

The present invention relates to capacitive sensors used for the measurement of displacements and more particularly for the measurement of very small displacements such as the torsion to which a motor shaft is subjected. These measurements of displacements make it possible to determine the value of the physical quantity which caused the displacement: temperature, pressure, force, acceleration, etc. Thus, measurement of the torsional angle of a motor shaft makes it possible to determine the value of the motor torque transmitted by this shaft.

Such capacitive sensors are known for example from the documents EP-A-108,894 and US-A-3,487,402; the known sensors consist of capacitors whose plane electrodes, parallel in the case of document EP-A-108,894 or cylindrical and coaxial in the case of document US-A-3,487,402, are situated a small distance apart but are fixed in two regions which are relatively far apart, in such a way that the displacements of these two regions, one with respect to the other, provoke variations in capacitance which are sufficient to be exploited by measurement electronics associated with the sensor. These known sensors are produced in such a way that, in fact, the two regions can be displaced the one with respect to the other only in a rotational motion about a same geometrical axis; these known sensors cannot therefore be used to determine a torsion by the method which consists in placing a sensor eccentrically with respect to the torsional axis so as to measure a translational displacement perpendicular to this axis.

The purpose of the present invention is to avoid this disadvantage.

This is achieved by using capacitive sensors with cylindrical electrodes where the internal electrodes are not limited to being able to be displaced only in a rotational motion about their own axis of symmetry which is fixed with respect to their external electrodes.

According to the invention, there is proposed a capacitive displacement sensor comprising a first and a

second support having a first and second longitudinal axis respectively, parallel to one another, these supports being provided with electrodes to form capacitors, characterised in that, in order to measure
5 relative displacements of the two supports perpendicularly to the first and second axes, the first support includes a cylindrical hole whose geometrical axis constitutes the first axis, the second support includes a cylindrical bar whose geometrical axis constitutes the second axis, this bar being arranged so as
10 to pass freely through the cylindrical hole and to thus have, with the hole, facing walls, and the electrodes are held by the facing walls of the hole and of the bar and, at least some, have boundaries parallel to the first and
15 second axes.

It should be noted that there is likewise known, through the US patent 4,054,049, to produce a capacitive sensor including a cylindrical hole and a cylindrical bar which are coaxial and hold, on their internal wall and on
20 their external wall respectively, electrodes which are all cylindrical. This sensor is intended for measuring translations of the bar in the hole along the direction of their common axis; this measurement is deduced from the variation in capacitance due to the fact that, in the
25 translation, an electrode of the bar leaves or re-enters slightly the volume of an electrode held by the wall of the hole. Such a sensor is not at all suited for measurements of displacements which might occur perpendicularly to the common direction of the axis of the hole and of
30 the bar since the variations in capacitance which are due to such displacements are very small with this type of sensor.

The present invention will be better understood and other characteristics will emerge with the aid of the description hereafter and of the figures relating
35 thereto, which represent:

- Figure 1, a basic diagram of a capacitive sensor according to the invention,

- Figures 2, 3 and 5, sectional views, of

capacitive sensors according to the invention,

- Figure 4, a developed view of a portion of the sensor already represented in Figure 3,

- Figure 6, a view showing an angle sensor, according to the invention, mounted in a motor shaft.

Figure 1 shows how a capacitive sensor according to the invention is produced. Figure 1 represents a mechanical assembly comprising two undeformable sub-assemblies A and B and a sensor C, made from a solid cylinder 1 and from a hollow cylinder 2, which, at rest, as will be indicated further on, have a same longitudinal axis ZZ' . A trihedral reference frame $oxyz$ is tied to the sub-assembly A and a trihedral reference frame $o'x'y'z'$ is tied to the sub-assembly B. The sensor C includes electrodes situated on the cylindrical wall of the solid tube 1 and on the internal wall of the hollow tube 2; these electrodes determine a certain capacitance. The cylinder 1 is rendered integral with the sub-assembly A by a rigid link L1, symbolised by a rod; similarly, the cylinder 2 is rendered integral with the sub-assembly B by a rigid link L2 symbolised by another rod.

The purpose of the sensor C of Figure 1 is to measure small displacements of B in the reference frame $oxyz$ tied to A, these displacements being limited to translations parallel to a direction XX' which is fixed with respect to $oxyz$; in this setup, the relative displacements of A and B are identical to the relative displacements of cylinders 1 and 2 owing to the rigid links L1, L2. The assembly according to Figure 1 is produced in such a way that, at rest, that is to say in an initial position serving as origin in the measurement of the displacements between A and B,

- the axes of the cylinders 1 and 2 coincide with the axis ZZ'
- the axis ZZ' is perpendicular to the direction XX' of the displacements to be measured.

These displacements of B with respect to A determine an eccentricity of the solid cylinder 1 in the hollow cylinder 2, the axes of the cylinders 1 and 2

remaining parallel.

Figure 2 is a sectional view, in a plane perpendicular to ZZ' passing through the cylinders 1 and 2, of the sensor C of Figure 1. The hollow cylinder 2 holds, over the whole of its internal wall, and electrode C0; in Figure 2 this electrode is represented as a conductive layer lining the internal wall of the cylinder 2 but, in embodiments where the cylinder 2 is of a conductive material, such a layer will not be necessary. The solid cylinder 1 is an insulating cylinder which holds, on its cylindrical wall, two conductive layers forming electrodes: one electrode proper C1 arranged, in the section according to Figure 2, between two generatrices of the cylinder which are about 70 degrees distant, and a guard electrode G which is insulated from the electrode C1 and whose section is included between two generatrices of the cylinder which are a few degrees distant from the two generatrices delimiting the electrode C1. The electrodes C0 and C1 constitute the two electrodes of a capacitor whose capacitance varies with the eccentricity E of the cylinders 1 and 2 with respect to one another; the inverse of the value of the capacitance is a substantially linear function of the eccentricity E, the linearity being all the better

- the closer to 1 is the ratio of the radius of the solid cylinder 1 and of the inner radius of the hollow cylinder 2,
- the smaller is the angle between the generatrices which delimit the electrode C1,
- the smaller compared with the radius of the solid cylinder is the maximum value which the eccentricity can take.

Figure 3 is a sectional view, relating to another way of producing the sensor C of Figure 1. Here again, the hollow cylinder 2 holds, over the whole of its internal wall, an electrode C0 represented as a conductive layer and the solid cylinder A holds a guard electrode G. By contrast, this guard electrode does not surround one but two electrodes proper, C1 and C2, as is

apparent in Figure 4, which is a developed view of these electrodes after a cut along a generatrix of the solid cylinder; the edges of the cut are represented with broken lines in Figure 4. Figure 4 also shows the connections D1, D2, Dg relating to the electrodes C1, C2, G respectively.

The sensor according to Figures 3 and 4 differs from the sensor according to Figure 2 essentially by the presence of the additional electrode C2, symmetric with the electrode C1 with respect to the axis of the solid cylinder 1; this additional electrode constitutes, with the electrode C0, a second measurement capacitor whose capacitance also varies with the eccentricity E, but in the sense opposite to the variations in the capacitor constituted by the electrode C1 together with the electrode C0. Let C1 and C2 be the values of the two capacitors C1, C0 and C2, C0; it should be noted that, with dimensions which are equal otherwise, the ratio $(C1-C2)/(C1+C2)$, obtained with the sensor according to Figures 3 and 4, exhibits better linearity as a function of the eccentricity E than the linearity of C1 as a function of E in the case of the sensor according to Figure 2. Moreover, when the measurement of the eccentricity E is made with the aid of the ratio $(C1-C2)/(C1+C2)$ [sic], the possible drifts related to the variation in the dielectric constant of the interelectrode medium, are eliminated; the same is true for the zero drifts related to the dimensional variations of the cylinders 1 and 2 with temperature. By contrast, these drifts disturb the measurement of the eccentricity E made from the sole value of the capacitor C1.

These capacitive sensors, with electrodes arranged as indicated in Figures 2 and 3, allow the measurement of very small displacements along the direction XX' but are practically insensitive to very small displacements along the axis ZZ' (see Figure 1) common to the cylinders 1 and 2 in their rest position, and are also practically insensitive to very small displacements along an axis YY' perpendicular to XX' and ZZ', that is

to say along an axis which would be perpendicular to XX' in the plane of Figures 2 and 3.

Figure 5 shows, seen in section along a plane perpendicular to the axes of the two electrode-holder cylinders, a capacitive sensor allowing measurement of very small displacements along the axes XX' and YY' which have just been discussed above. The sensor differs from that described with the aid of Figures 3 and 4 only by the appending of two additional electrodes, C3, C4, on the wall of the solid cylinder 1; these electrodes are situated at 90 degrees from the electrodes C1, C2, about the axis of the cylinder 1. This arrangement of electrodes makes it possible to measure the components, along XX' , of the displacements with the aid of the capacitors C1 and C2 consisting of the electrodes, C0, C1 and C0, C2 respectively, and the components, along YY' , with the aid of the capacitors C3, C4 consisting of the electrodes C0, C3 and C0, C4 respectively.

Figure 6 shows how, with a capacitive sensor of the type described with the aid of Figures 1, 3 and 4, a torsional angle sensor has been produced which has been mounted on a motor shaft 3. Figure 6 is a simplified view in which various elements have not been represented so as to simplify the drawing and facilitate understanding.

The motor shaft 3 is hollow and comprises three metal portions: an intermediate tube 30 prolonged at each of its ends by tubes 31, 32 which have been represented over a small portion only of their length. These tubes 31, 32 have been drawn with broken lines and their junction with the tube 30, which in the example described is a junction via flanges rendered integral by screws, has not been represented. Moreover, only one half of these three tubes, obtained through a sectioning plane passing through the axis MM' of the shaft 3, appears in Figure 6, so as to leave visible the contents of the intermediate tube 30.

The tube 30 is not of constant thickness over the whole of its length: it possesses two thick portions, A, B, situated at its two ends respectively, on either side

of a thinner portion H. Under the loads experienced by the motor shaft 3 during its operation, the torsion is greater in the portion H than in the remainder of the shaft and it is there that a measurement is made with a capacitive sensor so as to make it possible to determine the value of the torque transmitted by the shaft 3. To do this, two metal parts 2, 4 forming plugs, bear respectively upon the internal wall of the portions A, B, with which they are rendered rigidly integral by welding; in Figure 6 these links by welding have been drawn with thicker lines. The parts 2 and 4 are drilled with cylindrical holes which are aligned along a same axis ZZ' when the shaft 3 is not subjected to any torque. The hole drilled in the part 2 is a hole whose metal wall corresponds to the electrode C0 of the Figures 2, 3 and 5. One end of an insulating ceramic cylindrical bar 1 is implanted in the hole in the part 4; the mounting of the bar 1 in the part 4 is done by hooping, the ceramic bar being cooled and the metal part 4 being heated before being assembled. The bar 1 is prolonged inside and slightly beyond the hole drilled in the part 2. In the vicinity of its passage through the hole drilled in the part 2 the bar 1 holds, upon its wall, two electrodes C1, C2 obtained by silk-screen printing; these electrodes correspond to the electrodes C1, C2 described with the aid of Figures 3 and 4.

In Figure 6 the guard electrode held by the bar 1 and corresponding to the electrode G of Figures 3 and 4, has not been represented, as likewise have not been represented:

- three other capacitive sensors which are offset by 90, 180 and 270 degrees respectively about the axis MM' , with respect to the sensor drawn in this figure,
- the coupling device affording the electrical link between the four sensors which rotate with the motor shaft 3 about the axis MM' and the electronic circuits for utilisation of the signals provided by the capacitors; these electronic circuits are fixed with respect to the axis MM' and the coupling device is, in

the example described, a rotating transformer with plural windings, whose rotor is integral with the motor shaft 3 and whose stator is fixed with respect to the axis MM' of the shaft 3.

5 It should be noted that, the link L1 of the sensor according to Figure 1, corresponds, in Figure 6, to the weld between the part 2 and the thick portion A of the tube 30, whilst the link L2 corresponds, in Figure 6, to the part 4 and to the weld between the part 4 and the
10 thick portion B of the tube 30.

By way of example, the motor shaft of Figure 6 is driven by a 300 kW motor at a speed of rotation which can reach 10,000 revolutions per minute, and its outer diameter is 5 centimetres.

15 The present invention is not limited to the examples described above, thus, the capacitive sensors according to the invention can comprise any integer number of regularly distributed electrodes; and it should be observed that, with three electrodes distributed at
20 120 degrees from one another, it is possible to make the same measurements of displacement as with the four-electrode sensor according to Figure 5, but the exploitation of the signals is more complicated.

Similarly, with one or more capacitive sensors
25 according to the invention, it is possible to measure not only rotational angles of a region A with respect to a region B, but it is also possible to measure any displacement of small amplitude of a region with respect to another, on condition that the arrangement of these
30 regions allows the production, between them, of a setup akin to the basic setup according to the Figure 1.



CLAIMS

1. Capacitive displacement sensor comprising a first and a second support (1, 2) having a first and second longitudinal axis respectively, parallel to one another, these supports being provided with electrodes (C0, C1-C4, G) to form capacitors, characterised in that, in order to measure relative displacements of the two supports perpendicularly to the first and second axes, the first support (2) includes a cylindrical hole whose geometrical axis constitutes the first axis, the second support (1) includes a cylindrical bar whose geometrical axis constitutes the second axis, this bar being arranged so as to pass freely through the cylindrical hole of the first support and to thus have, with the wall of the hole, facing walls, and the electrodes (C0, C1-C4, G) are held by the facing walls of the hole and of the bar and, at least some (C1-C4, G), have boundaries parallel to the first and second axes.
2. Capacitive sensor according to Claim 1, characterised in that the wall of the hole of the first support (2) is wholly conductive and constitutes one of the electrodes (C0), and in that the cylindrical bar (1) is insulating and holds the other electrodes (C1-C4, G).
3. Capacitive sensor according to Claim 2, characterised in that the said other electrodes comprise n main electrodes (C1-C4), where n is a positive integer, arranged substantially along n generatrices of the cylindrical bar and distributed at $360^\circ/n$ from one another, and a guard electrode (G) which partially surrounds each of the main electrodes.
4. Torsional angle sensor for a motor shaft of given geometrical axis (MM'), characterised in that it includes: m capacitive sensors (m positive integer) according to any one of the preceding claims, arranged with the geometrical axis (ZZ') of their bar at least substantially parallel to the axis (MM') of the motor shaft* (3).
5. Angle sensor according to Claim 4, characterised in that it includes a hollow cylindrical part (30)



intended to be intercalated into the motor shaft (3) to constitute a piece thereof, and in that the m capacitive sensors are housed inside the hollow cylindrical part, with their first supports (2) integral with one of the
5 ends of the piece and their bars (1) integral with the other end of the piece.