

PATENT SPECIFICATION

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(54) MOVEMENT INDICATING APPARATUS

(71) We, TIMEX CORPORATION, a corporation organized under the laws of the State of Delaware, U.S.A., of Waterbury, Connecticut 06720, United States of America, 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:—

This invention relates generally to indicating apparatus including a transducer having a second order transfer function and, more particularly, to transducers such as gyroscopes of the type employed in modern aircraft, guided missiles, and the like.

Precision instruments of various kinds have transducers which require damping in order to perform accurately, particularly gyroscopes, accelerometers, and other transducers wherein the movement of masses is utilized to measure velocity and other functions. A good example of the problem is found in the field of gyroscopes mounted within housings filled with oil or other liquid. Several different types of liquid damping systems have been developed, usually including vanes or blades attached to the moving mass and operating against the resistance offered by the liquid. Various combinations of valve-controlled passages and interconnected chambers provide means for varying the amount of damping in controlled fashion.

The most perplexing problem encountered is that which arises from the fact that the viscosity of fluids, such as silicone oils, varies with changes in ambient temperature. Any variation in the viscosity of the damping fluid changes the damping ratio and thereby causes an inaccurate output signal indication of the function being measured, for example, the rate input to a rate gyroscope.

The prior art includes a number of temperature and/or damping compensation mechanisms intended to lessen the effects of changes in damping of a gyroscope in order to obtain a constant damping force. Examples of such art is contained in U.S. Patent No. 2,955,472 issued October 11, 1960 to Walter J. Krupick et al, U.S. Patent No. 2,951,373 issued September 6, 1960 to Thomas O. Summers, U.S. Patent No. 2,839,931 issued June 24, 1958 to Harold W. Pope, U.S. Patent No. 2,839,932 issued June 24, 1958 to Paul F. Hanna, U.S. Patent No. 3,466,934 issued September 16, 1969 to Kenneth E. Pinard, U.S. Patent No. 2,839,933 issued June 24, 1958 to George J. Shapone, U.S. Patent No. 3,241,376 issued March 22, 1966 to Poket, U.S. Patent No. 3,352,163 issued November 14, 1967 to H. W. Boothroide. The abovementioned patents are mention as being representative of the prior art only and other pertinent patents may exist.

In all these prior art systems, however, complicated and costly mechanisms are required to compensate the damping ratio for changes caused by temperature variations. In contrast with the prior art, the present invention seeks to provide electronic means for directly compensating the output signal in proportion with damping variations caused by temperature and thereby substantially eliminates the prior art need for temperature or damping compensating mechanisms.

In accordance with the invention, there is provided indicating apparatus comprising a device having a second order transfer function, said device comprising a member whose movements in response to an input are damped and means responsive to movements of said member to provide a first electrical signal; and means responsive to said first electrical signal and to indications of variations of damping for providing a second electrical signal indicative of said input and substantially unaffected by variations in the damping of said member.

In order that the invention may be better understood, an embodiment thereof will

now be described by way of example only and with reference to the accompanying drawings in which:—

Figure 1 is a block diagram showing the indicating apparatus having means for compensating the output of a transducer having a second order transfer function for damping/temperature variations in accordance with the present invention;

Figure 2 is a schematic circuit diagram of the indicating apparatus comprising the compensation means of the present invention;

Figure 3 is a graph by way of example of the system's damping ratio as a function of temperature;

Figure 4 is a cutaway view of a rate gyroscope for use in the apparatus of Figure 2; and

Figure 5 is a schematic diagram of a (microsyn) signal generator for use in the apparatus of Figure 2.

Referring to Figure 1, a block diagram is shown which depicts in a functional manner the signal compensator or system/network 1, 2 used in conjunction with a device having a second order transfer function, hereinafter referred to as the second order system 3. The system 3 is, for example, of the type which produces a signal e_s in response to the movement of a damped member, for compensating the signal e_s for damping variations such that an output signal e_o is provided which is indicative of an input 4 and is unresponsive to or independent of variations of the selected damping factor of the second order system's 3 movable member.

The damping (variation) sensor 2 is physically attached to the system 3, but is functionally part of the signal compensator 1. It includes a variable element which is sensitive to the damping factor of the second order system 3 (or other property, for example, temperature, of the system 3 which is related to, influences, is controlled by or controls the damping) for varying the transfer function of the signal compensator 1, 2 as the second order system's damping factor varies.

The signal compensator 1, in response to damping variations indicated by the damping (variation) sensor 2, compensates or modifies or introduces a signal (voltage) component to the output signal e_s of the second order system 3 so as to provide the compensated output signal e_o .

Generally speaking, the zeros of the transfer function of the signal compensator 1, 2 are made to cancel the variable poles of the second order system's 3 transfer function. The signal compensator's poles are invariant and they, instead of the (variable) poles of the second order system, determine the total system response to any input 4.

Reference will now be made to Figure 2 which illustrates the preferred embodiment of the present invention.

The preferred embodiment of the invention uses, for example, a single-degree-of-freedom fluid damped rate gyroscope 5 as the second order system 3 depicted in Figure 1. The rate gyroscope 5 is a type of transducer which responds to an angular rate input 7 (radian/sec) to provide an output electrical signal. This output signal is an A.C. voltage, which by its amplitude and phase, indicates the magnitude and direction of the gimbal excursion, i.e. the movable member of the second order system. The output signal of the rate gyroscope 5 is coupled to the input of a demodulator 6. The demodulator 6, which does not form part of the invention, is used to remove the A.C. carrier frequency. However, it is possible that other embodiments of the invention (not shown), e.g. second order systems not employing a carrier frequency, would not utilize the demodulator 6. In this background the signal voltage e_s will be referred to in the specification as being the output signal of the second order system or rate gyroscope 5.

As noted above, the output signal e_s of the rate gyroscope 5 is influenced by variation in the damping caused, for example, by changes in temperature. The signal compensator 1, 2 shown in Figure 2 is designed to compensate the rate gyroscope's 5 output signal e_s for such influence and, to this end, it provides a compensated output signal e_o which is indicative of the rate input 7 and substantially independent of damping/temperature variations.

The signal compensator 1, 2 is designed to have a transfer function G_c , i.e. a ratio which relates the compensated output signal e_o to the rate gyroscope signal e_s by the relationship $G_c = e_o/e_s$, having component-terms which compensate for changes in the damping component-terms of the transfer function G_s of the rate gyroscope 5 such that the transfer function Y_s of the entire system/network comprising the combination of the rate gyroscope 5 and the signal compensator 1, 2 remains substantially constant with damping variations. The transfer function of the entire system can be simply represented by the following relationship:

$$Y_s = G_s \cdot G_c \quad (1A)$$

where Y_s is independent of damping variations. This relationship will be more fully explained in connection with the signal compensator 1, 2 shown in Figure 2.

The damping ratio variations in the transfer function G_s are dependent upon the temperature of the fluid damping system of the rate gyroscope 5. The relationship of the temperature with the damping factor makes it desirable, in accordance with the preferred embodiment of the present invention, to utilize a damping (variation) sensor 2 which is responsive to the temperature of the fluid damping system in order to make the compensating transfer function G_c responsive to change in the damping ratio of the rate gyroscope 5. This is effected by providing the signal compensator 1, 2 with a transfer function which varies with temperature inversely as the transfer function of the rate gyroscope 5 such that the transfer function Y_s of the combination of the rate gyroscope 5 with the signal compensator 1, 2 remains substantially constant over a wide temperature range.

The signal compensator 1 includes an active filter and a summing amplifier. Since active filters are known in the field such as is described in U.S. Patent No. 3,987,370 issued October 19, 1976 to Alan E. Schutz, and in "Active Filters" Wireless World, March 1970, pp. 134—139, they, therefore, will not be described in detail herein. Briefly, however, the active filter includes three operational amplifiers 10, 11, 12 connected in a closed loop configuration which comprises resistors R_2 , R'_2 , R_1 , R'_1 , R_0 and capacitors C_1 , C_0 and a feedback connection 13. Each of the operational amplifiers 10, 11, 12 have an inverting and non-inverting input indicated by a minus and a plus sign, respectively. The resistor R_x couples the output signal e_s of the rate gyroscope 5 to the inverting input of operational amplifier 10. The output signal voltage Y_2 of operational amplifier 10 is coupled via resistor R_1 to the inverting input of operational amplifier 11. The output signal voltage Y_1 of operational amplifier 11 is coupled via resistor R_0 to the inverting input of operational amplifier 12. Resistor R'_2 is connected between the output of operational amplifier 10 and its inverting input. Resistor R'_1 and capacitor C_1 are connected in parallel between the output of operational amplifier 11 and its inverting input. Capacitor C_0 is connected from the output of operational amplifier 12 to its inverting input. And the output signal voltage Y_0 of operational amplifier 12 is coupled via resistor R_2 to the inverting input of operational amplifier 10. The non-inverting inputs of operational amplifiers 10, 11 and 12 are connected to ground potential.

With the feedback connection 13 as shown in Figure 2, i.e., with the output of the operational amplifier 12 coupled back to the inverting input of operational amplifier 10, and assuming the following relationships exist:

$R'_1 = R_1$	$R_x = R_2$	$T_0 = R_0 C_0$
$R'_2 = R_2$	$T_g = \frac{1}{2\pi F_g}$	$T_1 = R_1 C_1$
$R_{y0} = R_{y1} = R_{y2} = R_z$		

then the signal voltage Y_2 at the output of operational amplifier 10 can be represented as follows:—

$$Y_2 = -Y_0 - e_s; \text{ and } Y_1 = \frac{-Y_2}{1 + T_1 S} \text{ and } Y_0 = \frac{-Y_1}{T_0 S} \quad (1B)$$

where S is the Laplace Operator. The signal voltages Y_0 , Y_1 , Y_2 are coupled to the inverting input of operational amplifier 14, indicated by a minus sign, by means of resistors R_{y0} , R_{y1} and R_{y2} respectively. Resistor R_z is a feedback resistor which couples the compensated output signal e_c of operational amplifier 14 to the inverting input. The arrangement of resistors R_{y0} , R_{y1} , R_{y2} and R_z with the operational amplifier 14 forms a Summing Amplifier. The voltage e_- at the inverting input of operational amplifier 14, as is known, can be represented as follows:

$$e_- = \frac{Y_0 + Y_1 + Y_2 + e_c}{4} \quad (1C)$$

The damping (variation) sensor 2 comprises resistor R_t which is a temperature responsive element, for example, a thermistor having a negative temperature coefficient, in heat exchange relationship (indicated by dot-dash line) with the temperature of the fluid damping means of the rate gyroscope 5. Resistor R_t can be affixed by conventional means either inside or outside the case of the rate gyroscope 5.

The signal voltage Y_1 at the output of operational amplifier 11 is coupled via resistors R_a and R_c to the damping (variation) sensor 2. This arrangement results in a resistive network comprising resistors R_a , R_c and R_t being connected to the non-inverting input, indicated by a plus sign, of operational amplifier 14 in such a manner as to form a voltage divider network such that the voltage e_+ at the non-inverting input of operational amplifier 14 can be represented as follows:

$$e_+ = \frac{R_b}{R_d + R_b} \cdot Y_1 \quad (1D)$$

where $R_b = R_d + R_t$.

Amplifier 14 operates to make $e_- = e_+$, or

$$Y_0 + Y_1 + Y_2 + e_c = \frac{4R_b}{R_d + R_b} \cdot Y_1 \quad (1E)$$

Equation (1E) may be combined with the three equations of (1B) to obtain the transfer function G_c of the signal compensator:

$$G_c = \frac{e_c}{e_0} = \frac{1 + \frac{4}{1 + R_a/R_b} T_0 S + T_0 T_1 S^2}{1 + T_0 S + T_0 T_1 S^2} \quad (1F)$$

The middle term in the numerator of (1F) has a temperature-dependent coefficient because the resistance of R_t is included in the resistance R_b .

Since the rate gyroscope 5 is a second order system, its transfer function G_s can be represented mathematically by the following equation:

$$G_s = \frac{G_0}{1 + 2 D_s T_s S + T_s^2 S^2} \quad (1G)$$

where

$$f_s = \frac{1}{2 T_s}$$

is the undamped natural frequency, D_s is the damping ratio of the rate gyroscope 5, S is the Laplace operator and G_0 is the low frequency (signal) gain of the rate gyroscope 5.

In accordance with the relationship (1A), and with the substitution therein of equations (1F) and (1G), the transfer function Y_s of the entire system shown in Figure 2 can be represented by the following expression:

$$Y_s = \frac{G_0}{1 + 2 D_s T_s S + T_s^2 S^2} \cdot \frac{1 + 2 D_0 T_0 S + T_0^2 S^2}{1 + 2 D_0 T_0 S + T_0^2 S^2} \quad (1H)$$

where: $D_0 = \frac{2}{1 + \frac{R_a}{R_b}} \frac{T_0}{T_s}$, $D_s = \frac{1}{2} \frac{T_0}{T_s}$ and $T_1 = \frac{T_s^2}{T_0}$.

It can be seen from expression (1H) that the signal compensating transfer function G_c can be expressed as a fraction having a numerator polynomial which becomes equal to the denominator polynomial of the transfer function G_s of the rate gyroscope 5 when D_o is equal to D_g . Therefore, the resistance values of R_a and R_c are selected in relation to the value of R_t , a thermistor whose resistance decreases at temperature increases, such that the factor D_o is maintained substantially equal to the damping factor D_g over a wide temperature range.

When the term D_o is maintained exactly equal to the term D_g , the expression (1H) simplifies to:

$$Y_s = \frac{G_o}{1 + 2 D_o T_g S + T_g^2 S^2} \quad (1I)$$

where D_o is constant and equal to the selected damping ratio for the entire system 1, 2, 3 or approximately 0.7 of critical damping.

When D_o is only approximately equal to D_g , the entire system-transfer function Y_s has an equivalent damping ratio $D_o + \Delta D$, where the deviation ΔD from the (invariant) D_o is given by the formula

$$\Delta D = \frac{1.89 (D_g - D_o)}{1 + 1.78 D_g D_o} \quad (1J)$$

The signal compensator 1 shown in Figure 2 provides the results indicated in tables 2 and 3 with the component values (which can be selected empirically or by calculation) listed in table 1.

TABLE 1

$f_g = 23 \text{ Hz}$	$T_g = 6.9 \text{ m-sec.}$	$R_0 = R_1 = R'_1 = 20 \text{ k-ohms}$
$T_0 = 9.8 \text{ m-sec.}$	$C_0 = 0.5 \text{ mfd.}$	$R_{y0} = R_{y1} = R_{y2} = R_z = 20 \text{ k-ohms}$
$T_1 = 4.9 \text{ m-sec.}$	$C_1 = 0.25 \text{ mfd.}$	$R_x = R_2 = R'_2 = 20 \text{ k-ohms}$
Rate gyroscope (with demodulator)		$R_a = 11.014 \text{ k-ohms}$
Mfg. <u>Timex Corporation</u>		
Model <u># SD-000 Series</u>		$R_c = 0.523 \text{ k-ohms}$
The thermistor R_t material has a negative temperature coefficient of approximately $-3.9\%/^{\circ}\text{C}$ @ 25°C . Values of R_t at selected temperatures are given in table 2. Such thermistors are commercially available from, for example, Western Thermistor Corporation, Oceanside, California.		

TABLE 2

T (°F)	R _t (k-ohms)	$D_e = \frac{2}{1 + \frac{R_a}{R_b}}$
-40	22.00	1.90
- 4	7.42	1.185
32	2.85	.663
68	1.22	.387
100	.620	.266
140	.290	.195
185	.137	.160

TABLE 3

t (°F)	D _e	D _g	ΔD
-40	1.9	2.3	.09
		1.8	-.03
- 4	1.18	1.22	.02
		.98	-.12
32	.66	.71	.05
		.59	-.08
668	.39	.45	.09
		.38	-.02
100	.27	.33	.10
		.27	-.00
140	.195	.23	.06
		.185	-.02
185	.160	.165	.01
		.132	-.05

Referring to Figure 3, a graph is shown by way of example to illustrate how well the circuit of Figure 2 compensates for temperature-induced damping variations in a rate gyroscope. The empirically determined damping curve, with a $\pm 10\%$ tolerance band, shows that the uncompensated damping ratio D_g may vary (see table 3) from a high value of 2.3 at -40°F . to a low value of .132 at 185°F . The values of D_e from table 2 are plotted in Figure 3 as small circles, and they are all within the tolerance band of D_g .

The values of D_e from table 2 have been used in the formula (1J), together with

values of D_e at the boundaries of the tolerance band, to calculate deviations ΔD from the nominal damping ratio D_o . These values of ΔD appear in table 3, and they have also been added to 0.7 to obtain a new tolerance band, as shown in Figure 3, for the entire compensated system. As shown, the damping ratio $D_o + \Delta D$ of the entire system is confined between the extremes of 0.58 and 0.80.

Figure 4 shows a simplified cut away drawing of a single-degree of-freedom rate gyroscope. The gyroscope comprises a cylindrical case 15 in which is mounted a first end housing 16, a second end housing and bearing holder 17 and a signal generator stator 18. The rotor of the signal generator, shown under the reference 19 is mounted on a shaft 20 rotatably mounted in the bearing holder on end housing 17. The other end of shaft 20 is fixed to a thin walled float cylinder 21 which is moveable axially of the core 15. The space outside the cylinder 21 is completely filled with viscous fluid and an active clearance space 22 exists between the cylinder and the case in order to provide a degree of damping. The assembly is balanced by four balance nuts 23.

Inside the cylinder 21 is housed a rotor and gimbal unit comprising an electrically driven gyroscopic rotor 24 and a stator 25 for gyro electric drive. The shaft 20 is provided with a narrow portion 26 so that all torsional forces are taken up in this area. The details of such rate gyroscopes are well known in the field, so they will not be described further herein.

Figure 5 shows a simplified drawing of a known (microsyn) signal generator. Since the details of such signal generators are also well known in the field, they will not be described herein in detail. Briefly, however, the microsyn signal generator is an electromagnetic variable-reluctance device that produces an output voltage proportional to the product of current excitation, shaft (rate input) rotation and excitation frequency.

There has thus been described an improved viscous damped inertia guidance instrument capable of electronically compensating the output signal of the instrument to provide a compensated output signal whose amplitude and phase response is unaffected by possible changes in fluid viscosity.

There has also been described an improved viscous damped rate gyroscope capable of electronically correcting the signal from the gyroscope to provide an output signal whose amplitude and phase response is unaffected by changes in temperature.

The improved rate gyroscope described above has an electronic circuit for compensating the output signal for temperature dependence of damping of a fluid damped spring restrained rate gyroscope which is able to achieve an overall performance of approximately 0.7 ± 0.2 of critical damping over a temperature range of approximately -45°C to $+85^\circ\text{C}$, while keeping the natural frequency constant.

WHAT WE CLAIM IS:—

1. Indicating apparatus comprising a device having a second order transfer function, said device comprising a member whose movements in response to an input are damped and means responsive to movements of said member to provide a first electrical signal; and means responsive to said first electrical signal and to indications of variations of damping for providing a second electrical signal indicative of said input and substantially unaffected by variations in the damping of said member.

2. Apparatus as claimed in claim 1, wherein the transfer function of said means varies inversely as the second order transfer function of said device in order to maintain a substantially constant overall transfer function irrespective of variations in damping.

3. Apparatus as claimed in either one of claims 1 or 2, wherein the movements of said member are damped by a fluid, and said means is responsive to temperature variations of said fluid in order to compensate said first signal in proportion to variations therein with temperature for providing said second signal.

4. Apparatus as claimed in claim 3 wherein said means comprises a signal compensation circuit responsive to said first signal and having a variable circuit element disposed in heat exchange relationship with said fluid so as to vary with changes in the fluid temperature, said signal compensation circuit and said circuit element being selected to provide a compensated signal which is substantially unresponsive to variations of fluid temperature.

5. Apparatus as claimed in claim 4, wherein the zeros of the signal compensation circuit transfer function are caused to vary as the poles of the second order transfer function of said device.



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values of D_g at the boundaries of the tolerance band, to calculate deviations ΔD from the nominal damping ratio D_0 . These values of ΔD appear in table 3, and they have also been added to 0.7 to obtain a new tolerance band, as shown in Figure 3, for the entire compensated system. As shown, the damping ratio $D_0 + \Delta D$ of the entire system is confined between the extremes of 0.58 and 0.80.

Figure 4 shows a simplified cut away drawing of a single-degree of-freedom rate gyroscope. The gyroscope comprises a cylindrical case 15 in which is mounted a first end housing 16, a second end housing and bearing holder 17 and a signal generator stator 18. The rotor of the signal generator, shown under the reference 19 is mounted on a shaft 20 rotatably mounted in the bearing holder on end housing 17. The other end of shaft 20 is fixed to a thin walled float cylinder 21 which is moveable axially of the core 15. The space outside the cylinder 21 is completely filled with viscous fluid and an active clearance space 22 exists between the cylinder and the case in order to provide a degree of damping. The assembly is balanced by four balance nuts 23.

Inside the cylinder 21 is housed a rotor and gimbal unit comprising an electrically driven gyroscopic rotor 24 and a stator 25 for gyro electric drive. The shaft 20 is provided with a narrow portion 26 so that all torsional forces are taken up in this area. The details of such rate gyroscopes are well known in the field, so they will not be described further herein.

Figure 5 shows a simplified drawing of a known (microsyn) signal generator. Since the details of such signal generators are also well known in the field, they will not be described herein in detail. Briefly, however, the microsyn signal generator is an electromagnetic variable-reluctance device that produces an output voltage proportional to the product of current excitation, shaft (rate input) rotation and excitation frequency.

There has thus been described an improved viscous damped inertia guidance instrument capable of electronically compensating the output signal of the instrument to provide a compensated output signal whose amplitude and phase response is unaffected by possible changes in fluid viscosity.

There has also been described an improved viscous damped rate gyroscope capable of electronically correcting the signal from the gyroscope to provide an output signal whose amplitude and phase response is unaffected by changes in temperature.

The improved rate gyroscope described above has an electronic circuit for compensating the output signal for temperature dependence of damping of a fluid damped spring restrained rate gyroscope which is able to achieve an overall performance of approximately 0.7 ± 0.2 of critical damping over a temperature range of approximately -45°C to $+85^\circ\text{C}$, while keeping the natural frequency constant.

WHAT WE CLAIM IS:—

1. Indicating apparatus comprising a device having a second order transfer function, said device comprising a member whose movements in response to an input are damped and means responsive to movements of said member to provide a first electrical signal; and means responsive to said first electrical signal and to indications of variations of damping for providing a second electrical signal indicative of said input and substantially unaffected by variations in the damping of said member.

2. Apparatus as claimed in claim 1, wherein the transfer function of said means varies inversely as the second order transfer function of said device in order to maintain a substantially constant overall transfer function irrespective of variations in damping.

3. Apparatus as claimed in either one of claims 1 or 2, wherein the movements of said member are damped by a fluid, and said means is responsive to temperature variations of said fluid in order to compensate said first signal in proportion to variations therein with temperature for providing said second signal.

4. Apparatus as claimed in claim 3 wherein said means comprises a signal compensation circuit responsive to said first signal and having a variable circuit element disposed in heat exchange relationship with said fluid so as to vary with changes in the fluid temperature, said signal compensation circuit and said circuit element being selected to provide a compensated signal which is substantially unresponsive to variations of fluid temperature.

5. Apparatus as claimed in claim 4, wherein the zeros of the signal compensation circuit transfer function are caused to vary as the poles of the second order transfer function of said device.



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6. Apparatus as claimed in either one of claims 4 or 5 wherein the means for providing the first signal has a transfer function:—

$$\frac{G_0}{1 + 2 D_s T_s S + T_s^2 S^2}$$

where said circuit element causes D_s to be substantially equal to D_r throughout a wide range of temperature.

7. Apparatus as claimed in any one of claims 4 to 6 wherein the device is a gyroscope having a housing containing said fluid, and wherein said member is a rotor-carrying gimbal mounted within said housing; means providing a first signal in response to movement of the gimbal relative to the housing; and wherein said variable circuit element is disposed in heat exchange relationship with the housing so as to vary with changes in the fluid temperature.

8. Apparatus as claimed in claim 7 wherein said gyroscope is a fluid damped single-degree-of-freedom rate gyroscope and wherein said gimbal is rotatable about an axis perpendicular to its axis of spin in response to an angular rate input; and wherein said first signal is proportional to the angular displacement of the gimbal; and wherein the signal-compensating means is responsive both to damping variations and to said first signal to provide a compensated signal indicative of said angular rate input and substantially unresponsive to damping variations caused by variations in temperature.

9. Apparatus as claimed in any one of claims 4 to 8 wherein the signal-compensating means comprises an active filter circuit having a first amplifier with an input coupled to receive said first signal, a second amplifier having an input coupled to an output of said first amplifier, and a third amplifier having an input coupled to an output of said second amplifier and an output coupled to said input of said first amplifier in a closed loop configuration; a damping (variation) sensor responsive to the temperature of said fluid; and a summing amplifier having a first input coupled to the outputs of said first, second third amplifiers and a second input coupled to said second amplifier and said damping (variation) sensor, and an output providing said compensated signal.

10. Apparatus as claimed in claim 9 wherein the rate gyroscope has a transfer function:—

$$\frac{G_0}{1 + 2 D_r T_r S + T_r^2 S^2}$$

where D_r is the damping factor of the rate gyroscope and varies with temperature; and the signal-compensating means has a transfer function:—

$$\frac{1 + 2 D_s T_s S + T_s^2 S^2}{1 + 2 D_0 T_r S + T_r^2 S^2}$$

where the damping (variation) sensor causes D_s to be substantially equal and vary as D_r with temperature, and D_0 is a selected constant damping factor of the combination of the rate gyroscope and signal-compensating means.

11. Apparatus as claimed in any one of claims 3 to 6 wherein said device comprises a primary winding connected to a voltage/current source, and a secondary winding magnetically coupled to the primary winding and producing an output signal which varies in amplitude and phase as the magnetic coupling between the primary and secondary windings varies with angular displacement between the primary and secondary windings, said angular displacement being damped by a temperature influenced damping means.

12. Apparatus as claimed in claim 11, wherein the device is a microsyn of a rate gyroscope.

13. Apparatus as claimed in claim 11, wherein the device is a microsyn of a rate integrating gyroscope.

14. Indicating apparatus substantially as hereinbefore described with reference to Figures 1 and 2 of the accompanying drawings.



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