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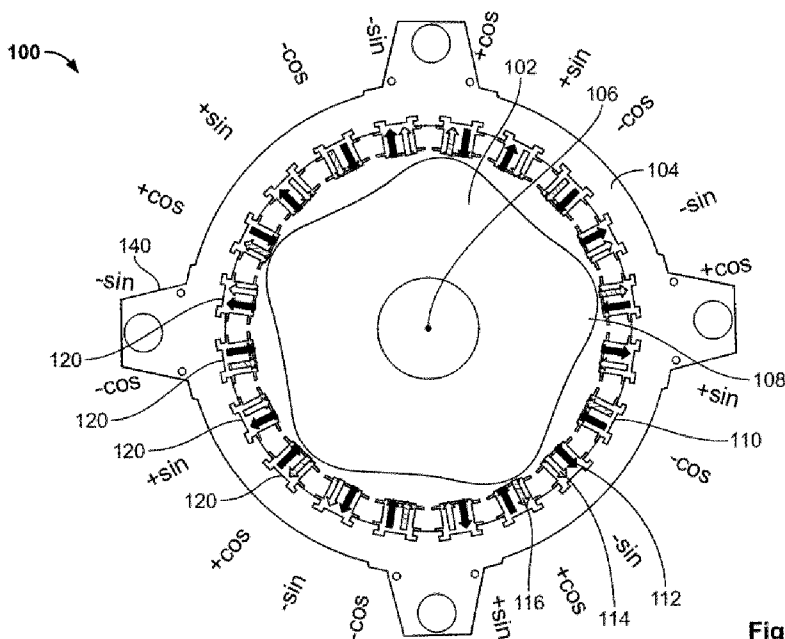
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(54) Title: MAGNETOELECTRONIC ANGLE SENSOR HAVING FOUR RETENTION DEVICES



(57) Abstract: The present invention relates to a magnetoelectronic angle sensor having an at least partially ferromagnetic stator and an at least partially ferromagnetic rotor (102) which are opposite each other, with an air gap being formed. The rotor (102) has p lobes which are arranged in such a manner that the magnetic resistance in the air gap changes periodically when the rotor (102) rotates about a rotation axis (106). p is a natural number which is greater than or equal to 2. The stator comprises a stator yoke (104) and teeth (110) which are separated from each other by grooves. There is provided on the stator teeth a magnetic field exciter which produces a predetermined magnetic flux distribution in the air gap and a magnetic flux receiver. The magnetic field exciter may also be provided on the rotor. In addition, the stator has identical retention devices (140) or identical magnetic discontinuities which are distributed in a uniform manner in the peripheral direction of the stator and which are arranged in such a manner with respect to the magnetic field exciter that the signal distortions induced by the re-

Fig. 1

tention devices or magnetic discontinuities in the magnetic flux receiver are compensated for / reduced in an output signal of the angle sensor.



**MAGNETOELECTRONIC ANGLE SENSOR HAVING FOUR RETENTION DEVICES**

The present invention relates to a magnetoelectronic angle sensor, in particular a reluctance resolver having a rotationally symmetrical, at least partially ferromagnetic stator and a rotationally symmetrical, at least partially ferromagnetic rotor, which are opposite each other, with an air gap being formed. The rotor has  $p$  lobes which are arranged in such a manner that the magnetic resistance in the air gap changes periodically when the rotor rotates about a rotation axis. The stator has a stator yoke and  $4p$  teeth which are separated from each other by grooves. On the stator or the rotor there is arranged a magnetic field exciter which produces a predetermined magnetic flux distribution in the air gap. This is detected by a magnetic flux receiver which is arranged on the stator teeth and which comprises a secondary sinusoidal winding and a secondary cosine winding which is offset through  $90$  electrical degrees relative to the secondary sine winding. Furthermore, the stator has four identical retention devices or four identical magnetic discontinuities which are distributed in a uniform manner in the peripheral direction of the stator.

Angle sensors which are based on the principle of a changing magnetic flux intensity in the air gap between the stator and rotor are known in many varieties. In principle, various principles for producing and detecting the magnetic flux are considered in this instance. In synchro-systems (resolvers, synchros), electromagnetic coils in the form of primary and secondary windings are used. Synchro-systems in the form of resolvers or synchros are known as precise and robust angle sensors. In so-called passive reluctance resolvers, both the primary winding and the secondary winding are accommodated in

the stator, whilst the rotor influences the magnetic flux distribution without any winding, that is to say, passively, only with magnetically soft components. Owing to a non-uniform construction of the rotor, for example, by providing lobes, the magnetic flux between the primary windings and the secondary windings in the stator is influenced in a different manner, from which the angular position of the rotor with respect to the stator can be derived via the induced voltage.

Figure 2 is a schematic cross-section through a five-speed resolver 200 having five assembly projections 240 which are fitted to the stator, as known from the prior art. In this instance, a ferromagnetic rotor 202 is rotatably supported within a stator 204 about a rotation axis 206. The rotor has five lobes 208 which bring about a variable air gap between the teeth of the stator and the rotor during rotation about the axis. In the case of a rotor having five lobes, the magnetic resistance changes in the air gap with a period of  $360^\circ/5 = 72^\circ$  when the rotor rotates once about the rotation axis. Consequently, resolvers having such rotors are referred to as five-speed resolvers.

The stator of the five-speed resolver 200 shown in Figure 2 has a total of 20 teeth 210. From US 5,300,884, it is known that the number of teeth arranged on the stator is generally  $2np$ ,  $n$  being equal to 2 for a resolver and  $n$  being equal to 3 for a synchro, and  $p$  being the number of lobes formed on the rotor. For a resolver, the number of teeth provided on the stator is accordingly equal to  $4p$ . Furthermore, the stator 204 has five assembly projections 240 which are arranged in a state distributed in a uniform manner in the peripheral direction of the stator. Using the five assembly projections,

the five-speed resolver is mounted on an electrical machine, for example, an electric motor.

Each tooth 210 of the stator 204 carries a primary winding and a secondary winding. The secondary winding is constructed either as a secondary sine winding or as a secondary cosine winding. Through the primary winding flows an alternating current which produces a varying magnetic flux in the respective tooth. This induces in the secondary winding a signal whose size (amplitude) is dependent on the magnetic flux. The magnetic fluxes which occur on the teeth 210 are indicated in Figure 2 with arrows: the arrow 212 indicates the direction of the magnetic flux produced by a primary winding when the current through the primary winding is positive; the arrow 214 indicates the direction of a magnetic flux which induces a positive voltage in a secondary sine winding; and an arrow 216 indicates the direction of a magnetic flux which induces a positive voltage in a secondary cosine winding. All the primary windings are arranged in series and wound or wired in such a manner that the magnetic flux produced by them in two adjacent teeth is directed in opposing directions. In addition, the primary windings are arranged on the stator teeth (210) in such a manner that they produce a magnetic flux which extends radially in the teeth.

With regard to the secondary windings, the 20 teeth of the stator shown in Figure 2 can be divided into five groups of four sequential teeth. In this instance, the first tooth of a group in each case carries a first secondary cosine winding (indicated with "+cos" in Figure 2), the second tooth of a group in each case carries a first secondary sine winding (indicated with "+sin" in Figure 2), the third tooth of a group in each case carries a second secondary cosine winding

(indicated with "-cos" in Figure 2) and the fourth tooth of a group in each case carries a second secondary sine winding (indicated with "-sin" in Figure 2). The first secondary cosine winding of each group is offset through 90 electrical degrees relative to the first secondary sine winding of the respective group. The second secondary cosine winding of each group is offset through 90 electrical degrees relative to the second secondary sine winding of the respective group. The first secondary sine winding and the second secondary sine winding of each group are wound or wired in such a manner that the signals induced in them extend in opposing directions. The first secondary cosine winding and the second secondary cosine winding of each group are wound or wired in such a manner that the signals induced in them extend in opposing directions. In addition, the first secondary cosine winding of a group is wound or wired in such a manner that a positive voltage is induced therein when the magnetic flux which induces the voltage in the first secondary cosine winding is directed in an opposing manner to the magnetic flux which is produced by the primary winding of the first tooth, and the first secondary sine winding of the same group is wound or wired in such a manner that a positive voltage is induced therein when the magnetic flux which induces the voltage in the first secondary sine winding is directed in an opposing manner to the magnetic flux which is produced by the primary winding of the second tooth.

The angular value for the relative position of the rotor with respect to the stator can be derived from two output signals of the angle sensor, the first output signal of which is equal to the sum of the signals induced in the secondary sine windings, and the second output signal is equal to the sum of the signals induced in the secondary cosine windings.

Figure 2 shows that a uniform distribution of the five assembly projections along the outer stator periphery leads to all five assembly projections being arranged in the vicinity of teeth which have identical secondary windings. For example, in Figure 2 each assembly projection is arranged in the vicinity of a tooth having a first cosine winding and in the vicinity of a tooth having a first secondary sine winding. This arrangement has the following disadvantage:

Each assembly projection acts as a magnetic discontinuity which influences the magnetic flux distribution in the stator. Each assembly projection thereof distorts the induced signal in the secondary windings closest to it. Measurements and computer simulations have shown that the induced voltage in a secondary winding which is arranged beside an assembly projection is greater than the induced voltage in a secondary winding which is not arranged beside an assembly projection.

The distortions of the signals induced in the secondary windings brought about by the assembly projections accumulate in the two output signals of the arrangement shown in Figure 2, since the signals produced in the first secondary cosine windings are always distorted and since the signals in all first secondary cosine windings or the first secondary sine windings have the same polarity. In order to compensate for the distortion of the two output signals by the magnetic projections, there are arranged on the stator shown in Figure 2 five additional ferromagnetic portions between the five assembly projections.

The distortions of the signals induced in the first secondary cosine windings and the first secondary sine windings, which

distortions are caused by the assembly projections, are compensated for when a distortion of the signals induced in the second secondary cosine windings and second secondary sine windings is brought about. Consequently, the additional ferromagnetic portions in Figure 2 are arranged in the vicinity of teeth having a second secondary cosine winding and a second secondary sine winding. However, the additional ferromagnetic portions narrow the space around the stator, which impairs the guiding of lines, fitting of a wiring board, etcetera. Complete compensation by fitting additional ferromagnetic portions can practically also hardly be carried out.

Generally, the stator is composed of magnetically soft metal sheets. These are punched from a large metal sheet with a punching tool. The punched metal sheets generally have a permeability which is dependent on the direction, which has an unfavourable effect on the precision of the angle sensor. In addition, owing to mechanical tensions which are already present in the original material, the metal sheets are mechanically deformed (curved) during the punching operation. The dimension of the teeth and the position thereof on the stator are also subjected to tolerances.

In order to compensate for the influence of the direction-dependent permeability, the mechanical deformations of the metal sheets and the tolerance differences of the teeth on the precision of the angular value determination, the metal sheets are first rotated with respect to each other before being stacked one on the other. The assembly projections and teeth of a rotating metal sheet then overlap with the assembly projections and teeth of a non-rotated metal sheet only when the relationship between the number of teeth

arranged on the stator and the number of assembly projections provided on the stator is a whole number.

It is known that this condition is complied with for a stator having  $4p$  teeth when the number of assembly projections is equal to  $p$ . Table 1 sets out the minimum number of assembly projections to be provided on a stator for a stator having  $4p$  teeth.

Table 1

Number of lobes on the rotor ( $p$ )	Number of teeth on the stator ( $4p$ )	Number of assembly projections
2	8	2
3	12	3
4	16	4
5	20	5
6	24	6
7	28	7
8	32	8
9	36	9
10	40	10

In Table 1, it can clearly be seen that for values of  $p$  greater than 4, the number of assembly projections to be provided is greater than the number of assembly projections which is required to ensure adequate fixing of the angle sensor. Generally, four assembly projections are completely adequate for this purpose. In special cases, however, only two assembly projections may also be sufficient to secure the angle sensor to an application.

The number of assembly projections set out in Table 1 is absolutely required in order to ensure complete covering of the teeth or assembly projections during a rotation of the metal sheets with respect to each other. Since, as shown in Table 1, the number of assembly projections provided on the

stator increases significantly as the value of  $p$  increases (that is, the number of lobes on the rotor), it is desirable for all  $p$  values to provide stator configurations with a maximum of four assembly projections.

An object of the present invention is therefore to provide an angle sensor which has four assembly projections provided on the stator, which can be produced in a particularly simple and cost-effective manner and which further has improved precision.

Another object of the present invention is to provide an angle sensor which has two assembly projections provided on the stator, which can be produced in a particularly simple and cost-effective manner and which further has improved precision.

Another object of the present invention is to compensate for the signal distortions caused by the assembly projections, without having to fit additional ferromagnetic portions to the stator.

An angle sensor (passive reluctance resolver) according to the present invention comprises a rotor and a stator which are opposite each other, with an air gap being formed, the rotor being provided with an uneven number of lobes  $p$  which are arranged in such a manner that the magnetic resistance in the air gap changes periodically when the rotor rotates about a rotation axis, and the stator being provided with  $4p$  teeth which are separated from each other by grooves. There are further arranged on the stator: a magnetic field exciter which produces a predetermined magnetic flux distribution in the air gap, a magnetic flux receiver and four identical

retention devices which are distributed in a uniform manner in the peripheral direction of the stator. The magnetic flux receiver is arranged on a stator tooth and comprises a secondary sine winding and a secondary cosine winding which is offset through 90 electrical degrees relative to the secondary sine winding.

Another angle sensor according to the present invention comprises a rotor and a stator which are opposite each other with an air gap being formed, the rotor being provided with  $p$  lobes which are arranged in such a manner that the magnetic resistance in the air gap changes periodically when the rotor rotates about a rotation axis and the stator is provided with  $4p$  teeth which are separated from each other by grooves. There are further arranged on the stator: a magnetic field exciter which produces a predetermined magnetic flux distribution in the air gap, a magnetic flux receiver and two identical retention devices which are distributed in a uniform manner in the peripheral direction of the stator. The magnetic flux receiver (also commonly termed magnetic field receiver) is arranged on a stator tooth and comprises a secondary sine winding and a secondary cosine winding which is offset through 90 electrical degrees relative to the secondary sine winding.

In the present invention, the magnetic field exciter may also be arranged on the rotor.

In the present invention, in place of the four identical retention devices, four identical magnetic discontinuities may be provided.

According to an advantageous embodiment of the present invention, the magnetic field exciter (also commonly termed magnetic flux exciter) comprises a primary winding, which is arranged on a stator tooth.

According to another advantageous embodiment of the present invention, the stator is arranged outside the rotor.

However, the rotor could also be arranged outside the stator. In this instance the stator teeth are then arranged on the outer edge of the stator yoke and the lobes are formed on the inner edge of the rotor.

According to another advantageous embodiment of the present invention, the retention device is a hole which is provided in the stator yoke.

According to another advantageous embodiment of the present invention, the magnetic field exciter comprises  $4p$  primary windings which are arranged in series, a primary winding being provided on each stator tooth and the primary windings being wound or wired in such a manner that the magnetic flux which is produced by them in two adjacent teeth is directed in opposing directions.

According to another advantageous embodiment of the present invention, the magnetic flux receiver comprises  $2p$  secondary sine windings and  $2p$  secondary cosine windings, and the  $4p$  teeth of the stator form  $p$  groups of four sequential teeth each, a first secondary cosine winding being arranged on the first tooth of each group, a first secondary sine winding being arranged on the second tooth of each group, a second secondary cosine winding being arranged on the third tooth of

each group, a second secondary sine winding being arranged on the fourth tooth of each group, the first secondary cosine winding of each group being offset through 90 electrical degrees with respect to the first secondary sine winding of the respective group, the second secondary sine winding of each group being offset through 90 electrical degrees with respect to the second secondary sine winding of the respective group, the first secondary sine winding and the second secondary sine winding of each group being wound or wired in such a manner that the signals which are induced therein extend in opposing directions and the first secondary cosine winding and the second secondary cosine winding of each group being wound or wired in such a manner that the signals which are induced therein extend in opposing directions.

According to another advantageous embodiment of the present invention, a first output signal of the angle sensor is equal to the sum of the signals induced in the  $2p$  secondary sine windings, a second output signal of the angle sensor is equal to the sum of the signals induced in the  $2p$  secondary cosine windings, and the angular value for the relative position of the rotor with respect to the stator can be derived from the first output signal and the second output signal.

According to another advantageous embodiment of the present invention, the first secondary cosine winding of a group is wound or wired in such a manner that a positive voltage is induced therein when the magnetic flux which induces the voltage in the first secondary cosine winding is directed counter to the magnetic flux produced by the primary winding of the first tooth, and the first secondary sine winding of a group is wound or wired in such a manner that a positive

voltage is induced therein when the magnetic flux which induces the voltage in the first secondary sine winding is directed counter to the magnetic flux produced by the primary winding of the second tooth.

In order to compensate for the signal distortions caused by the retention devices or the magnetic discontinuities, according to another advantageous embodiment of the present invention, the retention devices or the magnetic discontinuities are each arranged between two teeth, in such a manner that the signal distortions produced by them in the secondary windings of the two teeth are the same.

An advantage of the present invention is that a single punching tool is sufficient for the punching of all the stator sheets, which reduces the tool and production costs.

For better understanding of the present invention, it is explained in greater detail with reference to the embodiment illustrated in the following Figures. Furthermore, some features or feature combinations from the different embodiments shown and described may also constitute solutions which are independent per se, inventive or in accordance with the invention.

In the drawings:

Figure 1 is a schematic cross-section through a five-speed resolver having four assembly projections which are fitted to the stator according to an embodiment of the present invention;

Figure 2 is a schematic cross-section through a five-speed resolver having five assembly projections which are fitted to the stator according to the prior art.

Figure 1 is a schematic cross-section through a five-speed resolver 100 having four assembly projections 140 which are fitted to the stator according to an embodiment of the present invention. In this instance, a ferromagnetic rotor 102 is rotatably supported about a rotation axis 106 within a stator. The rotor has five lobes 108 which bring about a variable air gap between the teeth of the stator and the rotor during rotation about the axis 106.

The stator of the five-speed resolver 100 shown in Figure 1 has 20 teeth 110 and four assembly projections 140. The four assembly projections are arranged so as to be distributed in a uniform manner on the outer edge of the stator yoke 104, in the peripheral direction of the stator (that is to say, with angular spacing of 90 degrees). Using the four assembly projections 140, the five-speed resolver can be assembled on an electrical machine, for example, an electric motor.

Each tooth 110 of the stator carries a primary winding and a secondary winding. The secondary winding is constructed either as a secondary sine winding or as a secondary cosine winding. An alternating current which produces a varying magnetic flux in the tooth is passed through the primary winding of a tooth. This induces an (electrical) signal in the secondary winding of the tooth. In Figure 1, the magnetic fluxes produced in the teeth 110 are indicated by arrows: an arrow 112 indicates the direction of the magnetic flux produced by a primary winding when the current through the primary winding is positive; an arrow 114 indicates the direction of a magnetic flux which induces a positive voltage in a secondary sine winding; and an arrow 116 indicates the direction of a magnetic flux which induces a positive current

in a secondary cosine winding. All the primary windings are arranged in series and wound or wired in such a manner that the magnetic flux produced by them in two adjacent teeth is directed in opposing directions. In addition, the primary windings on the stator teeth 110 are arranged in such a manner that they produce a magnetic flux which extends radially in the teeth.

With regard to the secondary windings, the 20 teeth of the stator shown in Figure 1 are divided into five groups 120 of four sequential teeth each, respectively. The first tooth of a group in each case carries a first secondary cosine winding (designated "+cos" in Figure 1), the second tooth of a group in each case carries a first secondary sine winding (designated "+sin" in Figure 1), the third tooth of a group in each case carries a second secondary cosine winding (designated "-cos" in Figure 1), and the fourth tooth of a group in each case carries a second secondary sine winding (designated "-sin" in Figure 1). The first secondary cosine winding (+cos) of each group is offset through 90 electrical degrees with respect to the first secondary sine winding (+sin) of the respective group. The second secondary cosine winding (-cos) of each group is offset through 90 electrical degrees with respect to the second secondary sine winding (-sin) of the respective group. The first secondary sine winding (+sin) and the second secondary sine winding (-sin) of each group are wound or wired in such a manner that the signals induced therein extend in opposing directions. The first secondary cosine winding (+cos) and the second secondary cosine winding (-cos) of each group are wound or wired in such a manner that the signals induced therein extend in opposing directions. In addition, the first secondary cosine winding (+cos) of a group is wound or wired

in such a manner that a positive voltage is induced therein when the magnetic flux which induces the voltage in the first secondary cosine winding is directed in an opposing direction to the magnetic flux produced by the primary winding of the first tooth and the first secondary sine winding (+sin) of the same group is wound or wired in such a manner that a positive voltage is induced therein when the magnetic flux which induces the voltage in the first secondary sine winding is directed in an opposing direction to the magnetic flux produced by the primary winding of the second tooth.

The number of complete periods which the signal which can be tapped at the secondary windings passes through during a complete mechanical revolution, that is to say, 360 degrees, of the rotor, is equal to the number of lobes (108) provided on the rotor (102). This means that, in the case of a five-speed resolver, the electrical angle of 360 degrees is already achieved with a mechanical rotation of 72 degrees.

The angular value for the relative position of the rotor 102 with respect to the stator can be derived from two output signals of the angle sensor, of which the first output signal is equal to the sum of all of the signals induced in the secondary sine windings, and the second output signal is equal to the sum of all the signals induced in the secondary cosine windings.

The embodiment shown in Figure 1 enables the four assembly projections to be distributed along the stator periphery in such a manner that each of the four assembly projections is arranged in the vicinity of teeth which have different secondary windings. For example, in Figure 1, the upper assembly projection is arranged between a tooth having a

second secondary sine winding (-sin) and a tooth having a first secondary cosine winding (+cos), the lower assembly projection is arranged between a tooth having a first secondary sine winding (+sin) and a tooth having a second secondary cosine winding (-cos), the left assembly projection is arranged between a tooth having a second secondary sine winding (-sin) and a tooth having a second secondary cosine winding (-cos), and the right assembly projection is arranged between a tooth having a first secondary sine winding (+sin) and a tooth having a first secondary cosine winding (+cos).

Since each assembly projection acts as a magnetic discontinuity, each assembly projection distorts the signal which is induced in the secondary winding next to it. However, since these signal distortions relate both to first secondary sine windings and second secondary sine windings, and the signal distortions induced in the first secondary sine windings and the signal distortions induced in the second secondary sine windings have a different polarity, these signal distortions are reduced/compensated for in the output signal of the angle sensor. Similarly, since the signal distortions caused by the assembly projections relate both to first secondary cosine windings and second secondary cosine windings, and the signal distortions induced in the first secondary cosine windings and the signal distortions induced in the second secondary cosine windings have a different polarity, these signal distortions are reduced/compensated for in the output signal of the angle sensor.

The compensation of the signal distortions induced by the assembly projections in the output signals is optimum when each of the four assembly projections is arranged in such a

manner between two closest/adjacent teeth that the influence thereof on the teeth is equal. This is, for example, the case when the signal distortions induced in the secondary windings of the two teeth are identical.

The present invention is not limited to an embodiment in which the assembly projections are located between two teeth, but also includes embodiments in which each of the four assembly projections is located close to only one tooth and accordingly induces a signal distortion only in the secondary winding of this tooth.

Since, in the present invention, the signal distortions induced by the assembly projections are reduced/compensated for in the output signals, no additional ferromagnetic portions 224 are required between the assembly projections, as shown in Figure 2. Additional space for introducing lines, fitting the wiring board, etcetera, thereby remains.

The present invention is not limited to an angle sensor having five lobes which are constructed on the rotor and 20 teeth which are provided on the stator, that is to say,  $p = 5$ . Instead, Table 2 shows that, for all natural  $p$  values, from 2 to 10 angle sensors having four assembly projections provided on the stator can be set out and that all these angle sensors comply with the following condition:

$$\frac{\text{Number of teeth provided on the stator}}{\text{Number of assembly projections provided on the stator}} = m \quad (1)$$

$m$  being a whole number. This condition ensures that the assembly projections and teeth of a stator sheet which was rotated with respect to another stator sheet can be brought

into alignment with the assembly projections and teeth of the other stator sheet. If the condition 1 is complied with, then all the stator sheets can be punched with a single punching tool when the stator is produced, and the stator sheets which are punched in this manner can be rotated with respect to each other before being stacked one above the other in order to compensate for the influence of the direction-dependent permeability, the mechanical deformations and the tolerance differences. The angle sensor of the present invention can consequently be produced in a cost-effective manner and further has improved precision.

Table 2 sets out resolvers for  $p = 2, 3, \dots, 10$  and different numbers of assembly projections provided on the stator. The first column contains the number of lobes  $p$  formed on the rotor, the second column contains the number of teeth provided on the stator, which for resolvers is equal to  $4p$ , and the following columns contain for  $m = 2, 3, 4, \dots, 10$  the relationship between the number of teeth provided on the stator ( $4p$ ) and the respective  $m$  value. If this relationship is a whole number, it sets out the number of assembly projections provided on the stator which comply with the condition 1.

Table 2

Number of lobes $p$	Number of teeth $4p$	$4p/2$	$4p/3$	$4p/4$	$4p/5$	$4p/6$	$4p/7$	$4p/8$	$4p/9$	$4p/10$
2	8	4	2.7	2	1.6	1.3	1.1	1	0.9	0.8
3	12	6	4	3	2.4	2	1.7	1.5	1.3	1.2
4	16	8	5.3	4	3.2	2.7	2.3	2	1.8	1.6
5	20	10	6.7	5	4	3.3	2.9	2.5	2.2	2
6	24	12	8	6	4.8	4	3.4	3	2.7	2.4
7	28	14	9.3	7	5.6	4.7	4	3.5	3.1	2.8
8	32	16	10.7	8	6.4	5.3	4.6	4	3.6	3.2
9	36	18	12	9	7.2	6	5.1	4.5	4	3.6
10	40	20	13.3	10	8	6.7	5.7	5	4.4	4

Table 2 shows that, for each natural  $p$  which is greater than or equal to 2, a resolver with four assembly projections provided on the stator can be set out. Since four assembly projections are in most cases sufficient for securing the resolver to an application, and in particular resolvers with an uneven  $p$  are particularly advantageous, resolvers with four assembly projections provided on the stator and an uneven  $p$  are in accordance with the present invention.

It can further be seen in Table 2 that, for each natural  $p$  which is greater than or equal to 2, not only resolvers having four assembly projections provided on the stator, but also resolvers having two assembly projections provided on the stator can be set out. Since, in special cases, only two assembly projections are also sufficient in order to secure the angle sensor to an application, resolvers having only two assembly projections provided on the stator are also in accordance with the present invention.

Although the previous embodiments have always been based on an angle sensor having four assembly projections 140 arranged on the edge of the stator yoke 104, an angle sensor according to the present invention may also have a hole which is provided in the stator yoke and which acts as a retention device.

Although the previous embodiments have always been based on an angle sensor in which the stator is arranged outside the rotor 102, the teeth 110 are provided on the inner edge of the stator yoke 104 and the lobes are formed on the outer edge of the rotor 102, in an angle sensor according to the present invention the rotor may also be arranged outside the

stator, the teeth may be provided on the outer edge of the stator yoke and the lobes may be formed on the inner edge of the rotor.

Although the previous embodiments have always been based on an angle sensor in which the rotor does not contain any primary winding (passive reluctance resolver), in an angle sensor according to the present invention the primary winding may also be provided on the rotor.

**List of reference numerals:**

<b>Reference numeral</b>	<b>Description</b>
100	Reluctance resolver, magnetoelectronic angle sensor
102	Rotor
104	Stator yoke
106	Rotation axis
108	Lobe on the rotor
110	Tooth (Pole) on the stator
112	Magnetic flux through the primary winding
114	Magnetic flux which induces a positive voltage in a secondary sine winding
116	Magnetic flux which induces a positive voltage in a secondary cosine winding
120	Group of four sequential teeth
140	Retention device; assembly projection
200	Reluctance resolver; magnetoelectronic angle sensor
202	Rotor
204	Stator
206	Rotation axis
208	Lobe on the rotor
210	Tooth (Pole) on the stator
212	Magnetic flux through the primary winding
214	Magnetic flux which induces a positive voltage in a secondary sine winding
216	Magnetic flux which induces a positive voltage in a secondary cosine winding
224	Additional ferromagnetic portion
240	Retention device; assembly projection

**Patent Claims:**

1. Magneto-electronic angle sensor having an at least partially ferromagnetic stator and an at least partially ferromagnetic rotor (102) which are opposite each other, with an air gap being formed,

wherein the rotor (102) has  $p$  lobes which are arranged in such a manner that the magnetic resistance in the air gap changes periodically when the rotor (102) rotates about a rotation axis (106),  $p$  is an uneven natural number which is greater than or equal to 3, and

the stator has a stator yoke (104) and  $4p$  teeth (110) which are separated from each other by grooves,

having a magnetic field exciter which is arranged on the stator or the rotor (102) and which produces a predetermined magnetic flux distribution in the air gap,

having a magnetic flux receiver which is arranged on the stator teeth (110) and which has a secondary sine winding and a secondary cosine winding which is offset through 90 electrical degrees relative to the secondary sine winding, and

the stator further has four identical retention devices (140) or four identical magnetic discontinuities which are distributed in a uniform manner in the peripheral direction of the stator.

2. Magneto-electronic angle sensor having an at least partially ferromagnetic stator and an at least partially

ferromagnetic rotor (102) which are opposite each other, with an air gap being formed,

wherein the rotor (102) has  $p$  lobes which are arranged in such a manner that the magnetic resistance in the air gap changes periodically when the rotor (102) rotates about a rotation axis (106),  $p$  is a natural number which is greater than or equal to 2, and

the stator has a stator yoke (104) and  $4p$  teeth (110) which are separated from each other by grooves,

having a magnetic field exciter which is arranged on the stator or the rotor (102) and which produces a predetermined magnetic flux distribution in the air gap,

having a magnetic flux receiver which is arranged on the stator teeth (110) and which has a secondary sine winding and a secondary cosine winding which is offset through 90 electrical degrees relative to the secondary sine winding, and

the stator further has two identical retention devices (140) or two identical magnetic discontinuities which are distributed in a uniform manner in the peripheral direction of the stator.

3. Magneto-electronic angle sensor according to either claim 1 or claim 2, characterised in that the magnetic field exciter comprises at least one primary winding which is arranged on a stator tooth (110).

4. Magneto-electronic angle sensor according to any one of claims 1 to 3, characterised in that the stator is arranged outside the rotor (102), the teeth (110) are arranged on the inner edge of the stator yoke (104) and the lobes are formed on the outer edge of the rotor (102).

5. Magneto-electronic angle sensor according to any one of claims 1 to 3, characterised in that the rotor is arranged outside the stator, the teeth are arranged on the outer edge of the stator yoke and the lobes are formed on the inner edge of the rotor.

6. Magneto-electronic angle sensor according to any one of claims 3 to 5, characterised in that the magnetic field exciter comprises  $4p$  primary windings which are arranged in series, a primary winding being provided on each stator tooth (110) and the primary windings being wound or wired in such a manner that the magnetic flux produced by them in two adjacent teeth has opposing directions.

7. Magneto-electronic angle sensor according to claim 6, characterised in that the magnetic flux receiver comprises  $2p$  secondary sine windings and  $2p$  secondary cosine windings,

the  $4p$  teeth of the stator form  $p$  groups (120) of four sequential teeth each,

a first secondary cosine winding being arranged on the first tooth of each group (120), a first secondary sine winding being arranged on the second tooth of each group (120), a second secondary cosine winding being arranged on the third tooth of each group (120) and a second secondary sine winding being arranged on the fourth tooth of each group (120),

the first secondary cosine winding of each group (120) being offset through 90 electrical degrees with respect to the first secondary sine winding of the respective group,

the second secondary cosine winding of each group (120) being offset through 90 electrical degrees with respect to the second secondary sine winding of the respective group,

the first secondary sine winding and the second secondary sine winding of each group (120) being wound or wired in such a manner that the signals which are induced therein extend in opposing directions,

the first secondary cosine winding and the second secondary cosine winding of each group (120) being wound or wired in such a manner that the signals which are induced therein extend in opposing directions.

8. Magneto-electronic angle sensor according to claim 6 or 7, characterised in that the primary windings are arranged in such a manner that they produce a magnetic flux which extends radially.

9. Magneto-electronic angle sensor according to claim 8, characterised in that an output signal of the angle sensor is formed on the basis of the sum of the signals induced in the  $2p$  secondary sine windings and the sum of the signals induced in the  $2p$  secondary cosine windings, and

an angular value for the relative position of the rotor (102) with respect to the stator (104) can be derived from the output signal of the angle sensor.

10. Magneto-electronic angle sensor according to claim 8 or 9, characterised in that the first secondary cosine winding of a group (120) is wound or wired in such a manner that a positive voltage is induced therein when the magnetic flux which induces the voltage in the first secondary cosine winding is directed counter to the magnetic flux produced by the primary winding of the first tooth, and

the first secondary sine winding of a group (120) is wound or wired in such a manner that a positive voltage is induced therein when the magnetic flux which induces the voltage in the first secondary sine winding is directed counter to the magnetic flux produced by the primary winding of the second tooth.

11. Magneto-electronic angle sensor according to either claim 9 or claim 10, characterised in that the retention devices or the magnetic discontinuities are arranged in such a manner that signal distortions induced by the retention devices or magnetic discontinuities in the secondary windings compensate for/reduce each other in the output signal of the angle sensor.

12. Magneto-electronic angle sensor according to any one of claims 1 to 11, characterised in that the retention device is an assembly projection (140) which is arranged on the edge of the stator yoke (104).

13. Magneto-electronic angle sensor according to any one of claims 1 to 11, characterised in that the retention device is a hole which is provided in the stator yoke (104).

14. Magneto-electronic angle sensor according to any one of claims 1 to 13, characterised in that  $p$  is equal to 5.

15. Magneto-electronic angle sensor according to any one of claims 1 to 14, characterised in that the magneto-electronic angle sensor is a resolver.

16. Magneto-electronic angle sensor having an at least partially ferromagnetic stator and an at least partially ferromagnetic rotor (102) which are opposite each other, with an air gap being formed,

wherein the rotor (102) has  $p$  lobes which are arranged in such a manner that the magnetic resistance in the air gap changes periodically when the rotor (102) rotates about a rotation axis (106),  $p$  is a natural number which is greater than or equal to 2, and

the stator has a stator yoke (104) and teeth (110) which are separated from each other by grooves,

having a magnetic field exciter which is arranged on the stator or the rotor (102) and which produces a predetermined magnetic flux distribution in the air gap,

having a magnetic flux receiver arranged on the stator teeth (110) and

the stator further has identical retention devices (140) or identical magnetic discontinuities which are distributed in a uniform manner in the peripheral direction of the stator and which are arranged in such a manner with respect to the magnetic field exciter that the signal distortions induced by

the retention devices or magnetic discontinuities in the magnetic flux receiver are compensated for/reduced in an output signal of the angle sensor.

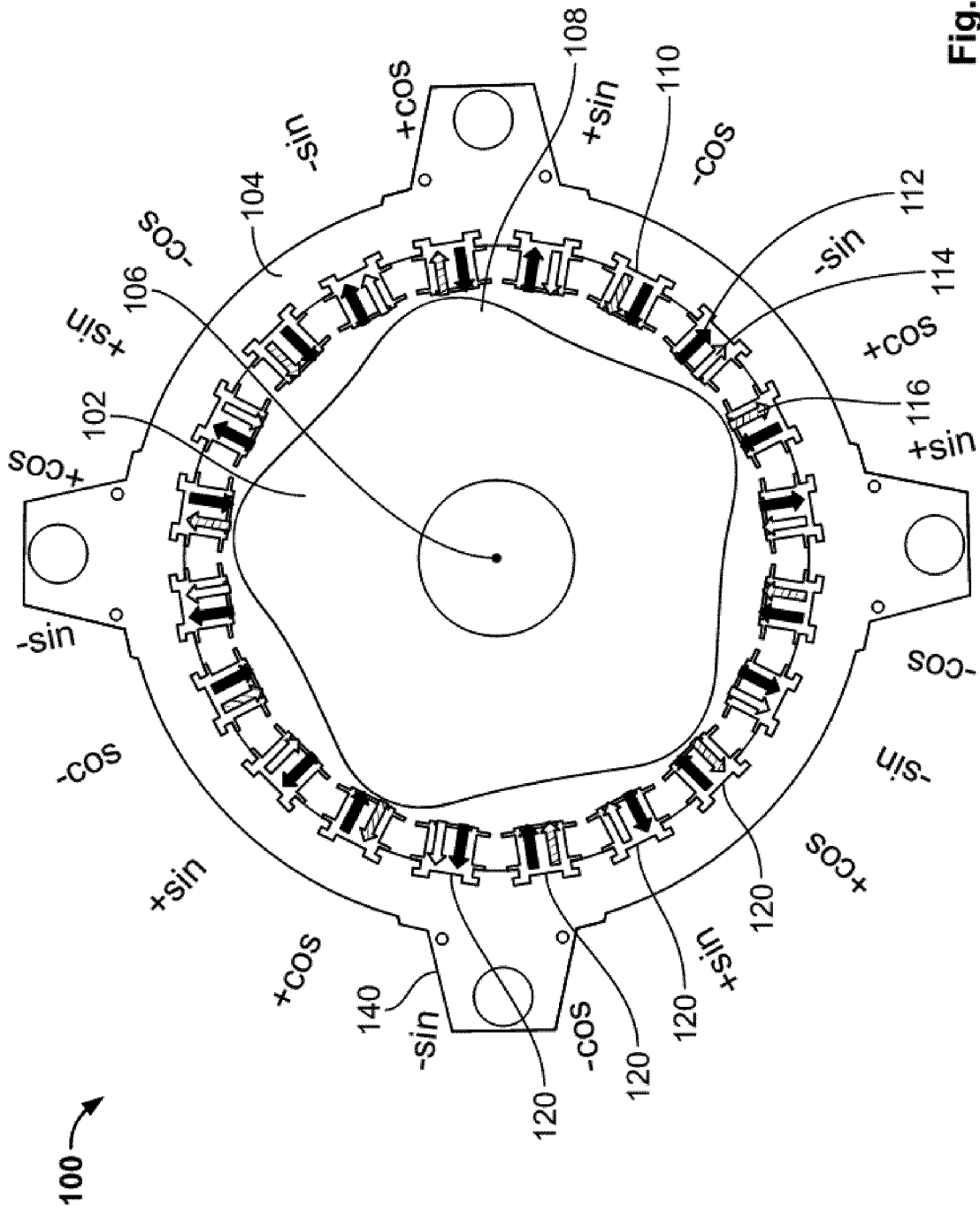


Fig. 1

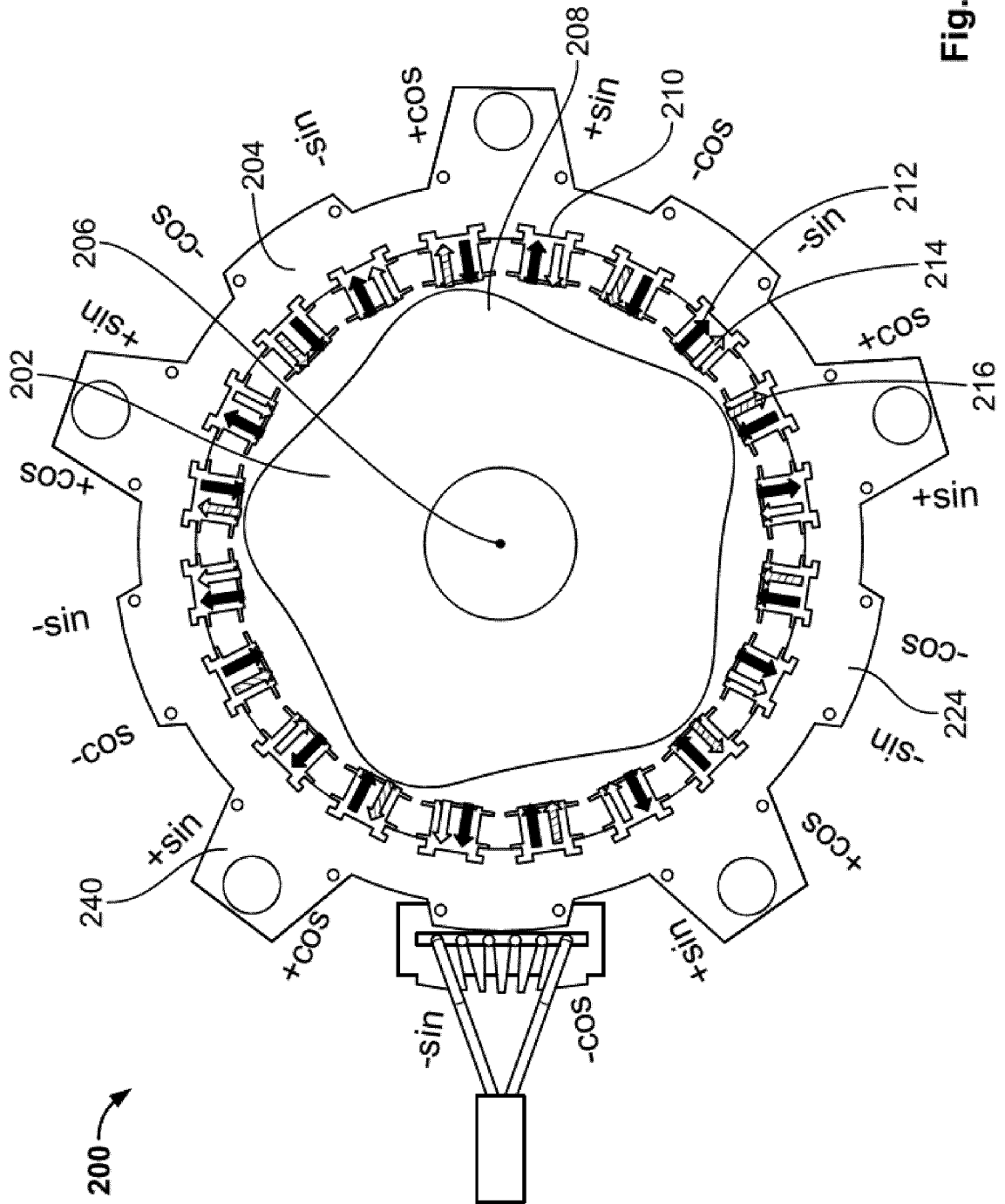


Fig. 2