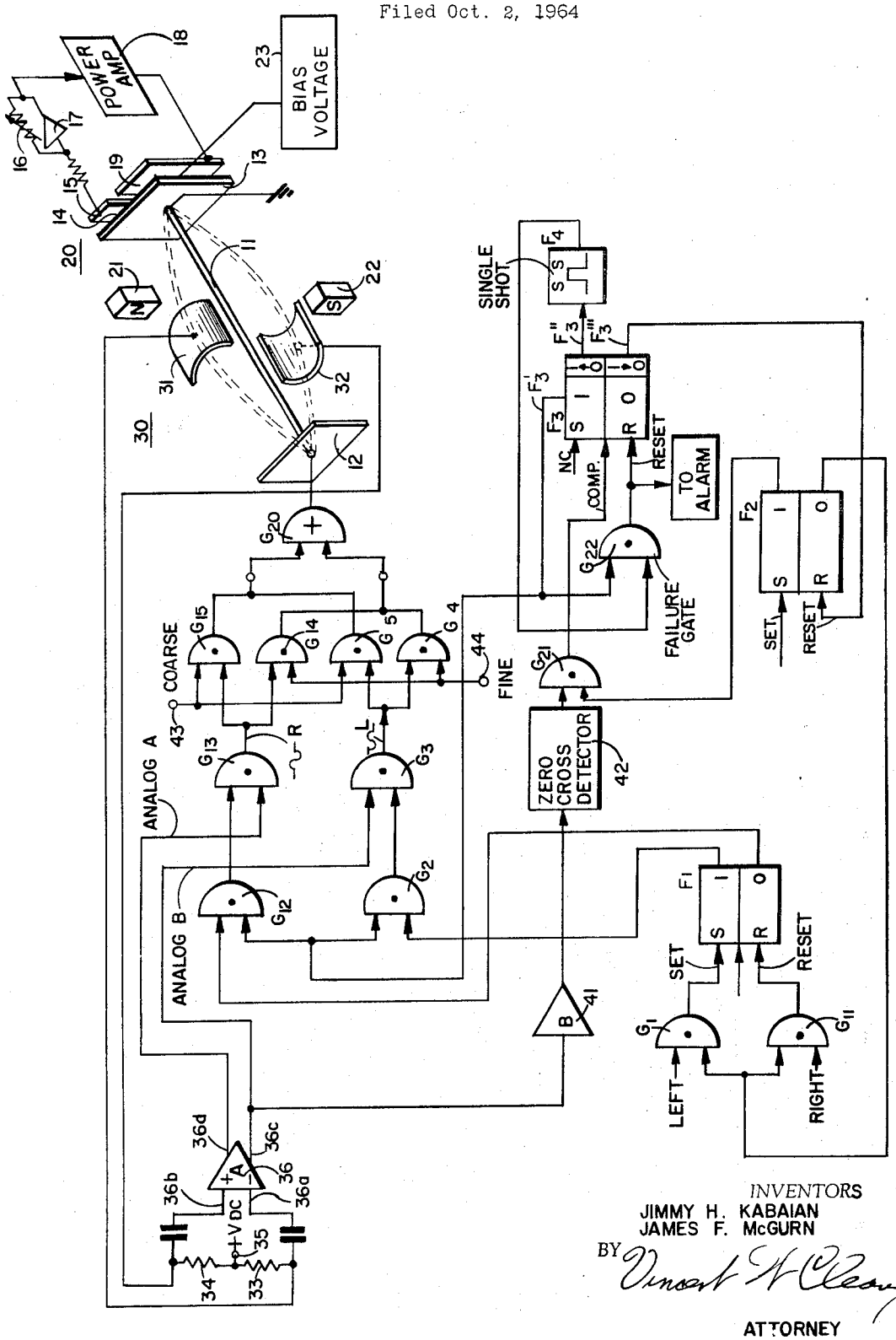
Nov. 28, 1967 J. H. KABAIAN ETAL 3,354,724

STABLE REFERENCE APPARATUS

Filed Oct. 2, 1964



INVENTORS
JIMMY H. KABAIAN
JAMES F. McGURN
BY Vincent H. Cleary
ATTORNEY

United States Patent Office 3,354,724 Patented Nov. 28, 1967

3,354,724

STABLE REFERENCE APPARATUS

Jimmy H. Kabaian, Lynwood, and James F. McGurn, Anaheim, Calif., assignors to North American Aviation, Inc.

Filed Oct. 2, 1964, Ser. No. 401,184
5 Claims. (Cl. 73—505)

This invention relates to an inertially stable reference apparatus and more specifically to means for torquing a string type oscillatory stable reference apparatus.

In United States Patent No. 3,106,847, dated Oct. 15, 1963, to Mullins et al., there is disclosed a vibratory string type stable reference apparatus. In copending application, Ser. No. 422,995, entitled Stable Reference Apparatus, filed Jan. 4, 1965 in the name of W. H. Quick and assigned to the assignee of the present application there is disclosed a means for torquing the vibratory plane of the vibrating string of the above mentioned patent. The embodiment of the invention disclosed in the present application includes an improved method of torquing such a vibrating string reference apparatus.

An object of the invention is to provide a new and improved torquing means for torquing a vibrating string stable reference apparatus.

Another object of the invention is the provision of a torquing means for providing variable torquing of a vibrating string reference apparatus.

A still further object of the invention is to provide a high speed detector type circuit for accurately controlling the torquing of a vibrating string reference apparatus.

In order to accomplish the above objects, a unique torquing device is employed which produces a plurality of torquing signals for torquing a vibratory string reference apparatus in one direction. By so doing, the string can be selectively torqued at a fine or a coarse rate.

Other objects of the invention will become apparent from the following description taken in conjunction with the drawing.

The above mentioned patent and patent application illustrate a vibrating string type reference apparatus describing means for vibrating the string apparatus and means for torquing the vibrating string. In the present invention, the vibrating means for the string is by way of example similar to that described in the above identified patent. The embodiment of the present invention employs such a vibrating means, however, other vibrating mechanism could be used with the torquing of the present invention.

More specifically with reference to the drawing, which illustrates the functional interrelation of the electrical, mechanical and magnetic aspects of a preferred embodiment of the invention, the disclosed vibrating string gyro comprises a fine gold-plated quartz fiber **11** which is stretched to the limit of practicable tension and secured at two points thereof to a pair of vibratory end bars or diaphragms **12** and **13** which are fixedly secured to each other in the illustrated mutually spaced relationship by means to be described more particularly hereinafter. The string or fiber **11** is preferably of circular cross-section and may be on the order of one to three mils in diameter, having a length of one to two inches. The diaphragms **12** and **13**, both of which are formed integrally with a quartz supporting body, as described more fully in the above identified patent, may be of a thickness on the order of 60 mils and are caused to vibrate in opposition so as to move the ends of the string precisely axially, that is, both diaphragms move inwardly together and outwardly together.

The vibrating system thus formed is dynamically balanced so that the resulting Q is high. A high degree of symmetry of the vibrating diaphragms **12, 13** is employed

to insure that the motion of the string end points is solely axial. For purposes of maintaining stability of the reference plane of a device of this nature, it is desirable that the variation in tension of the string during its vibration is held to a minimum. For example, despite all precautions, some transverse vibration of the support will be imparted to the string support points in such a way as to produce an elliptical vibratory string path. With such an elliptical path, a variation in tension of the string due to nonlinearity will give rise to undesired precession, that is, rotation of the plane of vibration. By proper choice of initial tension and the dimensions determining frequency, and by controlling the amplitude of the end motion, the tension variation can be greatly reduced. The amplitude of the end motion is governed by the operation of the longitudinal driving system which will be described below, together with the dimensions of the vibratory diaphragms. The thickness and distance between supporting points of such diaphragms will govern the resonant frequency thereof at which they are driven. The frequency of the resonant drive is twice that of the string. The string mass per unit length together with the tension is appropriately adjusted for the desired amplitude length ratio. Such a ratio is the ratio of the amplitude of transverse motion of the string to the length of string between support points. By means of a slight trimming of the driving oscillator amplitude, the minimum tension variation condition will be achieved with the amplitude length ratio very close to the desired value.

The resonant system comprising the quartz string vibrating bars or diaphragms **12** and **13**, together with the body which forms the support therefor, may be sealed in a case evacuated to a degree that the Q of the resonant bars or diaphragms is exceedingly high, on the order of 100,000, and small driving forces are required to maintain oscillation. With the small driving force required, vibration can be imparted to the resonant system by applying an A-C voltage across the capacitor gap to provide an electrostatic drive.

The electrostatic drive comprises a closed loop oscillator including an electrode **14** plated on or otherwise secured to the outer surface of vibratory diaphragm **13** and a capacitive pickoff plate **15** secured to a case in which the instrument is to be mounted. Pickoff device **14, 15** provides a signal indicating amplitude and phase of the driving motion which is amplified by amplifier **17**, the gain of which is controlled by a thermistor **16** in its feedback circuit, and applied to a power amplifier **18**. The signal output of the power amplifier **18** is fed to an electrostatic drive comprising the electrode **14** plated on the diaphragm **13** and a second plated electrode **19** fixed to the instrument case. A D-C bias voltage from a source **23** is applied to electrode **14** in order to excite the pickoff and forcing sections, thereby greatly enhancing the efficiency of the A-C voltage in driving the resonator. Thus, it will be seen that there is provided a feedback oscillator including the vibratory diaphragm **13** as a frequency controlling element thereof which applies a driving voltage at twice the string frequency to the diaphragm **13** across the gap between electrodes **14** and **19**.

The thermistor **16**, having a resistance which decreases with temperature, will operate normally to limit the signal flowing in the driving oscillator circuit, and thus tend to maintain a constant amplitude of vibration. This thermistor has a second significant function which arises by reason of the desire for operating the string in the desired constant tension condition. For operation in such a constant tension condition difficulties are normally encountered in starting vibration when an end drive is employed. For this reason, the thermistor **16** is utilized to cause the starting end motion amplitude to be substantially greater, on the order of approximately 75 percent greater, than the

normal operating amplitude. The increased starting amplitude is caused by the thermal characteristics of the thermistor **16** which when cold has a relatively high resistance, thereby allowing a larger signal to flow through the driving oscillator circuit. Shortly after the vibration is started and the thermistor heats up, its resistance decreases thereby decreasing the gain of amplifier **17** and the signal flow in the driving oscillator circuit is decreased to a point where it maintains a steady level.

A torquing current is supplied from the detector circuit to pass through the vibrating string **11**. This torquing current cooperates with a magnetic field passing through the plane of vibration to rotate the plane of vibration. The magnetic assembly **20** shown in the drawing, creates this field by way of magnets **21** and **22**. Preferably, these magnets are positioned midway between the ends of string **11**. Since the action of the current in the string **11** and this magnetic field to produce a torque is described in the above patent and patent application, details thereof will not be disclosed herein. In addition, it will be readily understood that the torquing presented in this embodiment could be done by way of inducing a current in the string **11** as shown in the above identified patent or by other means such as electrostatically.

An electrostatic pickoff assembly **30** is employed to produce a signal current that varies as a function of the velocity of the vibrating string **11**. This pickoff assembly includes concave capacitive plates **31** and **32** which are positioned concentric and concave of and with the neutral position of string **11** as illustrated in the drawing. Preferably, these plates are located midway between the ends of string **11**. A voltage is maintained between the grounded string **11** and the plates **31** and **32** by way of a voltage source **35** which is applied to these plates through high resistances **33** and **34**. Thus, paths between plate **31** and the string **11** and plate **32** and the string **11** are connected to a low impedance A-C differential amplifier **36**. The current into this amplifier varies as the velocity of the string **11**. That is, when the string **11** approaches plate **31**, the capacitance thereof will increase while the capacitance between plate **32** and the string will decrease. Similarly as the string **11** approaches plate **32**, the capacitance between thereof will also increase while the capacitance between plate **31** and the string will decrease. This will be reflected as a variation in the current through the plates **31** and **32**. The signal from plate **31** is applied to the negative input **36***a* of differential amplifier **36**. The signal from plate **32** is applied to the positive input **36***b* of differential amplifier **36**. The current signals at inputs **36***a* and **36***b* are a function of the velocity of the string **11** and are 180 degrees out of phase with each other. The differential amplifier **36** is used in order to suppress variations in resistor values and supply voltages. Suppression of second harmonic is also accomplished. Differential amplifier **36** has a stable closed loop gain. The degree of stability of amplifier **36** directly determines the accuracy to which a vibrating string can be torqued.

The output **36***c* of the amplifier **36** will be a continuous wave which is applied to an AND gate G_3. The output **36***d* will also be a continuous wave applied to AND gate G_{13}. At the input of amplifier **36**, these continuous waves are a function of the pickoff current from the plates **31** and **32** and are 180 degrees out of phase with each other. These continuous waves applied to AND gates G_{13} and G_3 form the basis for the waveform to be applied to string **11** to rotate its plane of vibration in either a clockwise or counter clockwise direction.

The output **36***c* of amplifier **36** is applied through an amplifier **41** to a zero crossing detector **42**. The signal applied to the zero crossing detector **42** is an A-C wave. When this A-C wave goes from a negative value to a positive value, there will be a pulse at the output of detector **42**, which is applied to AND gate G_{21}. Thus, the pulses from detector **42** are separated by the time length of 360 degrees of vibration of string **11**.

AND gates G_1 and G_{11} determine the direction of rotation that the torquing signal will rotate the plane of vibration. If there is a one on the input of left AND gate G_1, the plane of vibration will be rotated to the left. If there is a one on the input of right AND gate G_{11}, the plane of vibration will be rotated in the opposite direction, to the right. The last command from the computer to these gates will determine the direction of torquing. Preferably some means should be employed to prevent ones simultaneously occurring on both the left and the right gates G_1 and G_{11}.

If there is a one input from the computer on G_1, an RS flip-flop F_1 will have a true output having a one at its upper output which is applied to gate G_2. If there is a one input on gate G_{11}, a one will be applied to the reset input of F_1 and the flip-flop F_1 will be false with a one on the lower output of F_1. This one would be applied to AND gate G_{12}. The AND gates G_2 and G_{12} and flip-flop F_3 determine the time width of the torquing signal and the repetition rate of the torquing signal that is, the torquing rate. The RS flip-flop F_2 must receive a command from the computer in order for the torquing signal to be applied to the string **11**. Normally from an initial condition, the RS flip-flops F_2 and F_3 are false having a zero at the upper output and a one on the lower output. When a one command is applied to the set input of F_2, the output of F_2 becomes true so that AND gate G_{21} will pass the next pulse from detector **42** which is representative of the negative to positive going signal from output terminal **36***c*. When this pulse proceeds through AND gate G_{21}, it renders RS flip-flop F_3 true. The AND gate G_1 is connected to the complementary input of RS flip-flop F_3. When there is a one on the complementary input of F_3, flip-flop F_3 will switch states regardless of the preceding state. When flip-flop F_3 goes true, it will apply a one to the AND gates G_2 and G_{12} over line F_3. Dependent upon whether a left or right signal has been applied to AND gates G_1 or G_{11}, one of the AND gates G_2 or G_{12} will be turned on. On the next successive pulse from detector **42**, the flip-flop F_3 goes false.

The lower output F_3''' produces a pulse when flip-flop F_3 goes from true to false. This pulse renders flip-flop F_2 false. This is an indication that one complete torque pulse has been applied to the string **11** and the flip-flop F_2 is ready to accept the next torque command.

The one so produced at the output of either gate G_2 or G_{12} will open either AND gate G_3 or AND gate G_{13} respectively. If AND gate G_{13} is opened, its output will be applied to both AND gates G_{14} and G_{15}. Likewise, if AND gate G_3 is opened, its output will be applied to AND gates G_4 and G_5. The AND gates G_5 and G_{15} have a relatively high gain whereas AND gates G_4 and G_{14} have a relatively low gain. If a one is present on the coarse input terminal **43**, either the output of AND gate G_{13} will be passed through AND gate G_{15} or the output of AND gate G_3 will be passed through AND gate G_5. Likewise if a one is present on the fine input terminal **44**, either the torquing signal from G_{13} will be passed through gate G_{14} or the torquing signal from gate G_3 will be passed through the AND gate G_4. The outputs of the AND gates G_4, G_5, G_{14} and G_{15} are connected through an OR gate G_{20} to the vibrating string **11** so as to torque the plane of vibration of the string **11**. Hence, it may be said that the torquing of G_4 and G_{14} varies as a function of a constant K_1 with the torquing of G_5 and G_{15} varying as a function of a larger constant K_2.

Hence, it is seen that if it is desired, for example, to pass a relatively large torquing signal to torque the plane of vibration to the left, a one is applied to the input of left gate G_1 and a one is applied to the coarse terminal **43**. If it is desired to pass a fine or a relatively small torquing signal to the left, a one occurs on G_1 and also the fine terminal **44**. If a fine or coarse signal is desired to rotate the plane to the right, a one is applied at the input of right gate G_{11} and depending upon fine or coarse output, ones are

applied to 43 and/or 44. Thus, it is seen that either fine, coarse, or fine and coarse left torquing can be achieved. The same is true of a right direction torquing. Thus, the string can be torqued the desired amount quickly and accurately.

By the circuitry illustrated, the torquing signals passed through gates G_3 and G_{13} and consequently through the string 11 can only be discrete signals that have a time width of 360 degrees of vibration of the spring 11. The reason for this is that the pulse from G_{21} complements flip-flop F_3. The first pulse from G_{21} sets F_3 to true. The second such pulse will always switch the flip-flop F_3 from true to false. As the result, the upper output F_3' will become zero, closing AND gates G_2 and G_{12} and also as a result, effect closing of AND gates G_3 and G_{13}. Thus, it is seen that a complete cycle and only a complete cycle starting at a zero crossing can be passed at one time. A failure circuit, employing a single shot or monostable multivibrator F_4 and an AND gate G_{22}, is included. The single shot F_4 provides a 1½ torque period delayed signal triggered by signal on F_3''. The delayed F_3'' signal is compared with the output F_3' at gate G_{22}. If the output of F_3 is still true when the delayed F_3'' arrives at gate G_{22}, an alarm signal resets F_3 to zero thereby inhibiting continuous unintentional torquing due to a malfunction.

It will be understood that such a torquing signal R which would be 180 degrees out of phase with the torquing pulse L is available at the output of gate G_{13}. Pulse R is in phase with the velocity of the string whereas pulse L is 180 degrees out of phase with the velocity. This phase relationship enables torquing of the plane of vibration of the string in opposite directions due to the opposite torquing effective between the magnetic field and the current through the string.

Although the invention has been described and illustrated in detail, it is to be clearly understood that this is by way of illustration and example only with the spirit and scope of the invention being limited only by the terms of the appended claims.

We claim:

1. A spatial direction indicator comprising support means, a string mounted between two points of said support means, means for effecting vibration of said string at a predetermined frequency in a vibratory plane, magnetic means providing a magnetic field around said plane of vibration, means for providing a first alternating current signal having an amplitude which varies in accordance with the vibrations of said string times a factor K_1, means for providing a second alternating current signal having an amplitude which varies in accordance with the vibrations of said string times a factor K_2 wherein K_1 and K_2 are not equal, and means for selectively conducting said first or said second signal through said string to effect rotation of said vibratory plane.

2. A spatial direction indicator comprising support means, a string mounted between two points of said support means, means for effecting vibration of said string at a predetermined frequency in a vibratory plane, magnetic means providing a magnetic field around said plane of vibration, means for providing a first alternating current signal having an amplitude which varies in accordance with the vibrations of said string times a constant K_1, means for providing a second alternating current signal having an amplitude which varies in accordance with the vibrations of said string times a constant K_2 where K_2 is smaller than K_1, and wherein said first and said second signal have the same time width and phase and means coupling said first and said second signals to said string to effect rotation of said vibratory plane.

3. A spatial direction indicator comprising support means, a string mounted between two points of said support means, means for effecting vibration of said string at a predetermined frequency in a vibratory plane, magnetic means providing a magnetic field around said plane of vibration, means for providing a first alternating current signal having an amplitude which varies as a function of the vibrations of said string times a factor K_1, means for providing a second alternating current signal having an amplitude which varies as a function of the vibrations of said string times a factor K_2 wherein K_1 is less than K_1 and wherein said first signal and said second signal are of the same phase, means for providing a third alternating current signal having an amplitude which varies as a function of the vibrations of said string times the factor K_1, means for providing a fourth alternating current signal having an amplitude which varies as a function of the vibrations of said during the factor K_2 wherein said third and said fourth signals have the same phase, and wherein said third and said fourth signals are opposite in phase to said first and said second signals, and means selectively coupling said first, said second, said third, or said fourth signals to said string so as to selectively effect coarse or fine rotation of said vibratory plane in a first direction by said first or said second signal respectively and in a second direction by said third or said fourth signal respectively.

4. A spatial direction indicator as set forth in claim 3 wherein said first and said second signals are in phase with the velocity of said string and wherein said third and said fourth signals are 180 degrees out of phase with the velocity of said string.

5. A spatial direction indicator as set forth in claim 4 wherein the time width of said first, second, third and fourth signals is 360 degrees of vibration of said string.

References Cited

UNITED STATES PATENTS

3,047,766	7/1962	Glass.
3,106,847	10/1963	Mullins et al.

JAMES J. GILL, *Primary Examiner.*

R. C. QUEISSER, *Examiner.*

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,354,724 November 28, 1967

Jimmy H. Kabaian et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 6, line 31, for "during" read -- string times --.

Signed and sealed this 21st day of January 1969.

(SEAL)
Attest:

Edward M. Fletcher, Jr.
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents