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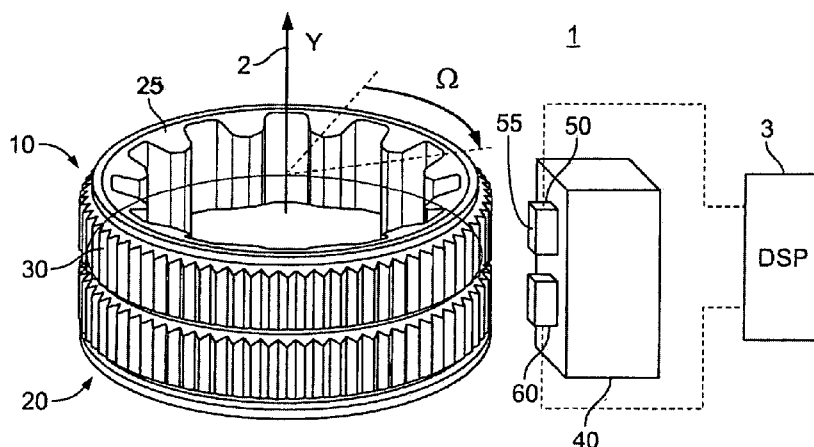


Fig. 1

(57) Abstract: A device is indicated for measuring torque and angle with improved accuracy. The device here comprises magnetic sensors, on the back of which a magnetic bias is imposed. Hall effect sensors or sensors based on the magnetoresistance effect may be used here, their detection signal being modulated by changes to the magnetic field direction and density as a result of movement of a target wheel with magnetic targets in front of the sensor. To correct signal background and amplitude, two signals of a sensor are here combined, which in each case detect the rotation of the target wheel. To determine the torque acting on an axle, a second sensor is in each case provided to detect the rotation angle of a second target wheel and the torque is ascertained directly from the angle difference of the first and second target wheels from the corrected detection signals.

DEVICE FOR MEASURING TORQUE AND ANGLE OF ROTATION WITH IMPROVED ACCURACY

The present invention relates to devices for measuring the rotation angle of a rotatable body and/or the torque acting thereon.

Such devices are used in particular in electrical power-assisted steering systems in the automotive sector, which are often used to help the driver with steering.

In generally known electric power-assisted steering systems ("Electric Power Steering, EPS" or "Electric Power Assisted Steering, EPAS") electromechanical power-assisted steering provides electrical assistance, using an electric motor to amplify the force exerted by the driver on a vehicle steering wheel when steering.

The amount of electrical assistance depends on the steering movement, in particular on the rotation angle and/or the torque.

This angle has to be accurately measured, not only to provide precisely the amount of assistance needed, but also for safety reasons.

A mechanism generally used to determine the torque acting on a steering wheel is the determination of the twist angle of a "flexible" torsion bar with known torsional stiffness, which connects an input shaft with an output shaft. The input shaft is connected to the steering wheel of the vehicle and the output shaft to the toothed rack of the vehicle. The torsion bar converts the torque acting on the steering wheel into a twist angle of $\pm 5^\circ$.

By measuring the twist angle as a difference in the angles of the input shaft and the output shaft, the torque may be determined with the known torsional stiffness.

A device is known from DE-A-100 60 287 for measuring an angle and/or a torque of a rotatable body, the rotation angle being detected by means of magnetic or optical sensors. One example proposes two detection wheels, which each comprise two optically readable code tracks. The two code tracks are of the same construction on each detection wheel and are arranged offset relative to one another, such that associated sensors output a digital signal which corresponds to the rotary motion of the code tracks. The rotation angle of the detection wheel is calculated from the offset of the two digital signals.

From the difference between the rotation angles of the two detection wheels, or "difference angle", it is thus also possible to calculate the torque transmitted by the rotatable body.

However, such a device has the disadvantage that detection wheels with complex code tracks are required, in order to achieve a high angular resolution. Also, incorporation of such a device into a steering shaft is difficult and has to be done before assembly of the latter. These disadvantages make manufacture and fitting of such devices more complex and expensive.

A device for determining rotation angle and torque using two relatively simple detection wheels is known from EP-A-1 295 780. Rotation of each individual wheel is determined by a pair of magnetic sensors, which are arranged at the edge of the wheel and spaced such that a satisfactory phase shift arises between the detection signals of the individual sensors. Each sensor of the sensor pair outputs a periodic detection signal corresponding to the rotation angle of the detection wheel. Since angle determination around the maxima of the detection signal has a tendency to major errors, it is determined which sensor is situated in the linear range of the detection signal and only the corresponding sensor is used to determine the angle.

The objective of the present invention is to provide a torque and rotation angle sensor, which may be produced particularly simply and inexpensively and moreover exhibits improved accuracy.

This is achieved in the present invention by using magnetic sensors, on the back of which a magnetic bias is imposed. Hall effect sensors or sensors based on the magneto-resistance effect may be used here, their detection signal being modulated by changes to the magnetic field direction and density as a result of movement of a target wheel with magnetic targets in front of the sensor.

Such sensors can be straightforwardly integrated for example into a steering system for a vehicle. A further advantage is the simplicity of fitting the target wheel into such a system. The target wheel may here in particular also be manufactured integrally with a shaft during the manufacturing process.

However, the accuracy of such sensors may be affected significantly by the strength of the magnetic field, the distance from the target wheel, temperature and other factors. In addition, the signal background is considerable compared to the amplitude, such that signal correction is needed to eliminate the influence of these effects.

This problem is solved in the present invention by combining two signals of a rotation angle sensor with magnetic bias imposed on the back, which signals correspond in each case to the rotation of the target wheel.

By means of signal processing a background component is ascertained in each detection signal and a compensated detection signal is output.

If a Hall sensor is used, it may take the form of a 3D Hall sensor, the rotation angle of the target wheel being ascertained using detection of the orthogonal components B_z and B_x of the magnetic flux density. In the case of detection using the magneto-resistance effect, the rotation angle sensor is formed by a sensor pair which outputs the necessary two signals. If applied to determine the torque acting on an axle, a second Hall sensor is used, or a second sensor pair in the case of detection using the magneto-resistance effect, these detecting the rotation angle of a second target wheel. In this case, the first target wheel is fastened to the above-stated axle, which is coupled via a torsion element with known torsional stiffness to the axle of the second target wheel. From the difference angle between the first and second target wheels, the torque may then be ascertained directly from the corrected detection signals.

For a better understanding of the present invention, the latter is explained in greater detail with reference to the exemplary embodiments illustrated in the figures below. Identical parts are here provided with identical reference numerals and identical component names. Furthermore, individual features or combinations of features from the embodiments disclosed and described may also in themselves constitute independent inventive solutions or solutions according to the invention.

Fig. 1 shows a schematic representation of the structure of a first embodiment of the present invention, in which use is made of a device according to the invention for measuring rotation angle and a device according to the invention for measuring torque;

Fig. 2 shows a schematic representation of the profiles of the detection signals of a device for measuring rotation angle according to Fig. 1 as a function of the relative rotation angle.

Fig. 3 shows a block diagram for signal processing of the detection signals and calculation of a difference angle according to the embodiment of Fig. 1;

Fig. 4 shows a schematic representation of the structure of a second embodiment of the present invention;

Fig. 5 shows a schematic representation of the profiles of the detection signals of a device for measuring rotation angle according to Fig. 4 as a function of the relative rotation angle.

Fig. 6 shows a block diagram for signal processing of the detection signals and calculation of a difference angle according to the second embodiment of the present invention.

Fig. 1 shows a schematic representation of the structure of a device according to the invention for measuring rotation angle and a device according to the invention for measuring torque, or torque sensor 1.

The device comprises a magnetic sensor 50, which is situated at a fixed position spaced from the outer edge of a rotatable body or rotary element.

The rotary element may be mounted coaxially on an axle 2, or on a shaft, in order to be rotated in a clockwise direction or in the opposite direction about the axis of rotation and to detect the corresponding rotation angle.

In the embodiment shown, the rotary element is a target wheel 10, which comprises a plurality of magnetic targets 30. The magnetic targets 30 are distributed at substantially uniform intervals over the circumference of the target wheel 10 and arranged radially on the outside of the target wheel 10.

If the target wheel 10 consists of ferromagnetic material, the targets 30 are formed by an outer tooth/groove profile, as shown in Fig. 1.

To fasten it to the rotatable axle or shaft, the target wheel 10 additionally comprises fastening means in the form of an inner toothed profile 25. However, other known fastening variants may also be used, such as for example grooves, etc.

The magnetic sensor 50 receives a bias magnetic field ("magnetic back-bias") by way of an element 40, e.g. a permanent magnet, which generates a bias field arranged on the back of the magnetic sensor 50, i.e. on the side remote from the target wheel 10. The element 40 generating the bias field and the magnetic sensor 50 are held at a fixed position relative to one another. The element 40 generating the magnetic field may be incorporated together with the magnetic sensor 50 in a sensor component.

The element 40 generating the bias field generates magnetic field lines, which flow through the magnetic sensor 50 and changes to which are detected by the magnetic sensor 50.

The magnetic sensor 50 is positioned and spaced relative to the target wheel 10 in such a way that the rotary motion of the magnetic targets 30 relative to the stationary magnetic sensor 50 brings about a change in the magnetic flux through the magnetic sensor 50.

An arrangement is alternatively also conceivable in which the magnetic sensor moves with the rotary element, while magnetic targets are provided stationarily around the rotary element.

When the magnetic targets 30, move past the sensor 50, the direction and/or density of the magnetic field lines of the bias field are changed at the location of the sensor. The magnetic sensor outputs a periodic detection signal, which maps the tooth profile of the target wheel 10. The signal amplitudes are largely independent of the rotational speed of the target wheel 10, which constitutes a distinct advantage over inductive systems.

Preferably, the element 40 generating the bias field generates a substantially homogeneous bias field at the location of the sensor 50, which is perpendicular or substantially perpendicular to the plane of the magnetic sensor 50 (for example in the Z direction). If a torque is thus applied to the shaft and/or to the target wheel 10, which brings about a rotary motion about the axis of rotation 2, the corresponding rotation angle in the direction of rotation may be detected by detection of the changes in the magnetic field lines by the magnetic sensor 50.

In the first embodiment the measurement principle of the magnetic sensor 50 is based on the known Hall effect.

The magnetic sensor 50 used is such that it can detect changes in magnetic flux density in two mutually orthogonal directions. In this case, the first direction is parallel to the surface of the magnetic sensor 50 (X axis) and the second direction is perpendicular thereto (Z axis). The magnetic sensor 50 is then arranged relative to the targets 30 in such a way that the first direction is oriented tangentially to the circumference of the target wheel 10 (tangential direction) and the second direction radially to the target wheel 10 (radial direction), or perpendicular to the plane of the magnetically sensitive surface of the magnetic sensor 50 (i.e. perpendicular to the X-Y plane). The tangential and radial directions are orthogonal to the direction of the axis of rotation (Y axis).

In the present embodiment a "three-dimensional (3D)" Hall sensor is preferably used, which, in contrast to conventional Hall sensors, with which measurements of magnetic flux density can be performed with a Hall element in only one direction (Z axis), also allows detection in an additional orthogonal plane (X-Y plane).

Fig. 2 shows the profile of the components of the magnetic flux density B_z and B_x , detected by the 3D Hall sensor 50 in the present embodiment, as a function of the relative rotation angle α of the target wheel. The upper part of Fig. 2 is a schematic representation of the relative positioning of the tooth/gap profile of the target wheel 10 relative to the 3D Hall-sensor 50 and the permanent magnet 40 arranged on the back of the sensor, which positioning results from the rotary motion of the target wheel 10 about a mechanical rotation angle Ω in the direction of rotation shown. For clarity's sake, the teeth 30, which move successively past the sensor 50, are numbered consecutively from 1 to 6. The lines shown between the tooth/gap profile and the sensor 50 indicate (schematically) the orientation of the magnetic flux lines around the sensor 50 and the modification thereof by the relative positioning of the tooth/gap profile in relation to the 3D Hall sensor. Through the relative motion of the magnetic targets 30 and the sensor 50, the magnetic bias field results both in a periodic change in component B_z of the magnetic flux density in the radial direction (Z axis) and in component B_x of the magnetic flux density in the tangential direction (X axis).

In the lower part of Fig. 2 the periodic change in the values of components B_Z and B_X of the magnetic flux density, dependent on the rotation angle and brought about in the sensor 50, is shown as a function of the relative rotation angle α .

The vertical dashed lines represent values for components B_X and B_Z for the positioning of the teeth 1 to 6 shown in the upper part of Fig. 2.

In this respect, the maximum values of B_Z are numbered consecutively from 1 to 6, these values being detected when the respective tooth is substantially opposite the sensor 50. These maximum values correspond to an orientation of the bias field which is substantially perpendicular to the plane of the sensor, the B_X component reaching a zero crossing.

On the other hand, the minimum value of the B_Z component is reached when a gap 35 is opposite the sensor 50, as shown in Fig. 2 for teeth 3 and 4.

The two components of the magnetic flux density, B_Z and B_X , are evaluated in the 3D Hall sensor 50, which generates two different detection signals in the form of output voltage signals U_Z and U_X . These detection signals U_Z and U_X are proportional to the corresponding component of the magnetic flux density B_Z and B_X respectively and exhibit a phase difference of substantially 90 degrees.

In the case of a tooth/gap profile with N uniformly spaced teeth 30, the values of these components, or the two detection signals, approximately follow a sine/cosine function with a period corresponding to a mechanical absolute rotation angle of $360^\circ/N$. It should be noted that the mechanical rotation angle Ω of the target wheel 10 arises as $\Omega = \alpha/N$ from the relative rotation angle α , or as $\Omega = n \times 360^\circ / N + \alpha_0/N$, wherein n indicates the number of detected maxima since the zero position (e.g. the positioning of tooth 1), and α_0 indicates the angular value since the last maximum. The angular values α_0 may be calculated directly from the measured detection signals using the sine/cosine function.

For an absolute rotation angle of less than $360^\circ / N$, no maxima are detected from the zero position ($n=0$) and the absolute rotation angle is simply $\Omega = \alpha_0/N$.

The angular accuracy of such a sine/cosine sensor is, however, limited by the magnetic offset effect.

If a permanent magnet 40 is used, as is standard, the component of the magnetic flux density B_Z , as indicated in Fig. 2, in principle displays a considerable background or offset value, $B_{Z,offset}$, of approx. 200-500 mT, which is substantially constant and independent of the rotary motion of the target 30. On the other hand, the amplitudes of the components B_X and B_Z changed by the mechanical rotation are generally in the range of from 0.2 to 2 mT. In comparison to the amplitude, component B_X displays a relatively small offset value, $B_{X,offset}$.

Taking account of the offset effect brought about by the magnetic bias, the two components B_Z and B_X , or the respective detection signals U_Z and U_X are as follows:

$$B_X = \Delta B_X \times \sin(\alpha) + B_{X,offset}$$

$$B_Z = \Delta B_Z \times \cos(\alpha) + B_{Z,offset}$$

wherein ΔB_X and ΔB_Z are the amplitudes of the respective components B_X and B_Z , and $B_{Z,offset}$, $B_{X,offset}$ are the respective offset values.

The occurrence of such an offset in the two detection signals actually distorts the rotation angle measurements carried out, which have to be compensated.

The present invention allows simple determination of the amplitude and of the offset value of the respective detection signals, such that corrected rotation angle calculation may be performed on the basis of the values determined.

The amplitude and offset of the respective detection signals may be determined as follows from maximum and minimum values of the detection signal.

To calculate the amplitudes ΔB_X and ΔB_Z , the maximum value and minimum value of the corresponding detection signals of the respective components B_X and B_Z are ascertained and the amplitudes then calculated as the difference between the ascertained maximum and minimum values for the respective components. The offset value $B_{X,offset}$ or $B_{Z,offset}$ is calculated in each case as half the sum of maximum value and minimum value.

The detection signals may then be compensated directly after a specific number of signal periods, and the $\sin(\alpha)$ and $\cos(\alpha)$ measured values calculated as follows by the corrected detection signals of the 3D Hall sensor 50:

$$\sin(\alpha) = \frac{B_X - B_{Xoffset}}{\Delta B_X}$$

$$\cos(\alpha) = \frac{B_Z - B_{Zoffset}}{\Delta B_Z}$$

On the basis of such corrected measured values the mechanical absolute rotation angle $\Omega = \alpha / N$ may for example be calculated using the arctangent of the ratio of the sine and cosine signals obtained in this way. For a rotation angle of less than $360^\circ/N$, only at most one target 30 will have passed the sensor 50 and the absolute rotation angle Ω may be ascertained directly from the measured detection signals. Otherwise the number n of maxima of the B_Z component is ascertained, and the corresponding angular fraction $n \times 360^\circ / N$ is added to the measured value α_0 , as described above. For example, for a target wheel with 100 uniformly spaced targets 30 the mechanical rotation angle would be calculated which corresponds to the relative positioning of the tooth 2 shown in Fig. 2 of the above equation with $n=1$, $N=100$ and $\alpha_0=45^\circ$.

Using the method according to the invention, the magnetic offset of the magnetic sensor may be straightforwardly calculated and compensated during operation, which enables an increase in angular accuracy. In particular, the method illustrated allows automatic offset compensation in the case of dynamic rotational movements.

To measure torque, as shown in Fig. 1, a second device for measuring rotation angle is arranged in the direction of the axis of rotation, with a second target wheel 20 and a second magnetic sensor 60. In this case, the structure and function correspond to the above-described device, i.e. in particular the second magnetic sensor ascertains the rotation angle of the second target wheel. The first target wheel may in this case be connected to an input shaft and the second target wheel to an output shaft, said shafts being coupled via a torsion element with known torsional stiffness.

Like the first magnetic sensor 50, the second magnetic sensor 60 also receives a bias magnetic field by means of the element 40 generating the bias field.

The torque may then be determined by means of the known torsional stiffness from the difference between the rotation angle Ω_1 of the first target wheel 10 and the rotation angle Ω_2 of the second target wheel 20. In this respect, the torsion element is designed such that,

at the expected angles, operation proceeds in the elastic measuring range of the torsion element. The resultant torque is then directly proportional to the rotation angle difference.

In the present embodiment the rotation angle difference is detected by way of the detection signals of the first and second 3D Hall sensors 50, 60.

If the first target wheel 10 is rotated by a mechanical rotation angle value Ω_1 , the first 3D Hall sensor 50 delivers two electrical detection signals U_{Z1} and U_{X1} , which are directly proportional to the orthogonal components of the magnetic field B_{Z1} and B_{X1} at the location of the first 3D Hall sensor 50. These components are as follows:

$$B_{Z1} = \Delta B_{Z1} \times \sin(\alpha) + B_{Z\text{offset}}$$

$$B_{X1} = \Delta B_{X1} \times \cos(\alpha) + B_{X\text{offset}}$$

wherein ΔB_{X1} , ΔB_{Z1} are the amplitudes and $B_{Z\text{offset}}$, $B_{X\text{offset}}$ the offset values of the respective components B_{X1} and B_{Z1} . α is the relative rotation angle of the first target wheel 10.

Twisting of the torsion element is proportional to the torque acting on the first target wheel 10. A difference $\Delta\alpha$ of the relative rotation angle of the first 10 and second target wheels 20 is therefore obtained. The second sensor 60 likewise delivers two electrical detection signals U_{Z2} and U_{X2} , which are directly proportional to the orthogonal components of the magnetic field B_{Z2} and B_{X2} at the location of the second 3D Hall sensor 60. These components are as follows:

$$B_{Z2} = \Delta B_{Z2} \times \sin(\alpha + \Delta\alpha) + B_{Z\text{offset}}$$

$$B_{X2} = \Delta B_{X2} \times \cos(\alpha + \Delta\alpha) + B_{X\text{offset}}$$

wherein ΔB_{X2} , ΔB_{Z2} are the amplitudes and $B_{Z\text{offset}}$, $B_{X\text{offset}}$ the offset values of the respective components B_{X2} and B_{Z2} . $\alpha + \Delta\alpha$ is the relative rotation angle of the second target wheel 20.

In this embodiment the two 3D Hall sensors 50, 60 preferably have similar characteristics and spacing with regard to the respective target wheel 10, 20. The detection signals for the respective components B_Z and B_X of the two 3D Hall sensors 50, 60 then represent identical amplitudes and offset values, which simplifies calculation accordingly.

The amplitudes and offsets of the respective detection signals are determined by the above-described methods.

As described above, the $\sin(\alpha)$ and $\cos(\alpha)$ values may be calculated as follows by the corrected detection signals $B_{Z1,corr}$ and $B_{X1,corr}$ of the first 3D Hall sensor 50:

$$\cos(\alpha) = \frac{B_{Z1} - B_{Zoffset}}{\Delta B_Z} = B_{Z1,corr}$$

$$\sin(\alpha) = \frac{B_{X1} - B_{Xoffset}}{\Delta B_X} = B_{X1,corr}$$

The values $\sin(\alpha + \Delta\alpha)$ and $\cos(\alpha + \Delta\alpha)$ are calculated by means of the corrected detection signals $B_{Z2,corr}$ and $B_{X2,corr}$ of the second 3D Hall sensor 60:

$$\cos(\alpha + \Delta\alpha) = \frac{B_{Z2} - B_{Zoffset}}{\Delta B_Z} = B_{Z2,corr}$$

$$\sin(\alpha + \Delta\alpha) = \frac{B_{X2} - B_{Xoffset}}{\Delta B_X} = B_{X2,corr}$$

The difference angle $\Delta\alpha$ may then be calculated using the known sine-cosine formula:

$$\sin(\alpha - (\alpha + \Delta\alpha)) = \sin(\alpha) \times \cos(\alpha + \Delta\alpha) - \cos(\alpha) \times \sin(\alpha + \Delta\alpha)$$

$$\sin(-\Delta\alpha) = \sin(\alpha) \times \cos(\alpha + \Delta\alpha) - \cos(\alpha) \times \sin(\alpha + \Delta\alpha)$$

For difference angle values $\Delta\alpha$ of less than 4° the following applies $\sin(-\Delta\alpha) \approx -\Delta\alpha$. The relative error in the angle range (-4.4° to $+4.4^\circ$) is only at most 0.1%.

The difference angle $\Delta\alpha$ is then determined as follows:

$$-\Delta\alpha = \frac{B_{X1} - B_{Xoffs}}{\Delta B_X} \times \frac{B_{Z2} - B_{Zoffs}}{\Delta B_Z} - \frac{B_{Z1} - B_{Zoffs}}{\Delta B_Z} \times \frac{B_{X2} - B_{Xoffs}}{\Delta B_X}$$

or may be calculated directly from the corrected detection signals $B_{X1,corr}$, $B_{Z1,corr}$, $B_{X2,corr}$ and $B_{Z2,corr}$ using the following formula:

$$-\Delta\alpha = B_{X1,corr} \times B_{Z2,corr} - B_{Z1,corr} \times B_{X2,corr}$$

This evaluation method is very sensitive to minuscule angular differences.

The difference angle may be determined by analogue electronic operations (multiplication, subtraction, comparison), as illustrated in Fig. 3. Using the above-described procedure, torque may be determined directly from the angular difference.

To carry out the above-described operations, the device for measuring torque further comprises a processing unit 3, which processes the detection signals. The processing unit 3 is shown schematically in Fig. 3. It comprises a peak detector 310, 311, 312, 313 for each detection signal, which ascertains the maximum and minimum values of each detection signal. The offset value is calculated for each detection signal by means of the ascertained maximum and minimum values and then forwarded to a respective subtraction unit 320, 321, 322, 323, which subtracts the offset value from the measured signal.

Minimum and maximum values are also sent to a respective amplitude calculation unit, which calculates the amplitudes of the respective signal as described above.

The offset-corrected signal is passed from the subtraction unit 320, 321, 322, 323 to a respective division unit 330, 331, 332, 333, which divides the resultant signal by the calculated amplitude so as to output a corrected detection signal $B_{X1,corr}$, $B_{Z1,corr}$, $B_{X2,corr}$ and $B_{Z2,corr}$.

Calculation of the corrected detection signals is carried out in the same manner for all four detection signals B_{Z1} , B_{X1} , B_{Z2} and B_{X2} .

The resultant corrected detection signals $B_{Z1,corr}$ and $B_{X2,corr}$, or $B_{Z2,corr}$ and $B_{X1,corr}$ are then multiplied together in a corresponding multiplication unit 340, 341.

In a further subtraction unit 360 the rotation angle difference is then calculated as the difference between the above products.

Signal processing may also be carried out digitally in a digital signal processor (DSP).

Fig. 4 shows a schematic representation of the structure of a second embodiment of the device for measuring rotation angle and the device for measuring torque, or torque sensor 4, according to the invention.

In the second embodiment the measurement principle of the magnetic sensors is based on the known magneto-resistance effect.

In this embodiment "AMR", "GMR" or "TMR" sensors may preferably be used. For simplicity's sake, these sensors are hereinafter designated XMR sensors.

The magnetic sensors are configured such that they can detect changes in the magnetic flux density parallel to the magnetically sensitive surface of the sensor (X axis) and output a corresponding detection signal.

To ascertain the rotation angle of the target wheel 10, in the second embodiment two XMR sensors are used, which output two different detection signals.

As shown in Fig. 4, the device for measuring the rotation angle of the upper target wheel 10 comprises a first XMR sensor R1 and a second XMR sensor L1, which are arranged stationarily at a fixed distance in the radial direction from the target wheel 10. The two XMR sensors R1, L1 are here arranged next to one another at a fixed distance from one another in the tangential direction with regard to the direction of rotation of the target wheel 10.

A magnetic bias is imposed on each XMR sensor R1, L1. To this end, as in the first embodiment, an element generating a magnetic field is arranged on the back of the sensor. This element may for example be a permanent magnet 40.

Through rotary motion of the tooth/gap profile in front of the XMR sensors R1, L1, the magnetic bias results in a periodic change in the magnetic flux density B_x in the tangential direction of the rotary motion (X axis) as a function of the rotation angle, which change may be detected by the XMR sensors R1, L1.

Fig. 5 shows a schematic representation of the profiles of the detection signals of the device for measuring rotation angle according to Fig. 4 as a function of the relative rotation angle of the target wheel.

The upper part of Fig. 5 schematically represents the relative positioning of the tooth/gap profile of the target wheel 10 relative to the XMR sensors R1, L1 arranged next to one another and the permanent magnet 40 arranged on the back of the XMR sensors. The lines

shown between the tooth/gap profile and each XMR sensor indicate the orientation of the magnetic flux lines around the respective XMR sensor and the modification thereof by the relative positioning of the tooth/gap profile relative to the XMR sensor.

To illustrate the origin of the sensor signal the teeth are numbered consecutively from 1 to 6 as in Fig. 2. The maxima of the resultant signal B_{XL} are accordingly numbered consecutively from 1 to 6, wherein the maximum n ($n = 1$ to 6) corresponds to the respective position of the tooth n centrally opposite the sensor.

As in the first embodiment, a waveform is obtained for each XMR sensor R1, L1 according to a circular trigonometric function. In this case, the distance between the XMR sensors is selected according to the invention such that a specific phase difference arises between the detection signal as a function of the relative rotation angle α of the first XMR sensor R1 and of the second XMR sensor L1. To simplify determination of the rotation angle α the two XMR sensors are here spaced such that the phase difference between the detection signals is 90° .

There are therefore two detection signals, which are proportional to the following measured components B_X of the magnetic flux density:

$$B_{XL} = \Delta B_{XL} \times \cos(\alpha) + B_{Xoffset}$$

$$B_{XR} = \Delta B_{XR} \times \sin(\alpha) + B_{Xoffset}$$

wherein ΔB_{XL} and $B_{Xoffset}$ are the amplitude and the offset value of component B_X at the location of the XMR sensor L1, and ΔB_{XR} is the amplitude of component B_X at the location of the XMR sensor R1.

The first XMR sensor R1 and the second XMR sensor L1 may additionally be selected such that they exhibit identical sensitivity.

When making the above-described selection of XMR sensors and their positioning, both background $B_{Xoffset}$ and amplitudes ΔB_{XL} and ΔB_{XR} should be regarded as identical for the two detection signals.

The rotation angle difference $\Delta\alpha$ between the first target wheel 10 and the second target wheel 20 is detected via the detection signals from four XMR sensors.

The mechanical rotation angle $\Omega = \frac{\alpha}{N}$ of the first target wheel 10 is ascertained by the electrical detection signals output by the first XMR sensor R1 and second XMR sensor L1, which are directly proportional to the parallel components of the magnetic field B_{XR1} and B_{XL1} at the location of the respective XMR sensor R1 or L1:

$$B_{XR1} = \Delta B_{X1} \times \sin(\alpha) + B_{X1offset}$$

$$B_{XL1} = \Delta B_{X1} \times \cos(\alpha) + B_{X1offset}$$

wherein ΔB_{X1} and $B_{X1,offset}$ are the amplitude and the offset value of components B_{XR1} and B_{XL1} .

The first and second target wheels 10, 20 are coupled together as in the first embodiment by a torsion element. This results, in the second embodiment, in a difference $\Delta\alpha$ between the rotation angles of the first and second target wheels 10, 20 owing to the torque applied to the target wheels.

The relative rotation angle $\alpha + \Delta\alpha$ of the second target wheel 20 is ascertained by a second sensor pair. The second sensor pair comprises a third XMR sensor R2 and a fourth XMR sensor L2, which likewise output two electrical detection signals proportional to the following components:

$$B_{XR2} = \Delta B_{X2} \times \sin(\alpha + \Delta\alpha) + B_{X2offset}$$

$$B_{XL2} = \Delta B_{X2} \times \cos(\alpha + \Delta\alpha) + B_{X2offset}$$

wherein ΔB_{X2} and $B_{X2offset}$ are the amplitude and offset value of components B_{XR2} and B_{XL2} , and $\alpha + \Delta\alpha$ is the rotation angle of the second target wheel 20.

In the exemplary embodiment all the XMR sensors have similar characteristics, in particular with regard to their sensitivity and spacing from the respective target wheels. The amplitudes and offset values of the detection signals for the respective XMR sensors may therefore be regarded as identical.

The amplitudes and offsets of the respective detection signals are determined by the above-described methods, and the sine and cosine values of the rotation angles α and $\alpha + \Delta\alpha$ are calculated by the corrected detection signals.

The corrected detection signals $B_{XL1,corr}$ and $B_{XR1,corr}$ of the XMR sensor L1 and of the XMR sensor R1 are then calculated as follows:

$$\cos(\alpha) = \frac{B_{XL1} - B_{X1offset}}{\Delta B_{X1}} = B_{XL1,corr}$$

$$\sin(\alpha) = \frac{B_{XR1} - B_{X1offset}}{\Delta B_{X1}} = B_{XR1,corr}$$

The corrected detection signals $B_{XL2,corr}$ and $B_{XR2,corr}$ of the XMR sensor L2 and of the XMR sensor R2 are calculated as follows:

$$\cos(\alpha + \Delta\alpha) = \frac{B_{XL2} - B_{X2offset}}{\Delta B_{X2}} = B_{XL2,corr}$$

$$\sin(\alpha + \Delta\alpha) = \frac{B_{XR2} - B_{X2offset}}{\Delta B_{X2}} = B_{XR2,corr}$$

According to the sine-cosine formula $\sin[\alpha - (\alpha + \Delta\alpha)]$ for small angles, the difference angle may be calculated as follows:

$$-\Delta\alpha = \frac{B_{XL1} - B_{X1offset}}{\Delta B_{X1}} \times \frac{B_{XR2} - B_{X2offset}}{\Delta B_{X2}} - \frac{B_{XR1} - B_{X1offset}}{\Delta B_{X1}} \times \frac{B_{XL2} - B_{X2offset}}{\Delta B_{X2}}$$

or may be calculated directly with regard to the corrected detection signals using the following formula:

$$-\Delta\alpha = B_{XL1,corr} \times B_{XR2,corr} - B_{XR1,corr} \times B_{XL2,corr}$$

In this embodiment as in the first embodiment, the device for measuring torque comprises a processing unit for carrying out the above-described operations.

Calculation of the corrected detection signals and rotation angle difference then accordingly proceeds by analogue electronic operations (multiplication, subtraction, comparison), as discussed above in relation to the first embodiment. Signal processing may also be carried out digitally in a digital signal processor (DSP).

Because of the identical nature, addressed above, of the amplitudes and offset values of the individual detection signals for each pair of XMR sensors, these only need to be calculated once however. The processing unit may therefore also be simplified accordingly. As shown in Fig. 6, in the second embodiment the processing unit 6 comprises just two peak detectors 610, 620, which ascertain the maximum and minimum values of the detection signals for each pair of XMR sensors. The offset value and the amplitude are calculated for these detection signals by means of the ascertained maximum and minimum values, as discussed in relation to the first exemplary embodiment.

The peak detector 610 ascertains the maximum and minimum value of the detection signal from an XMR sensor of the first sensor pair R1, L1, for example the XMR sensor R1, and calculates the offset value $B_{X1,offset}$ and the amplitude ΔB_{X1} for the two XMR sensors R1 and L1.

The offset value $B_{X2,offset}$ and the amplitude ΔB_{X2} for the XMR sensors of the second sensor pair R2, L2 are calculated by the second peak detector 620, which ascertains the maximum and minimum values of the detection signal of just one XMR sensor of the second sensor pair R2, L2, for example the XMR sensor R2.

The calculated offset values and amplitudes are then sent to the subtraction units and division units. The corrected detection signals are here calculated by separate subtraction units 320, 321, 322, 323 and division units 330, 331, 332, 333 for each XMR sensor R1, L1, R2, L2, as described in the first embodiment.

The rotation angle difference $\Delta\alpha$ is then calculated from the corrected detection signals $B_{XL1,corr}$, $B_{XR1,corr}$, $B_{XL2,corr}$, $B_{XR2,corr}$ by the two multiplication units 340, 341 and the division unit 350. These operations correspond substantially to the processing unit 3 illustrated in Fig. 3 and are therefore not described again.

In one advantageous variant the processing unit 3 of the first embodiment may be used to determine maximum and minimum values of the detection signal of each XMR sensor and to ascertain the corresponding offset value and the amplitude for the respective XMR sensor.

Calculation of the corrected detection signals and rotation angle difference then proceeds as for the above-described processing unit 3.

The invention is nevertheless not limited to the described exemplary embodiments.

In the first and second embodiments the bias magnetic field of each magnetic sensor is provided, or generated, by the same bias field-generating element 40. Alternatively, the bias magnetic field may be provided, or generated, for each magnetic sensor by a separate bias field-generating element. This element may be integrated in each sensor component. Advantageously, the bias field-generating element may be replaced in the second embodiment by two permanent magnets, in each case one for each sensor pair. Since the background effect of the bias field in the detection signal from each magnetic sensor may advantageously be compensated by the present invention, differences between the individual, bias field-generating elements may be simply cancelled out.

In the embodiments illustrated, the target wheel is a toothed wheel, which is made from ferromagnetic material with a radial tooth/gap geometry.

In one advantageous variant the target wheel may also be made integral with the rotatable shaft. In another alternative embodiment the magnetic targets may be set directly into the rotatable shaft.

In another advantageous embodiment, instead of the target wheel illustrated, a tubular rotatable element may be used, which comprises a plurality of annularly arranged orifices as targets. In this case, the tubular element may itself consist of a magnetic material.

CLAIMS:

1. A device for measuring the rotation angle of a rotatable body, comprising:

detection means (50, R1, L1), which are designed to output a detection signal which indicates a change in a magnetic field induced by the rotation of one of a number of targets (30) fixed to the rotatable body,

means of applying a bias field (40) to the detection means (50, R1, L1); and

signal processing means (3), which are such that they ascertain a background component caused by the bias field in the detection signal and output a compensated detection signal.
2. A device according to claim 1, wherein the signal processing means (3) are designed to ascertain a minimum and a maximum value in the amplitude of the detection signal, to calculate an offset value and a distance value of the detection signal using the ascertained minimum and maximum values, and to compensate the detection signal.
3. A device according to claim 2, wherein the offset value is a mean of the ascertained minimum and maximum values and the distance value is the difference between the ascertained minimum and maximum values.
4. A device according to any one of the preceding claims, wherein the detection signal is compensated after a predetermined number of detection periods.
5. A device according to any one of the preceding claims, wherein the detection means (50, R1, L1) are designed to output a detection signal which contains a first detection signal and a second detection signal with a phase difference of 90 degrees.
6. A device according to any one of the preceding claims, wherein the first detection signal corresponds to a component of the magnetic field parallel to the side (55) facing the targets (30) of the detection means (50, R1, L1), and the second detection signal corresponds to a component of the magnetic field perpendicular to the side (55) facing the targets (30) of the detection means (50, R1, L1).

7. A device according to any one of the preceding claims, wherein the detection means contain a 3D Hall sensor (50).
8. A device according to claim 5, wherein the detection means contain a first magneto-resistive sensor (R1) for outputting the first detection signal and a second magneto-resistive sensor (L1) for outputting the second detection signal, wherein the first and second detection signals correspond to a component of the magnetic field parallel to the side (55) facing the targets (30) of the respective magneto-resistive sensor (R1, L1).
9. A device according to claim 8, wherein the first (R1) and second (L1) magneto-resistive sensors are spaced such that the first and second detection signals exhibit a phase difference of 90 degrees.
10. A device according to any one of the preceding claims, wherein the rotatable body is a target wheel (10) with a tooth/gap profile with magnetic targets (30).
11. A device according to any one of the preceding claims, which comprises the rotatable body (10).
12. A device for measuring a torque applied to a shaft, which comprises:
 - a first device according to any one of claims 1 to 10 for measuring the rotation angle of the shaft,
 - a second device according to any one of claims 1 to 10 for measuring the rotation angle of a second shaft,
 - wherein the shaft is connected coaxially to the second shaft by a torsion element, and
 - wherein the torque is determined proportionally to the difference rotation angle from the rotation angle of the shaft and the rotation angle of the second shaft.
13. A device according to claim 12, wherein the shaft is the steering shaft of a steering system.
14. A steering system, comprising a device according to any one of the preceding claims.

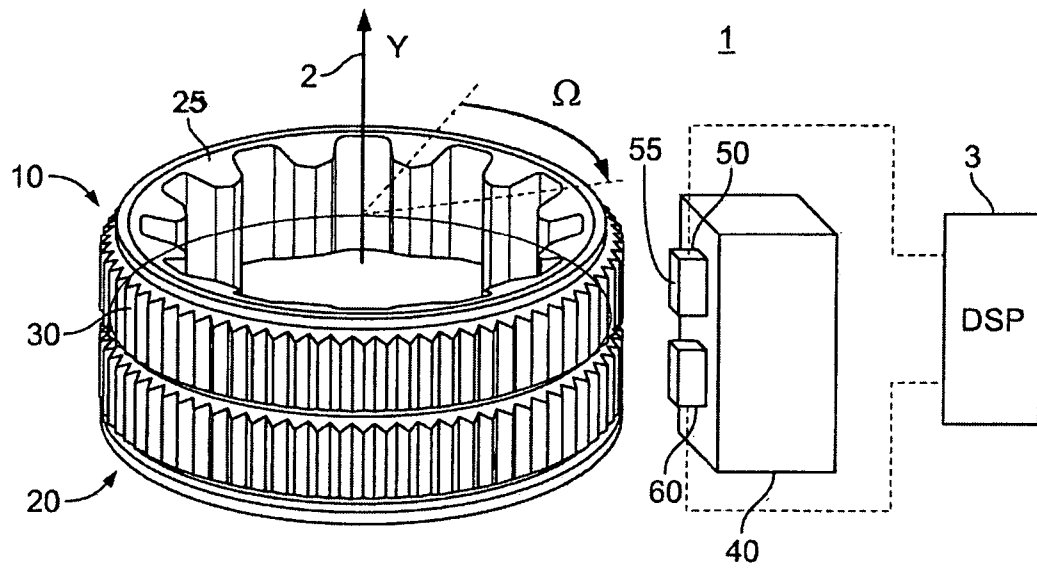
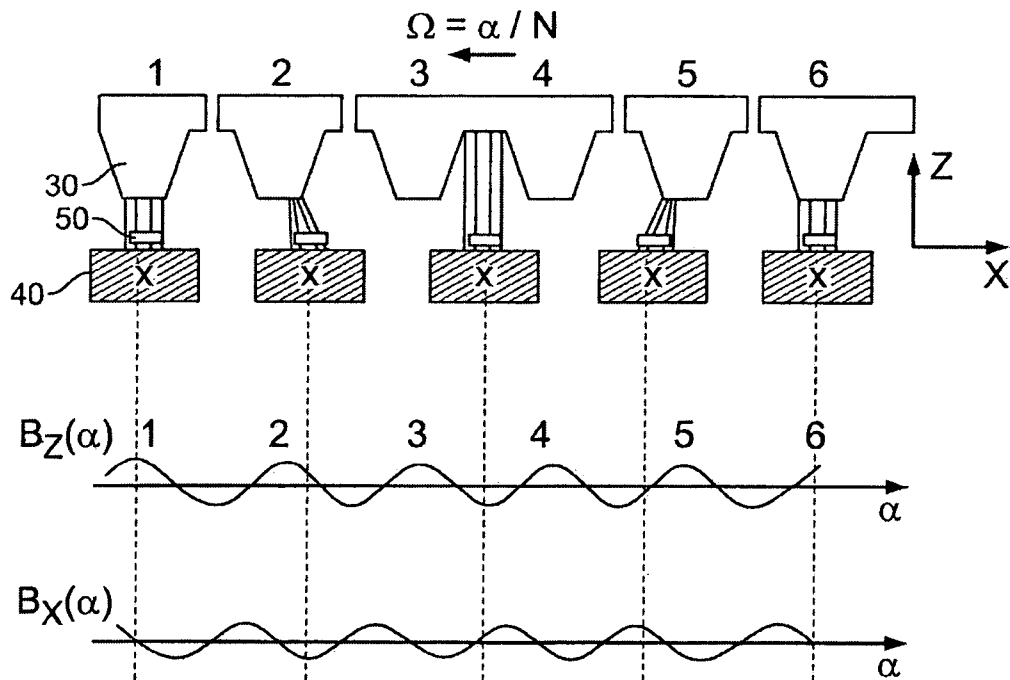


Fig. 1



$$B_Z = \Delta B_Z \times \cos(\alpha) + B_{Z\text{offset}} \quad B_X = \Delta B_X \times \sin(\alpha) + B_{X\text{offset}}$$

Fig. 2

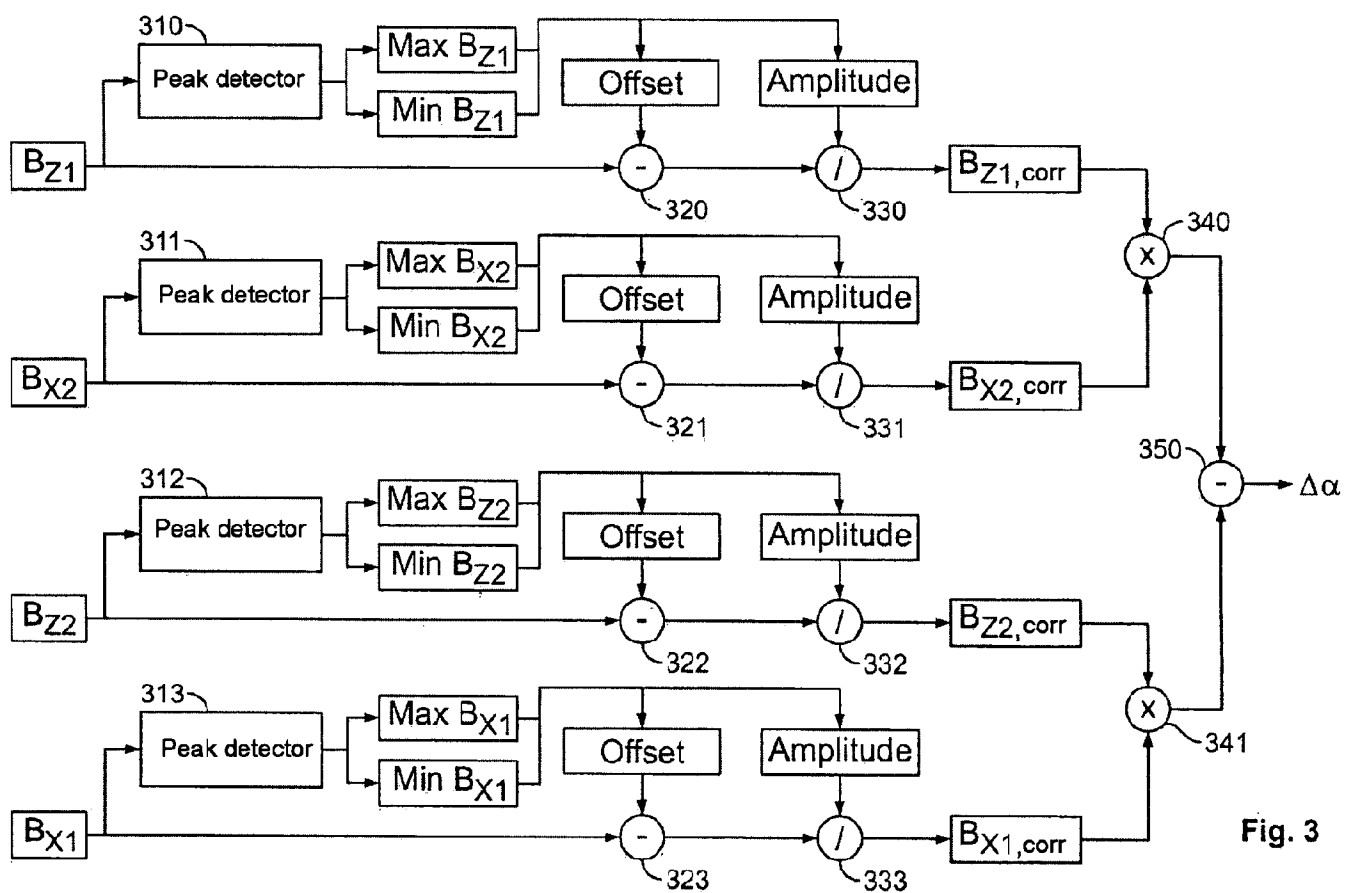


Fig. 3

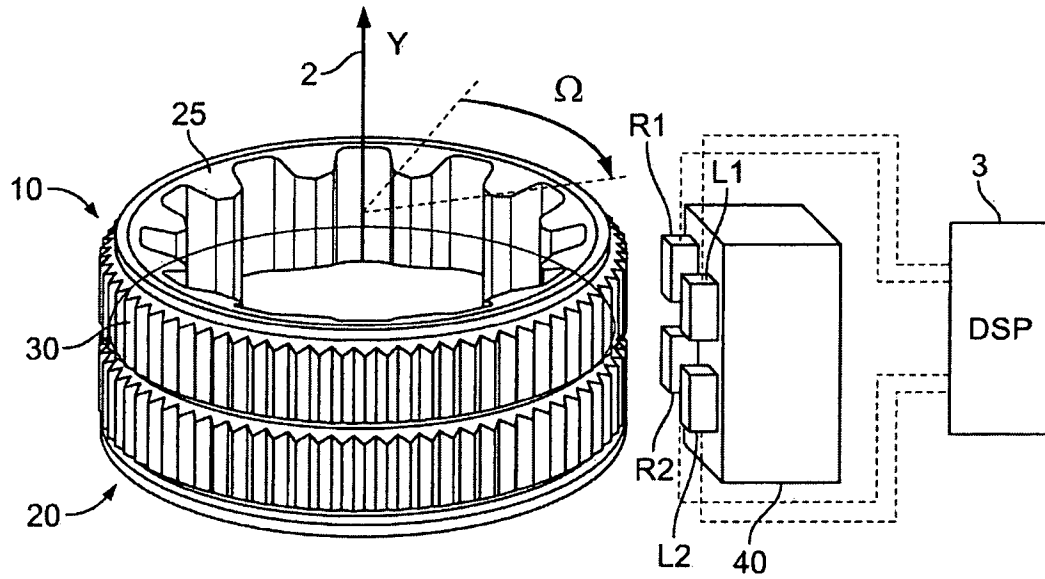
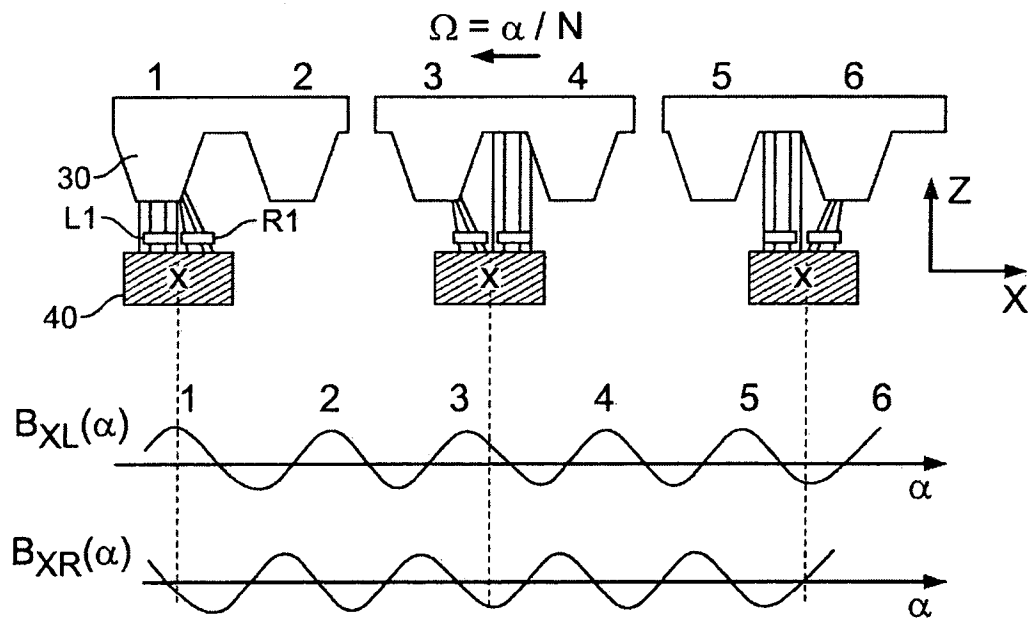


Fig. 4



$$B_{XL} = \Delta B_X \times \cos(\alpha) + B_{Xoffset}$$

$$B_{XR} = \Delta B_X \times \sin(\alpha) + B_{Xoffset}$$

Fig. 5

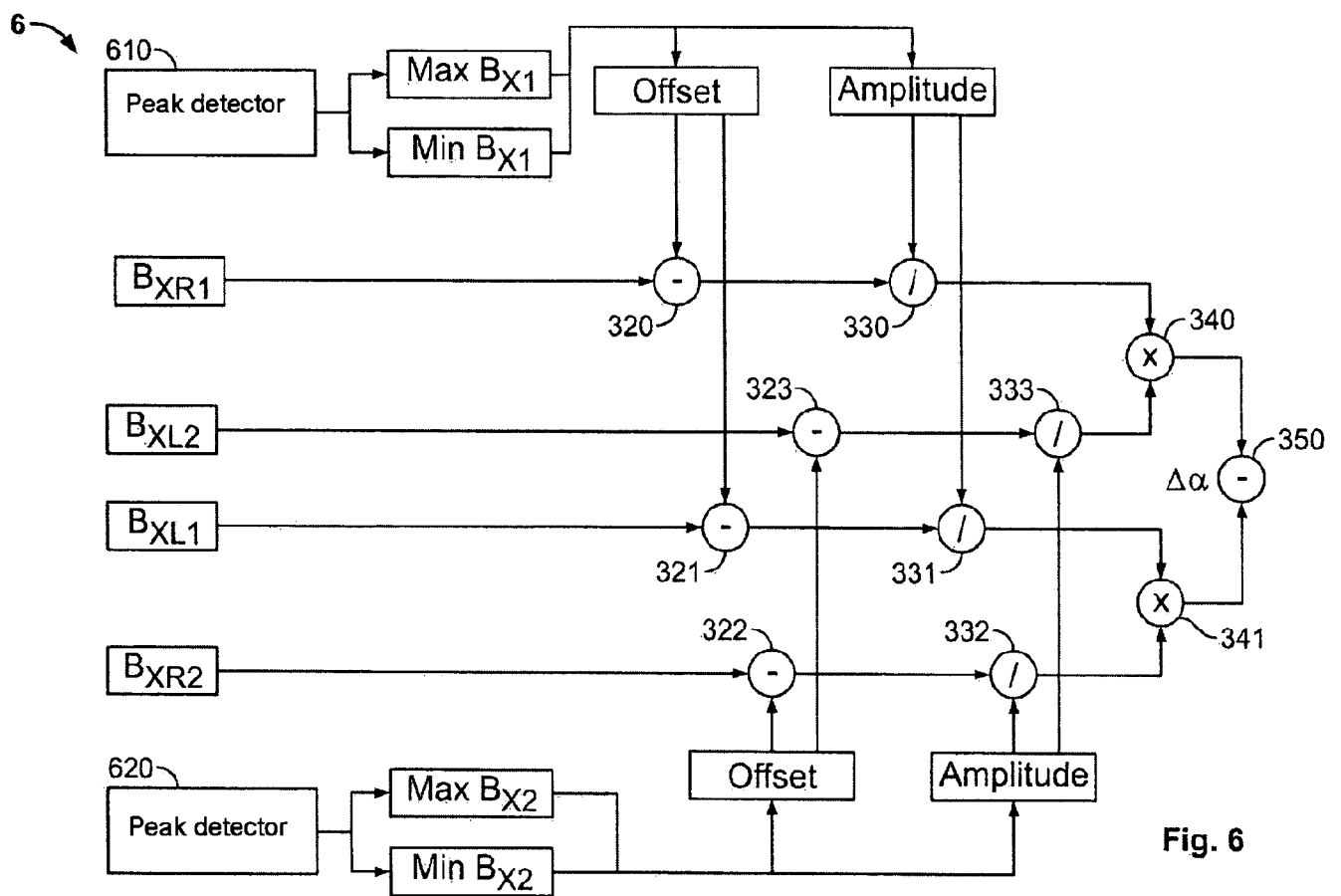


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2011/062117

A. CLASSIFICATION OF SUBJECT MATTER		
INV.	G01L3/10	G01L5/22
	B62D15/02	
		G01D5/244
		B62D5/04
		B62D6/10
ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols)		
G01D G01L B62D		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practical, search terms used)		
EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2003/178989 A1 (VIG RAVI [US] ET AL) 25 September 2003 (2003-09-25) paragraph [0005] - paragraph [0007] paragraph [0023] - paragraph [0028] figures 1-5	1-14
X	DE 100 60 287 A1 (BOSCH GMBH ROBERT [DE]) 7 June 2001 (2001-06-07) page 4, line 25 - page 7, line 59 figures 1-10	1-14
A	US 2003/076090 A1 (MUTH MICHAEL [DE]) 24 April 2003 (2003-04-24) paragraphs [0001], [0002] paragraph [0012] paragraph [0019] - paragraph [0021] figure 1	1-5, 10-14
	-/--	
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art. "&" document member of the same patent family		
Date of the actual completion of the international search		Date of mailing of the international search report
7 October 2011		20/10/2011
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Reto, Davide

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2011/062117

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 445 178 B1 (HOEKSTRA ERIC J [US]) 3 September 2002 (2002-09-03) column 3, line 57 - line 66 column 8, line 35 - line 43 -----	1-5

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2011/062117

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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DE 10060287	A1	07-06-2001	DE 10041095 A1 07-06-2001
US 2003076090	A1	24-04-2003	DE 10148918 A1 10-04-2003 EP 1300651 A2 09-04-2003
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