

United States Patent

Honig et al.

[15] 3,654,540

[45] Apr. 4, 1972

[54] MAGNETOSTRICTIVE DRIVE CIRCUIT FEEDBACK COIL

[72] Inventors: William M. Honig, New York; Richard H. Paschke, Medford; Jacob Haggag, Howard Beach, all of N.Y.

[73] Assignee: Cavitron Corporation, Long Island City, N.Y.

[22] Filed: Jan. 15, 1971

[21] Appl. No.: 106,675

[52] U.S. Cl. 318/118, 310/26

[51] Int. Cl. H01v 9/00

[58] Field of Search..... 318/114, 116, 118, 132, 130, 318/128, 127; 310/26, 25, 13, 15, 27, 8.1

[56] References Cited

UNITED STATES PATENTS

2,296,754	9/1942	Wolf et al.	310/25 X
2,848,672	8/1958	Harris	318/118
3,133,214	5/1969	Lawson et al.	310/15
3,470,399	9/1969	Johnson et al.	310/13

3,505,544 4/1970 Helms.....310/13

FOREIGN PATENTS OR APPLICATIONS

1,132,125 10/1968 Great Britain.....310/26

Primary Examiner—D. F. Duggan
Attorney—Philip Sperber

[57] ABSTRACT

A feedback coil is placed in surrounding relation to a magnetostrictive member which is vibrating under the influence of a drive coil being energized by a power amplifier. Ideally, the voltage induced in the feedback coil should be proportional only to the vibrational amplitude of the magnetostrictive member. The induced voltage is fed back to the input of the power amplifier insuring that the member is vibrating at one of its resonant frequencies. The feedback coil is designed so that there is no transformer coupling between the feedback and drive coils. The feedback coil can be positioned along the length of the device in one of two ways, so as to maximize the induced voltage. Each way relies on a different magnetostrictive effect.

6 Claims, 3 Drawing Figures

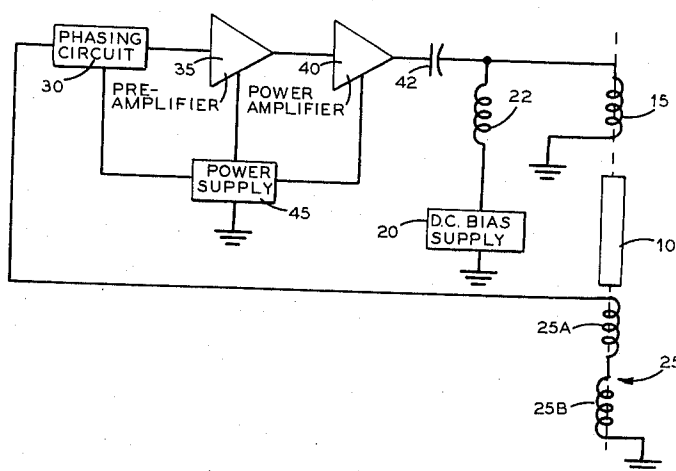


FIG. 1

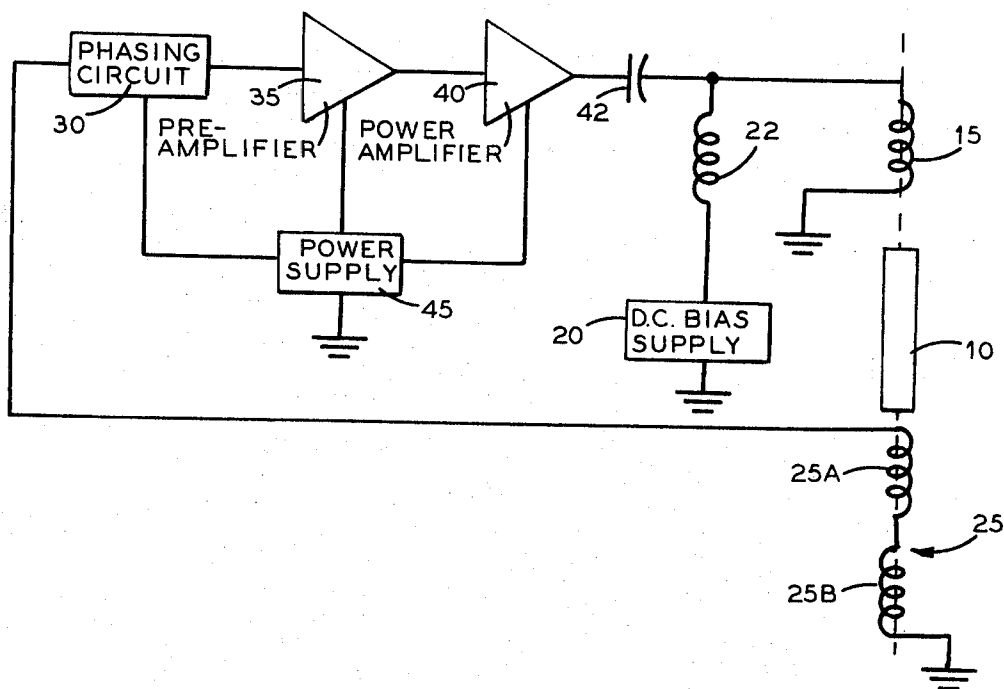


FIG. 2

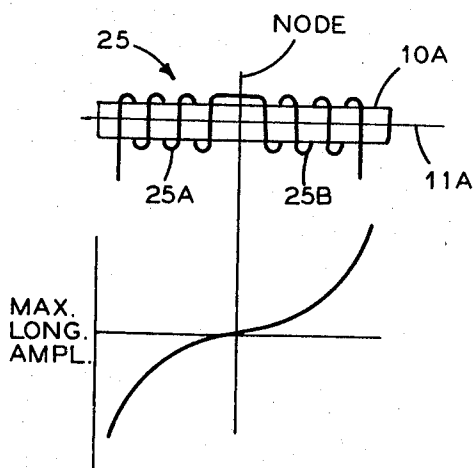
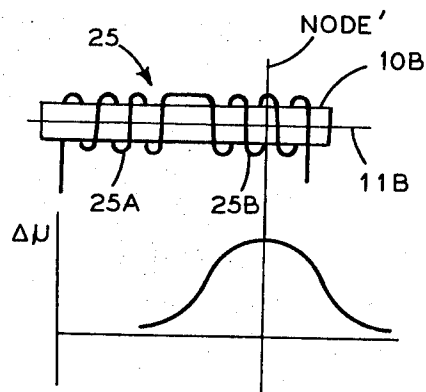


FIG. 3



INVENTORS
 William M. Honig
 Richard H. Paschke
 Jacob Haggag
 BY
Edwin C. Pearson
 ATTORNEY

MAGNETOSTRICTIVE DRIVE CIRCUIT FEEDBACK COIL

BACKGROUND OF THE INVENTION

This invention relates generally to electro-mechanical resonant systems, and more particularly is directed to improvements in the design of a feedback coil which is in surrounding relation to a magnetostrictive member which is vibrating under the influence of a drive coil being energized by a power amplifier. The feedback coil is used to insure that the magnetostrictive member vibrates at the resonant frequency at which it is designed to operate. The important features of the design include the manner in which the feedback coil is actually wound to eliminate any transformer coupling between the feedback and power coils, and the positioning of the feedback coil along the length of the magnetostrictive member to maximize the sensitivity of the voltage induced in the feedback coil. There are two different possible positions depending upon which magnetostrictive effect is the most important.

In general, electro-mechanical resonant systems are driven into acoustic vibration by means of a drive coil which is energized by an electrical AC power from an oscillation generator. This AC power produces a magnetic field in the region of the coil in which is placed a magnetostrictive member. Compression or standing waves are set up in the magnetostrictive member causing it and other parts connected thereto to vibrate. Usually a tool is connected to the magnetostrictive member by way of a tool holder whereby the high frequency longitudinal vibrations set up in the tool may be employed in performing ultrasonic machining, forming, welding, cleaning or other operations. The maximum amplitude of vibration at the working end of the tool is obtained when the frequency of the electrical power applied to the drive coil is equal to one of the resonant frequencies of the combined magnetostrictive member, tool holder and tool. The desired resonant frequency can change due to various factors such as the use of different tools, tool wear and variations in temperature and loading. In order for such a system to be useful and practical, the frequency applied to the drive coil should be capable of being varied so as to maintain the appropriate drive frequency.

It has previously been proposed to effect the necessary adjustment of the frequency either manually by an operator or automatically under the control of a feedback signal varying with the impedance of the magnetostrictive member, as in U.S. Pat. No. 2,872,578 issued Feb. 3, 1959 to Kaplan and Turner and assigned to the assignee of this application. Also a feedback signal may be obtained from a pickup device such as a piezo-electric crystal or a resonant pin which is coupled to the mechanically vibrating part of the resonant system as in U.S. Pat. No. 3,304,479 issued Feb. 14, 1967 to C. Kleesattel et al. and assigned to the assignee of this application and U.S. Pat. No. 3,419,776 issued Dec. 31, 1968 to C. Kleesattel et al. and assigned to the assignee of this application. In such existing systems the frequency of the oscillation generator is modified by the feedback signal. However such generators usually are of a complex construction and require a number of amplification stages.

Another more desirable approach of the automatic frequency control type is to use a feedback coil in surrounding relation to the magnetostrictive member to act as a sensor. The voltage induced in said feedback coil is then used to control the frequency of the power amplifier which is used to energize the drive coil. This approach is usually referred to as a feedback stabilized oscillator.

One of the problems in using feedback coils is that some of the power applied to the drive coil is coupled directly to the feedback coil by pure magnetic coupling, hereinafter to be called the transformer coupling effect. This means that the feedback signal is influenced in part by power that has not acoustically acted upon the magnetostrictive member. Therefore the transformer coupling effect should be minimized or eliminated as much as possible.

One way to solve the transformer coupling effect problem is to magnetically shield the two coils by some type of physical barrier. The disadvantage of such an approach is that it increases the overall bulk of the completed device and the effect and/or sensitivity of at least one of the coils is diminished.

Another way to solve the transformer coupling effect problem is to wind the drive coil about one portion of the magnetostrictive member and the feedback coil about the remaining portion of the member with some type of shielding mechanism therebetween. An example of such a shielding mechanism is to have the drive coil to include a few reverse windings positioned over the feedback coil or between the feedback and drive coils, cancelling any type of transformer effect between the two coils. Such a design is disclosed and claimed in U.S. Pat. No. 3,151,284 issued Sept. 29, 1964 to C. Kleesattel and assigned to the assignee of this application. The problem with such designs is that shielding occurs at only one frequency setting of the drive power and incomplete shielding will occur at drive powers both higher and lower than this. In addition, since only a portion of the magnetostrictive member is surrounded by a drive coil, the maximum number of ampere turns cannot be used to drive the magnetostrictive member.

All electro-mechanical resonant systems have a tendency to vibrate at various spurious frequencies other than the frequency at which it is designed to operate. Another advantage of the feedback coil of this invention is that it helps to maintain oscillations at the correct frequency by preventing oscillations at many of these spurious frequencies. In particular, due to the way in which each half of the feedback coil is wound relative to the other half, those spurious frequency modes which induce essentially equal and opposite voltages in each half of the feedback coil will be eliminated for the most part.

Therefore, the principal object of this invention is to provide a new and improved feedback coil for use with an electro-mechanical resonant system to insure that the mechanically vibrating part of said system continues to vibrate at one of its natural resonant frequencies.

Another object of this invention is to provide a new and improved feedback coil for use with an electro-mechanical resonant system which is designed so that there is no transformer effect between said feedback coil and the drive coil of the system.

A still further object of this invention is to provide a new and improved feedback coil for use with an electro-mechanical resonant system, said coil being designed to minimize any transformer effect with the drive coil and said coil being positioned so as to maximize the voltage induced therein.

An even further object of this invention is to provide a new and improved feedback coil for use with an electro-mechanical resonant system for eliminating many of the spurious frequency modes at which said system may have a tendency to vibrate.

In accordance with the objects of this invention, the drive coil is in surrounding relation to the entire length of the magnetostrictive member and the feedback coil is in surrounding relation to a portion of or to the entire length of the member. However, half of the windings of the feedback coil are wound in one direction (such as clockwise) and the other half of the windings of the feedback coil are wound in the reverse direction, (such as counterclockwise), with the transition region to be hereinafter referred to as the reversal point. This results in the net voltage in the feedback coil due to the transformer effect between the feedback and drive coils being zero, since any such induced voltage is equal in magnitude but opposite in direction in the two halves of the feedback coil. However, there are two other effects that could give rise to an induced voltage in the feedback coil.

One such effect is the motional velocity effect. Since the magnetostrictive member is being vibrated by a drive coil, it may be considered the equivalent of a moving magnet which gives rise to an induced voltage in any surrounding coil. To obtain the maximum benefit to this effect, the feedback coil should be positioned so that its reversal point is at the node of

longitudinal motion of the member, such that when half of the turns of the feedback coil sense a voltage due to motion in one direction, the other half of the turns sense a voltage due to motion in the other motion. Since the two halves are wound in opposite direction, relative to each other, the induced voltage reinforce each other.

Another effect resulting in an induced voltage in the feedback coil is that as the magnetostrictive member is vibrated, there is a changing stress pattern along the length of member resulting in a changing permeability of the magnetostrictive member, along its length. This changing permeability in the presence of a DC magnetic field, which is often used to bias a magnetostrictive member, results in an induced voltage in the feedback coil, hereinafter to be called the permeability effect. The maximum rate of change of permeability occurs in the vicinity of the node of longitudinal motion of the magnetostrictive member and is symmetrical thereabout. To maximize the sensitivity of the feedback coil to the permeability effect, the coil should be displaced from the node a certain distance, such that that portion of the member experiencing the maximum rate of change of permeability should be surrounded by one half of the feedback coil. In such a position, the motional velocity effect still induces some voltage but a portion thereof is cancelled out since the reversal point of the feedback coil is not at the node of longitudinal motion. However, this configuration is most advantageous whenever the permeability effect is the most significant.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more thorough understanding of the invention, reference may be made to the following description of an exemplary embodiment, taken in conjunction with the figures of the accompanying drawings, in which:

FIG. 1 is a circuit diagram illustrating an electro-mechanical resonant system embodying the present invention wherein the two coils have been removed from the magnetostrictive member for ease of explanation;

FIG. 2 is a schematic diagram of a portion of FIG. 1 illustrating the position of the feedback coil relative to the node of longitudinal motion of the magnetostrictive member in one embodiment of the invention; and

FIG. 3 is a schematic diagram of a portion of FIG. 1 illustrating the portion of the feedback coil relative to the node of longitudinal motion of the magnetostrictive member in another embodiment of the invention.

DESCRIPTION OF EXEMPLARY EMBODIMENTS

Referring to FIG. 1, it will be seen that an electro-mechanical resonant system embodying the invention may include a mechanical portion made up in part by a magnetostrictive member 10. The magnetostrictive member 10 may either be made from any ferromagnetic, magnetic or ferrite material having a high tensile strength and highly magnetostrictive in character, such as permanickel, nickel or permendur. A drive coil 15 which is energized by alternating current from a power circuit (to be discussed in more detail below) establish an alternating electromagnetic field setting up compressional waves in the magnetostrictive member 10 causing it to vibrate. In actuality, the coil 15 is wound around the magnetostrictive member 10, but for ease in explanation it is shown removed therefrom in FIG. 1. The vibration of the magnetostrictive member is sinusoidal such that the amplitude of vibration varies in magnitude along the length of the member in a sinusoidal fashion. Points at which there is no amplitude are referred to as nodes of longitudinal motion and points at which the amplitude is a maximum for any particular frequency are referred to as antinodes of longitudinal motion. A DC bias supply 20 is coupled to the drive coil 15 via an inductor 22 for polarizing the magnetostrictive member 10. The inductor 22 is used to prevent the AC power which is energizing the drive coil 15, from flowing into the DC bias supply 20.

A feedback coil 25 is wound around the magnetostrictive member 10, but for ease in explanation it is shown removed therefrom in FIG. 1. The feedback coil 25 develops a voltage proportional to the vibration of the magnetostrictive member because of two different effects, to be described in more detail hereinafter. The output of the feedback coil is delivered to a phasing circuit 30, then to a pre-amplifier 35 where the signal is amplified and then to the power amplifier 40, the latter two components comprising the power circuit. This signal controls the frequency of the output of the power amplifier 40 which is then applied to the drive coil 15 via a capacitor 42 to insure that the magnetostrictive member vibrates at one of its resonant frequencies. The capacitor 42 is used to prevent the DC power from the DC bias supply 20 from flowing into the power amplifier 40. The power circuit comprising the preamplifier 35 and the power amplifier 40, is energized by the power supply 45. The purpose of the phasing circuit 30 is to compensate for phase shifts in the pre-amplifier 35 and power amplifier 40 and for phase shifts between the drive coil 15, the magnetostrictive member 10 and the feedback coil 25.

While the drive coil 15 is wound in one direction, the feedback coil 25 may be considered to have two portions 25a and 25b. There are the same number of windings in each portion 25a and 25b. However each portion is wound in an opposite direction, that is, one portion is wound in a clockwise manner and the other portion is wound in a counterclockwise manner with a reversal point 25c somewhere in the transition region between the two portions. Due to this oppositely wound feature, any induced voltage caused by the magnetic field of the drive coil 15, (the transformer effect) is cancelled out within the feedback coil 25.

Referring to FIG. 2 a magnetostrictive member 10a having a longitudinal axis 11a is shown having a feedback coil 25 of the nature described above in surrounding relation thereto. The magnetostrictive member 10a is under the influence of a drive coil (not shown) of the nature described with respect to FIG. 1. The magnetostrictive member 10a is vibrated such that there is a node of longitudinal motion somewhere along its length, designated as the NODE on FIG. 2. The feedback coil 25 is positioned along the length of the magnetostrictive member 10a, such that the reversal point 25c between the portions 25a and 25b occurs at the NODE. FIG. 2 includes a graph showing the sinusoidal nature of the amplitude of vibration of a resonating member. Even though the direction of vibration of the magnetostrictive member 10a is in opposite directions adjacent to each of the portions 25a and 25b of the feedback coil 25, since each portion is oppositely wound relative to the other portion, the induced voltages in each portion of the feedback coil 25 reinforce each other. This induced voltage is caused by the motion of the magnetostrictive member 10a which is magnetized due to the current in the drive coil (the motional velocity effect).

Referring to FIG. 3, a magnetostrictive member 10b having a longitudinal axis 11b is shown to have a feedback coil 25 of the nature described above in surrounding relation thereto. The magnetostrictive member 10b is under the influence of a drive coil (not shown) of the nature described with respect to FIG. 1. The magnetostrictive member 10b is vibrated such that there is a node of longitudinal motion somewhere along its length, designated as NODE' on FIG. 3. FIG. 3 includes a graph showing the change in permeability ($\Delta\mu$) of the magnetostrictive member 10b as it is subjected to the varying current of the drive coil (not shown) versus the length of the member 10b. Since the maximum changes in permeability occur on both sides of the NODE' and since a voltage is induced in the feedback coil directly proportional to the amount of change in permeability ($\Delta\mu$) (the permeability effect), the feedback coil 25 is positioned so that the NODE' is approximately near the center of one portion 25b of the feedback coil 25. It is true that the voltage induced in the other portion 25a of the feedback coil 25, due to this permeability effect, will be in the opposite direction. However, as can be seen from the graph in FIG. 3, the change in permeability declines rapidly at

points removed from the NODE', hence the subtraction of the induced voltage in portion 25a from the induced voltage in portion 25b will be very slight.

Finally, it is recognized that usually both the motional velocity effect and the permeability effect occur simultaneously when a magnetostrictive member vibrates in the presence of a DC magnetic field. Therefore the choice of whether to position the feedback coil in accordance with the embodiment of FIG. 2 or in accordance with the embodiment of FIG. 3 depends upon which effect is preponderant.

The above-described embodiments of the invention is intended to be merely exemplary, and those skilled in the art will be able to make numerous variations and modifications of it without departing from the spirit and scope of the invention. All such variations and modifications are intended to be included within the scope of the invention as defined in the appended claims.

We claim:

1. An electro-mechanical resonant system comprising a work performing, variably loaded mechanical part including a magnetostrictive member and having a drive coil in surrounding relation thereto, a power circuit operative to supply alternating current to said drive coil so that the latter establishes an alternating electromagnetic field which sets up compressional waves in said magnetostrictive member at a resonant frequency of said mechanical part, a pickup coil in surrounding relation to the magnetostrictive member so that a voltage is induced in said pickup coil directly related to the actual frequency of the compressional waves, said pickup coil having two portions each with an equal number of windings, with the first portion being wound in a clockwise direction about the magnetostrictive member and the second portion being wound in a counterclockwise direction about the magnetostrictive member, and a circuit means connecting said pickup coil to said power circuit so that the power supplied to said drive coil is controlled by said alternating feedback voltage.

2. A pickup coil for use with a magnetostrictive member being vibrated by a drive coil energized by a power circuit, wherein said pickup coil is in surrounding relation to the magnetostrictive member whereby a voltage is induced in said pickup coil directly related to the actual frequency of vibration of the magnetostrictive member, said pickup coil includes two portions, each with an equal number of windings, with the first portion being wound in a clockwise direction about the magnetostrictive member and the second portion being wound in a counterclockwise direction about the magnetostrictive member, and a circuit means connects said pickup coil to the power circuit so that the power supplied to the drive coil is controlled by the induced feedback voltage.

3. An electro-mechanical resonant system comprising a work performing, variably loading mechanical part including a magnetostrictive member having a longitudinal axis and having a drive coil in surrounding relation thereto, a power circuit operative to supply alternating current to said drive coil so that the latter establishes an alternating electromagnetic field which sets up longitudinal compressional waves in said magnetostrictive member at a resonant frequency of said mechanical part, a pickup coil in surrounding relation to the magnetostrictive member so that a voltage is induced in said pickup coil directly related to the actual frequency of the compressional waves, said pickup coil having two portions, each with an

equal number of windings, with the first portion being wound in a clockwise direction about the magnetostrictive member, the second portion being wound in a counterclockwise direction about the magnetostrictive member and the reversal point positioned at a node of longitudinal motion, and a circuit means connecting said pickup coil to said power circuit so that the power supplied to said drive coil is controlled by said alternating feedback voltage.

4. A pickup coil for use with a magnetostrictive member having a longitudinal axis and being vibrated by a drive coil energized by a power circuit, wherein said pickup coil is in surrounding relation to the magnetostrictive member whereby a voltage is induced in said pickup coil directly related to the actual frequency of vibration of the magnetostrictive member, said pickup coil includes two portions, each with an equal number of windings, with the first portion being wound in a clockwise direction about the magnetostrictive member, the second portion being wound in a counterclockwise direction about the magnetostrictive member and the reversal point being positioned at a node of longitudinal motion, and a circuit means connects said pickup coil to the power circuit so that the power supplied to the drive coil is controlled by the induced feedback voltage.

5. An electro-mechanical resonant system comprising a work performing, variably loaded mechanical part including a polarized magnetostrictive member having a longitudinal axis and having a drive coil in surrounding relation thereto, a power circuit operative to supply alternating current to said drive coil so that the latter establishes an alternating electromagnetic field which sets up longitudinal compressional waves in said magnetostrictive member at a resonant frequency of said mechanical part, a pickup coil in surrounding relation to the magnetostrictive member so that a voltage is induced in said pickup coil directly related to the actual frequency of the compressional waves, said pickup coil having two portions, each with an equal number of windings, with the first portion being wound in a clockwise direction about the magnetostrictive member, the second portion being wound in a counterclockwise direction about the magnetostrictive member and a node of longitudinal motion of said member approximately at the center of one of the portions of the pickup coil, and a circuit means connecting said pickup coil to said power circuit so that the power supplied to said drive coil is controlled by said alternating feedback voltage.

6. A pickup coil for use with a polarized magnetostrictive member having a longitudinal axis and being vibrated by a drive coil energized by a power circuit, wherein said pickup coil is in surrounding relation to the magnetostrictive member whereby a voltage is induced in said pickup coil directly related to the actual frequency of vibration of the magnetostrictive member, said pickup coil includes two portions, each with an equal number of windings, with the first portion being wound in a clockwise direction about the magnetostrictive member, the second portion being wound in a counterclockwise direction about the magnetostrictive member and a node of longitudinal motion of said member approximately at the center of one of the portions of the pickup coil, and a circuit means connects said pickup coil to the power circuit so that the power supplied to the drive coil is controlled by the induced feedback voltage.

* * * * *