

The present invention relates to an electromagnetic detector designed to log the position and orientation of a moving body in a given space and in particular to log the exact position, in an aircraft, of the helmet, equipped with a helmet sight, worn by the pilot.

An electromagnetic position and orientation detector generally includes a fixed transmitter with three coils energized alternately by the generator and a moving sensor with three coils, for providing, via each of its coils, an induced signal relating to the energizing of each of the coils of the transmitter; calculating means coupled to the coils of the sensor make it possible to determine, as a function of the induced signals, the position and orientation of the sensor. In the case of the logging of the position of the helmet in an aircraft, the cockpit of the aircraft constitutes the given space and the helmet the moving body.

Such detectors are described for example in French Patent 2 458 838 and US Patent 4 396 885. To determine the position and orientation of a body moving in a space, the transmitter occupies a fixed place in the space and the sensor is fixed to the moving body. To each position of the body there correspond, for each coil of the sensor, three signals which are induced by the three coils respectively of the transmitter; in total there are nine induced signals which serve in calculating the position and direction of the body.

This calculation is corrupted by errors due to the imperfections in the paths which go from the electrical energizing generator to the calculating means; indeed, these paths exhibit imperfections in gain both at transmission and at reception: imprecision, non-linearities, drifting.

Through the Patent US 4 054 881 it is also known to produce an electromagnetic position and orientation detector with, in addition to the moving sensor, a fixed antenna whose induced signal serves to produce a negative feedback in the transmission paths in order to maintain the level of the electromagnetic field created by the

transmitter constant. Such a device can eliminate the errors in the transmission paths but has no effect on the errors due to the imperfections in gain which affect the elements situated between, and including, the sensor up to, but not including, the calculating means.

The aim of the present invention is to avoid or at least reduce the drawbacks of these detectors.

The subject of the present invention is a fixed sensor whose signal serves as reference signal in order, during the calculations, to correct the errors engendered in the nine induced signals, such as defined by Claim 1.

Other subjects and other characteristics will emerge with the aid of the description below and the figures referring thereto, which represent:

- Figure 1, a diagram of a detector according to the invention,

- Figure 2, a diagram of another detector according to the invention.

In these various figures, the corresponding elements are denoted with the same symbols.

The electromagnetic position and orientation detector according to the invention is produced from a known detector; the operation of such a detector is recalled below, with the aid of Figure 1, but without for the moment taking into account the element 8 which is peculiar to the invention.

Detectors of position and orientation of a solid in a space, which use electromagnetic coupling between a fixed transmitter and a moving sensor, are constituted principally by:

- an electrical signal generator 2, for delivering energizing signals and a partitioning signal

- a fixed transmitter 3 for receiving, via three amplifiers 21, 22, 23, the signal from the generator 2 and generating in the space, in an identifiable manner, three independent magnetic field vectors B1, B2, B3; here, the term independent means that the directions of the fields are distinct and that not all three fields are contained in the same plane

- a moving sensor 4 placed at a point of the space and which receives, along three independent axes, the three fields created by the transmitter,

5 - a device for processing the three field components induced by each of the three magnetic field vectors in the sensor 4; there are therefore nine components to be processed in order to determine the position and orientation of the sensor at a given moment.

10 The transmitter 3 and the sensor 4 are usually produced with the aid of triples 31, 32, 33 and 41, 42, 43 of mutually orthogonal coils arranged along the axes, not represented, of a reference trihedron.

15 The processing device includes, most generally, in series starting from the outputs of the sensor 4: a multiplexer, 5, an amplifier, 50, a synchronous demodulator, 6, an analog/digital converter, 7 and calculating means, 1, formed from a microprocessor. The calculating means trigger the signal generator 2 which provides an energizing signal for exciting the coils 31, 20 32, 33 of the transmitter separately one after the other in the course of successive excitation cycles. A cycle partitioning signal formed by a start-of-cycle pulse followed by nine pulses regularly distributed over the duration of a cycle, is provided by the generator 2 on a control input of the multiplexer 5; the latter can thus 25 connect up separately and successively the three coils 41, 42, 43 of the sensor 4 to the input of the amplifier 50 during the time for which a coil of the transmitter is excited in the course of a cycle; during a cycle the 30 multiplexer 5 thus delivers nine signals corresponding to the signals induced successively by the three coils of the transmitter 3 in each of the three coils of the sensor 4.

35 The synchronous demodulator 6 performs a demodulation of the signals provided by the amplifier 50, by virtue of the energizing signal which the generator 2 delivers to it permanently, once it is triggered. The partitioning signal is also supplied to the calculating means 1 in order to enable them to recognize the origin

of the signals which arrive at them through the converter
7.

There are two main methods for obtaining the position and orientation of the sensor with respect to the transmitter.

The first method uses the laws of electromagnetism which give formulae for predicting the fields created at all points.

The characteristic values $\vec{B}_1 \cdot \vec{B}_2$, $\vec{B}_1 \cdot \vec{B}_3$, $\vec{B}_2 \cdot \vec{B}_3$, $\vec{B}_1 \cdot \vec{B}_1$, $\vec{B}_2 \cdot \vec{B}_2$, $\vec{B}_3 \cdot \vec{B}_3$, which do not depend on the rotation of the sensor but solely on its position, are calculated from the nine field measurements performed in the frame constituted by the sensor. By virtue of these six parameters and the laws of electromagnetism, the position of the sensor with respect to the transmitter is calculated.

Knowing this position, the nine components of the fields are calculated in the frame of the transmitter. Comparison of these nine components with those seen by the sensor gives the relative rotation of the sensor with respect to the transmitter.

The second method uses a prior experimental charting of the fields in space, with a sensor having a defined orientation, thus making it possible to circumvent the distortions due either to the metal masses present nearby, or to the imperfections of the transmitter and sensor with respect to electromagnetic theory.

In both methods, the precision of the transmission, reception and measurement chains directly influences the precision of the values obtained for the position and orientation.

The detectors described below make it possible to circumvent this drawback and can be used with one or the other of the two aforementioned position and orientation extraction methods. They simply require that the differences in makeup between the coils of the receiver and the reference coil are negligible or are otherwise measured and known.

The detector, such as it is drawn in Figure 1, is

distinguished from a conventional detector by the adjoining of a fixed sensor 8 produced with the aid of a coil whose position and orientation are known with precision in the reference frame of the transmitter 3.

5 The coil of the fixed sensor 8 is handled in the same way as the coils 41, 42, 43 of the moving sensor 4, that is to say its induced signal is supplied to the multiplexer 5. The multiplexer 5 therefore includes one more signal input than the corresponding multiplexer of
10 a conventional detector; the partitioning signal which it receives from the signal generator 2 is then formed by a start-of-cycle pulse followed, not by nine, but by twelve pulses regularly distributed over the duration of a cycle, since each time one of the three coils of the
15 transmitter 3 is energized, the signals induced in the four sensor coils must be taken into account in succession.

 The measurement of the signal induced in the fixed sensor 8, compared with the theoretical value which
20 this signal should have owing to its position and orientation in the first above-described method for determining the position and orientation, or compared with the value of the signal induced in the sensor 8 during the experimental charting of the fields in the second above-
25 described method, makes it possible to correct, in the nine measurements made per cycle with moving sensor, the errors due to the transmission, reception and measurement chains; the way to proceed in order to perform these corrections is described below, by considering two cases.

30 The first case is that in which the detector according to Figure 1 is linear both in its three transmission paths and in its measurement path and in which, at the time of the measurement, the reception path exhibits an error in gain G_r and each transmission path
35 an error in gain G_{ej} , where j is the reference for the transmitter coil of the relevant path less 30. For simplicity, in what follows the coils $j = 1, 2$ and 3 will be the coils 31, 32, 33 respectively of the transmitter 3, whilst the coils $i = 1, 2$ and 3 will be the coils 41,

42 and 43 respectively of the moving sensor 4.

Each calculation of the magnetic coupling M_{ij} between the coil of path j at transmission and the coil $i = 1, 2$ or 3 of the sensor 4, is therefore corrupted by a global error in gain $Ge_j.Gr$. Now, calculation of the coupling M_{4j} between the fourth coil, that is to say that of the fixed sensor 8, and the coil of path j is corrupted by the same error $Ge_j.Gr$. These calculated magnetic couplings can therefore be written:

$$M_{ij} = Ge_j.Gr.M'_{ij}$$

$$M_{4j} = Ge_j.Gr.M'_{4j}$$

in these formulae M'_{ij} and M'_{4j} are the true values of the relevant magnetic couplings. Thus, the true value to be taken into account in the calculations, in order to determine the position and orientation of the moving sensor 4, can be written

$$M'_{ij} = M_{ij}.M'_{4j}/M_{4j}$$

M'_{ij} can therefore be calculated since M_{ij} and M_{4j} are calculated and since, in the first method of determination alluded to above, M'_{4j} will be the theoretical value of the coupling as calculated for the sensor 8, whereas, in the second method, it will be the value charted during the experimental measurement of the fields.

The second case to be considered is that in which the detector is not linear in its transmission and measurement paths. In this case if e_j is the level instigated on the coil j of the transmitter, the actual level of transmission is $e'_j = f_j(e_j)$ where f_j is a function. Similarly, if r_i is the level actually received on the coil i of the sensor 8, the reception level, such as it is seen, that is to say such as it will be taken into account in the calculations, can be written $r'_i = g(r_i)$ where g is a function.

On taking the polynomials

$$e'_j = b_j.e_j + c_j.e_j^2 + \dots$$

$$\text{and } r' : a + b.r + c.r^2 + \dots$$

as models for the functions f_j and g , and on inserting therein $r_i = M_{ij}.e'_j$ it follows that

$$r'i = a + b.bj.Mij.ej + b.cj.Mij.ej^2 + c.Mij^2.(bj^2.ej^2 + cj^2.ej^4 + 2bj.cj.ej^3) + \dots$$

in this formula it is apparent that the coefficient of order 1 of the function $r'i = hij(ej)$ and which will be called Kij , is homogeneous to the error in gain $Gej.Gr$ in the case where the detector is linear:

$$kij = b.bj.Mij$$

therefore the detector is used as indicated below.

Through successive transmissions at different levels ej , the coefficients of order 1 of the functions hij and $h4j$, that is to say kij and $k4j$, are determined.

In the case of processing according to the first method, a knowledge of $M4j$ makes it possible to determine the error in gain $b.bj$:

$$b.bj = k4j/M4j$$

$$\text{and } Mij = kij/b.bj = kij.M4j/k4j$$

In the case of processing by experimental charting of the field, $k'4j$ charted initially and compared with the value $k4j$ measured during utilization makes it possible to recover the relative error between the two series of measurements, whence:

$$Mij = kij.k'4j/k4j$$

Figure 2 is a diagram of a detector according to the invention in which the measurement reference, instead of being given by a fixed sensor in a free field, such as the sensor 8 of Figure 1, is given by three transformers 9a, 9b, 9c; the primary windings of these transformers are wired in series with the coils of a transmitter 3 similar to that of Figure 1, for example the primary winding of the transformer 9a with the coil 31; secondary windings of these transformers are wired in series between the output of a multiplexer 5 and the input of an amplifier 50; these two circuits are similar to the circuits 5 and 50 of Figure 1, the only difference being that the multiplexer now requires only three signal inputs. Interrupters 91, 92, 93 are wired in parallel respectively with the secondary windings of these transformers and are controlled with the aid of the partitioning signal already mentioned when describing Figure 1. In

respect of the remainder of the circuit, Figure 2 is identical to Figure 1.

In the wiring according to Figure 2, the partitioning signal is formed by a start-of-cycle pulse followed not now by twelve but by eighteen pulses regularly distributed over the duration of the cycle; in these eighteen successive pulses, the odd-numbered pulses are used, by the multiplexer 5, as in the case of a conventional detector which includes no electromagnetic coupling other than that between the transmitter 3 and the moving sensor 4, that is to say they serve in the temporal multiplexing of the signals induced in each of the coils of the moving sensor 4 by each of the coils of the transmitter 3; on the other hand the nine even-numbered pulses are used by a decoder 10 to control the opening of one and only one of the interrupters 9a, 9b, 9c; this opening of an interrupter occurs during half the duration of the taking into account of each of the three induced signals created by the energizing signal applied to the coil of the transmitter 3 which is in series with the primary of the transformer to whose secondary the relevant interrupter is wired.

The additional coupling coefficients K_j , with $j = 1, 2$ and 3 , afforded by the transformers 9a, 9b, 9c, respectively, make it possible to eliminate the error in gain and thus to determine the true value M'_{ij} of the magnetic coupling between coil j of the transmitter and coil i of the sensor, i and j having the same meanings as in the explanations relating to Figure 1. By using the same references as those used during the calculations relating to Figure 1, it follows in fact, during measurement with transformer, that

$$r_{i1} = (K_j + M'_{ij}) G_{ej} \cdot Gr_{ej}$$

and without transformer, that

$$r_{i2} = M'_{ij} \cdot G_{ej} \cdot Gr_{ej}$$

$$\text{whence } r_{i1} - r_{i2} = K_j \cdot G_{ej} \cdot Gr_{ej}$$

$$G_{ej} \cdot Gr_{ej} = (r_{i1} - r_{i2}) / K_j$$

$$\text{thus giving } M'_{ij} = K_j \cdot r_{i2} / (r_{i1} - r_{i2})$$

thus, K_j being known and r_{i1} , r_{i2} being obtained through

calculation, the true value M'_{ij} of the coefficient of coupling between coil j of the transmitter 3 and coil i of the sensor 4 can be calculated by the calculation means 1.

5 The present invention is not limited to the examples described and, in particular, the wiring according to Figure 2 can be modified thus by arranging the secondaries of the transformers 9a, 9b, 9c not in series with the output of the multiplexer 5 but by
10 joining each of them to an input of a multiplexer 5 which would include six signal inputs. The partitioning signal should then include, per cycle, a start-of-cycle pulse and twelve pulses regularly distributed over the duration of the cycle in such a way that, while one of the coils
15 of the transmitter 3 is receiving the energizing signal from the generator 2, the signals induced in the three coils of the moving sensor 4 and in the secondary of the transformer whose primary is receiving the energizing signal, that is to say whose primary is in series with
20 that one of the coils of the transmitter which is energized, are taken into account in succession.



CLAIMS

1. Electromagnetic position and orientation detector including an electrical energizing generator (2), a fixed transmitter (3) with three coils (31, 32, 33) energized alternately by the generator, a moving sensor (4) with three coils (41, 42, 43), for providing, via each of its coils, an induced signal relating to the energizing of each of the coils of the transmitter and calculating means (1) coupled to the coils of the sensor in order to determine, as a function of the induced signals, the position and orientation of the sensor, characterized in that, in order to take into account the imprecision of the gains in the signals between the generator (2) and the calculating means (1), it includes a fixed sensor (8, 9a, 9b, 9c, 91, 92, 93) arranged in a link with electromagnetic coupling between the electrical generator and the calculating means, in order to provide the calculating means with a reference signal so as to correct the calculations performed from the induced signals.
2. Detector according to Claim 1, characterized in that the fixed sensor consists of a coil (8) in order to provide an induced signal relating to the energizing of each of the coils of the transmitter (3), this signal being sent via the link to the calculating means (1) in order to serve as reference signal.
3. Detector according to Claim 1, characterized in that the fixed sensor consists of three transformers (9a, 9b, 9c) whose primary windings are in series respectively with the three coils of the transmitter (3) and whose secondary windings are in series in the coupling between the three coils of the moving sensor and the calculating means, and of three interrupters (91, 92, 93) in parallel with the three secondary windings respectively, each interrupter being intended to be closed in order to short-circuit the winding with which it is in parallel, during a part of the time for which the coil in series with this winding provides the induced signal relating to the energizing of each of the coils of the transmitter, each secondary winding thus providing, during the time



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for which the interrupter in parallel with it is open, a coupling signal which serves as reference signal.