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FOR ABSTRACT SEE THE NEXT SHEET

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[Fortsetzung auf der nächsten Seite]

(54) Title: METHOD FOR DETERMINING A ZERO POINT ERROR IN A VIBRATORY GYROSCOPE

(54) Bezeichnung: VERFAHREN ZUR ERMITTLUNG EINES NULLPUNKTFEHLERS IN EINEM CORIOLISKREISEL

(57) Abstract: The invention relates to a method for determining the zero point error of a vibratory gyroscope (1). According to said method, the resonator (2) of the vibratory gyroscope (1) is impinged by appropriate interference forces in such a way that at least one intrinsic vibration of the resonator (2), which differs from the excitation vibration and the readout vibration of the resonator (2), is induced and a modification of a readout signal that represents the readout vibration, resulting from the excitation of the intrinsic vibration(s) is determined as a value for the zero-point error.

(57) Zusammenfassung: Bei einem Verfahren zur Ermittlung des Nullpunktfehlers eines Corioliskreisels (1) wird der Resonator (2) des Corioliskreisels (1) mit entsprechenden Störkräften so beaufschlagt, dass wenigstens eine Eigenschwingung des Resonators (2), die sich von der Anregungsschwingung und der Ausleseschwingung des Resonators (2) unterscheidet, angeregt wird und eine Änderung eines die Ausleseschwingung repräsentierenden Auslesesignals, die aus der Anregung der wenigstens einen Eigenschwingung resultiert, als Mass für den Nullpunktfehler ermittelt wird.

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Method for determination of a zero error in a Coriolis gyro

The invention relates to a method for determination of a zero error in a Coriolis gyro.

Coriolis gyros (also referred to as vibration gyros) are being used increasingly for navigation purposes. Coriolis gyros have a mass system which is caused to oscillate. This oscillation is generally a superimposition of a large number of individual oscillations. These individual oscillations of the mass system are initially independent of one another and can each be referred to abstractly as "resonators". At least two resonators are required for operation of a vibration gyro: one of these resonators (the first resonator) is artificially stimulated to oscillate, and this is referred to in the following text as the "stimulating oscillation". The other resonator (the second resonator) is stimulated to oscillate only when the vibration gyro is moved/rotated. This is because Coriolis forces occur in this case, which couple the first resonator to the second resonator, absorb energy from the stimulating oscillation of the first resonator, and transfer this to the read oscillation of the second resonator. The oscillation of the second resonator is referred to in the following text as the "read oscillation". In order to determine movements (in particular rotations) of the Coriolis gyro, the read oscillation is tapped off, and a corresponding read signal (for example the read oscillation tapped-off signal) is investigated to determine whether any changes have occurred in the amplitude of the read oscillation, which represent a measure of the rotation of the Coriolis gyro. Coriolis gyros may be implemented both as open-looped systems and as closed-loop systems. In a closed-loop system, the amplitude of the read oscillation is continuously reset to a fixed value - preferably zero - via respective control loops.

An example of a closed-loop version of a Coriolis gyro will be described in the following text, with reference to Figure 2, in order to illustrate further the method of operation of a Coriolis gyro.

A Coriolis gyro 1 such as this has a mass system 2 which can be caused to oscillate and is also referred to in the following text as a "resonator". A distinction must be drawn between this expression and the "abstract" resonators mentioned above, which represent individual oscillations of the "real" resonator. As already mentioned, the resonator 2 may be regarded as a system composed of two "resonators" (the first resonator 3 and the second resonator 4). Both the first and the second resonator 3, 4 are each coupled to a force sensor (not shown) and to a tapping system (not shown). The noise which is produced by the force sensors and the tapping systems is indicated schematically here by Noise1 (reference symbol 5) and Noise2 (reference symbol 6).

The Coriolis gyro 1 furthermore has four control loops:

A first control loop is used to control the stimulating oscillation (that is to say the frequency of the first resonator 3) at a fixed frequency (resonant frequency). The first control loop has a first demodulator 7, a first low-pass filter 8, a frequency regulator 9, a VCO (Voltage Controlled Oscillator) 10 and a first modulator 11.

A second control loop is used to control the stimulating oscillation at constant amplitude, and has a second demodulator 12, a second low-pass filter 13 and an amplitude regulator 14.

A third and a fourth control loop are used to reset those forces which stimulate the read oscillation. In this case, the third control loop has a third demodulator 15, a third low-pass filter 16, a quadrature regulator 17 and a third modulator 22. The fourth control loop contains a fourth demodulator 19, a fourth low-pass filter 20, a rotation rate regulator 21 and a second modulator 18.

The first resonator 3 is stimulated at its resonant frequency ω1. The resultant stimulating oscillation is tapped off, is phase-demodulated by means of the first demodulator 7, and a demodulated signal component is supplied to the first low-pass filter 8, which removes the sum frequencies from it. The tapped-off signal is also referred to in the following text as the stimulating oscillation tapped-off signal. An output signal from the first low-pass filter 8 is applied to a frequency regulator 9, which controls the VCO 10 as a function of the signal supplied to it, such that the in-phase component essentially tends to zero. For this purpose, the VCO 10 passes a signal to the first modulator 11, which itself controls a force sensor such that a stimulating force is applied to the first resonator 3. If the in-phase component is zero, then the first resonator 3 oscillates at its resonant frequency ω1. It should be mentioned that all of the modulators and demodulators are operated on the basis of this resonant frequency ω1.

The stimulating oscillation tapped-off signal is also supplied to the second control loop and is demodulated by the second demodulator 12, whose output is passed to the second low-pass filter 13, whose output signal is in turn supplied to the amplitude regulator 14. The amplitude regulator 14 controls the first modulator 11 as a function of this signal and of a nominal amplitude [illegible], such that the first resonator 3 oscillates of constant amplitude (that is to say the stimulating oscillation has a constant amplitude).

As has already been mentioned, Coriolis forces - indicated by the term FC·cos(ω1·t) in the drawing - from a movement/rotation of the Coriolis gyro 1, which couple the first resonator 3 to the second resonator 4, and thus cause the second resonator 4 to oscillate. A resultant read oscillation at the frequency ω2 is tapped off, so that a corresponding read oscillation tapped-off signal (read signal) is supplied to both the third and the fourth control loop. In the third control loop, this signal is demodulated by the third demodulator 15, sum frequencies are removed by the third low-pass filter 16, and the low-pass-filtered signal is supplied to the quadrature regulator 17, whose output signal is applied to the third modulator 22 so as to reset corresponding quadrature components of the read oscillation. Analogously to this, in the fourth control loop, the read oscillation tapped-off signal is demodulated by the fourth demodulator 19, passes through the fourth low-pass filter 20, and a correspondingly low-pass-filtered signal is applied on the one hand to the rotation rate regulator 21, whose output signal is proportional to the instantaneous rotation rate, and is passed as a rotation rate measurement result to a rotation rate output 24, and on the other hand to the fourth modulator 18, which resets corresponding rotation rate components of the read oscillation.

The Coriolis gyro 1 as described above may be operated both in a double-resonant form and in a non-double-resonant form. If the Coriolis gyro 1 is operated in a double-resonant form, then the frequency ω2 of the read oscillation is approximately equal to the frequency ω1 of the stimulating oscillation while, in contrast, in the non-double-resonant case, the frequency ω2 of the read oscillation is different from the frequency ω1 of the stimulating oscillation. In the case of double resonance, the output signal from the fourth low-pass filter 20 contains corresponding information about the rotation rate while, in contrast, in the non-double-resonant case, the output signal from the third low-pass filter 16. In order to switch between the different double-resonant/non-double-resonant operating modes, a doubling switch 25 is provided, which alternatively connects the outputs of the third and the fourth low-pass filter 16, 20 to the rotation rate regulator 21 and the quadrature regulator 17.

The mass system 2 (resonator) generally has two or more natural resonances, that is to say different natural oscillations of the mass system 2 can be stimulated. One of these natural oscillations is the artificially produced stimulating oscillation. A further natural oscillation is represented by the read oscillation, which is stimulated by the Coriolis forces during rotation of the Coriolis gyro 1. As a result of the mechanical structure and because of unavoidable manufacturing tolerances, it is impossible to prevent other natural oscillations of the mass system 2, in some cases well away from their resonance, also being stimulated, in addition to the stimulating oscillation and the read oscillation. However, the undesirably stimulated natural oscillations result in a change in the read oscillation tapped-off signal, since these natural oscillations are also at least partially read by the read oscillation signal tap. The read oscillation tapped-off signal is accordingly composed of a part that is caused by Coriolis forces and a part which originates from the stimulation of undesired resonances. The undesirable part causes a zero error in the Coriolis gyro, whose magnitude is unknown, in which case it is not possible to differentiate between these parts when the read oscillation tapped-off signal is tapped off.

The object on which the invention is based is to provide a method by means of which the influence as described above of the oscillations of "third" modes can be established and the zero error can thus be determined.

This object is achieved by the method as claimed in the features of patent claim 1. The invention also provides a Coriolis gyro, as claimed in patent claim 7. Advantageous refinements and developments of the idea of the invention are contained in the respective dependent claims.

According to the invention, in the case of a method for determination of a zero error of a Coriolis gyro, the resonator of the Coriolis gyro has appropriate disturbance forces applied to it such that at least one natural oscillation of the resonator is stimulated, which differs from the stimulating oscillation and from the read oscillation of the resonator, in which case a change in a read signal which represents the read oscillation and results from the stimulation of the at least one natural oscillation is determined as a measure of the zero error.

In this case, the expression "resonator" means the entire mass system of the Coriolis gyro that is caused to oscillate, that is to say with reference to Figure 1, that part of the Coriolis gyro which is annotated with the reference number 2.

One major idea on which the invention is based is to artificially stimulate undesired natural oscillations of the resonator (that is to say natural oscillations which are neither the stimulating oscillation nor the read oscillation) and to observe their effects on the read oscillation tapped off signal. The undesired natural oscillations are in this case stimulated by application of appropriate disturbance forces to the resonator. The "penetration strength" of such disturbances to the read oscillation tapped-off signal represent a measure of the zero error (bias) of the Coriolis gyro. Thus, if the strength of a disturbance component contained in the read oscillation tapped-off signal is determined and is compared with the strength of the disturbance forces producing this disturbance component, then it is possible to derive the zero error from them.

The artificial stimulation of the natural oscillations and the determination of the "penetration" of the natural oscillations to the read oscillation tapped-off signal preferably takes place during operation of the Coriolis gyro. However, the zero error can also be determined without the existence of any stimulating oscillation.

The disturbance forces are preferably alternating forces at appropriate disturbance frequencies, for example a superimposition of sine and cosine forces. In this case, the disturbance frequencies are simultaneously equal to, or essentially equal to, the natural oscillation frequencies of the resonator. The changes in the read signal (disturbance component) can be determined by subjecting the read signal to a demodulation process based on the disturbance frequencies.

The zero error contribution which is caused by one of the natural oscillations (that is to say by one of the "third" modes) is preferably determined by determination of the strength of the corresponding change in the read signal. Determination of the corresponding resonance Q factor of the natural oscillation, and by calculation of the determined strength and resonance Q factor.

The resonance Q factor of a natural oscillation is preferably determined by detuning the corresponding disturbance frequency, while at the same time measuring the change that this produces in the read signal.

In order to investigate the effects of the undesired natural oscillations on the read oscillation tapped-off signal, two or more of the natural oscillations can be stimulated at the same time, and their "common" influence on the read oscillation tapped-off signal can be recorded. All of the disturbance natural oscillations of interest are, however, preferably stimulated individually, and their respective effect on the read oscillation tapped-off signal is observed separately. The zero error contributions obtained in this way from the individual natural oscillations can then be added in order to establish the "overall zero error" (referred to here as the "zero error") produced by the natural oscillations.

The disturbance component can be determined directly from the read oscillation tapped-off signal.

The invention also provides a Coriolis gyro, which is characterized by a device for determination of a zero error of the Coriolis gyro. The device has:

- a disturbance unit which applies appropriate disturbance forces to the resonator of the Coriolis gyro such that at least one natural oscillation of the resonator is stimulated, which differs from the stimulation oscillation and the read oscillation of the resonator, and
- a disturbance signal detection unit, which determines a disturbance component, which is contained in a read signal that represents the read oscillation and has been produced by the stimulation of the at least one natural oscillation, as a measure of the zero error.

If the disturbance forces are produced by alternating signals at specific disturbance frequencies, the disturbance signal detection unit has a demodulation unit by means of which the read signal is subjected to a demodulation process (synchronous demodulation at the disturbance frequencies). The disturbance component is determined from the read signal in this way.

The disturbance signal detection unit preferably has two demodulators which operate in quadrature with respect to one another, two low-pass filters and a control and evaluation unit, with the demodulators being supplied with the read oscillation tapped-off signal, with the output signals from the two demodulators being filtered by in each case one of the low-pass filters, and with the output signals from the low-pass filters being supplied to the control and evaluation unit, which determines the zero error on this basis.

The control and evaluation unit acts on the disturbance unit on the basis of the signals supplied to it, by which means the frequencies of the disturbance forces can be controlled by the control and evaluation unit.

Both the strength of the disturbance component in the read signal and the resonance Q factor of the corresponding natural oscillation must be determined in order to determine the zero error. These values are then correlated in order to obtain the zero error. In order to determine the resonance Q factor, the frequency of the disturbance unit must be detuned over the resonance while at the same time carrying out a measurement by means of the disturbance signal detector unit. This is preferably achieved by means of software, whose function is as follows:

- searching for the "significant" third disturbing natural resonances
- moving away from the associated resonance curve

- calculation of the Q factor and the strength of the stimulation, and the "visibility" of this third oscillation in the read channel
- calculation of the contribution of this third oscillation to the bias on the basis of the Q factor, strength and "visibility".

The bias can be compensated for by calculation, by means of the software.

The invention will be described in more detail in the form of an exemplary embodiment in the following text, with reference to the accompanying figures in which:

Figure 1 shows the schematic design of a Coriolis gyro which is based on the method according to the invention;

Figure 2 shows the schematic design of a conventional Coriolis gyro;

Parts and devices which correspond to those from Figure 2 are annotated with the same reference symbols in the drawings, and will not be explained again. The method according to the invention will be explained in more detail using an exemplary embodiment in the following description with reference to Figure 1.

The Coriolis gyro is additionally provided with a control and evaluation unit 26, a modulator 27 (disturbance unit) with a variable frequency ωmod and a preferably adjustable amplitude, two demodulators 28, 29, which operate in quadrature at the frequency ωmod, and a fifth and a sixth low-pass filter 30 and 31. The disturbance unit 27 produces an alternating signal at the frequency ωmod, which is added to the force input for the stimulating oscillation (first resonator 3). Furthermore, this signal is supplied as a reference signal to the demodulators 28, 29. An alternating force, which corresponds to the alternating signal, is thus additionally applied to the resonator 2. This alternating force stimulates a further natural oscillation (also referred to as a "third" natural mode) of the resonator 2 in addition to the stimulating oscillation, whose effects can be observed in the form of a disturbance component in the read oscillation tapped-off signal. In this example, the read oscillation tapped-off signal is subjected to a demodulation process in phase and in quadrature with respect to the stimulation produced by the modulator 27, which process is carried out by the demodulators 28, 29, at the frequency ωmod (disturbance frequency). The signal obtained in this way is low-pass filtered (by the fifth and the sixth low-pass filters 30, 31), and is supplied to the control and evaluation unit 26. This control and evaluation unit 26 controls the frequency ωmod and, if appropriate, the stimulation amplitude of the alternating signal that is produced by the modulator 27, in such a way that the frequencies and strengths of the "significant" third natural modes as well as their Q factors are determined continuously. The control and evaluation unit 26 uses this to calculate the respective instantaneous bias error, and supplies it for correction of the gyro bias.

Patent Claims

1. A method for determination of a zero error in a Coriolis gyro in which

- the resonator of the Coriolis gyro has appropriate disturbance forces applied to it such that at least one natural oscillation of the resonator is stimulated, which differs from the stimulating oscillation and from the read oscillation of the resonator, and
- a change in a read signal which represents the read oscillation and results from the stimulation of the at least one natural oscillation is determined as a measure of the zero error.

2. The method as claimed in claim 1, **characterized** in that the disturbance forces are alternating forces at appropriate disturbance frequencies, with the disturbance frequencies being natural oscillation frequencies of the resonator.

3. The method as claimed in claim 2, **characterized** in that the change in the read signal is recorded by subjecting the read signal to a demodulation process based on the disturbance frequencies.

4. The method as claimed in one of claims 1 to 3, **characterized** in that the zero error contribution which is produced by one of the at least one natural oscillations is determined by determination of the strength of the corresponding change in the read signal, determination of the corresponding resonance Q-factor of the natural oscillation and by calculation of the determined strength and resonance Q-factor.

5. The method as claimed in claim 4, **characterized** in that the resonance Q-factor of a natural oscillation is

determined by detuning the corresponding disturbance frequency while at the same measuring the change produced by this in the read signal.

6. The method as claimed in one of the preceding claims, **characterized** in that two or more successive nature oscillations of the resonator are stimulated, corresponding changes in the read signal are recorded, and corresponding zero error contributions are determined, with the zero error of the Coriolis gyro being determined by addition of the zero error contributions.

7. A Coriolis gyro **characterized** by a device for determination of the zero error of the Coriolis gyro having:

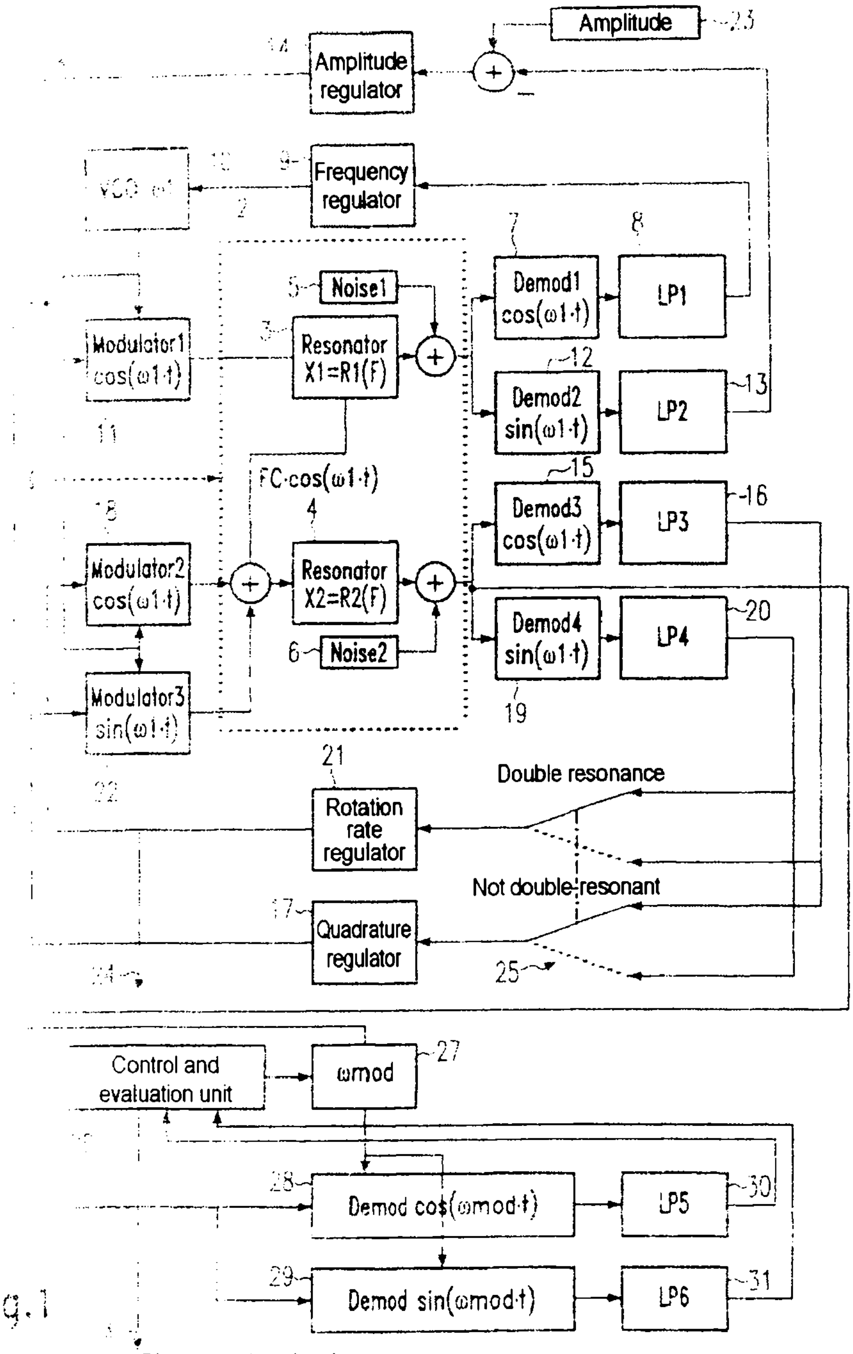
- a disturbance unit which applies appropriate disturbance forces to the resonator of the Coriolis gyro such that at least one natural oscillation of the resonator is stimulated, which differs from the stimulating oscillation and the read oscillation of the resonator, and
- a disturbance signal detection unit, which determines a disturbance component, which is contained in a read signal that represents the read oscillation and has been produced by the stimulation of the at least one natural oscillation, as a measure of the zero error.

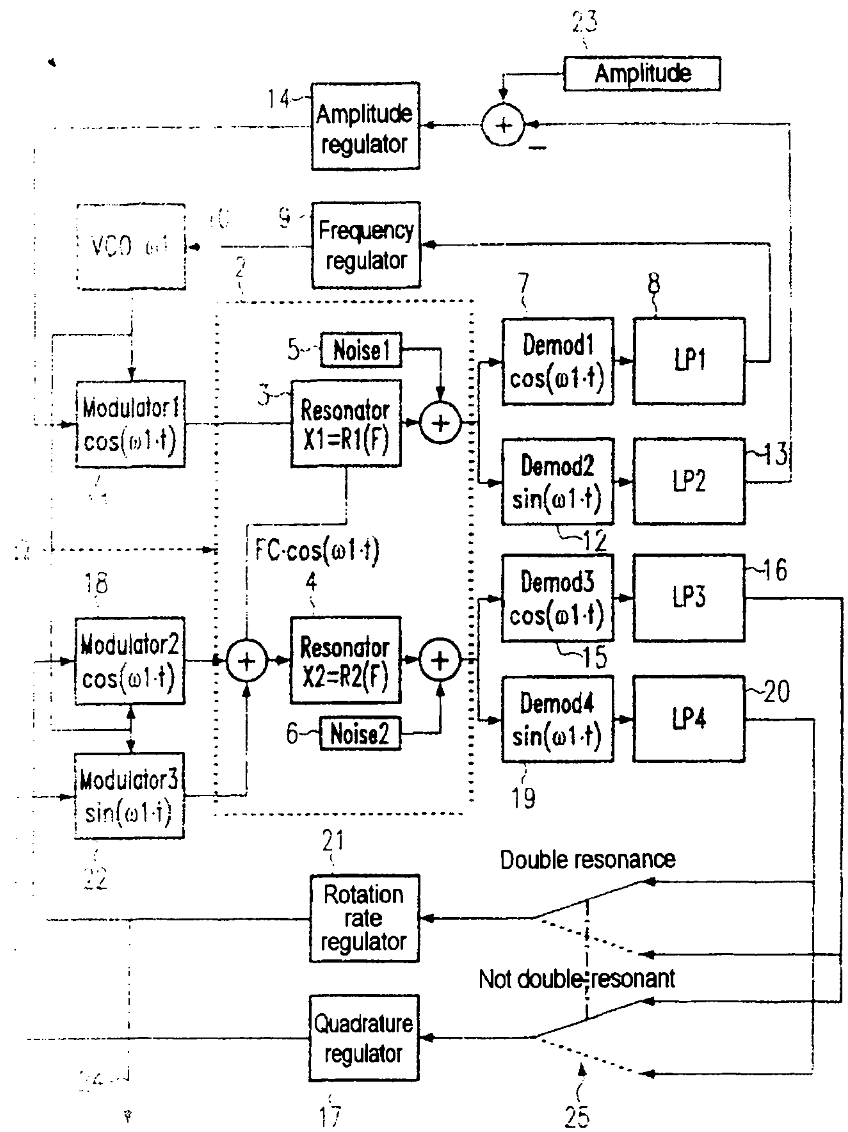
8. The Coriolis gyro as claimed in claim 7, **characterized** in that the disturbance signal detection unit comprises two demodulators, which operate in quadrature with respect to one another, two low-pass filters and a control and evaluation unit, with the demodulators being supplied with the read oscillation tapped-off signal, with the output signals from the demodulators being filtered by in each case one of the low-pass filters being supplied to the control and evaluation unit, which determines the zero error on this basis.

9. The Coriolis gyro as claimed in claim 8, **characterized** in that the control and evaluation unit acts on the disturbance unit on the basis of the signals supplied to it, by which means the frequencies of the disturbance forces can be controlled by the control and evaluation unit.

10. A method for determination of a zero error in a Coriolis gyro substantially as herein described with reference to Figure 1.

11. A Coriolis gyro substantially as herein described with reference to Figure 1.


Amplitude
23
14
Amplitude regulator
+
−
10
9
Frequency regulator
2
7
8
5
Noise1
Demod1 cos(ω1·t)
LP1
3
Resonator X1=R1(F)
+
Modulator1 cos(ω1·t)
12
Demod2 sin(ω1·t)
LP2
13
11
FC·cos(ω1·t)
15
Demod3 cos(ω1·t)
LP3
16
18
4
Modulator2 cos(ω1·t)
+
Resonator X2=R2(F)
+
Demod4 sin(ω1·t)
LP4
20
6
Noise2
Modulator3 sin(ω1·t)
19
21
Double resonance
22
Rotation rate regulator
Not double resonant
17
Quadrature regulator
25
24
Control and evaluation unit
ωmod
27
28
Demod cos(ωmod·t)
LP5
30
29
Demod sin(ωmod·t)
LP6
31
Bias correction signal
Fig.1



23
Amplitude
14
Amplitude regulator
VCO ω1
10
9
Frequency regulator
2
7
8
5
Noise1
Demod1 cos(ω1·t)
LP1
3
Resonator X1=R1(F)
Modulator1 cos(ω1·t)
Demod2 sin(ω1·t)
LP2
13
11
12
FC·cos(ω1·t)
18
4
Demod3 cos(ω1·t)
LP3
16
Modulator2 cos(ω1·t)
Resonator X2=R2(F)
15
Demod4 sin(ω1·t)
LP4
20
6
Noise2
Modulator3 sin(ω1·t)
19
21
22
Double resonance
Rotation rate regulator
Not double-resonant
Quadrature regulator
24
17
25

Fig.2