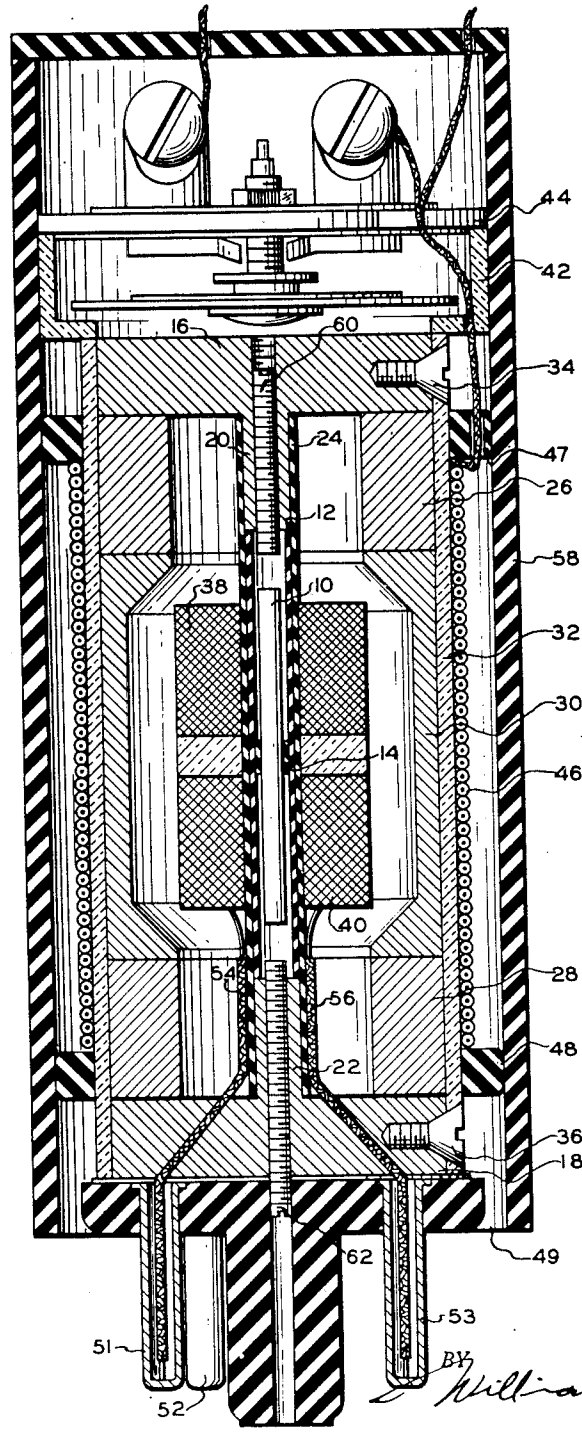
Nov. 15, 1949 N. E. LEE 2,487,815

MAGNETOSTRICTIVE ROD UNIT

Filed May 13, 1944 3 Sheets-Sheet 1

FIG.1.




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MAGNETOSTRICTIVE ROD UNIT

Filed May 13, 1944 3 Sheets-Sheet 2

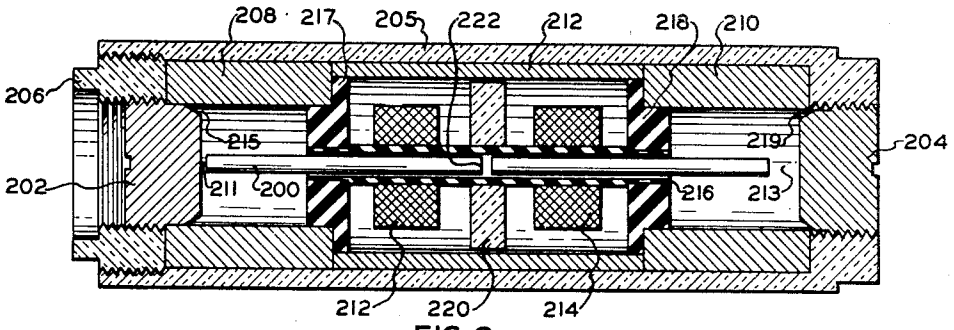



FIG. 2.

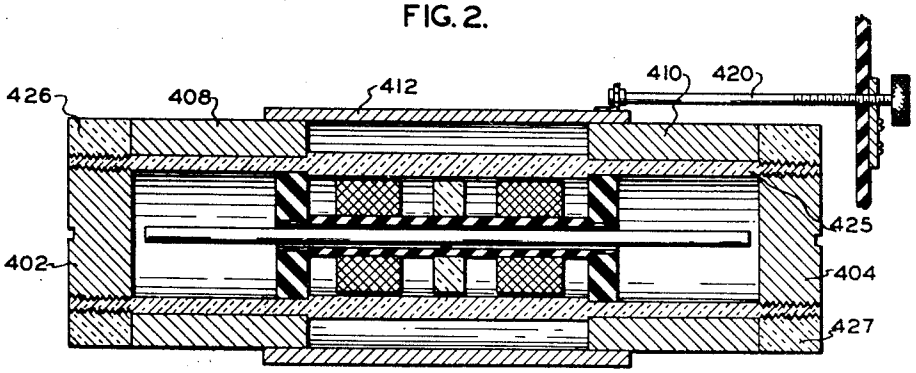



FIG. 4.

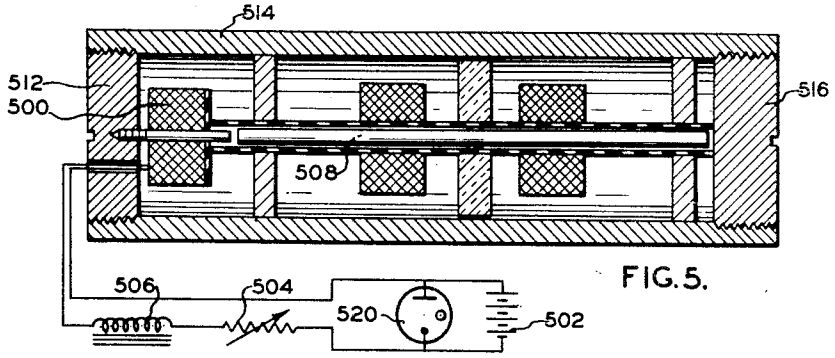



FIG. 5.

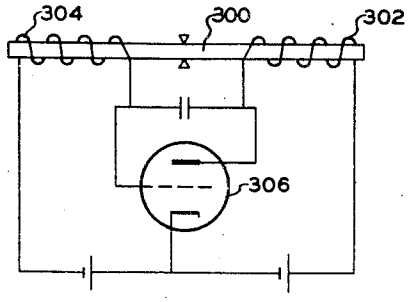



FIG. 3.

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Nov. 15, 1949 N. E. LEE 2,487,815

MAGNETOSTRICTIVE ROD UNIT

Filed May 13, 1944 3 Sheets-Sheet 3

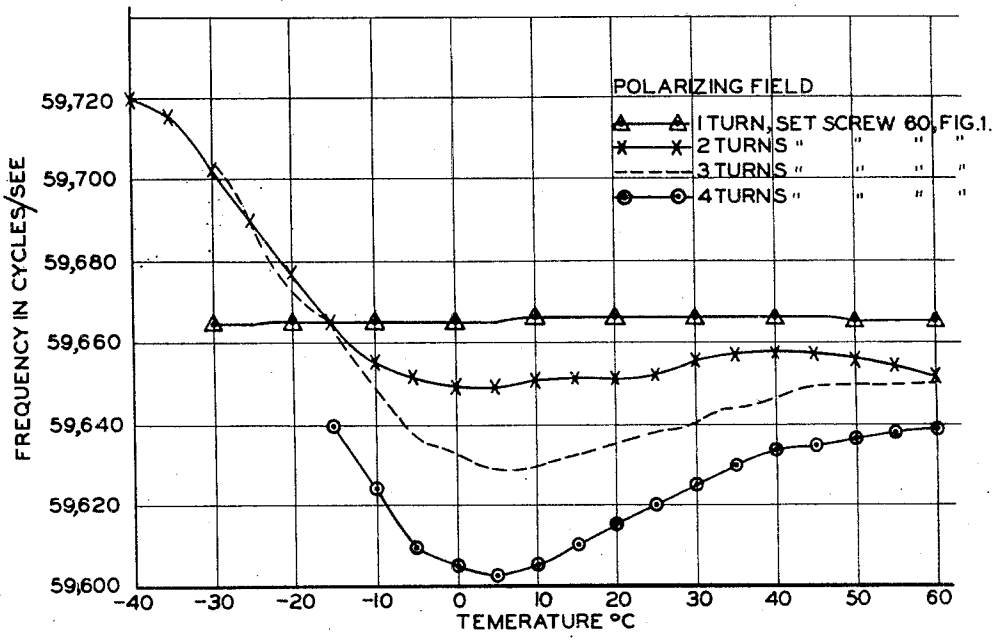



FIG.6.

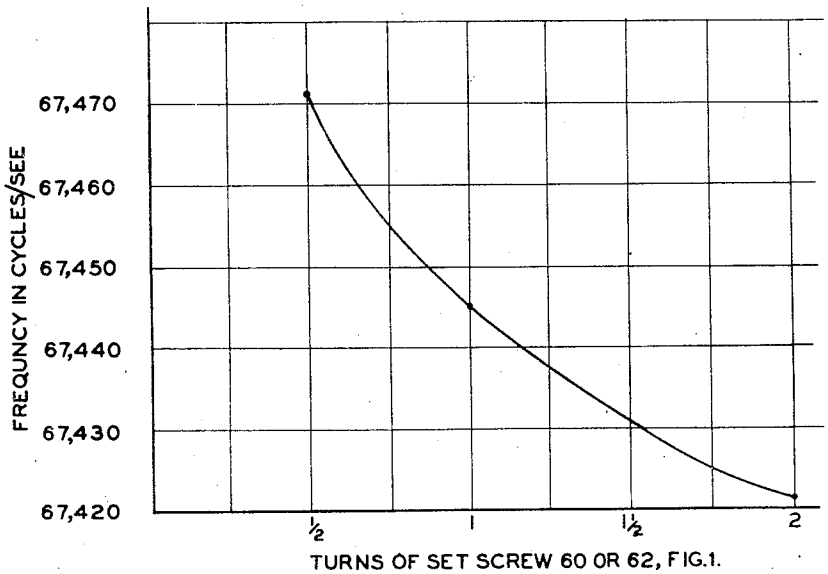



FIG.7.

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Patented Nov. 15, 1949

2,487,815

# UNITED STATES PATENT OFFICE

2,487,815

## MAGNETOSTRICTIVE ROD UNIT

Norman E. Lee, Red Bank, N. J.

Application May 13, 1944, Serial No. 535,567

12 Claims. (Cl. 171—209)

(Granted under the act of March 3, 1883, as amended April 30, 1928; 370 O. G. 757)

1

The invention described herein may be manufactured and used by or for the Government for governmental purposes, without the payment to me of any royalty thereon.

This invention relates to a magnetostriction oscillator, and particularly to a method and means for adjusting the frequency of a magnetostriction oscillator vibrating element to its required frequency which eliminates the comparatively difficult finish grinding process commonly used for this purpose in the prior art.

The phenomenon of magnetostriction is the expansion or contraction of magnetic materials as the result of magnetization, and the converse change of magnetization as the result of strain. The phenomenon may be used as the basis of an oscillator having high frequency stability. The oscillators of this type are well-known in the art, and therefore, only a brief summary of the operating features of a typical magnetostriction oscillator will suffice for the purpose of this disclosure. A typical magnetostriction oscillator circuit is illustrated in Fig. 3. The steady component of plate current flowing through a plate coil **302** produces a steady magnetization and strain in a magnetostrictive rod **300**. Any small change in plate current results in a change of magnetization of that portion of the rod which is within the plate coil **302**. This results in an elongation or contraction of this portion of the rod, and causes a compressional wave to move toward the other end of the rod. When this compressional wave reaches the portion of the rod that lies inside of the grid coil **304**, the resulting change in magnetic field induces a voltage in the grid coil **304** which causes a change in plate current. This change in plate current in turn starts another compressional wave in the bar which, after reaching that portion of the rod which lies inside of the grid coil, is reflected from the grid end of the rod back to the plate end where it is again reflected toward the opposite end of the rod. If the polarity of the grid and plate coils is correct, the induced and the reflected waves at the plate end are in phase, and will reinforce one another. The tendency of the amplitude to build up is increased to the point of oscillation by tuning the electrical circuit so that it has the same natural period as the rod. Because the change in length of an initially unmagnetized rod is of the same sign for

2

both polarities of magnetization, the rod will vibrate at twice the frequency of the electrical circuit if it is not polarized. To ensure that the rod is polarized throughout its length, it is usually permanently magnetized and placed in the coils so that the field of the plate coil increases its magnetization. Nickel, Monel metal, Nichrome, Invar, Stoic metal, and other nickel alloys are used for making magnetostrictive rods with low temperature coefficients and high magnetic retentivity. Their polarization is obtained by permanently magnetizing them in advance in a solenoid type of magnetizer capable of carrying strong direct current. With most substances the permanent magnetism is sufficiently strong to keep the rods sensitive as oscillators through years of normal use as standards of frequency in spite of any demagnetizing effects of the oscillation. The plate current of the oscillator tube also assists in maintaining the polarization provided by the rod.

The desired frequency in the magnetostriction oscillators is obtained by giving proper dimensions to the magnetostriction rods and by adjusting the parameters of the oscillator circuits to the natural frequency of the rod. The design and manufacturing difficulties do not necessarily produce rods of the expected frequency, and the known method of obtaining the desired frequency ordinarily consists of a laborious finish grinding process which adjusts the dimensions of the rod by a series of steps to the dimensions which eventually produce the sought frequency. This finish grinding process often results in complete ruining of the magnetostrictive rods which takes place when the dimensions of the rod are accidently reduced beyond the desired limits. Such haphazard method for obtaining the desired frequency with the magnetostriction oscillators complicated their use in the prior art, and limited their usefulness as sources of standard frequencies in spite of the fact that the magnetostriction oscillators otherwise have high frequency stability, and are otherwise very useful sources of standard frequency.

The invention discloses a new method and apparatus for conveniently adjusting the frequency of a magnetostriction rod to the desired value. The method provides relatively wide frequency adjustment which eliminates the difficult finish

grinding process previously used in the art for obtaining the same result, and thus increases the usefulness, versatility, and frequency precision which were unobtainable with the magnetostriction oscillators known to the prior art. The invention utilizes the phenomenon of magnetostriction which, as previously mentioned, is the expansion or contraction of magnetic materials as the result of magnetization. Thus, by varying the degree of magnetization of the magnetostriction rod, minute expansions or contractions of the magnetostriction rod may be obtained which in turn produce corresponding changes in the natural period of the rod. According to one method, the dimensional changes of the rod are obtained by varying the reluctance of the magnetic circuit of the magnetostrictive rod. By making the reluctance of the magnetic circuit of the rod adjustable, very fine adjustment and uniform change in the natural frequency of the magnetostrictive rods over relatively wide frequency limits is made possible, and since the change in the reluctance may be easily reversed, the desired frequency may now be obtained with the disclosed method in a very simple manner by "tuning" the reluctance circuit of the rod and the rod itself.

According to another method the frequency of the magnetostriction rod is adjusted by varying the degree of its magnetization.

Still another feature of the invention resides in the provision of an electro-magnetic structure for a magnetostriction oscillator in which there is a maximum degree of coupling between the rod and the pickup coils, only a limited degree of coupling between the coils, and in which the pickup coils with relatively low effective Q are used.

It has been found also that the temperature coefficient of the magnetostriction rod assembly varies considerably with temperature, and that low temperature coefficients may be obtained by varying the reluctance of the rod's magnetic circuit.

It is, therefore, the principal object of this invention to provide a new method and apparatus for an effective adjustment of the frequency of the vibrating elements in the magnetostriction oscillators to the desired values.

Another object of this invention is to provide a magnetostriction oscillator which may act as an adjustable frequency standard.

Still another object of this invention is to provide a magnetostriction oscillator the frequency of which may be varied over relatively wide limits either by adjusting the reluctance of the magnetic circuit of the magnetostriction rod, or by varying the degree of its magnetization.

Still another object of this invention is to provide electrically, magnetically, and mechanically stable structure for a magnetostriction rod assembly with maximum degree of coupling between the rod and the grid-plate coils, and a limited amount of coupling between the grid and plate coils.

Still an additional object of this invention is to provide a new method and apparatus for adjustment of the temperature coefficient of the magnetostriction rod unit.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims. My invention itself, however, both as to the organization and method of operation, together with the further objects and advantages thereof, may best be understood by reference to the following description in connection with the accompanying drawings in which:



Figure 1 is a vertical cross-sectional view of a plug-in assembly of a magnetostriction rod provided with a temperature control means, conventional grid and plate coils and new means for adjusting the frequency of the magnetostriction rod.

Figure 2 illustrates a modified form of means for adjusting the frequency of the magnetostriction rod.

Figure 3 is a schematic diagram of a conventional magnetostriction oscillator.

Figure 4 is still another modification of means for adjusting the frequency of the magnetostriction rod.

Figure 5 illustrates a magnetostriction rod assembly in which the frequency of the rod is adjusted by electrical means.

Figure 6 shows a family of curves illustrating frequency versus temperature relationship of a magnetostrictive rod with several degrees of magnetization.

Figure 7 shows a frequency versus turns of one set-screw curve, i. e. frequency vs. reluctance of the magnetic circuit of the rod curve.

Referring now to Fig. 1, a magnetostriction rod **10** is mounted in a tube **12** made of insulating material, such as hard rubber, synthetic resins, etc., by means of a bushing **14** which may be made of rubber or metal. In the latter case it may form an integral part of rod **10** thus forming a very stable rod suspension. This assembly is held in a fixed position by means of a magnetic head **16** and a magnetic base **18** made of magnetic material and equipped with the centrally located cylindrical extensions **20** and **22**, the extreme ends of which form a sliding fit with tube **12** and an outer insulator tube **24**, tubes **12** and **24** also acting as spacers for the magnetic head **16** and base **18**. Two insulator tubes **12** and **24** are illustrated, tube **12** acting as the rod support and tube **24** as a mandrel and support for the grid and plate coils **38** and **40**. The head **16** also rests on side rings **26, 28,** and **30**, rings **26** and **28** being two permanent magnets made of "Alnico" or any other permanent magnet material, and ring **30** being a magnetic space made of magnetic material such as iron, which provides a magnetic path for the flux produced by the magnetostriction rod and the two permanent magnets. Surrounding the magnetic heads **16** and **18**, and the side rings **26, 28,** and **30** is a highly conductive shield tube **32** made of copper, aluminum, etc., which shields the rod unit from the electrostatic and electromagnetic fields produced by an electric heater element, and which also holds the entire magnetostriction rod assembly together by means of set screws **34** and **36**. The grid and plate coils **38** and **40**, as mentioned previously, are mounted on the cylindrical tube **24**. The upper portion of the outer shield tube **32** is enlarged at **42** where it acts as a support for a thermostatic control relay **44** which regulates the temperature of the magnetostriction rod assembly by means of a heating coil **46** mounted on the shield tube **32** between two insulator rings **47** and **48**. Prongs **49** and **50** are connected to a source of D. C. potential which supplies power for maintaining the interior of the unit at substantially constant temperature. The magnetostriction rod unit is mounted on a tube base **49**, the connecting prongs **51, 52,** and **53** of which (the remaining prong not appearing in the drawing) being used to connect the grid and plate

coils 38 and 40 by means of conductors 54 and 56 (only two conductors out of four being visible in the figure) to the control grid and the plate respectively of a vacuum tube 306, as illustrated in Fig. 3. The base plate 18 is attached to the base 49 by means of two setscrews which are not visible in Fig. 1. Surrounding the entire magnetostriction rod unit is a thermal shield 58 which is made of some heat insulating material, such as "Masonite," synthetic resins, hard rubber, etc., this cover acting as a thermal shield for maintaining the magnetostriction rod assembly at substantially constant temperature. The magnetic head 16 and base 18 and their extensions 20 and 22 are centrally bored and threaded to accommodate adjustable setscrews 60 and 62 made of magnetic material. The longitudinal axes of the setscrews 60 and 62, because of their central position, coincide with the longitudinal axis of the magnetostriction rod 10. The magnetic circuit of the magnetostriction rod 10 is accordingly as follows: magnetostriction rod 10, air gap between rod 10 and extension 20, magnetic head 16, magnet 26, magnetic spacer 30, magnet 28, magnetic base 18, extension 22, setscrew 62, and the opposite pole of the magnetostriction rod 10. The magnetic circuit of the rod is composed of magnetic materials of high permanency, and is designed to give maximum output from the oscillator by operating the magnetostriction rod on that portion of the flux change-stress curve where this change is maximum.

The magnetic setscrews 60 and 62 comprise that means which is used for adjusting the reluctance of the magnetic circuit of the magnetostriction rod, thereby adjusting its natural period to the required frequency of the magnetostriction oscillator. The setscrews 60 and 62 may be provided witih a fine micrometer thread which produces extremely fine magnetic means for adjusting the frequency of the oscillator over relatively wide frequency limits. The adjustment of the setscrews 60 and 62 changes the polarizing field flowing through the magnetostriction rod 10, and this in turn changes its natural frequency by changing its dimensions because of the ensuing expansion or contraction of the vibrating element. The changes in polarizing field throughout the rod for frequency adjustment do not appreciably change the output of the oscillator.

Fig. 2 discloses a somewhat different mechanical arrangement of parts of the magnetic circuit which nevertheless accomplishes the same purpose as the corresponding parts of the magnetic circuit disclosed in Fig. 1. The magnetostriction rod assembly disclosed in Fig. 2 uses a much longer magnetostriction rod 200 which is necessary for obtaining low natural period oscillations. When this is the case, the magnetic head 202 and 204, which correspond in their function to the magnetic head 16 and base 18 of Fig. 1, may not have any extensions, such as extensions 20 and 22 in Fig. 1, but instead form a threaded engagement with a non-magnetic shield 205 and a locking nut 206 made of non-magnetic material. The variation in the reluctance of the magnetic circuit of the magnetostriction rod is now obtained by changing the relative position of the magnetic head 202 and 204 with respect to the magnetostriction rod 200 and permanent magnets 208 and 210 which is obtained in this case by screwing in or out the magnetic heads 202 and 204. This changes the dimensions of the air-gaps 211, 213 and the reluctance path at



215 and 217 where the magnetic heads approach the permanent magnets 208 and 210. The magnetic circuit of the magnetostriction rod is otherwise similar to the magnetic circuit of the magnetostriction rod in Fig. 1. It consists of the magnetic heads 202, 204, permanent magnets 208, 210 and a magnetic spacer 212 which, besides acting as a link for closing the magnetic circuit of the rod, also acts as a mechanical spacer between the permanent magnets 208 and 210. The non-magnetic shield 205 surrounds the grid and plate coils 212 and 214 which are mounted on an insulating tube 216, the latter being supported by two end washers 217 and 218 made of insulating material. The oscillator coils 212 and 214 are separated from each other by means of a non-magnetic shield 220 which prevents mutual coupling between the coils 212 and 214. As in the case of Fig. 1, the magnetostriction rod is suspended by means of a ring 222 which in this case is an integral part of the magnetostriction rod 200. Ring 222 holds the rod in the central position with respect to the entire assembly. The remaining elements of the magnetostriction rod assembly, such as thermostatic control, thermostatic shield, and coil connections shown in Fig. 1 are not illustrated in Fig. 2.

Fig. 4 discloses another mechanical modification for adjusting the reluctance of the magnetic circuit of the magnetostriction rod. In this case the magnetic heads 402 and 404 remain fixed and variable reluctance is obtained by varying the reluctance of the magnetic circuit by changing the longitudinal position of a magnetic sleeve 412 with respect to the permanent magnets 408 and 410. The reluctance of the magnetic circuit may be varied in this case by varying the longitudinal position of the magnetic sleeve 412 by means of a micrometer screw 420. In Fig. 4 the magnetostriction unit is held together by means of a non-magnetic sleeve 425 and end nuts 426 and 427.

When frequency stability requirements are not especially high, frequency adjustment arrangement disclosed in Fig. 5 may be used. This arrangement is especially useful when remote frequency control is desirable. In this figure the magnetization of the rod is adjusted by varying the current flowing through a field coil 500 connected to a source of direct current potential 502 through a large resistor 504 and a choke coil 506. By varying the resistor 504, the elastic constants of the magnetostrictive rod 508 may be varied which produces the necessary change in its natural period. Coil 500 is mounted on a magnetic rod 510 which is connected to a magnetic head 512. The magnetic circuit in this case consists of an iron tube 514 and two magnetic heads 512 and 516. The potential across the frequency controlling circuit may be stabilized by means of a voltage regulator tube 520 The circuit elements 500, 504, and 506 must have a substantially constant temperature coefficient in the region of their duty cycle.

The following examples are quoted as illustrative of the frequency adjustments which may be obtained by means of the invention disclosed in Figs. 1 through 4. For a 61 kilocycle magnetostriction rod ⅛ of an inch change in the longitudinal position of one setscrew at one end of the magnetostriction rod assembly, such as setscrew 60 or 62, Fig. 1, produces approximately 61.5 cycles change in the natural frequency of the rod.

Besides providing very simple and effective

means for adjusting the frequency of the magnetostriction rod, the disclosed arrangement of the elements of the rod unit results in maximum degree of coupling between the rod and the grid coil on one side, and the rod and the plate coil on the other side. The losses in the coupling coils and their effective Q (independent of the magnetostriction rod) are adjusted by varying the air gap between the coils and the magnetic spacer until the desired relatively low effective Q for the coils is obtained. When this is the case the coils themselves do not have any sharply defined resonance frequency of their own so that the frequency of the oscillator and its stability are under a more effective control of the magnetostriction rod.

Fig. 7 illustrates a typical frequency vs. turns curve, the turns referring to the turns of the adjustable setscrew 60 or 62, Fig. 1. The frequency effect produced by turning only one setscrew is illustrated in Fig. 7. A 26 cycle change is produced when the setscrew is turned from ½ to 1 turn position in this specific illustration.

The advantages of the disclosed method of adjusting the natural frequency of the magnetostriction rod as compared to the prior finish grinding methods for accomplishing the same purpose may become more apparent from the following example: A change in length equal to .000002'' is required in the length of a magnetostriction rod the natural period of which is equal to $f_o$=100 kc. if a frequency change of two cycles is desired. Such changes in length are difficult to obtain under ordinary machine shop practices. The disclosed method makes it possible to obtain frequency changes of even much smaller magnitudes in a continuous and reversible manner by magnetostrictively adjusting the elastic constants of the rod. The disclosed method enables one to use ordinary machine shop practices in reducing the dimensions of the magnetostriction rod material indicated by theoretical computations with the finishing tolerances being in the order of plus or minus .0001''.

The remaining frequency adjustments may then be accomplished by varying the reluctance of the magnetic circuit.

Fig. 6 discloses a family of typical curves which show changes in natural frequency of a single magnetostriction rod over a temperature range from −40° to +60° C. for different settings of the set-screws used for adjusting the reluctance of the rod's magnetic circuit. The curves definitely indicate that by changing the reluctance of the circuit, the temperature coefficient of the unit may be varied and made substantially constant so that it remains constant over an extremely wide range of temperatures. Accordingly, if the natural period of the oscillator need not have some specific frequency, a variation in the reluctance of the circuit may be used for obtaining the optimum temperature coefficient rather than the desired natural frequency.

It is believed that the construction and operation of the disclosed method and means for adjusting the natural frequency of the vibrating element for the magnetostriction oscillator and the temperature coefficient of the vibrating element unit as well as the many advantages thereof thereof will be apparent from the foregoing description to those skilled in the art. It will therefore be apparent that while I have shown and described my invention in several preferred forms, many changes and modifications may be made without departing from the spirit of my invention as sought to be defined by the following claims.



I claim:

1. A magnetostriction rod unit comprising a series magnetic circuit of a magnetic base, a first ring-shaped permanent magnet mounted on said base, a ring-shaped magnetic spacer, a second ring-shaped permanent magnet, a magnetic head, and a magnetostriction rod mounted between said base and said head and surrounded by said spacer.

2. A magnetostriction rod unit as defined in claim 1 which further includes instrumentalities for adjusting an air gap between said magnetic base and said magnetostriction rod.

3. A magnetostriction rod unit as defined in claim 1 which further includes instrumentalities for adjusting an air gap between said magnetic head and said magnetostriction rod.

4. A magnetostriction rod unit as defined in claim 1 which further includes instrumentalities for adjusting the circuit reluctance of said rod.

5. A magnetostriction rod unit as defined in claim 1 which further includes a threaded hole in said magnetic base and a threaded hole in said magnetic head, and a setscrew in each of said holes positioned along the center line of said magnetostriction rod, said setscrews being in series magnetic circuit of said magnetostriction rod whereby change in position of said setscrews varies the reluctance of said series magnetic circuit.

6. A magnetostriction rod unit as defined in claim 1 which further includes a high conductivity shield surrounding said magnetic head, permanent magnets, magnetic spacer and said magnetic base; an electrical heater mounted on the outer surface of said shield, and a thermal insulator surrounding said unit.

7. A magnetostriction rod unit as defined in claim 1 which further includes a grid coil and a plate coil surrounding said rod, a base for said unit of thermionic tube type having prongs made of conducting material, and connections between said grid and plate coils and said prongs.

8. A magnetostriction rod unit as defined in claim 1 which further includes a grid coil and a plate coil mounted on said rod, said coils and said magnetic spacer being so constructed and arranged that said coils are devoid of sharply defined resonance frequency of their own.

9. A magnetostriction rod unit comprising a non-magnetic tube, two magnetic heads fitted into said tube, a magnetostriction rod and pickup coils fitted into said tube between said magnetic heads, two ring-shaped permanent magnets mounted over said tube with an air gap therebetween, an adjustable magnetic sleeve mounted over said permanent magnets so as to bridge said air gap, and means for adjusting the position of said magnetic sleeve with respect to said magnets so as to vary the reluctance of the magnetic circuit of said rod and said permanent magnets.

10. A magnetostriction rod unit comprising a magnetostriction rod, a tube made of insulating material, means for suspending said rod in said tube, a magnetic head and a magnetic base positioned respectively above and below said tube, a first permanent magnet mounted on said base, a second permanent magnet mounted below said magnetic head, a magnetic spacer between said first and second permanent magnets, said mag-

nets and said spacer being so constructed and arranged as to form a housing for said tube.

11. A method of adjusting the temperature coefficient of frequency of a magnetostriction oscillator vibrating element to an optimum value which comprises the steps of: providing an adjustable reluctance path for said element, and adjusting said reluctance path to adjust the temperature coefficient of said element to the optimum volume.

12. A magnetostrictive rod, a magnetic circuit for said rod, and instrumentalities for adjusting the temperature coefficient of frequency of said rod by varying the reluctance of said magnetic circuit.

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