(12) **Oversettelse av europeisk patentskrift**

(11) **NO/EP 2522956 B1**

NORGE

(19) NO

(51) Int Cl.

G01C 21/16 (2006.01)
G01C 25/00 (2006.01)

Patentstyret

(45)	Oversettelse publisert	2020.02.24
(80)	Dato for Den Europeiske Patentmyndighets publisering av det meddelte patentet	2019.11.20
(86)	Europeisk søknadsnr	12290158.0
(86)	Europeisk innleveringsdag	2012.05.09
(87)	Den europeiske søknadens Publiseringsdato	2012.11.14
(30)	Prioritet	2011.05.13, FR, 1101455
(84)	Utpekte stater	AL ; AT ; BE ; BG ; CH ; CY ; CZ ; DE ; DK ; EE ; ES ; FI ; FR ; GB ; GR ; HR ; HU ; IE ; IS ; IT ; LI ; LT ; LU ; LV ; MC ; MK ; MT ; NL ; NO ; PL ; PT ; RO ; RS ; SE ; SI ; SK ; SM ; TR
(73)	Innehaver	MBDA France, 1 Avenue Réaumur, 92350 Le Plessis-Robinson, Frankrike
(72)	Oppfinner	De Picciotto, François, 13 rue des Frères Morane, 75015 Paris, Frankrike
(74)	Fullmektig	BRYN AARFLOT AS, Stortingsgata 8, 0161 OSLO, Norge

(54) Benevnelse **Method for automatically managing a pitch rate gyro mounted on a aircraft**

(56) Anførte publikasjoner

EP-A1- 0 392 104
US-A- 4 017 187
FR-A1- 2 826 447
US-A1- 2010 133 374

Method for automatically managing a pitch rate gyro mounted on a aircraft

The invention relates to a method for automatically managing a pitch rate gyro mounted on an inertial navigation flying device, likely to be rolled, as well as a flying device, in particular an air missile, provided with such a pitch rate gyro.

It is know that inertial navigational drifts reduce the range of a missile. Furthermore, when the missile is an inexpensive missile (for example an air-to-surface missile), a reduction of the drift is generally sought, without resorting to additional sensors (other than the inertial measurement unit already present on the missile), so as to avoid increasing costs.

A known method to overcome this problem consists in causing the autorotation of the missile (always in the same direction) about its longitudinal axis. On average, this forced rotation cancels out most of the drifts, as detailed for example in document US2010/0133374 that discloses a missile with an alternating roll direction and the correction of radial scale bias errors.

However, this conventional method is not altogether satisfactory, as it fails to correct scale factor defects of the pitch rate gyro. For this reason, the pitch rate gyro must generally be replaced by a gyroscope, which generates numerous additional constraints:

- additional costs (development, integration,...); ;
- if the inertial measurement unit relies on current “vibrating structure” technologies (for example of the MEMS type), the gyroscope can only operate for elevated rates of rotation (greater than 1000°/s), and retains a drift of approximately 1°/s, which greatly reduces the relevance of this solution (drift greater than the usual angular bias of an inexpensive MEMS measurement unit); and
- if the inertial measurement unit relies on older technologies (of the spinning gyro type), there is no constraint in terms of rate of rotation, but this technology is becoming obsolete.

Furthermore, the following devices are known:

- in document US-4 017 187, an inertial measurement apparatus with double rotation, comprising means to cancel out scale factor errors, by inverting the roll direction of the elements generating the roll of said apparatus;

- in document EP-0 392 104, an inertial navigation system comprising a plurality of gyroscopes.

The purpose of the present invention is to remedy these disadvantages. It relates to a method for automatically managing a pitch rate gyro mounted on an inertial navigation flying device, in particular an air missile, able to be rolled, said management method overcoming the need to replace the pitch rate gyro with a gyroscope, and thereby reducing the cost thereof, for comparable navigational performance levels.

For this purpose and according to the invention, the method is noteworthy in that, when using the pitch rate gyro, said flying device is automatically commanded to roll about its longitudinal axis, while alternating the roll direction, at regular intervals (every n revolutions, n being an integer greater than or equal to 1) so as to automatically cancel out the scale factor effect of the pitch rate gyro, in addition to correcting usual drifts, said correction being achieved by the roll of the flying device.

Thus, with this command of the flying device, intended to cause it to roll in alternating directions at regular intervals, the scale factor of the pitch rate gyro mounted on said flying device is naturally cancelled out, as detailed below, as are the other usual drifts. These other drifts are cancelled out according to the present invention in the same way as with the abovementioned single-direction roll method.

The need for a gyroscope is therefore strongly reduced (drift due to the scale factor of the pitch rate gyro eliminated), and the present invention also enables to retain one gyro for numerous applications. The present invention therefore reduces the cost, for navigational performance levels that are comparable with that achieved when using a gyroscope.

The invention applies to any type of inertial navigation missile, the rolling of which is possible without generating other constraints (range, operating concept...).

The rotation direction alternates after each revolution of the flying device (n = 1). However, it is also possible to select n greater than 1 (less frequent alternating), for example to reduce the induced aerodynamic forces.

The present invention also relates to an inertial navigation flying device, in particular an air missile, able to be rolled and comprising a pitch rate gyro.

According to the invention, said flying device is noteworthy in that it comprises automatic control means to command said flying device to roll about its longitudinal axis, while regularly alternating the roll direction so as to cancel out the scale factor effect of the pitch rate gyro, in addition to correcting usual drifts, said correction being achieved by the roll of the flying device.

Furthermore and advantageously, said automatic control means are part of the usual automatic control system of said flying device, conventionally comprising in particular means to cause the flying device to roll.

The present invention therefore enables to correct both the usual drifts (similar to the usual method for causing the autorotation of the flying device) and, additionally, the scale factor.

The figures of the appended drawing will provide a good understanding of how the invention can be achieved. In these figures, identical references describe similar elements.

Figure 1 shows, partially and very schematically, a missile provided with a pitch rate gyro, whereto the present invention applies.

Figure 2 is a graph showing an example of a command alternating the roll direction of a flying device.

Figure 3 is a schematic representation explaining the effects generated by the command alternating the roll direction of a flying device on the measurements performed by a pitch rate gyro.

The present invention applies to a flying device 1, in particular an air missile, as represented for example in figure 1, of the inertial navigation type, likely to be rolled (about its longitudinal axis 3 as shown by an arrow 4) and that comprises conventionally a pitch rate gyro 2. The present invention relates to the operational management of said pitch rate gyro 2. This pitch rate gyro 2 is well known, and its characteristics are not described in any further detail in the following description.

This flying device 1 comprises usual control means 5 that are part of the usual control system 6 (shown very schematically in figure 1) and that comprise all the elements necessary to fly and pilot the flying device 1, in particular so that it can reach and destroy a target. These control means 5 comprise, in particular, means to process information and to automatically generate flight commands enabling the flying device 1 to follow a trajectory leading it to target and piloting means (not shown), such as flight control devices or any other type of known element, which automatically apply these flight commands to the flying device 1. All these usual means are well known and will not be detailed further hereinafter.

According to the invention, said flying device 1 further comprises automatic control means 8 to command said flying device 1 to roll, causing its rotation about its longitudinal axis, while alternating its roll direction, at regular intervals, so as to cancel out the scale factor effect of the pitch rate gyro. An example of roll command p (in rad/s) applied according to the invention is shown by way of example in figure 2.

The purpose of the present invention is therefore to cause the flying device 1 to roll, not in a constant sign rotation about its longitudinal axis, but by alternating the roll direction regularly at each revolution.

The roll command is therefore a zero-mean periodic signal, contrary to the abovementioned usual method that relies on a constant sign command.

Thus, with this command of the flying device 1, intended to cause it to roll in alternating directions, the scale factor of the pitch rate gyro 2 mounted on said flying device 1 is naturally cancelled out, as detailed below, as are the other usual drifts. These other drifts are cancelled out according to the present invention in the same way as with the abovementioned usual single-direction roll method.

Figure 3 explains the scale factor correction. Figure 3 shows the following:

- an axis T illustrating the variation of time during a flight of the flying device 1;
- above said axis T, a trihedral R1 comprising the conventional axes x1, y1 and z1 associated with the flying device 1, being caused to roll (about x1) by the command according to the invention, and at regular intervals (at each revolution), alternating directions, (-w) and then (+w);
- below this axis T, a trihedral R2 comprising axes x2, y2 and z2 that is at ground level and fixed, wherein the measurements taken are transposed.

This figure 3 shows that, according to the invention, bias errors (angular or accelerometric) that are constant in the axes of the device cancel themselves out over a period (one revolution) when they are expressed in ground axes (R2 navigation coordinate system).

The inversion of the roll direction (± w) cancels out the scale factor effect of the gyro 2, which would otherwise become unacceptable. By way of example, in the case of a 0.1% error, and even for a low w value (for example of 1 Hz, i.e. 2π rad/s), the error generated in just 60 seconds would be 360°x60x0.001 = 21.6° with unacceptable consequences on the speed and position drifts. The solution according to the invention that consists in inverting the sign of w cancels out the time average of this error.

The need for a gyroscope is therefore strongly reduced (drift due to the scale factor of the pitch rate gyro eliminated) and the present invention also enables to retain one gyro for numerous applications. It therefore reduces the cost, for navigational performance levels that are comparable with that achieved when using a gyroscope.

It should be noted that:

- the projection of the rolling device axes onto the ground-level axes remains constant for the longitudinal axis X (unlike the axes Y and Z): the axis x1 remains constant and always equal to +x2 (unlike y1 and z1 that are rotating). For this reason, the usual autorotation does not correct longitudinal defects: bias and scale factor of the gyro X (and of the accelerometer X);
- for a rate of rotation 2 about X, the angular drift per second about the axis X1 = X2 is expressed as Δ + = bgx + fgx.w, where bgx is the angular bias X, and fgx the gyro scale factor X;
- in this state, if nothing is done, this term remains constant in the axes X1 and X2, and does not cancel itself out on average;
- the bgx term is present and there is nothing that can be done about it. However, with w = -w it is possible to ensure the continued rotation of the device 1 (thus the cancelling out of the other drifts corrected by the usual autorotation) and to achieve, this time, an angular drift per second Δ- = bgx-fgx.w.

  The bgx term remains. But the terms fgx are cancelled out on average over the course of a full cycle (being carried by X1 = X2, this being true in a rotating reference system or in a fixed ground-level reference system).

The present invention relates to the guiding and inertial navigation of the flying device 1, and more particularly the control (limitation) of inertial drifts during flight, that can apply to any inertial navigation missile, the rolling of which is possible without causing any other constraints (range, operating concept...).

The example of figure 2 showing the roll command p (expressed in rad/s) as a function of time t (expressed in seconds) includes an inversion of the command direction after each revolution of the flying device 1 about its longitudinal axis 3 (n = 1). However, it is also possible to select n greater than 1 (less frequent alternating), for example to reduce the induced aerodynamic forces. Since the rate of rotation can be slow, and the drift due to the scale factor generated in the course of a revolution in a first direction cannot be corrected (compensated) before the revolution in the other direction, it is generally preferable to change roll direction at each revolution.

Inertial shift measurements, following the application of the command according to the present invention (in particular to an inexpensive, short-range, air-surface missile, for which the added cost of a gyroscope is prohibitive), and the comparisons with usual drifts (without any correction attempt) and with a constant sign autorotation solution (without gyroscope and with a gyroscope) have shown that the present invention achieve inertial performance levels similar to the solution implementing a gyroscope (40% to 60% of shifts compensated, against 50% to 75% with the solution implementing a gyroscope, with the exception of the roll angle), but without added costs or equipment constraints (no gyroscope, no additional sensor).

Therefore, according to the invention:

- on the lateral axes:
  - the bias errors (angular or accelerometric) of the sensors carried by the axes y1 and z1 are in fact corrected (in the same way as with a usual autorotation);
  - the scale factor errors (angular or accelerometric) of the sensors carried by the axes y1 and z1 are also corrected (in the same way as with a usual autorotation);
- on the longitudinal axis:
  - the bias errors (angular or accelerometric) of the sensors carried by the axis x1 are not corrected (in the same way as with a usual autorotation);

- the accelerometric scale factor error of the sensor carried by the axis x1 is not corrected (in the same way as with a usual autorotation); but
- the angular scale factor error of the sensor carried by the axis x1 is corrected (in the same way as with a usual autorotation).

The present invention relates to any navigation system, i.e. a complete inertial sensor unit (excluding the longitudinal accelerator).

PATENTKRAV

1. Fremgangsmåte for automatisk styring av et langsgående gyrometer (2) som er montert på en luftmissil, som kan settes i rotasjon, fremgangsmåte ifølge hvilken det, gjennom bruk av det langsgående gyroskopet (2), automatisk kontrolleres nevnte missil (1) slik at den settes i rotasjon om dens langsgående akse (3), med vekslende rotasjonsretning, og dette på en jevn måte, rotasjonsretningen endres hver revolusjon for å kansellere effekten av skala faktoren til nevnte langsgående gyroskop (2), i tillegg til å korrigere avdrift, hvis korreksjon er oppnådd ved å rotere missilet (1).

2. Luftmissil, som kan settes i rotasjon og som omfatter et langsgående gyroskop (2), nevnte missil (1) omfatter automatiske styringsmidler (8) for å styre den slik at den roter om sin langsgående akse (3), under jevn veksling av rotasjonsretningen, rotasjonsretningen endres ved hver revolusjon for å kansellere effekten av skala faktoren av gyroskopet (2), i tillegg til å korrigere avdrift, hvis korreksjon er oppnådd ved å rotere missilet (1).

3. Missil ifølge krav 2, karakterisert ved at nevnte automatiske styringsmidler (8) er en del av et automatisk styringssystem (6) av nevnte missil (1).

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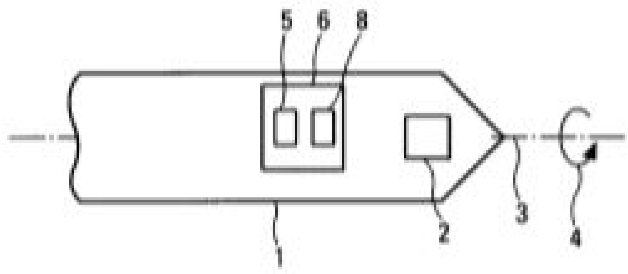

Fig. 1

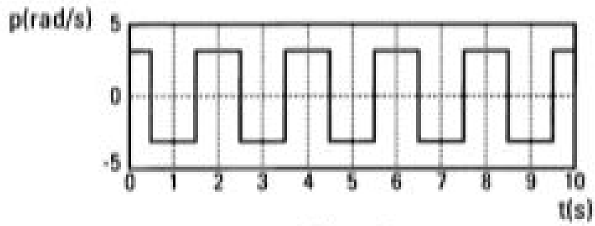

Fig. 2

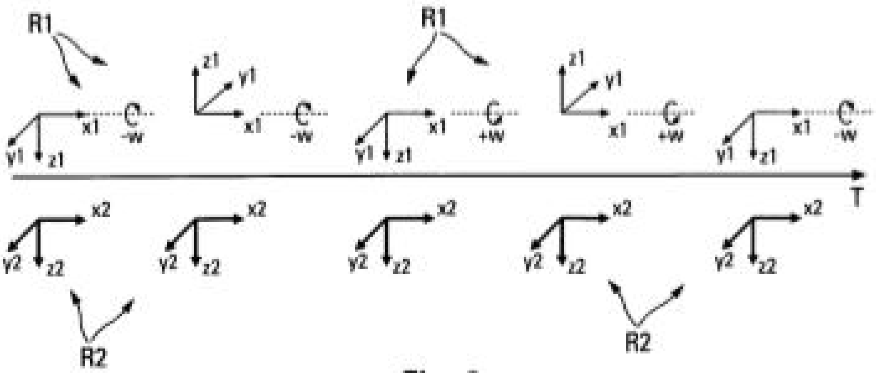

Fig. 3