Jan. 13, 1970 D. L. REXFORD 3,489,161

VARIABLE RESONANT FREQUENCY SPRING-MASS SYSTEM DEVICE

Filed July 30, 1968 2 Sheets-Sheet 1

Fig. 1.

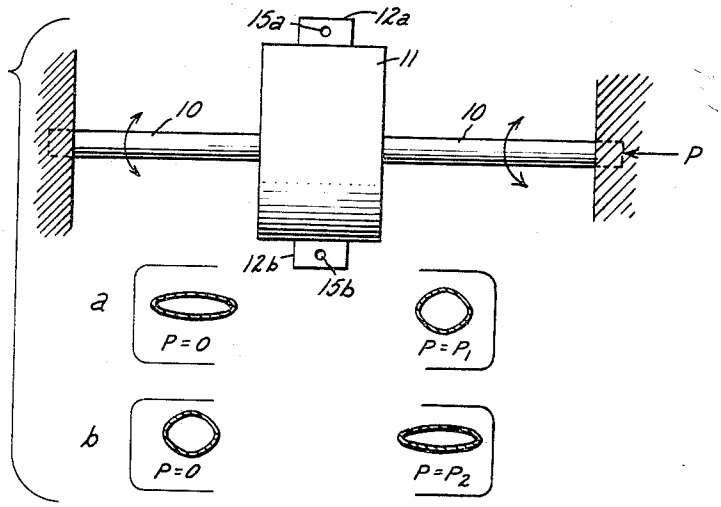
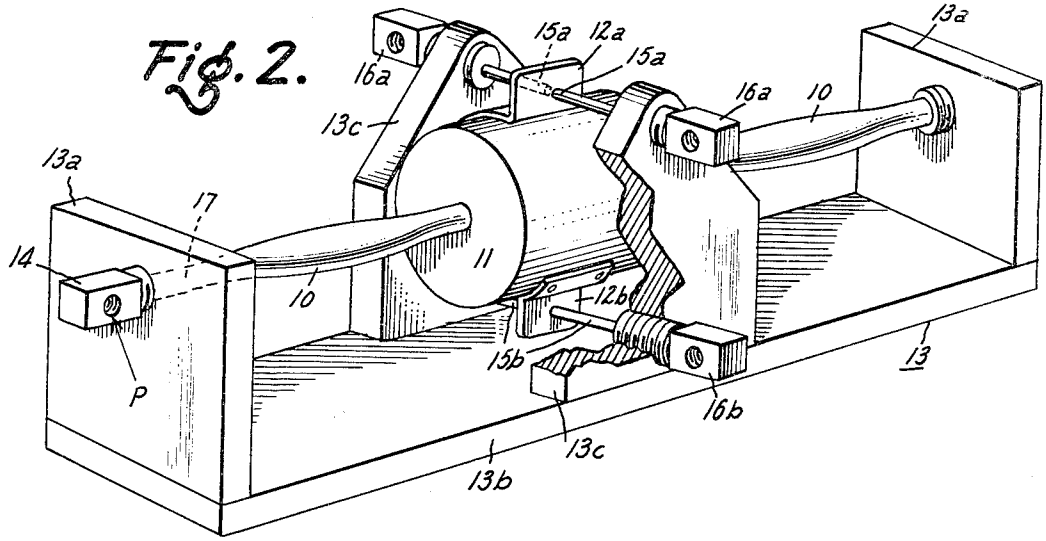


Fig. 2.



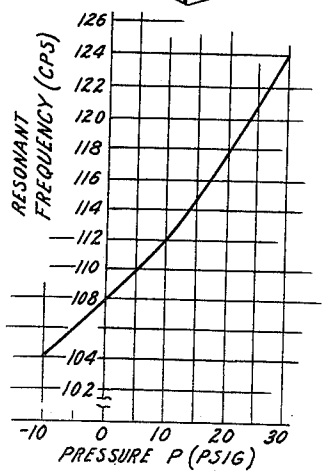


Fig. 3.

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VARIABLE RESONANT FREQUENCY SPRING-MASS SYSTEM DEVICE

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Fig. 4.

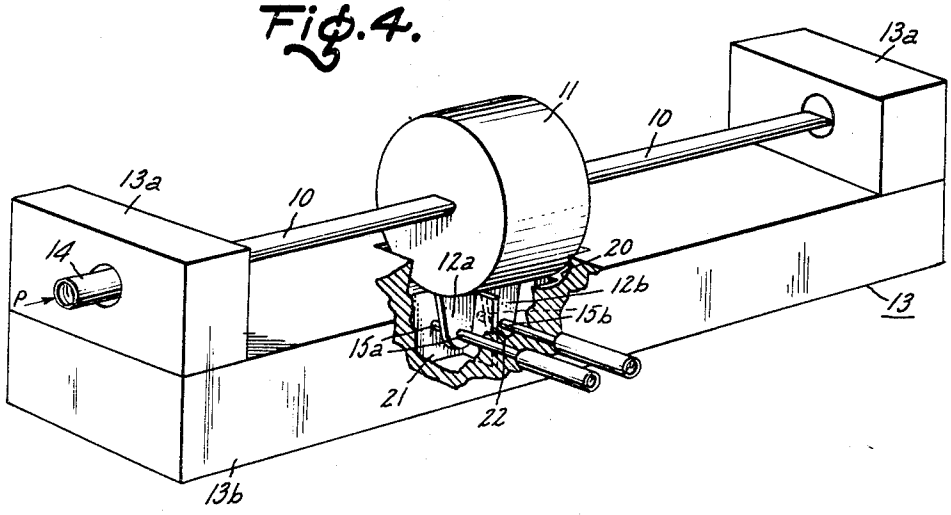
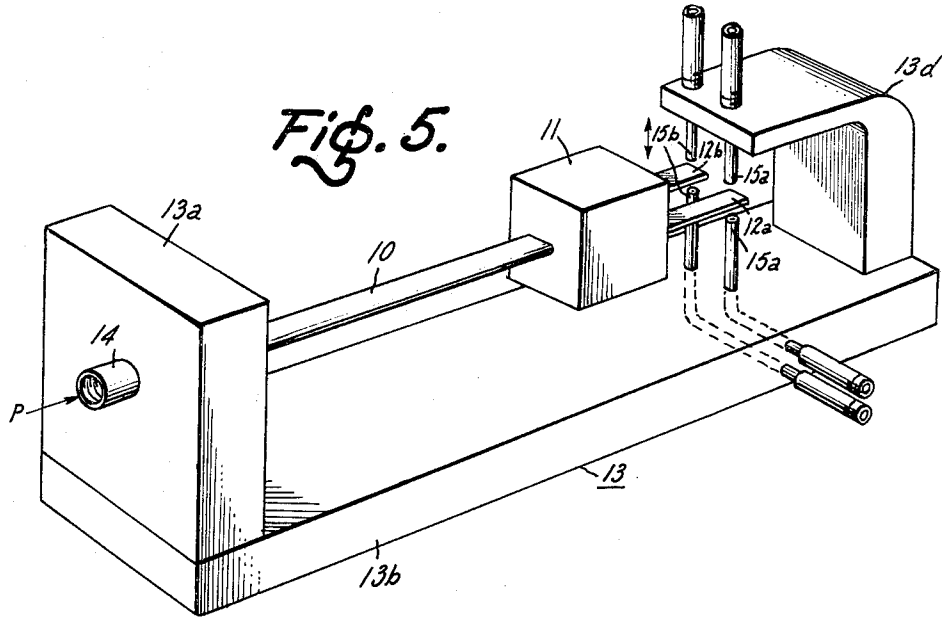


Fig. 5.



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VARIABLE RESONANT FREQUENCY SPRING-MASS SYSTEM DEVICE

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U.S. Cl. 137—82 24 Claims

ABSTRACT OF THE DISCLOSURE

A mechanical spring-mass system used as a frequency reference in fluidic systems for controlling speed, temperature and the like utilizes a fluid pressure signal in the hollow spring element of the spring-mass system for extending the frequency operating range of the system without the use of additional moving parts. The spring element has a first cross-sectional shape in the absence of the fluid pressure signal and a second shape in the presence of such signal thereby changing its spring constant and the resonant frequency of the spring-mass system. The fluid signal may be pressurized above or below ambient pressure for deforming the spring element to its second shape.

My invention relates to a mechanical spring-mass system having a controlled variable resonant frequency, and in particular, to a spring-mass system device wherein the frequency operating range thereof is varied by varying the spring constant as a result of a pressurized fluid signal applied thereto.

Mechanical-type frequency references are conventionally employed in fluidic control systems such as for jet engines, and gas and steam turbines for controlling parameters such as speed, temperature and the like. The mechanical-type frequency references most often employed are the spring-mass system and the Helmholtz resonator. The spring-mass system provides a more accurate control over a broad temperature range than the Helmholtz resonator type frequency reference but has the disadvantage of being limited to operation over a small frequency range of perhaps ±5% of the normal resonant frequency. The Helmholtz resonator has the desired wider range of frequency operation but the signal-to-noise ratio is not sufficiently high for many applications and the resonator is also relatively temperature sensitive.

Thus, there is need for providing a mechanical type frequency reference which is substantially temperature insensitive to thereby provide the more accurate control over a broad temperature range of the spring-mass system and having the wider frequency operating range of the Helmholtz resonator.

Therefore, one of the principal objects of my invention is to provide an improved mechanical type frequency reference useful in fluidic systems and having the advantages of both the spring-mass system and Helmholtz resonator type references.

A further object of my invention is to provide an improved mechanical spring-mass system as a frequency reference having an extended frequency range of operation.

Another object of my invention is to obtain the extended frequency operating range by means of a fluid pressure signal and without the use of additional moving parts.

In carrying out the objects of my invention, I provide a mechanical spring-mass system characterized as having a resonant frequency determined by the mass and the spring constant of the spring element. The spring element

is a hollow member in communication with a fluid pressure signal means such that upon application of a pressure signal, the cross section of the hollow member is deformed and the change in section modulus changes the spring constant thereby varying the resonant frequency of the spring-mass system. Driving nozzles associated with a first flapper mounted on the mass body cause mechanical oscillation thereof, and pick-off nozzles associated with a second flapper generate an output signal of the spring-mass system for utilization in an appropriate fluidic circuit.

The features of my invention which I desire to protect herein are pointed out with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, may best be understood by reference to the following description taken in conjunction with the accompanying drawings wherein:

FIGURE 1 is a side view of a simplified embodiment of my invention and also illustrates the changes in cross section of the spring member with a fluid pressure signal applied thereto;

FIGURE 2 is a perspective view, partly in section, of a first embodiment of my invention utilized as a torsional type spring-mass system;

FIGURE 3 is a graph illustrating the variation in resonant frequency of the spring-mass system of FIGURE 2 with the pressure of the fluid signal applied to the spring member;

FIGURE 4 is a perspective view, partly in section, of a second embodiment of a torsional type spring-mass system device constructed in accordance with my invention.

FIGURE 5 is a perspective view of a cantilever type spring-mass system device constructed in accordance with my invention.

Referring now in particular to FIGURE 1, there is shown a spring-mass system of the torsional type wherein a thin-walled hollow spring member **10** has both its ends rigidly fixed in position and capable of twisting in torsion as indicated by the arrows in response to mass **11** being subjected to a rotational oscillatory motion about its longitudinal axis. Mass body **11** is rigidly attached to spring member **10** passing therethrough, and the longitudinal axis of body **11** is aligned with the centerline axis of the spring member. A plate member **12***a* is fixed in position on mass **11** and is adapted to function as a flapper between two opposed nozzles **15***a* which are equally spaced from member **12***a* in the nonoscillatory state of mass **11**. Nozzles **15***a* are designated the pickoff nozzles. Mass **11** is caused to oscillate by means of a second flapper **12***b* fixed in position on mass **11** and interposed between a seiond pair of opposed, equally spaced, nozzles **15***b* designated the driving nozzles. Application of a variably pressurized fluid to the driving nozzles, wherein the fluid pressure variation or frequency is in the frequency operating range of the spring-mass system, causes rotational oscillation of mass **11** about its longitudinal axis at the corresponding frequency and resultant oscillatory torsion of spring member **10**. The spring-mass system frequency operating range is defined herein as the frequency band within the resonance curve centered at the natural resonant frequency of the spring-mass system and does not include the frequency range below such band, even though it is recognized that the system is also operable therein. The amplitude of oscillation is directly proportional to the proximity of the driving nozzle fluid pressure frequency to the resonant frequency of the spring-mass system. Oscillation of mass **11** generates unequal pressure (a differentially pressurized signal) within the pick-off nozzles **15***a* which output of

the spring-mass system is transmitted to suitable fluid amplifier circuitry (not shown) for processing of such output signal.

A cross section of spring member **10**, in the absence of a fluid pressure signal applied thereto may have the form illustrated in FIGURE 1*a* or FIGURE 1*b*. In FIGURE 1*a* with no signal applied ($P=0$ p.s.i.g.) the cross section of spring member **10** is an approximate elliptical shape. Upon application of a pressurized fluid signal $P=P_1$, where the pressure is greater than ambient pressure, the section modulus is changed in that the cross section of member **10** approaches a circular shape as illustrated thereby providing a stiffer cross section (increasing the spring constant) and hence increasing the resonant frequency of the spring-mass system.

In like manner,(the no-signal cross section of member **10** may be substantially circular, but slightly elliptical, as indicated in FIGURE 1*b* and the application of a pressure signal $P=P_2$, where the pressure is below ambient, causes a change in the section modules due to the resulting elliptical shape to thereby provide a less stiff cross section (decreased spring constant) and hence a lower resonant frequency. The principles above described are applicable to each of the embodiments of my invention to be hereinafter described.

FIGURE 2 illustrates a first embodiment of my torsional type variable frequency spring-mass system device. This early embodiment comprises the elements described in FIGURE 1 and further includes a support member indicated as a whole by numeral **13** for supporting the spring-mass system and pick-off and driving means. Support member **13** may be a single integral member although in the general case it is a composite structure comprising side support members **13***a*, base member **13***b* and pick-off, driving nozzle support members **13***c*. The foreground member **13***c* is partly broken away to more clearly illustrate the driving assembly at the bottom of the mass **11**. Side members **13***a* provide the fixed support for the two ends of spring member **10** and also provide an inlet for the pressurized fluid signal P supplied to member **10** at one end thereof. Support member **13**, or its components **13***a*, **13***b* and **13***c* are each fabricated from a material such as steel to obtain the necessary strength and rigidity for adequately supporting the spring-mass system. The ends of spring member **10** are rigidly supported within holes formed in side members **13***a* in any suitable manner such as by set screws, brazing, or suitable clamping means.

One of such holes **17** indicated at the left end of spring member **10** as viewed by the reader, also forms the inlet passage for pressurized fluid signal P and is provided with a suitable fitting **14** for external connection to the source of signal P (not shown). Pressurized air is generally used as the fluid medium for signal P and for supplying the driving nozzles, however, other gases may also be utilized, as desired. Pressurized liquid may also be employed in some applications.

Mass **11** is a cylindrical body of steel and for the characteristics illustrated in the graph of FIGURE 3, mass **11** has a length of one inch and diameter of one inch. Spring member **10** passes through mass **11** along the longitudinal axis thereof, is rigidly fixed thereto, and is fabricated from beryllium copper tubing having a wall thickness of .005 inch, outer diameter of ¼ inch and length of approximately 5¾ inch. The tubing was deformed into an approximate elliptical cross section having 9/32 inch width and ⅛ inch height outer dimensions. As indicated in the graph of FIGURE 3. this particular dimensioned spring-mass system has a natural mechanical resonant frequency of 108 cycles per second in the absence of any pressure signal P applied to the spring member.

Flappers **12***a*, **12***b* are vertically disposed thin flat metal plates rigidly connected to mass **11** in a longitudinal direction, and on opposite sides thereof. First and second pairs of nozzles **15***a*, **15***b* are positioned on opposite sides of flappers **12***a* and **12***b* to form the pick-off and driving assemblies, respectively. Each pair of nozzles is aligned and positioned perpendicular to an associated flapper in intercepting relationship therewith. Each pair of nozzles is equally spaced from the associated flapper for the condition of no input to the driving nozzles. The spacing between the ends of the pick-off nozzles **15***a* and flapper **12***a* is generally in the range of 0.002 to 0.003 inch and the driving nozzle **15***b* to flapper **12***b* spacing is generally in the range of 0.010 to 0.015 inch although these ranges are not deemed to be a limitation. The nozzles are rigidly supported by members **13***c* which include holes forming fluid flow passages in communication with the nozzles. These holes are provided with suitable fittings **16***b* and **16***a* for respective external connections to a first fluidic circuit (not shown) which supplies the pressurized driving signals to nozzles **15***b* and a second fluidic circuit (not shown) which processes the spring-mass system output signal obtained in nozzles **15***a* in a predetermined manner.

As depicted in the graph of FIGURE 3, the resonant frequency versus pressure signal P characteristics of my torsional spring-mass system are only slightly nonlinear in the range of fluid pressure signals from −10 to +30 p.s.i.g. These test results indicate a frequency change of approximately ½% per p.s.i. signal pressure.

A second embodiment of my torsional spring mass system is illustrated in FIGURE 4 wherein base member **13***b* is partly in section for purposes of more clearly illustrating the pick-off, driving assemblies. The chief distinction between the embodiments illustrated in FIGURES 4 and 2 is the location of the pick-off assembly, being located in a rectangular recess **21** formed through the bottom surface of base member **13***b* in the FIGURE 4 embodiment thereby obviating the need for nozzle support members **13***c* as in the case of the FIGURE 2 embodiment. In FIGURE 2 the mass **11** is positioned entirely above base member **13***b*, whereas in the FIGURE 4 embodiment approximately the lower ¼ of mass **11** is positioned within a curved recess **20** formed through the top surface of base member **13***b* and having a shape conforming to the outer cylindrical surface of mass **11**. Recesses **20** and **21** intersect to provide the space necessary for the oscillatory motion of flappers **12***a*, **12***b*. The pair of flappers **12***a* and **12***b* are rigidly attached to the bottom-most surface of mass **11** in a longitudinal direction, spaced apart and in alignment with each other. Two pairs of nozzles **15***a* and **15***b* are oriented with respect to flappers **12***a* and **12***b* as described with relation to the FIGURE 2 embodiment to form the pick-off and driving assemblies, respectively. As shown in the illustration, the nozzles are located within the rectangular recess **21**, and suitable passages are formed through base member **13***b* in communication with the nozzles at one end and terminating in ports (not shown) at the other end for transmitting the fluid pressure signals from the pick-off nozzles to suitable fluid amplifier circuitry (not shown), and for supplying the variable pressurized fluid to the driving nozzles.

The FIGURE 2 embodiment illustrates spring member **10** as having the elliptical cross section only in two regions between body **10** and the side support members **13***a*, whereas in FIGURE 4 the spring member is elliptical along its entire length. Obviously, the latter embodiment is preferred since a greater length of the spring member may be deformed upon application of pressure signal P, resulting in a greater effective change in spring constant.

Although mass **11** may also be a solid body of metal as in the case of the FIGURE 2 embodiment (except for the hollow center provided for spring member **10**), my preferred embodiment utilizes a hollow cylindrical body **11** which is filled with a heavy type oil for purposes of damping mechanical oscillations in the spring-mass system. Body **11** also has an inner passage for spring member **10** therethrough. A thin metal plate **22** may be inter-

posed in rectangular recess **21** between flappers **12***a* and **12***b* for purposes of eliminating any interaction between the two assemblies of flappers and nozzles, however, such separating plate is not required in most cases since such interaction is usually negligible. In a particular device constructed in accordance with the embodiment illustrated in FIGURE 4, mass **11** is a hollow, oil-filled cylinder having a length of ½ inch, outer diameter of ⅞ inch and wall thickness of 0.01 inch. Spring member **10** has an over-all length of 2½ inches between adjacent side walls of side support members **13***a*. The spring member **10** is fabricated from beryllium copper tubing having a wall thickness of 0.002 inch and an outer width dimension of ¼ inch and height of 1/16 inch in the absence of pressure signal P. The spring-mass system device incorporating these dimensions has a resonant frequency of 400 cycles per second in the absence of pressure signal P.

A cantilever type embodiment of my variable resonant frequency spring-mass system device is illustrated in FIGURE 5 wherein hollow spring member **10** has one end rigidly supported within side support member **13***a* and a second free end which passes into mass **11** and is rigidly attached thereto. Support member **13***d* retains the nozzles in a rigidly fixed position. The substantially linear oscillatory motion of the free end of the spring-mass system in the FIGURE 5 embodiment is in a vertical direction as indicated by the arrows for the particular orientation of the device having the longer width dimension of spring member **10** in the horizontal plane. This vertical motion is sensed by the pick-off assembly comprising horizontally disposed flapper **12***a* rigidly connected to mass **11** and a first pair of oppositely disposed, equally spaced nozzles **15***a* oriented perpendicular thereto. The vertical oscillatory motion is induced by the driving assembly comprising a second horizontally disposed flapper **12***b* and a second pair of nozzles **15***a* associated therewith.

In the FIGURE 5 embodiment, mass **11** is illustrated in the form of a cube or rectangularly shaped body, although it may also be cylindrical. The FIGURE 5 device may be converted to a horizontal motion device by merely orienting the device at a 90° angle such that base member **13***b* is vertically disposed and the longer width dimension of spring member **10** is in the vertical plane. The spring member in the FIGURE 5 embodiment is of the same type as in the FIGURES 2 and 4 embodiments, that is, initially formed into a substantially elliptical cross section.

It can be appreciated that the oscillatory motion of mass **11**, rotational in the FIGURES 2 and 4 embodiments and linear in the FIGURE 5 embodiment, is very small in amplitude as evidenced by the close spacing of the pick-off nozzles. However, even this amplitude is at least 5 to 10 times any steady-state deflection which mass **11** may have when the device is operating in its associated fluidic circuit. Also, the deformation of tube **10** due to signal P is slight, being approximately .030" in the minor axis of an ellipse having minor and major axes of 1/16" and ¼", respectively, for a signal $P=15$ p.s.i.g.

The variably pressurized fluid supplied to the driving nozzles in all of the hereinabove embodiments may represent a digital or analog signal (i.e., the pressure may vary in square pulse or sine wave form), the only criterion being that it have the required periodicity or frequency in the ferquency operating range of the device. Thus, the driving nozzles may be supplied from a digital or analog type fluidic circuit. The fluid pressure signals generated in the pick-off nozzles, however, are of the sine wave (analog) type and thus an analog type fluidic circuit would generally be employed to further process such output signals.

The fluid signal P supplied to spring member **10** may be a constant pressure on-off type signal or may be programmed to vary in accordance with a desired variation of a circuit or system parameter. Thus, in the case of my fluidic frequency reference device being utilized in a speed control circuit, the variable pressurized fluid supplied to the driving nozzles is a feedback signal having a pressure frequency representing the actual speed, and the fluid signal P supplied to spring member **10** is a reference signal having a pressure magnitude representing the reference or desired speed. Since the reference speed may be varied for particular purposes, signal P is correspondingly varied in pressure magnitude to obtain the desired (reference) resonant frequency of the spring-mass system which corresponds to the reference speed. Signal P may be programmed by any conventional means.

It is apparent from the foregoing that my invention attains the objectives set forth. In particular, my invention provides an improved mechanical spring-mass system frequency reference useful in fluidic systems since its various input and output signals are all of the fluid pressure type. My frequency reference has the advantages of both the spring-mass system and Helmholtz resonator type references in that it is substantially temperature insensitive to thereby provide accurate control over a broad temperature range, and the ability to vary the spring constant obtains an extended frequency range of operation. This wider frequency operating range is obtained without the use of additional moving parts by means of a fluid signal applied to the hollow spring member of my spring-mass system. As can be seen from the FIGURE 3 graph, the normal ±5% frequency range has been increased by at least a factor of two.

Having described three embodiments of my invention, it is believed obvious that modification and variation of my invention is possible in light of the above teachings. Thus, spring member **10** cross sections other than elliptical may be utilized, the criterion being that a relative change in section modulus is obtained upon application of signal P to thereby change the spring constant. Further, a single driving nozzle may be utilized instead of the depicted pair of opposed nozzles in the case wherein the driving pressure signal is of single polarity, without excessive loss in performance of my variable resonant frequency spring-mass device. Also, a single pick-off nozzle may be employed. Finally, other types of driving and pick-off assemblies may be utilized, either fluidic or non-fluidic. For example, the driving assembly may be of the electromagnetic type, and the pick-off assembly of the electrical capacitive type. Thus, it is evident that my invention also has utility in circuits other than of the fluidic type. It is, therefore, to be understood that changes may be made in the particular embodiments of my invention described which are within the full intended scope of the invention as defined by the following claims.

What is claimed is:

1. A spring-mass system adapted for use as a frequency reference in fluidic control systems comprising

a mechanical spring-mass system characterized as having a resonant frequency determined by the spring constant of the spring elements thereof, and

fluid pressure signal means in communication with said spring-mass system for varying the resonant frequency thereof.

2. A spring-mass system adapted for use as a frequency reference in fluidic control circuits comprising

a mechanical spring-mass system characterized as having a resonant frequency determined by the spring constant of the spring element thereof and a limited frequency operating range within approximately ±5% of the resonant frequency, and

fluid pressure signal means in communication with the spring element for varying the resonant frequency to thereby extend the frequency operating range of the mechanical spring-mass system by varying the spring constant thereof without additional moving parts.

3. The spring-mass system set forth in claim **2** wherein the spring element of said spring-mass system is char-

acterized as having a first cross sectional shape at a first resonant frequency of said spring-mass system in the absence of a fluid pressure signal applied thereto from said fluid pressure signal means, and having a second cross sectional shape at a second resonant frequency in the presence of the fluid pressure signal.

4. A spring-mass frequency reference device comprising

a thin-walled hollow spring member having at least one end thereof rigidly fixed in position,

a body having a known mass and a hollow portion forming an entrance for said spring member, said body rigidly attached to said spring member to form a mechanical spring-mass system having a mechanical resonant frequency determined by the spring constant of said spring member, the spring constant being a function of the section modulus of said spring member, and

means for varying the section modulus of said spring member to thereby vary the spring constant and the resonant frequency of said spring-mass system.

5. The spring-mass frequency reference device set forth in claim 4 wherein

said section modulus varying means comprises said spring member enclosed at a first end thereof and open at a second end, the open second end adapted to be supplied with a pressurized fluid signal for deforming said spring member to thereby vary the section modulus thereof from its value in the absence of the pressurized fluid signal.

6. The spring-mass frequency reference device set forth in claim 5 wherein

said spring member comprises a tube having a predetermined length and a first cross sectional shape in the absence of the pressurized fluid signal supplied to the interior of said tube, and having a second cross sectional shape upon said tube being supplied with the pressurized fluid signal.

7. The spring-mass frequency reference device set forth in claim 6 wherein

said thin-walled tube having an approximate elliptical cross section in the absence of the pressurized fluid signal and a substantially circular but slightly elliptical cross section upon said tube being supplied with the signal wherein the signal is at a pressure greaer than ambient.

8. The spring-mass frequency reference device set forth in claim 6 wherein

said thin-walled tube having a substantially circular but slightly elliptical cross section in the absence of the pressurized fluid signal and a substantially elliptical cross section upon said tube being supplied with the pressurized fluid signal wherein the signal is at a pressure less than ambient.

9. The spring-mass frequency reference device set forth in claim 6 wherein

both ends of said tube are rigidly fixed in position, the centerline axes of said tube and body being colinear and said body adapted to be rotationally oscillated about its centerline axis thereby causing a corresponding torsional oscillation of said spring member.

10. The spring-like frequency reference device set forth in claim 6 wherein

only one end of said tube is rigidly fixed in position and said body is adapted to be oscillated with a linear motion about the free end of said tube.

11. The spring-mass frequency reference device set forth in claim 6 and further comprising

a pair of flapper members rigidly connected to the outer surface of said body, and at least one nozzle associated with each flapper in intercepting relationship therewith, said nozzle rigidly fixed in position,

a first of said flappers and associated first nozzles comprising a driving assembly for causing mechanical oscillation of said body about its centerline axis upon said first nozzles being supplied with a fluid variably pressurized at a periodicity within the frequency operating range of said spring-mass system, and

a second of said flappers and associated second nozzles comprising a pick-off assembly for generating a fluid pressurized output signal having a frequency corresponding to the periodicity of the pressure variation of the fluid supplied to said first nozzles.

12. The spring-mass frequency reference device set forth in claim 9 wherein

said body is cylindrical in shape and the rotational oscillation thereof is about its longitudinal axis.

13. A spring-mass frequency reference device comprising

a thin-walled tubular member of predetermined length enclosed and rigidly fixed in position at a first end thereof and open at a second end, said tubular member having a wall thickness dimension and being fabricated of a material such that the cross section of said member is deformable,

a body having a known mass and a hollow interior portion along the longitudinal axis of said body, said tubular member passing into the hollow portion of said body and rigidly attached therein to form a mechanical spring-mass system having a mechanical resonant frequency determined by the spring constant of said tubular member,

a pair of flapper members rigidly connected to the outer surface of said body longitudinally thereof,

at least one nozzle associated with each flapper in intercepting relationship therewith, said nozzles rigidly fixed in position,

a first of said flappers and nozzles comprising a driving assembly for initiating mechanical oscillation of said body about its longitudinal axis upon said first nozzle being supplied with a fluid variably pressurized at a periodicity within the frequency operating range of said spring-mass system,

a second of said flappers and nozzles comprising a pick-off assembly for generating a fluid pressurized output signal having a frequency corresponding to the periodicity of the pressure variation of the fluid supplied to said first nozzles, and

means in communication with the open end of said tubular member for varying the resonant frequency of said spring-mass system to thereby increase the frequency operating range thereof without any additional moving parts.

14. The spring-mass frequency reference device set forth in claim 13 wherein

said flappers are positioned on opposite sides of said body.

15. The spring-mass frequency reference device set forth in claim 13 wherein

said flappers are positioned in alignment with each other.

16. The spring-mass frequency reference device set forth in claim 13 wherein

said resonant frequency varying means comprises means for supplying a fluid pressurized signal to the open end of said tubular member such that in the absence of the signal said tubular member has a first cross sectional shape and corresponding section modulus and in the presence of the signal said tubular member has a second cross sectional shape and section modulus of different magnitude which causes a corresponding variation in the spring constant to thereby vary the resonant frequency as compared to the condition of no signal.

17. The spring-mass frequency reference device set forth in claim 16 wherein

said tubular member having an approximate elliptical cross section in the absence of the pressurized fluid

signal and a substantially circular but slightly elliptical cross section upon said tubular member being supplied with the signal wherein the signal is at a pressure greater than ambient, the circular cross section of said tubular member providing a section modulus of greater magnitude than the section modulus associated with the elliptical cross section to thereby cause a corresponding increase in the spring constant and thereby increase the resonant frequency of the spring-mass system.

18. The spring-mass frequency reference device set forth in claim **16** wherein

said tubular member having a substantially circular but slightly elliptical cross section in the absence of the pressurized fluid signal and a substantially elliptical cross section upon said tubular member being supplied with the signal wherein the signal is a pressure less than ambient, the substantially elliptical cross section of said tubular member providing a section modulus of lesser amplitude than the section modulus associated with the circular cross section to thereby cause a corresponding decrease in the spring constant and thereby decrease the resonant frequency of the spring-mass system.

19. The spring-mass frequency reference device set forth in claim **16** wherein

only one end of said tubular member is rigidly fixed in position and said body is oscillated with a linear motion about the free end of said tubular member.

20. The spring-mass frequency reference device set forth in claim **16** wherein

both ends of said tubular member are rigidly fixed in position and said body is rotationally oscillated about its longitudinal axis upon said first nozzles being supplied with the fluid variably pressurized at periodicity within the frequency operating range of said spring-

mass system thereby causing a corresponding torsional oscillation of said tubular member.

21. The spring-mass frequency reference device set forth in claim **20** and further comprising

a member for supporting both ends of said tubular member in rigidly fixed position relative to said body, the latter member also supporting the nozzles in rigidly fixed position relative to their associated flappers.

22. The spring-mass frequency reference device set forth in claim **21** wherein

said supporting member includes a recess formed through the bottom surface thereof for containing said driving and pick-off assemblies.

23. The spring-mass frequency reference device set forth in claim **19** and further comprising

a member for supporting the first end of said tubular member in rigidly fixed position relative to said body, the latter member also supporting the nozzles in rigidly fixed position relative to their associated flappers.

24. The spring-mass frequency reference device set forth in claim **19** wherein

the linear oscillatory motion of said body about the free end of said tubular member is in a direction normal to the greater width dimension of said tubular member.

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ALAN COHAN, Primary Examiner

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