the magnetic element along the substantially linear second path, said second path being perpendicular to the first path, based on detection signals detected by the first magnetic field detector, the second magnetic field detector and the third magnetic field detector, wherein the position determining unit may be adapted to determine a position of the magnetic element along a substantially linear third path, said third path being perpendicular to the first path and the second path, based on the detection signals detected by the first magnetic field detector, the second magnetic field detector and the third magnetic field detector and wherein the position determining unit may be adapted to correct the determination of the first path by using the information related to the second path and the third path. With other words, the position determining unit is receiving information from each of the first, second and third magnetic field detector individually. This information is used to determine a first, a second and a third path, representing a complete coordinate system, i.e. being perpendicular to each other. With further information about the first path, being substantially identical, at least as far as its alignment in space is concerned, meaning being parallel, to the movement path of the linear actuator and thus of the magnetic element, the system may use the additional information of the second and third path to correct, that is enhance, the accuracy of the determination of the first path. However, the first path may also not be substantially identical, that is parallel, to the movement of the linear actuator but may represent an arbitrary path in three-dimensional space. Furthermore, the alignment and orientation of the first, second and third path may depend on the alignment and position of the magnetic field detectors. Also, said described principle of operation may also be used with more than three magnetic field detectors. Whether more than three magnetic field detectors are used to calculate three paths or more that three paths, all of which cannot be perpendicular to each other, may depend on the position and alignment as well. In a preferred embodiment four magnetic field detectors may be used for calculation three perpendicular paths.

According to a further exemplary embodiment, the linear actuator position determining system may comprise at least three magnetic field detectors, which at least three magnetic field detectors may be arranged in essentially the same plane. Thus, the direction and/or position of the magnetic element relative to each of the magnetic field detectors may be determined by the intensity or strength of the signal/information or by the alteration of the magnetic field itself. In other words, each magnetic field detector may detect the distance of the magnetic element in a virtual semi-sphere or hemisphere, i.e. the distance of the magnetic element to the respective magnetic field detector, either in absolute or relative values, representing the radius of the hemisphere. The orientation of the magnetic field detected or the alteration/information may be indicative of in which of the two hemispheres the magnetic element is located. Thus, the angular orientation with respect to the plane of the magnetic field detectors, the distance and/or the exact position may be determined in this way.

According to another exemplary embodiment, said at least three magnetic field detectors may be arranged in a redundant or failsafe arrangement. Thus, the malfunction of at least one or more magnetic field detectors may be detected and compensated for. This may include the operation of more than three magnetic field detectors, so that the position can be verified and thus the functionality and operation can be assured and upheld. Also further means within each of the magnetic field detectors may be implemented like for example a calibration and error correction circuit or the like. By this, the functionality and accuracy of the linear actuator position determining system may be guaranteed even in the event of a malfunction of a magnetic field detector.

According to a further exemplary embodiment, the arrangement of the at least three magnetic field detectors may comprise arranging said at least three magnetic field detectors in at least one way out of the group consisting of interweaving, overlapping, overlaying and side-by-side. Thus, the at least three magnetic field detectors may also not only be arranged side-by-side or with an arbitrary, however technical reasonable, distance, they may also be arranged at least partially on top and behind each other or an arbitrary combination thereof. Even a number of significant more than three magnetic field detectors may be arranged in a side-by-side and/or at least partially overlapping manner. Three arbitrary magnetic field detectors may thereby consist, (logically) build or form the aforementioned set of at least three magnetic field detectors. So, the interval of magnetic field detectors may me significantly smaller that the detectors themselves. Long arrangements with a multitude of magnetic field detectors may be arranged is such a way as well. Special measures to assure the functionality of each magnetic field detector may have to be implemented, like for example, generating the magnetic field by signals of different frequencies or generating magnetic fields themselves with a frequency dependent function.

According to a further exemplary embodiment, the method of determining the position of a movable object may comprise receiving a third detection signal from a third magnetic field detector, determining the position of the magnetic element attached to the movable object along the substantially linear, reciprocating first path using the first detection signal, the second detection signal and the third detection signal, determining the position of the magnetic element attached to the movable object along the substantially linear second path, said second path being perpendicular to the first path, using the first detection signal, the second detection signal and the third detection signal, determining the position of the magnetic element attached to the movable object along a substantially linear third path, said third path being perpendicular to the first path and the second path, using the first detection signal, the second detection signal and the third detection signal and correcting the determination of the first path by using the information related to the second path and the third path.

The above mentioned and further aspects, objects, objectives and advantages of the present invention will become apparent from the following description and the appended claims, taken in conjunction with the accompanying drawings. Identical or similar parts or elements are referred to with identical reference numbers.

The accompanying drawings, which are included to provide a further understanding of the invention and constitute a part of the specifications, illustrate exemplary embodiments of the invention. These exemplary embodiments are not to be taken limiting the scope of the invention.

Short description of the drawings

Fig. 1a to 1f show	exemplary position sensor devices, i.e. the relative alignment of magnetic field detectors to the magnetic element for illustrating the basic operation principle of the present invention.
Fig. 2 shows	a three-dimensional illustration of an exemplary embodiment of the linear actuator position determining system.
Fig. 3 shows	a top view of the linear actuator position determining system of Fig. 2.
Fig. 4 shows	a side view of the linear actuator position determining system of Fig. 2.
Fig. 5 shows	an illustration of the spatial operation principle of the present invention.
Fig. 6 shows	a two-dimensional illustration of an exemplary embodiment of the linear actuator position determining system.

Fig. 7 shows a detailed view of an exemplary embodiment of the sensor arrangement of the linear actuator position determining system.

Fig. 8 shows a detailed view of another exemplary embodiment of the sensor arrangement of the linear actuator position determining system.

Fig. 9 shows a three-dimensional illustration of an exemplary application of the linear actuator position determining system.

Fig. 10 shows a two-dimensional cross sectional illustration of an exemplary embodiment of a second application of the present invention.

Fig. 11 shows a two-dimensional cross sectional illustration of a further exemplary embodiment of the second application of the present invention.

Detailed description of exemplary embodiments

Below, exemplary embodiments of the position sensor device according to the present invention will be described. However, it is denoted, that these preferred embodiments also apply to the linear actuator position determining system and the method of determining the position of a movable object.

In Fig. 1a to 1f different exemplary embodiments of the position sensor device 3 are depicted. In other words, the relative alignment of the magnetic field detectors 1 and the magnetic element 2 is displayed. In those instances where more than one magnetic element 2 is displayed, the respective positions are to be taken as alternatives. The relative distances between the magnetic element 2 and the magnetic field detectors 1 and between the magnetic field detectors 1 themselves and the their respective sizes as displayed are not to be taken limiting of fixed. Quantitative dimensions are not displayed and Fig. 1a to 1f do not show quantitative proportions. The movement of the magnetic element 2 can be in any three-dimensional direction. Also, displayed forms and shapes are not to be taken limiting but rather depend on the actual technical implementation. The magnetic field detectors 1 may measure the position of the magnetic element 2, regardless of its position in three-dimensional space. No dimensional limitation may be taken from the drawings. In Fig. 1a, the three magnetic field detectors 2 form a right triangle, however different angels may be realized, as well. In Fig. 1b, the position sensor device 3 only comprises two magnetic field detectors 1. The magnetic element 2 may be in line with the centers of the magnetic field detectors 2, may be perpendicular to this axis or even feature a completely different angular orientation. In Fig. 1c, the position of the magnetic element 2 is in line with the centers of all three displayed magnetic field detectors 1. In Fig. 1d, the magnetic element is perpendicular to the axis of the magnetic field detectors 1 as displayed in Fig. 1c. In Fig. 1e, the three magnetic field detectors 1 form an equilateral triangle. Also, this arrangement may also be that of an isosceles triangle. Again, the depicted orientation of the magnetic element 2 in relation to the magnetic field detectors 1 is not to be taken limiting. In Fig. 1f, a position sensor device 3 with four magnetic field detectors is displayed. Here, the four magnetic field detectors 1 are arranged at the corners essentially a square. However, it is also possible to use an arrangement pattern that resembles a rectangle, a parallelogram, a rhomboid or also a trapezium. In all Fig. 1a to 1f, only one possible position of the magnetic element 2 is shown. It is pointed out, that this position is not a fixed one, rather the magnetic element 2 is moving around said depicted position in three-dimensional space.

In Fig. 2, a three-dimensional exemplary embodiment of the linear actuator position determining system 4 is displayed. The magnetic element 2 is attached to a linearly moving and reciprocating piston 6 of a linear actuator. The piston 6 is moving in a one-dimensional main direction 7. As can be seen, minor instabilities of the position of piston 6 may occur, due to the lack of additional guides. The position of the magnetic element 2 and thus of the position of the piston 6 of the linear actuator is determined by the so-called TR-Pad 5. The TR-Pad 5 is a plurality of magnetic field detectors 1, preferably in a two-dimensional arrangement. The TR-Pad may consist of a X by Y-matrix arrangement of magnetic field detectors 1 and may also additionally comprise electronics, PCBs, CPU and the like. It is preferably enclosed in a rugged housing and thus insensitive to e.g. splash water, oil, dust and the like. This arrangement may render the position sensor device 3 and thus the linear actuator position determining system 4 very resistant to potential magnetic or electromagnetic interferences. The piston 6 is substantially moving in only one predetermined linear direction, the so-called main-axis-direction. The linear actuator position determining system 4 thus is using its three-dimensional movement detection capability to detect three-dimensional movement of the magnetic element 2 and thus of the piston 6, using the two "unused" dimensions to measure unwanted movements of the magnetic elements, induced for example by mechanical tolerances of the piston arrangement by natural or unnatural wear out or defects. In any case, the mechanical tolerances and thus the deviations from the intended one-dimensional path are considered to be relatively small in comparison to the movement along the main axis. For security and redundancy reasons, the TR-Pad 5 may incorporate two or even more fully independent position sensor devices 3, each comprising at least three magnetic field detectors 1. A regular one-dimensional sensor may not be able to detect the described deviations in position detection, since these deviations occur in a way perpendicular to the main axis, that is the main direction of movement, and thus in the least sensitive part of a one-dimensional sensor. The three-dimensional sensor arrangement of the present invention however is able to detect movement perpendicular to the main axis with the same sensitivity and resolution as movement in the main axis.

In Fig. 3 a top view of the linear actuator position determining system 4 of Fig. 2 is displayed. The TR-Pad 5 is capable of detecting the movement of the magnetic element 2 along the full range of movement (and thus the measuring range) 8 of the linear actuator. The range of movement may be about 80mm. Different ranges are possible and are only limited by the movement of the piston 6, the linear actuator and the dimension of the TR-Pad 5. To eliminate false position readings, it is advisable to define the dimensions of the TR-Pad 5 in the main axis 7 large enough, so that the magnetic element 2 will stay within the boundaries of the TR-Pad 5. In other words, the entire movement area of the magnetic element 2 has to be above the area of one or more magnetic field detectors 1.

In Fig. 4 a side view of the linear actuator position determining system 4 of Fig. 2 is displayed. The distance 9 between the TR-Pad 5 and the magnetic element 2 may be 50 mm, however depending on the magnetic element 2 and the sensitivity of the individual magnetic field detectors 1 forming the TR-Pad 5 and thus the TR-Pad 5 itself, even distances up to 160mm or even more may be implemented. For a movement outside the movement along the main axis, i.e. a first erroneous movement direction 10, the TR-Pad 5 may detect the movement by its three-dimensional detection capability and may thus compensate for the inaccurate position of the magnetic element 2 and thus the piston 6. Based on the position determination of the TR-pad 5, a correction of the position of the piston 6 is possible.

In Fig. 5 an illustration of the spatial operation principle of the present invention is displayed. The main axis, that is the one-dimensional direction of movement 7, in this example is the X-axis, with the Y-axis being the first erroneous movement direction 10 and Z-axis being the second erroneous movement direction 11 of the magnetic element 2. Thus, the linear actuator position determining system 4 can detect deviations from the intended path along the main axis by comparing the estimated or set position versus the measured position. Thus, with the result of the measurement, the position may be corrected. Due to the fact, that the position of the magnetic element 2 is fixed to the piston 6 the according misalignment may be interpreted as being on the surface of a sphere with the position in direction of the x-axis being the radius or diameter. The deviations from the intended path result in a virtual piece of a sphere surface. The radius of the sphere may not necessarily be the length of the piston 6 but rather can be of any reasonable length, starting from the point of interference along the main axis to the magnetic element 2.

In Fig. 6 a two-dimensional illustration of an exemplary embodiment of the linear actuator position determining system 4 is displayed. Here, the TR-Pad 5 has two independent sensor channels 12,13. For safety reasons in may be necessary to have at least two absolute linear position determining systems 4 running side-by-side, meaning at the same time, independently from each other. In case one is malfunctioning, the second linear position determining system 4 may still provide valid measurements. A concurrent functionality may be possible, a master-slave-configuration or in case that more than two channels are implemented, a for example two-out-of-three configuration may be realized. Fig. 6 shows one possible design solution that places two sensor channels 12,13 physically next to each other, both concurrently monitoring the movement in the direction of the main axis of the piston 6.

In Fig. 7 a detailed view of an exemplary embodiment of the sensor arrangement of the linear actuator position determining system 4 is shown. To ensure a high output signal resolution and to allow that the magnetic element 2 may be placed within a relative short distance of the TR-Pad 5, the TR-Pad 5 may consist of a larger number of individual magnetic field detectors 1. For each sensor channel 12,13 a specific number of magnetic field detectors 1 may be placed in series to each other. The geometric alignment may be in a straight line, however may also be interweaving. In case the length of the TR-Pad 5 has to be increased, the number of required magnetic field detectors 1 has to increase proportionally. A small distance between and a large number of the magnetic field detectors 1 allows for a high-resolution position determination of the magnetic element 2. Each sensor channel 12,13 may comprise a single oscillator for generating the magnetic field and receiving the magnetic field. Thus, synchronization problems may be avoided. The exact frequency may also be controlled by the electronics of the TR-Pad 5. The oscillators of each sensor channel 12,13 or their respective frequencies may be different for increased signal separation and to avoid signal crosstalk between the sensor channels 12,13. Also, the sensor electronics may determine the optimal frequency for the oscillation, depending on external circumstances like the material of the piston 6, the housing of the TR-Pad 5 or other influences like external magnetic or electromagnetic fields. In case the electronics detect a rise in interference, a frequency change may be performed as well, thus adapting to a new optimal operation point.

In Fig. 8 a detailed view of another exemplary embodiment of the sensor arrangement of the linear actuator position determining system 4 is shown. Alternatively, it is possible to stack the sensor channels 12,13 behind each other or, in an alternative exemplary embodiment, on top of each other. A position-offset may be used to minimize influences between the sensor channels 12,13. This has the advantage of a slimmer TR-pad 5. Special measures may have to be implemented to avoid loss in signal bandwidth or measurements per second due to channel crosstalk.

In Fig. 9 a three-dimensional illustration of an exemplary application of the linear actuator position determining system is shown. Here, the application is measuring the absolute linear position of a hydraulic powered steering system. The hydraulic powered actuator 16 extends at both ends of the hydraulic cylinder 14 and may allow for synchronous turning of the wheels of a lifter. Other operation mechanisms of the powered actuator 16 like pneumatic of electric may be implemented as well. When the piston 6 on one side of the actuator 16 is extending, the piston at the opposite side (not shown) of the actuator is contracting. During operation the maximal total piston movement may be 160mm or +/- 80mm. When the lifter has to drive straight ahead, meaning the steering wheel is in the center position, the pistons 6 extending on both ends of the actuator have to have the exact same length. Thus, deviations in the position and thus the steering of the lifter may be detected and subsequently corrected. This results in an improved, more accurate and highly secure and fault-tolerant steering of the lifter.

In Fig. 10 a two-dimensional cross section illustration of an exemplary embodiment of a second application of the present invention is shown. Here, the application is measuring the position of an outer bearing ring 18 vs. an inner bearing ring 19 (which may be assembled by two parts 19a and 19b) of a bearing system 17. In a preferred embodiment, the outer bearing ring 18 is static, the inner bearing ring 19 is rotation. However, in different applications this may be reversed. In Fig. 10, the bearing system 17 is shown in part (upper part of bearing unit) in a cross sectional view. Every component of the displayed bearing system 17 may have magnetic properties, that is, a magnet will be attracted by each of the components. In this exemplary embodiment, the outer bearing ring 18 may remain static. As a consequence, all required sensor devices may have to be mounted or fixed to this part. The inner bearing ring 19 and the main shaft are rotating. In this application, two linear position determining systems 20 according to the present invention, i.e. a system comprising a magnetic element 2 and a TR-Pad 5, are used. Each of the linear position determining system 20 is mounted at a side of the outer bearing ring 18. In the areas of the magnetic elements 2 or with respect to the magnetic elements 2 themselves, there is no need for magnetical processing of any kind. The application may again be interpreted as a three-dimensional position determining system, however in this exemplary embodiment, the used coordinate system may be a rotational coordinate system or cylindrical coordinate system with the rotational axis or rotation angle being the one, main, referred axis or measured component. The left linear position determining system 20a is measuring "upwards", which is why a physical change in the targeted device, mainly the respective magnetic element 2, may be necessary. The measurement areas 21a,21b may be identical, however they can be different as well. They may represent the distances between TR-Pad 5 and magnetic element 2 as previously described.

The angle sensor according to this exemplary embodiment requires that one section of the left inner bearing ring 19a will feature a magnetically encoded region 25. This may only possible if the left inner bearing ring 19a is tooled from ferromagnetic material. Best angle sensor results may be achieved when at least the left inner bearing ring 19a has been hardened by well-known measures. The sensor quality may thus improve by a factor up to ten. To prevent that the signal emanated by the magnetically encoded region 25 will dissipate towards the left metallic body 28, i.e. the shaft carried by the bearing system 17, an air gap or stainless steel (non magnetic material) 26 may be placed between the outer left wall of the left, inner bearing ring 19a and the adjacent shaft. For optimal effectiveness, the gap or non-magnetic material 26 may be at least 1mm in thickness. In another, even more preferred embodiment, it may be at least 1.5mm in thickness. If Mu-Metal is used the thickness may be reduced significantly. To prevent that the MFS coil array (secondary sensor unit SSU) 23 of the angle sensor will be distracted or confused by the movements of the adjacent bearing balls 27, the magnetic shielding 26 is placed between the MFS coil array 23 and the bearing balls 27. In another preferred embodiment, only one magnetic element 2 in combination with a TR-Pad 5 may be implemented.

In Fig. 11 a two-dimensional illustration of a further exemplary embodiment of the second application of the present invention is shown. Here, an alternative linear/angle position sensor is shown. An arrangement of at least one MFS coil arrays 23 in combination with a magnetically encoded region 25 is displayed. This exemplary embodiment has been proven to be highly accurate and reliable.

It should be noted, that the term "comprising" does not exclude other elements or steps and that "a" or "an" does not exclude a plurality. Also, elements described in association with different embodiments may be combined.

LIST OF REFERENCE NUMBERS

1	Magnetic field detector
2	Magnetic element
3	Position sensor device
4	Linear actuator position determining system
5	TR-Pad
6	Piston of linear actuator
7	One-dimensional direction of movement
8	Measurement range/range of movement
9	Distance between magnetic element and TR-Pad
10	First erroneous movement direction
11	Second erroneous movement direction
12	Sensor channel A
13	Sensor Channel B
14	Hydraulic cylinder
15	TR-Pad electronics
16	Hydraulically powered actuator
17	Bearing system
18	Outer bearing ring
19a,b	Inner bearing ring
20a,b	Linear position determining system
21a,b	Measurement area
22	Incremental angle sensor system
23	MFS Coil Array (Secondary sensor unit SSU)
24	Gap or stainless steel
25	Magnetic encoded region (Primary Sensor)
26	Magnetic shielding
27	Bearing balls
28	Metallic body

Claims

1. A position sensor device (3), comprising
a magnetic element (2);
a first magnetic field detector (1) for detecting a magnetic field influenced by the magnetic element (2) at a first position;
a second magnetic field detector (1) for detecting a magnetic field influenced by the magnetic element (2) at a second position; and
a position determining unit;
wherein the magnetic element (2) is fixable to a movable object, being substantially movable along a linear first path;
wherein the position determining unit is adapted to determine a position of the magnetic element (2) along the linear first path based on detection signals detected by the first magnetic field detector (1) and the second magnetic field detector (1);
wherein the position determining unit is adapted to determine a position of the magnetic element (2) along a substantially linear second path, said second path being perpendicular to the first path, based on detection signals detected by the first magnetic field detector (1) and the second magnetic field detector (1); and
wherein the position determining unit is adapted to correct the determination of the position along the first path by using information related to the second path.

2. The position sensor device according to claim 1, further comprising
a third magnetic field detector (1) for detecting a magnetic field influenced by the magnetic element (2) at a third position.

3. The position sensor device according to claim 2, wherein the position determining unit is adapted to determine a position of the magnetic element (2) along the linear first path based on detection signals detected by the first magnetic field detector (1), the second magnetic field detector (1) and third magnetic field detector (1); wherein the position determining unit is adapted to determine a position of the magnetic element (2) along the substantially linear second path, said second path being perpendicular to the first path, based on detection signals detected by the first magnetic field detector (1), the second magnetic field detector (1) and the third magnetic field detector (1); and wherein the position determining unit is adapted to determine a position of the magnetic element (2) along a substantially linear third path, said third path being perpendicular to the first path and second path, based on detection signals detected by the first magnetic field detector (1), the second magnetic field detector (1) and the third magnetic field detector (1).

4. The position sensor device according to claim 3, wherein the position determining unit is adapted to correct the determination of the position along the first path by using the information related to the second path and the third path.

5. The position sensor device according to one of the claims 1 to 4, wherein the movable object is movable along a substantially reciprocating linear path (7).

6. The position sensor device according to one of the claims 1 to 5, wherein the magnetic element (2) is adapted to respond to a magnetic field.

7. The position sensor device according to one of the claims 1 to 6, wherein the magnetic element (2) is adapted to alter a magnetic field.

8. The position sensor device according to one of the claims 1 to 7, wherein the alteration of the magnetic field is at least one out of the group consisting of changing, partly eliminating, entirely eliminating, absorbing, weakening, modifying, withdrawing energy from and dampening the magnetic field.

9. The position sensor device according to one of the claims 1 to 8, wherein the magnetic element (2) is a magnetic field sink.

10. The position sensor device according to one of the claims 1 to 8, wherein the magnetic element (2) is a magnetic field source.

11. The position sensor device according to one of the claims 1 to 10, wherein the magnetic element (2) is an entity of the group consisting of an active element, a passive element, a RFID tag, a LC oscillating circuit and a LRC oscillation circuit.

12. The position sensor device according to one of the claims 2 to 11, wherein the first magnetic field detector (1), the second magnetic field detector (1) and the third magnetic field detector (1) are substantially identical magnetic field detectors (1).

13. The position sensor device according to one of the claims 2 to 12, wherein the first magnetic field detector (1), the second magnetic field detector (1) and the third magnetic field (1) detector each comprises a coil.

14. The position sensor device according to claim 13, wherein each of the respective coils is adapted to generate a magnetic field.

15. The position sensor device according to claim 14, wherein the magnetic field generated by each of the coils is generated by applying an electrical signal to the coil.

16. The position sensor device according to claim 15, wherein the electrical signal is a constant electrical signal.

17. The position sensor device according to claim 15, wherein the electrical signal is an alternating or pulsed electrical signal.

18. The position sensor device according to one of the claims 13 to 17, wherein each of the coils is adapted to respond to a magnetic field.

19. The position sensor device according to one of the claims 13 to 18, wherein each of the coils is adapted to perceive an alteration of the magnetic field, which magnetic field was generated by the same coil.

20. The position sensor device according to one of the claims 18 or 19, wherein the position determining unit is adapted to determine the position of the magnetic element (2) based on at least one out of the group comprising of a ratio of the generated magnetic field and received magnetic field, a difference of the generated magnetic field and received magnetic field and an amplitude of one of the generated and received magnetic fields.

21. The position sensor device according to one of claims 1 to 20, comprising a signal linearization unit adapted to generate a linear signal being characteristic for the position of the movable object based on the determined position of the magnetic element (2).

22. The position sensor device according to one of claims 13 to 21, comprising a driver unit adapted to provide the first, second and third magnetic field detectors (1) with a driver signal for generating a magnetic field in accordance with the driver signal and being adapted to process, particularly to filter, the respective received magnetic fields in accordance with the driver signal.

23. The position sensor device according to claim 22, wherein the driver unit is at least one out of the group comprising a printed circuit board, a microprocessor and a computer program element

24. The position sensor device according to any of claims 1 to 23, adapted as a position sensor device to be implemented in at least one of the group consisting of a Gearbox Input Shaft, Gearbox Output Shaft, Rear Axle Drive Shaft, Wheel Hub, Combustion Engine Control, Transmission Control, Automatic Transmission, Power Assist Steering, Clutch Control, Bearing Forces, Cam Shaft Position, Crank Shaft Position, Injection Valve Control, F1 Gearbox System, F1 Power Steering, F1 Rear Axle Drive Shaft, Racing Bike Steering, Propulsion Control, Large Size Combustion Engine, Tractor - Trailer Drive System, Rear Suspension Load, Clutch Control, Hydraulic Actuator, Helicopter, Construction Equipment, Fire Engine, Falk-Lifter, Concrete Mixer and Pumps, Crane Cabin Position, Dentist Drill, Operating Table, Stethoscope Control, Hammer Drill, Assembly Line Fastener Tool,

Wheel Fastener, Sander, Washing Machine, Vacuum Cleaner, Sports Equipment, Garden Tools: Grass Trimmer, Bicycle Gear Change Control, Oil & Water Drilling, Tunnelling & Mining, Paint Pump, Paint Mixer, Electric Powered Actuator, Hydraulic Powered Actuator, Pneumatic Powered Actuator, Flow Meter, Gas Turbine Engine, Wind Power Plant, Paper Printing Equipment, Explosion Save Potentiometer, Maintenance Tools, Robotics Position Control, Robotics Force Control, Engine Test Bed, Calibration Tool, Vibration & Resonance Test, Drum Speed Detection, Drive Belt Friction Test.

25. A linear actuator position determining system, comprising
a linear actuator (16) with substantially linear, reciprocating movement (7); and
a position sensor device (3) according to one of the claims 1 to 24.

26. A linear actuator position determining system according to claim 25, further comprising:
a third magnetic field detector (1) for detecting a magnetic field influenced by the magnetic element (2) at a third position;
wherein the position determining unit is adapted to determine a position of the magnetic element (2) along the substantially linear first path based on detection signals detected by the first magnetic field detector (1), the second magnetic field detector (1) and the third magnetic field detector (1);
wherein the position determining unit is adapted to determine a position of the magnetic element (2) along the substantially linear second path, said second path being perpendicular to the first path, based on detection signals detected by the first magnetic field detector (1), the second magnetic field detector (1) and the third magnetic field detector (1);

wherein the position determining unit is adapted to determine a position of the magnetic element (2) along a substantially linear third path, said third path being perpendicular to the first path and the second path, based on the detection signals detected by the first magnetic field detector (1), the second magnetic field detector (1) and the third magnetic field detector (1); and wherein the position determining unit is adapted to correct the determination of the first path by using the information related to the second path and the third path.

27. A linear actuator position determining system according to claim 26, comprising:
at least three magnetic field detectors (1);
wherein said at least three magnetic field detectors (1) are arranged in essentially the same plane.

28. A linear actuator position determining system according to claim 27, wherein said at least three magnetic field detectors (1) are arranged in a redundant or failsafe arrangement.

29. A linear actuator position determining system according to claim 27 or 28, wherein the arrangement of the at least three magnetic field detectors (1) comprises arranging said at least three magnetic field detectors (1) in at least one way out of the group consisting of interweaving, overlapping, overlaying and side-by-side.

30. A method of determining the position of a movable object, comprising the steps of
receiving a first detection signal from a first magnetic field detector (1);

receiving a second detection signal from a second magnetic field detector (1); determining the position of a magnetic element (2) attached to the movable object along a substantially linear, reciprocating first path using the first detection signal and the second detection signal;

determining the position of the magnetic element (2) attached to the movable object along a substantially linear second path, said second path being perpendicular to the first path, using the first detection signal and the second detection signal; and

correcting the determination of the first path by using the information related to the second path.

31. A method of determining the position of a movable object according to claim 30, receiving a third detection signal from a third magnetic field detector (1); determining the position of the magnetic element (2) attached to the movable object along the substantially linear, reciprocating first path using the first detection signal, the second detection signal and the third detection signal; determining the position of the magnetic element attached to the movable object along the substantially linear second path, said second path being perpendicular to the first path, using the first detection signal, the second detection signal and the third detection signal;

determining the position of the magnetic element attached to the movable object along a substantially linear third path, said third path being perpendicular to the first path and the second path, using the first detection signal, the second detection signal and the third detection signal; and

correcting the determination of the first path by using the information related to the second path and the third path.

1/6

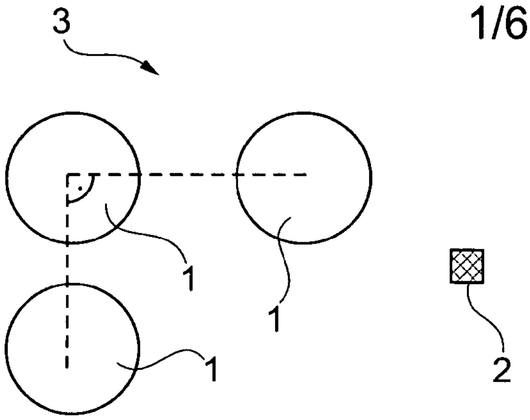


Fig. 1a

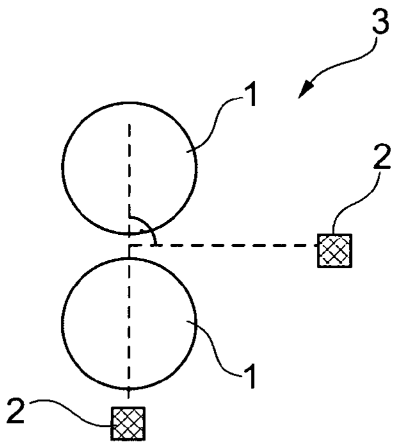


Fig. 1b

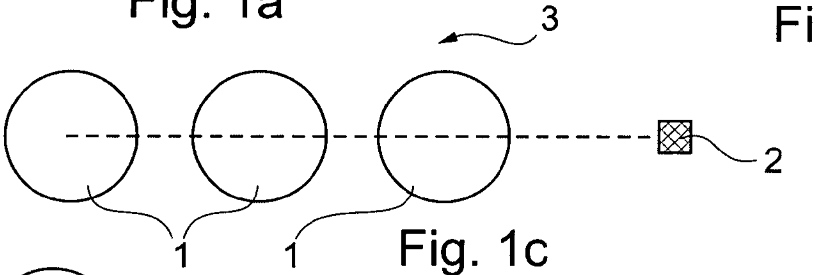


Fig. 1c

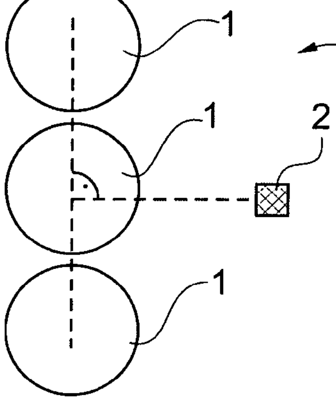


Fig. 1d

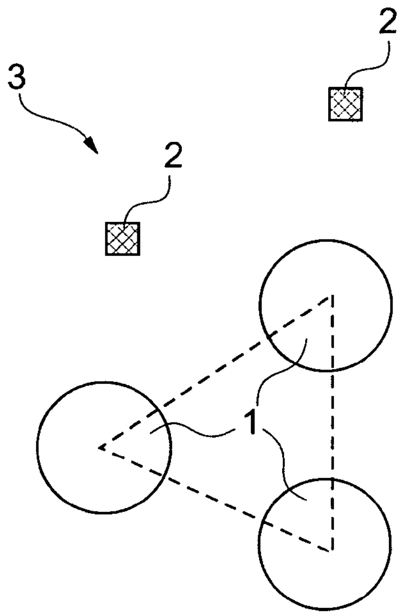


Fig. 1e

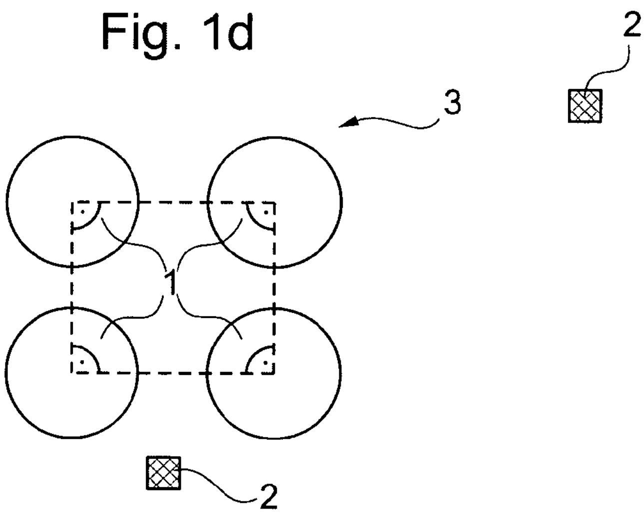


Fig. 1f

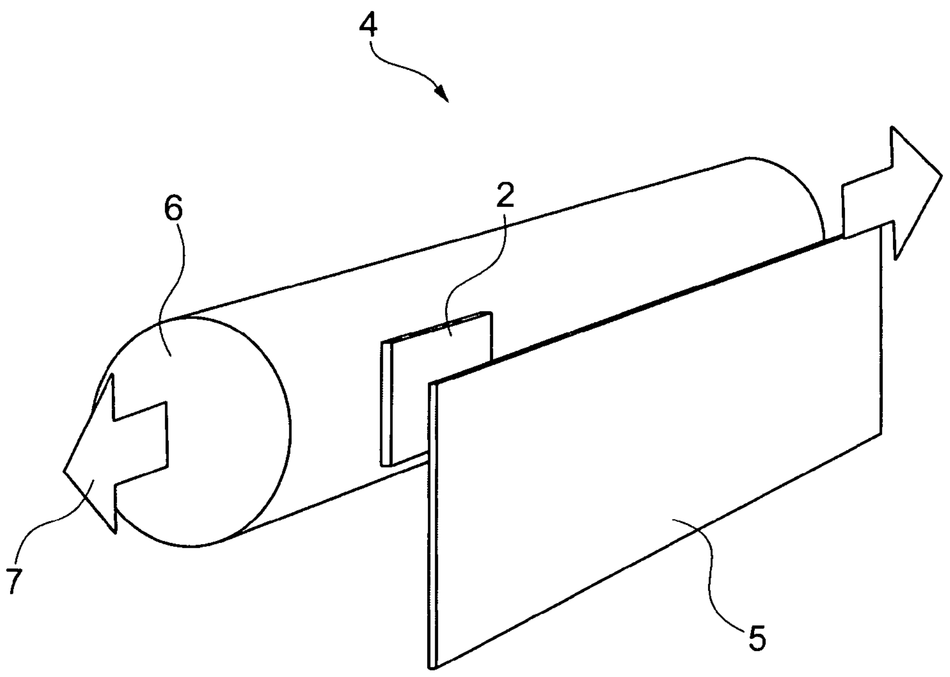


Fig. 2

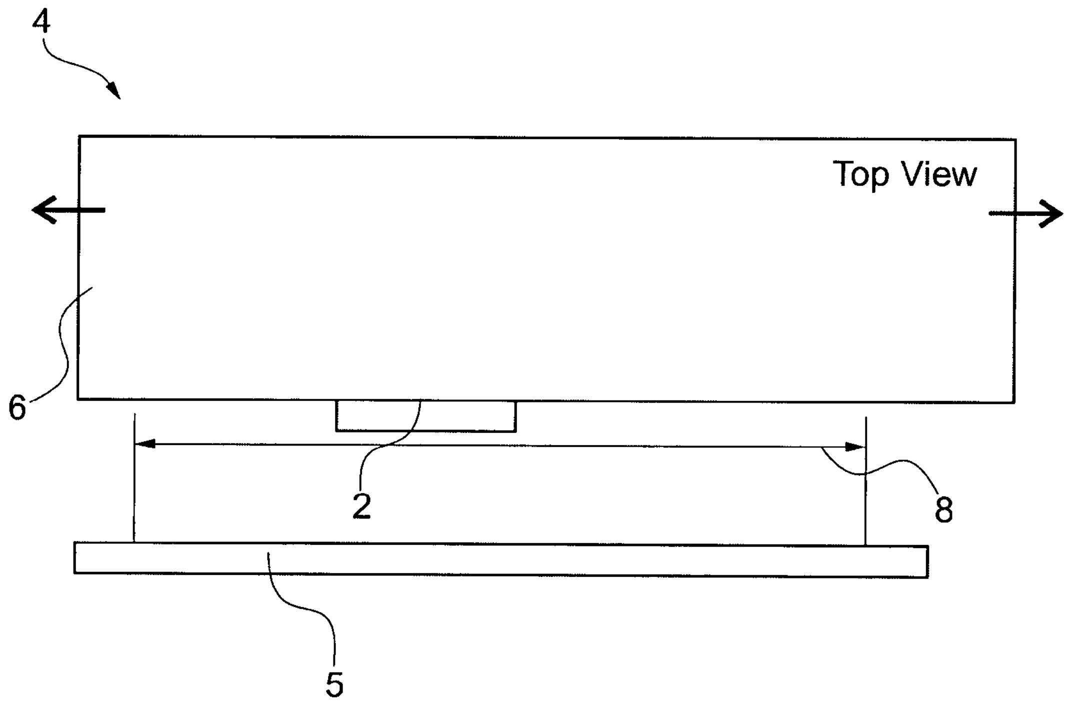


Fig. 3

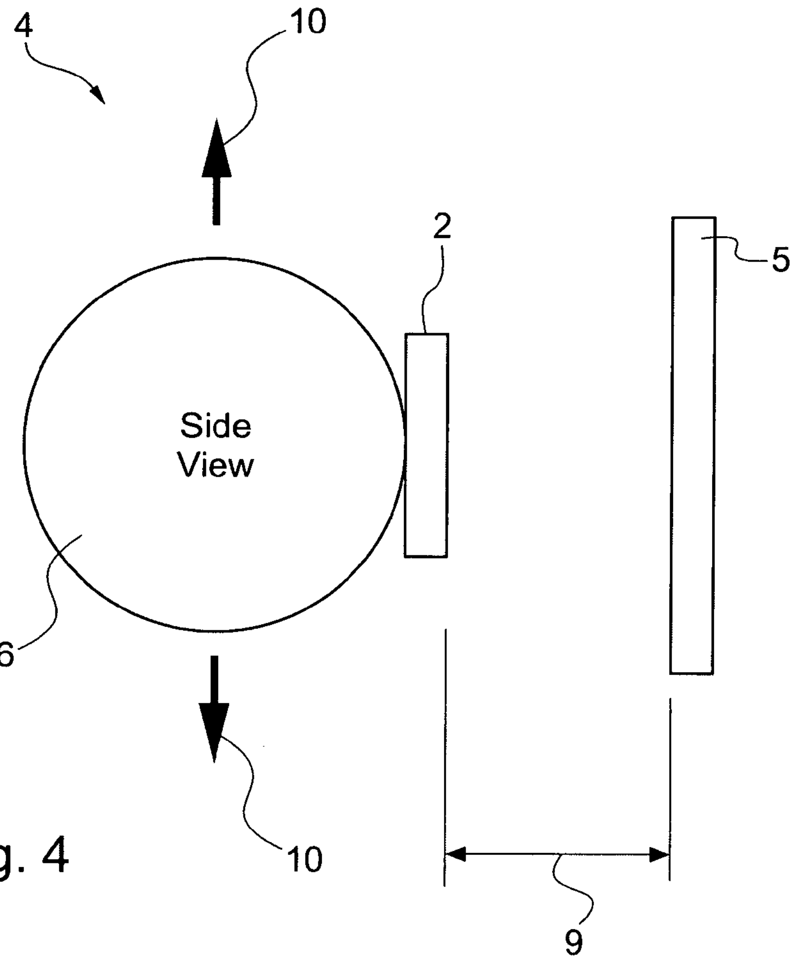


Fig. 4

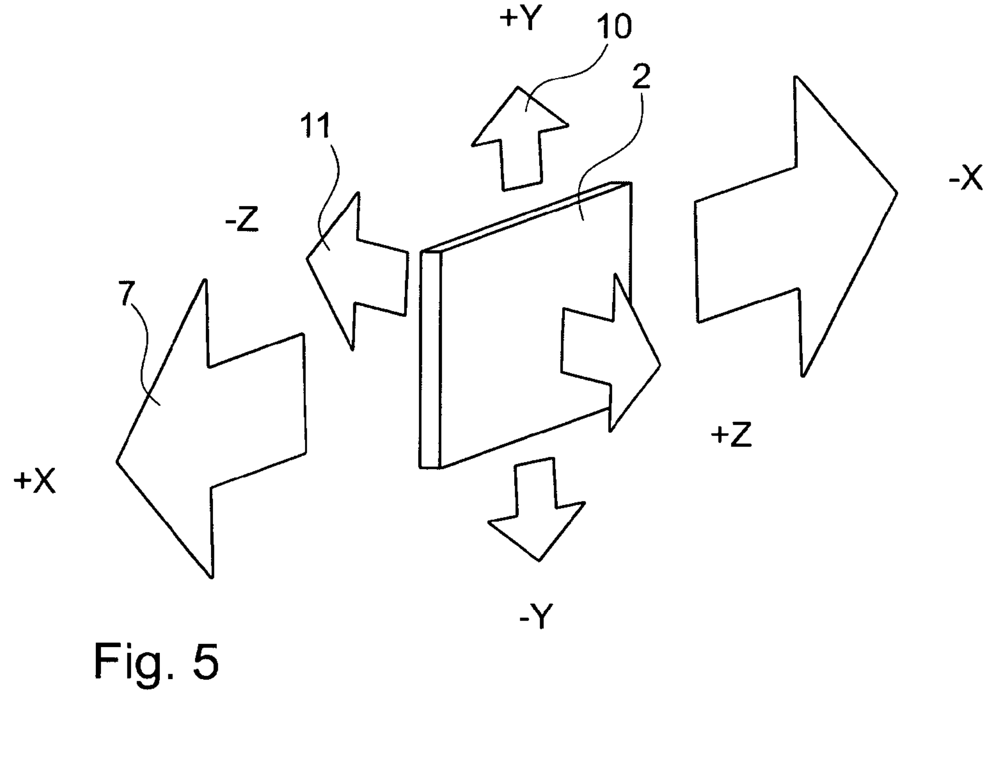
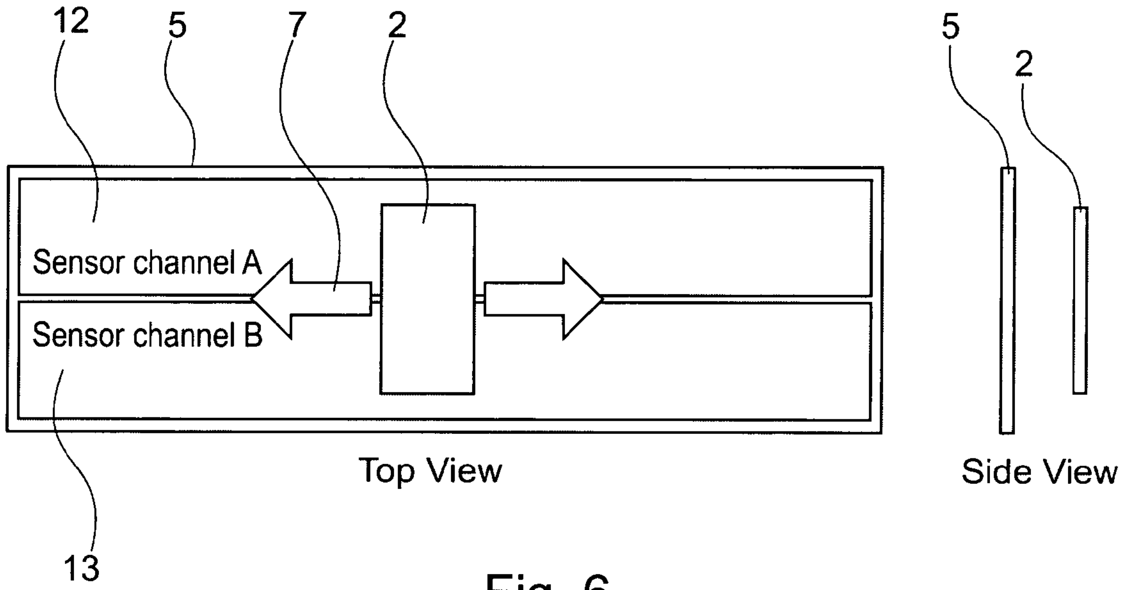


Fig. 5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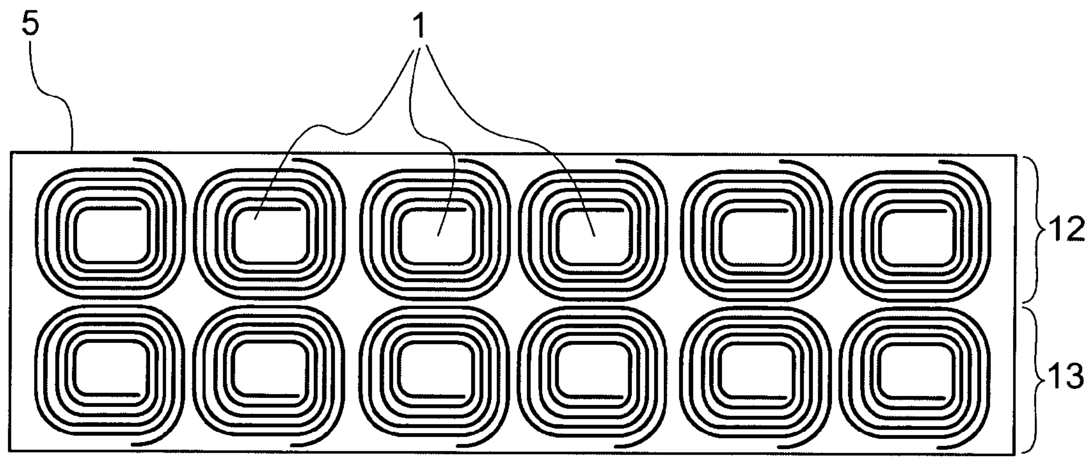
5
7
2
Sensor channel A
Sensor channel B
13
Top View
5
2
Side View

Fig. 6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1
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13

Fig. 7

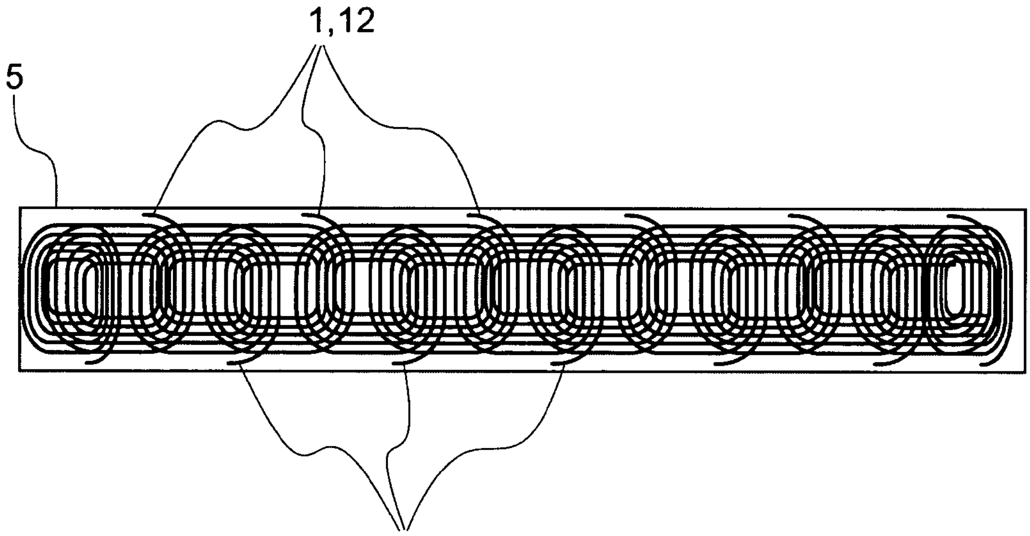


Fig. 8

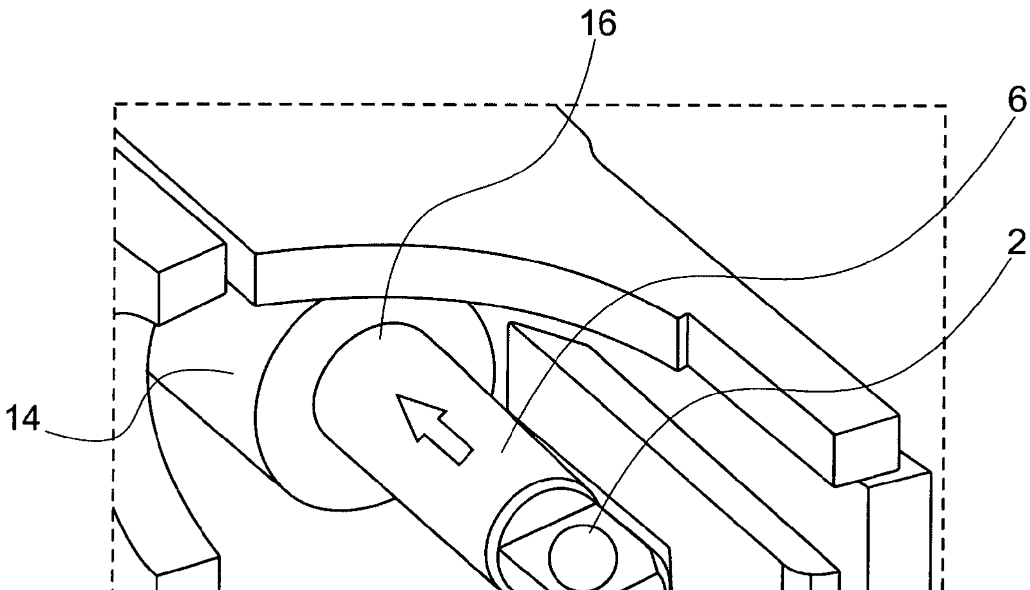
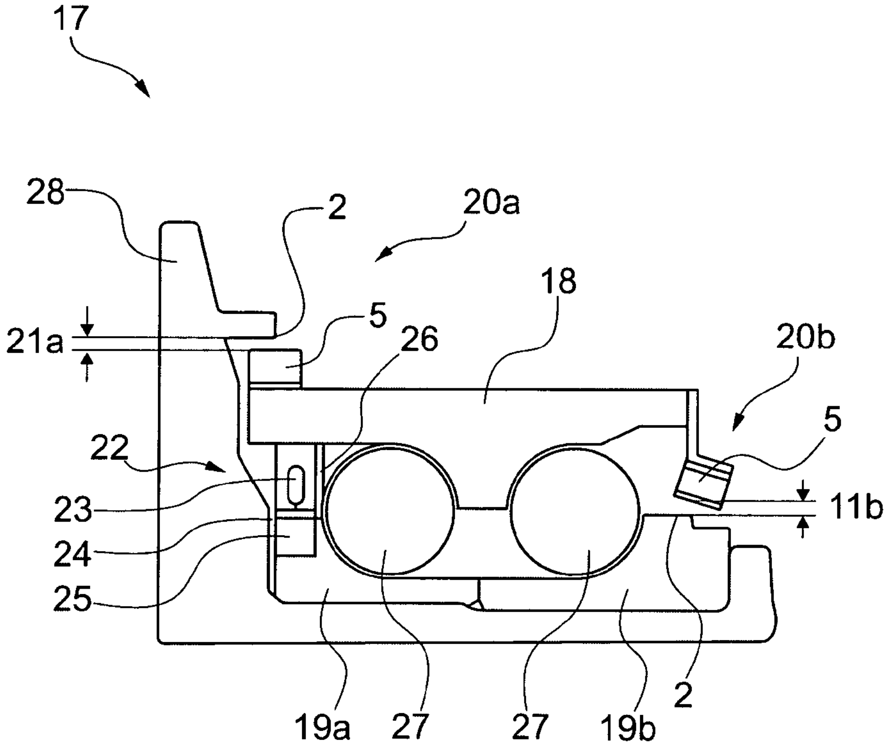


Fig. 9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19b
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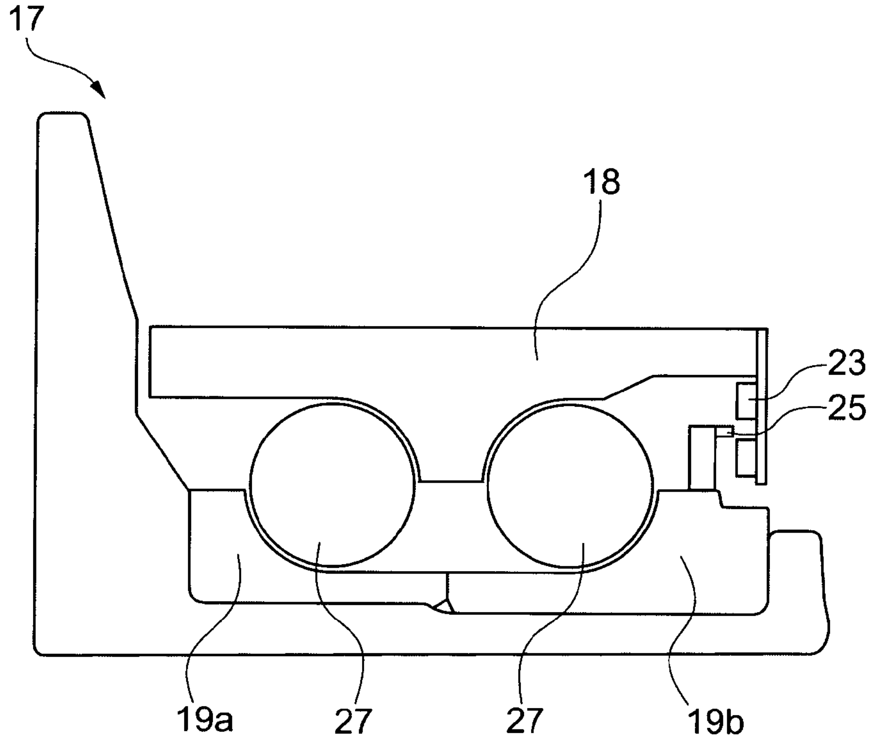
Fig. 10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19a
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19b

Fig. 11