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(54) STABILISATION SYSTEM, e.g. FOR A NAVAL RADAR INSTALLATION

(71) We, HOLLANDSE SIGNAAL-APPARATEN B.V. formerly known as N.V. Hollandse Signaalapparaten, of 40 Zuidelijke Havenweg, Hengelo (O), The Netherlands, a company organized and existing under the laws of The Netherlands, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention relates to a stabilisation system, for a platform on a moving craft, for example in a naval radar installation, in which a gyro housing contains a vertical gyro in a cardanic suspension and is mounted on the platform to be stabilised. The platform is itself cardanically suspended in the craft by means of two gimbal frames having coplanar orthogonal shafts about which the platform is stabilised. Stabilisation about each of said shafts is effected by a servo system controlled by said gyro.

In this specification, a vertical gyro is one that operates with its spin axis in a vertical position with respect to the earth's surface.

A similar system is described in the U.S. Patent 3,358,285. However, before the stabilisation mechanism there described can operate, the spin axis of the vertical gyro must, to some extent, be brought—from a random orientation—to a position vertical with respect to the earth's surface. Also, in addition to the difficulties caused by this run-up process, that the platform may already be stabilised by external means, through a ship's gyro situated, for example, in the meta-centre of the ship, the stabilisation process being taken over at a certain moment by use of the above-mentioned vertical gyro, while the vertical gyro will generally have a random orientation at that moment.

Hence, the object of the invention is to provide a stabilisation system of the type described in the opening paragraph, in which the process whereby the spin axis of the vertical gyro is brought to a position vertical

with respect to the earth's surface and the subsequent platform stabilisation, during which the gyro stabilising the platform is held in the vertical position by a pair of orthogonal accelerometers mounted on the platform is realised in a very simple way in one and the same system operating in two steps, the first step operating in two alternative modes, in which the same elements are used as much as possible in all the steps and modes of operation.

According to the invention, there is provided a stabilisation system for a cardanically mounted platform, comprising a vertical gyro cardanically mounted on the platform with a motor and a pickoff mounted on each maintaining the platform in an approximately horizontal position and a pair of control circuits for comparing the relative positions of the platform and gyro thereby to activate the motor to bring the gyro to a substantially vertical position, the system also including means for stabilising the platform using the vertical gyro, when it has been brought to the substantially vertical position.

The invention will now be further explained with the aid of the figures, in which:

Fig. 1 is a schematic representation of the stabilisation system, and

Fig. 2 illustrates in more detail that part of the stabilisation system which effects the stabilisation about one of the shafts pertaining to the system.

Like parts in both figures are denoted by like reference numerals.

The numeral 1 in Fig. 1 represents a platform to be stabilised. For this purpose this platform is held in a cardanic suspension by means of two concentric gimbal frames 2 and 3 and corresponding co-planar orthogonal shafts 4 and 5, respectively. If the platform to be stabilised is on board a ship, then the inner gimbal frame 2 is mounted in bearings in the gimbal frame 3, which is mounted in the ship on the shaft 5, which is parallel to the fore-and-aft line of the ship, as is conventional.

The inner gimbal frame 2 carries two servo motors 6 and 7. By means of the transmission systems 8 and 9 respectively, these servo motors can tilt the platform 1 to be stabilised to hold it in a certain fixed position with respect to an earth-fixed reference. A gyroscope 10 serves as such a reference; said gyroscope is in a cardanic suspension in a gyroscope housing 11 mounted on the platform to be stabilised. A construction in which the gyroscope housing is located on the platform to be stabilised has the advantage that deformation of the ship due to rolling and pitching do not influence the stabilisation. If the inaccuracies resulting from these deformations are of little significance or are corrected in another way, the gyroscope of the platform to be stabilised may simply be set up at a remote position, for instance in the meta-centre of the ship. The first case is known as local stabilisation, the latter case as external stabilisation. The gyroscope 10, which is also called a vertical gyro, contains a spin axis, which, when the gyroscope has taken the desired orientation, is exactly vertical with respect to the earth's surface. The vertical gyro 10 provides two misalignment voltages through synchro transmitters (pickoffs) 12 and 13 connected to the gyro. As soon as the platform and, hence, the gyroscope housing are taken from the zero position determined by the vertical spin axis of the gyro 10, these misalignment voltages are fed via servo amplifiers 14 and 15 respectively to the servo motors 6 and 7, which tilt the platform to be stabilised in such a way that these misalignment voltages are reduced to zero. In this way the platform is stabilised about the shafts 4, 5 by the servo systems (13,14,6,8), (12,15,7,9), controlled by the vertical gyro 10.

Although in operation the spin axis of the vertical gyro 10 is kept in a vertical position by means of the gyro control devices used, the spin axis of the gyro must previously have been brought to at least approximately the vertical from a random orientation.

To do this, in a first step the spin axis of the vertical gyro 10 is brought, at least approximately, from a random orientation to a position vertical with respect to the earth's surface by means of the above-mentioned synchro transmitters 12 and 13, first control circuits connected to each of these synchros, and two torque motors 16 and 17 connected to a corresponding first control circuit. Each of the first control circuits is composed successively of a demodulator, a compensation network, and a matching amplifier, which are indicated in Figure 2 by 18, 19 and 20 respectively. In a second step, during which gyro 10 stabilizes the platform, the spin axis of the vertical gyro 10 is held in said vertical position, in a known manner, by means of two accelerometers 21 and 22 respectively,

which are mounted on the platform to be stabilised, second control circuits connected with each of these accelerometers and the above-mentioned torque motors 16 and 17, whereby each of the second control circuits is composed successively of the filter indicated in Figure 2 by 23, the compensation network 19 and the matching amplifier 20. The gyro drive circuits of which each is formed by a combination of a first and a second control circuit, are indicated by 24 and 25 respectively.

There are two modes in which the first step of the stabilisation process can be carried out viz:

1. The first mode is used in conjunction with external stabilisation of the platform; in that case the platform stabilisation takes place by means of a ship's gyro situated, for example in the metacentre of the ship. The position of the platform 1 to be externally stabilised is compared with a reference position, indicated by the external gyro stabilisation system 26, by means of the synchro transmitters 41 and 42, which are at the output of the external gyro stabilisation system 26, and synchro receivers 43 and 44 connected to each of the transmission systems 8 and 9 respectively. If the position of the platform 1 does not correspond to this reference position, then the synchro receivers 43 and 44 provide control voltages which are fed to the servo motors 6 and 7 respectively, via the conductors 45 and 46 and the servo amplifiers 14 and 15. The switches indicated in Figure 1 by 27 and 28 are in the opposite position to that which is indicated. In order to switch easily from this external stabilisation to local stabilisation, that is, stabilisation by using the gyro suspended in the housing mounted on the platform to be stabilised, the spin axis of the vertical gyro must be brought to the vertical position, i.e. aligned with the externally stabilised platform within a defined limit of accuracy. To this effect the vertical gyro is controlled in this first mode by the externally stabilised platform by means of the synchro transmitters 12 and 13 coupled to the gyro itself, the gyro drive circuits 24 and 25 connected to each synchro, and the torque motors 16 and 17 connected to the corresponding gyro drive circuits. It should also be noted that external stabilisation can also be obtained by coupling the platform to be locally stabilised eventually to another stabilised platform so that the movements of the latter platforms are followed lavishly;

2. In the second alternative mode of the first step, the platform is temporarily fixed in position relative to the ship. In this situation the platform follows the ship's movements. Similar to the first mode of the first step, the spin axis of the gyro 10 must be brought at least approximately from a random orien-

tation to a position vertical with respect to the earth's surface by means of the synchro transmitters 12 and 13, the gyro drive circuits 24 and 25 and the torque motors 16 and 17. Since in this situation the platform is not stabilized, the vertical gyro is brought to the vertical position with a greater inaccuracy than in the first mode. However, this does not give rise to any objections because in the second step, during which gyro 10 stabilises the platform the spin axis of the vertical gyro is kept in an exactly vertical position by means of accelerometers.

So, it can be seen that in either of the two modes of the first step the spin axis of the vertical gyro is brought, at least approximately to the vertical position and in the two modes the gyro is controlled by the platform; the platform is kept in the horizontal position in the first mode by stabilization, and in the second mode is rendered approximately horizontal by being fixed in position relative to the ship.

The stabilization system is switched from the first into a second step when the spin axis of the gyro has been either (in the first mode) made vertical with respect to an externally maintained reference, or (in the second mode) when it has been placed into an approximately vertical position with respect to the ship. Switching from the first mode of the first step to the second step occurs when a precision indicator shows that the spin axis of the gyro has been aligned with the externally stabilised platform. Switching from the second mode of the first step to the second step occurs upon the expiration of a predetermined time.

In the following the parts of the stabilisation system that effects the stabilisation about the shaft 4 will now be further described with reference to Figure 2.

During external stabilisation (the first mode of the first step) the switch 28 in Figure 2 is in the opposite position to that which is indicated. In this switch position, the position of the platform is compared with the reference indicated by the external gyro stabilisation system 26 by means of the synchro transmission system 42, 44. If the two do not correspond, then the synchro receiver 44 emits a control signal, which is fed to the motor 7 via the conductor 46 and the servo amplifier, 15. If the platform is not being externally stabilised, the switch 28 is in the indicated position and the servo system formed by the amplifier 15 and the motor 7 is activated by the synchro transmitter 12; during the second mode of the first step, however, the platform remains fixed relative to the ship.

The switch 29 is in the indicated position in either mode of the first step. The vertical gyro 10 is then activated by the synchro 12 the demodulator 18, the compensation net-

work 19, the matching amplifier 20 and the torque motor 16. When the stabilization process is operated, in the second step, the vertical gyro is activated by the accelerometer 21, the filter 23, the compensation network 19, the matching amplifier 20 and the torque motor 16.

Now, if it is assumed that the platform is controlled by the vertical gyro, but the spin axis of this gyro is not in an exactly vertical position, the platform will show a similar deviation from the horizontal plane, that is, a deviation corresponding to an angular rotation θ of the platform about the shaft indicated in Figure 1 by 4. In that case, the accelerometer 21 produces a voltage

$$e = K_1(g\theta + a)$$

where g represents the gravitational acceleration, a an interfering acceleration due to a movement of the ship and K_1 a constant. The signal provided by the accelerometer in the second step is thus built up from two components, viz. a component which is a measure for the skew of the platform and a signal varying in amplitude and frequency due to the movement of the ship. The latter signal may be given by

$$K_1 a = K_1 a \sin \omega_s t,$$

where ω_s is the frequency of the pitching movement of the ship. The signal provided by the accelerometer is fed to the filter 23. The purpose of this filter is to provide ample damping for the ship's frequencies (ω_s), whose magnitudes are in the order of 0.5 to 1.25 rad./sec. For this purpose a low-pass filter has been chosen. The dimensions of this filter, are such that if F represents the transfer function of the filter, F is approximately equal to 1 for frequency values $\omega \ll 0.12$ rad/sec and a damping of 30 dB/oct occurs for frequency values $\omega \gg 0.12$ rad/sec. In view of this filter characteristic, the signal provided by the filter may now be expressed by:

$$K_1 g \theta_1.$$

This signal is fed to the compensation network 19. This network is composed of an amplifier 30, an integrator 31 and a summing element 32. A switch is provided between the integrator and the summing element; however, this switch is closed when the stabilisation process is taking place in the second step. If the transfer function of the compensation network is now given by

$$a_1 + \frac{a_2}{s}$$

then the signal provided by this network and fed to the matching amplifier 20 is represented by

$$K_1 g \theta_1 \left(a_1 + \frac{a_2}{s} \right)$$

- 5 Due to the fact that a 400 Hz pancake motor is used for the torque motor 16, the matching amplifier 20 functions as modulator. If K_2 represents the d.c. amplification of this modulator and K_3 the transfer function of the pancake motor, the torque exerted on the gyro is expressed by

$$K_1 g \theta_1 \left(a_1 + \frac{a_2}{s} \right) K_2 K_3$$

or

$$C_1 \left(1 + \frac{C_2}{sr} \right) \theta_1$$

- 15 where C_1 and C_2 are constants and τ the RC time of the integrator 31 pertaining to the compensation network. Since the transfer function of the gyro may be expressed by

$$\frac{C_3}{s}$$

- 20 the angle through which the gyro is turned is given by

$$\theta_0 = \left(1 + \frac{C_2}{sr} \right) \frac{1}{sr} \theta_1$$

where

$$\tau_1 = \frac{1}{C_1 C_3}$$

- 25 represents the time constant of the erection loop formed by the accelerometer, the gyro drive circuit and the pancake motor.

- 30 If it is now assumed that no spurious torques are exerted on the gyro and the spin axis of the gyro has turned about the shaft 34 through the same angle θ_1 as the platform about the shaft 4, then the term $C_1 \theta_1$ in the expression

$$C_1 \left(1 + \frac{C_2}{sr} \right) \theta_1$$

- 35 represents the torque that must be exerted on the gyro in order to bring this gyro in the desired vertical position (compare: Savet

—Gyroscopes: Theory and Design, Section 3—4).

If now an unbalance occurs in the gyro, for instance about the shaft indicated in Figure 1 by 34, then the resulting torsional unbalance produces precession about the shaft indicated in Figure 1 by 35. In order to eliminate this ever-increasing angular displacement, an increasing torque should be exerted on the axis 34. To this effect an integration, which is proportional to the unbalance occurring in the gyro, is carried out on the control torque or on a value proportional to this, such as, in the case considered, on the filtered signal from the accelerometer. Hence, the term

$$\frac{C_1 C_2}{sr} \theta_1$$

in the last-mentioned expression represents the unbalance compensation.

As regards the integration constants τ and τ_1 it may be noted that

$$\frac{\tau}{C_2} \gg \tau_1$$

in order that the control determining the vertical position is not too strongly influenced by the unbalance compensation (compare: Savet—Gyroscopes: Theory and Design, Section 6—5). The integrator 31 is so designed that it has a diminished time constant τ if the input voltage of the integrator exceeds a certain value. This implies that, as long as the gyro position has not yet approached the vertical position within a certain limit of accuracy, it is of little importance that the unbalance compensation influences the control determining the desired vertical position, while, on the other hand, the delayed effect on the gyro control is reduced.

In addition to the above-mentioned unbalance compensation, a ship's course and speed compensation and a compensation for the rotation of the earth can be provided in the gyro control.

The accelerometer 21 is sensitive to an increase in the speed of the ship. For the compensation of the resulting error in the signal from the accelerometer, a correction signal calculated by a computer, called Ve compensation (Ve= speed of the ship), together with the signal from the accelerometer 21 is fed to the filter 23 via the cable receiver/amplifier 36 (compare: Savet—Gyroscopes: Theory and Design, Section 6—12).

The accelerometer 22 is sensitive to a centrifugal acceleration which results from a change in the course of the ship. For the

compensation of the resulting error in the signal from the accelerometer, a correction signal calculated by the computer, called Ke.Ve compensation (Ke=course of the ship), together with the signal from the accelerometer 22, is fed to the respective filter via a cable receiver/amplifier (compare: Savet—Gyroscopes: Theory and Design, Section 6—13).

If the ship's heading is suddenly changed, an inaccuracy in the Ke.Ve compensation may occur and this may result in serious stabilisation errors. These errors may be reduced by switching the stabilisation system in a "free drift" mode. This switching is implemented by the computer which, to this effect, provides the integrator 31 and the summing element 32 with a signal via the cable receiver/amplifier 37. The integrator and the summing element are both provided with a hold circuit. The output voltage of the integrator and the summing element is kept constant during computer determined time intervals in the free drift mode through these hold circuits, and the gyro control is not influenced anymore by undesired accelerations. In the free drift mode the Ke.Ve compensation can be left out.

Finally, the compensation for the earth's rotation is also computer-determined and, together with the signal from the compensation network 19, is fed to the modulator 20, via the cable receiver/amplifier 38 (compare: Savet—Gyroscopes: Theory and Design, Section 6—4).

As previously mentioned, the gyro 10 activates the synchro 12, the demodulator 18, the compensation network 19, the matching amplifier 20 and the pancake motor 16 in the first and in the second mode of the first step. In the case in which external stabilisation is used (i.e. in the first mode of the first step), a precision indicator 39 and the lamp 40, the indicator being connected to the output of the amplifier 30 pertaining to the compensation network, indicate that the spin axis of the gyro is brought to the vertical position, i.e. aligned with the platform within a defined limit of accuracy and that the stabilisation process can be switched manually from the first mode of the first step to the second step. It should also be noted that the switch 33 between the integrator 31 and the summing element 32 is in the open (indicated) position during the second mode of the first step. During this mode the platform is fixed relative to the ship, and the spin axis of the gyro is only brought in an orientation approaching the vertical position, through which an unbalance compensation, which would exercise a retarding influence on the gyro control in the second mode of the first step, can be left out. Upon the expiration of a predetermined time a switch is made automatically

from the second mode of the first step to the second step, at the same time the switch 33 is being closed.

WHAT WE CLAIM IS:—

1. A stabilization system for a cardanically mounted platform, comprising a vertical gyro cardanically mounted on the platform with a motor and a pickoff mounted on each shaft of the gyro suspension, means for maintaining the platform in an approximately horizontal position and a pair of control circuits for comparing the relative positions of the platform and gyro thereby to activate the motors to bring the gyro to substantially vertical position, the system also including means for stabilizing the platform using the vertical gyro, when it has been brought to the substantially vertical position. 70
2. A system as claimed in claim 1, wherein the means for maintaining the platform in an approximately horizontal position comprises an external gyro. 75
3. A system as claimed in claim 1, wherein the means for maintaining the platform in an approximately horizontal position, comprises mechanical means for securing the platform in a fixed position relative to the part to which it is mounted. 80
4. A system as claimed in claim 2, wherein the platform is stabilized using the vertical gyro when the vertical gyro is in a vertical position with a predetermined accuracy. 85
5. A system as claimed in claim 3, wherein the platform is stabilized using the vertical gyro after a pre-set interval. 90
6. A system as claimed in any preceding claim, wherein each of the control circuits comprises in series a demodulator a compensation network and a matching amplifier. 95
7. A system as claimed in any preceding claim, wherein the means for stabilizing the platform using the vertical gyro includes a pair of orthogonal accelerometers and a corresponding pair of further control circuits, connected to the motors and the pickoffs of the vertical gyro. 100
8. A system as claimed in claim 7, wherein each further control circuit comprises in series a filter, a compensation network and a matching amplifier. 105
9. A system as claimed in claim 8, wherein each filter is connected to one of the accelerometers and a computer which provides correcting signals for changes in course or speed of the part on which the platform is mounted, the filter suppressing signals due to relatively higher frequency oscillatory movements of the part. 110
10. A system as claimed in claim 6 or 8, wherein one pair of networks is provided in the system, switched to form the first mentioned control circuits while the vertical gyro is being brought to the vertical position and to form the further control circuits during 125



compensation of the resulting error in the signal from the accelerometer, a correction signal calculated by the computer, called Ke.Ve compensation (Ke=course of the ship), together with the signal from the accelerometer 22, is fed to the respective filter via a cable receiver/amplifier (compare: Savet—Gyroscopes: Theory and Design, Section 6—13).

10 If the ship's heading is suddenly changed, an inaccuracy in the Ke.Ve compensation may occur and this may result in serious stabilisation errors. These errors may be reduced by switching the stabilisation system in a "free drift" mode. This switching is implemented by the computer which, to this effect, provides the integrator 31 and the summing element 32 with a signal via the cable receiver/amplifier 37. The integrator and the summing element are both provided with a hold circuit. The output voltage of the integrator and the summing element is kept constant during computer determined time intervals in the free drift mode through these hold circuits, and the gyro control is not influenced anymore by undesired accelerations. In the free drift mode the Ke.Ve compensation can be left out.

30 Finally, the compensation for the earth's rotation is also computer-determined and, together with the signal from the compensation network 19, is fed to the modulator 20, via the cable receiver/amplifier 38 (compare: Savet—Gyroscopes: Theory and Design, Section 6—4).

35 As previously mentioned, the gyro 10 activates the synchro 12, the demodulator 18, the compensation network 19, the matching amplifier 20 and the pancake motor 16 in the first and in the second mode of the first step. In the case in which external stabilisation is used (i.e. in the first mode of the first step), a precision indicator 39 and the lamp 40, the indicator being connected to the output of the amplifier 30 pertaining to the compensation network, indicate that the spin axis of the gyro is brought to the vertical position, i.e. aligned with the platform within a defined limit of accuracy and that the stabilisation process can be switched manually from the first mode of the first step to the second step. It should also be noted that the switch 33 between the integrator 31 and the summing element 32 is in the open (indicated) position during the second mode of the first step. During this mode the platform is fixed relative to the ship, and the spin axis of the gyro is only brought in an orientation approaching the vertical position, through which an unbalance compensation, which would exercise a retarding influence on the gyro control in the second mode of the first step, can be left out. Upon the expiration of a predetermined time a switch is made automatically

from the second mode of the first step to the second step, at the same time the switch 33 is being closed.

WHAT WE CLAIM IS:—

1. A stabilization system for a cardanically mounted platform, comprising a vertical gyro cardanically mounted on the platform with a motor and a pickoff mounted on each shaft of the gyro suspension, means for maintaining the platform in an approximately horizontal position and a pair of control circuits for comparing the relative positions of the platform and gyro thereby to activate the motors to bring the gyro to substantially vertical position, the system also including means for stabilizing the platform using the vertical gyro, when it has been brought to the substantially vertical position.

2. A system as claimed in claim 1, wherein the means for maintaining the platform in an approximately horizontal position comprises an external gyro.

3. A system as claimed in claim 1, wherein the means for maintaining the platform in an approximately horizontal position, comprises mechanical means for securing the platform in a fixed position relative to the part to which it is mounted.

4. A system as claimed in claim 2, wherein the platform is stabilized using the vertical gyro when the vertical gyro is in a vertical position with a predetermined accuracy.

5. A system as claimed in claim 3, wherein the platform is stabilized using the vertical gyro after a pre-set interval.

6. A system as claimed in any preceding claim, wherein each of the control circuits comprises in series a demodulator a compensation network and a matching amplifier.

7. A system as claimed in any preceding claim, wherein the means for stabilizing the platform using the vertical gyro includes a pair of orthogonal accelerometers and a corresponding pair of further control circuits, connected to the motors and the pickoffs of the vertical gyro.

8. A system as claimed in claim 7, wherein each further control circuit comprises in series a filter, a compensation network and a matching amplifier.

9. A system as claimed in claim 8, wherein each filter is connected to one of the accelerometers and a computer which provides correcting signals for changes in course or speed of the part on which the platform is mounted, the filter suppressing signals due to relatively higher frequency oscillatory movements of the part.

10. A system as claimed in claim 6 or 8, wherein one pair of networks is provided in the system, switched to form the first mentioned control circuits while the vertical gyro is being brought to the vertical position and to form the further control circuits during



stabilization of the platform by the vertical gyro.

11. A system as claimed in claim 10, wherein each compensation network comprises an amplifier, an integrator, a summing element and two hold circuits whereby the outputs of the integrator and the summing element are kept constant during computer determined time intervals occurring on sudden change of the course of the part on which the platform is mounted.

12. A system as claimed in claim 8, or in any of claims 9 to 11, when appendent to claim 8, wherein the signal to each matching amplifier comprises the output signal of the compensation network and a computer determined correction for the rotation of the earth.

13. A system as claimed in claims 5 and

11, wherein a switch is provided between the integrator and summing element, said switch isolating the integrator output during the present interval.

14. A system as claimed in any preceding claim, wherein the platform is for mounting in a ship.

15. A stabilization system for a cardanically mounted platform, substantially as hereinbefore described with reference to the accompanying drawings.

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