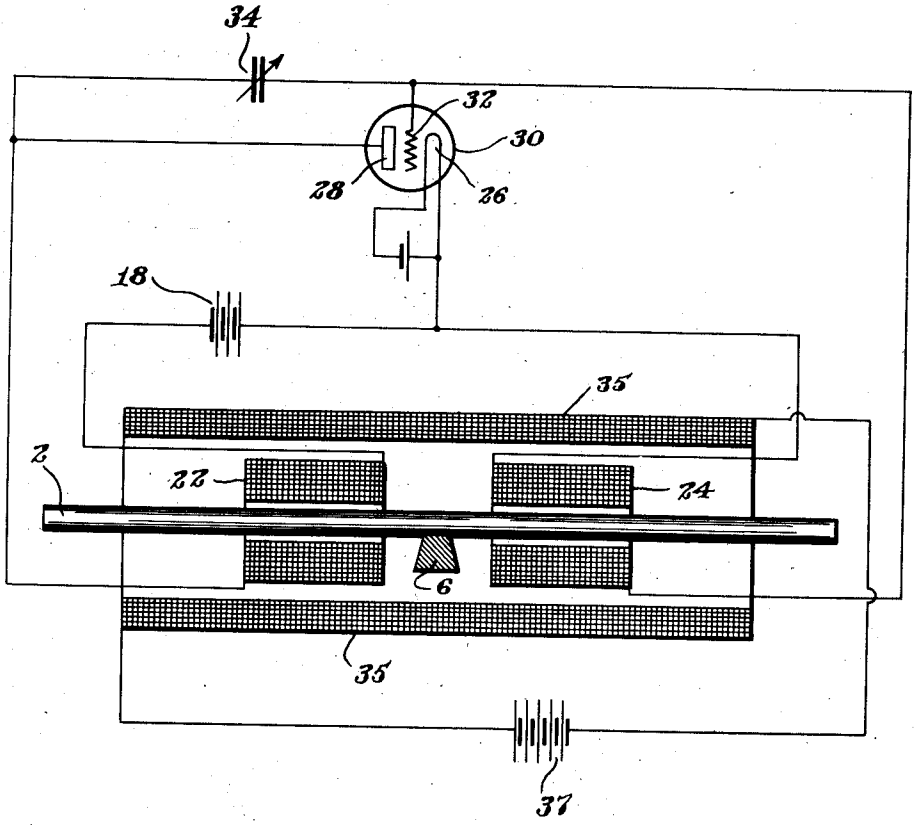
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VIBRATOR

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VIBRATOR

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The present invention relates to vibrators, and more particularly to vibrators having a low varying or substantially constant frequency with variations of temperature, and adapted to be operated magnetostrictively. Vibrators of this character are disclosed in United States Letters Patent 1,882,397, granted October 11, 1932, to George W. Pierce.

An object of the invention is to provide a new and improved vibrator of the above-described character. Other objects will be explained hereinafter, it being understood that it is intended to set forth, by suitable expression in the claims, all the novelty that the invention may possess.

The invention will be explained in greater detail in connection with the accompanying drawing, the single figure of which is a diagrammatic view of a vibrator embodying the present invention and connected into a magnetostrictive oscillator.

The vibrator is shown at 2, in the form of a rod, but it may have any other desired shape, as a tube. It is illustrated as positioned axially of a magnetic field, here shown as produced by coils 22 and 24. For symmetry, one of the coils is positioned on one side of the middle of the core 2 and the other on the other side. The coil 22 is connected, in series with the local battery 18, between the filament or cathode 26 and the plate or anode 28, in the output or plate circuit of a vacuum tube 30. The coil 24 is similarly connected in the input or grid circuit of the tube, between the filament 26 and the grid or third electrode 32. The coils 22 and 24 thus form electrical paths between the filament and the plate, and between the filament and the grid respectively. The grid and the plate may, if desired, be spanned by a variable condenser 34 or the tuning condenser may be connected in parallel with one or the other of the coils 22 and 24; or if the coils are suitably designed the condenser may be omitted altogether. An electric vacuum-tube oscillator is thus provided as described more fully in United States Letters Patent 1,750,124, granted March 11, 1930, to the said Pierce. As is also there stated, the local battery 18 may serve to supply the plate current, as well as to polarize the vibrator. In the illustrative drawing, polarization is effected by means of a separate winding 35, in series with a polarizing battery 37. A steady magnetizing or polarizing field is thus applied, over which the alternating field is superposed.

As is explained in the said Letters Patent 1,882,397, the frequency of a particular mode of vibration of a rod or bar is determined by its elasticity, length and density. For some modes of vibration, the frequency is affected also by the width, thickness, radius, and the like, of the rod or bar. Different bodies have different magnetostrictive properties. Alloys containing nickel, chromium, cobalt and steel, in proper proportions, have comparatively large magnetostriction.

The present invention is the result of tests made with a large number of magnetic alloys of iron, nickel, chromium and cobalt, in varying proportions. The temperature coefficient of frequency was measured, in each case, at several points in the temperature range from 20° C. to 100° C. These researches have developed that some of the alloys have very low, substantially zero, temperature coefficients of frequency of longitudinal vibration. It was found that the temperature coefficient of frequency is a function of composition, heat treatment, temperature and magnetization. Three compositions were found which gave temperature coefficients of the order of one to fifteen cycles in a million per centigrade degree, when properly heat-treated and magnetized. These show large dynamic magnetostriction effects, so as to constitute powerful magnetostrictive vibrators, and give good frequency stabilization when used in the audio range and up to about 100,000 cycles per second with a magnetostriction, vacuum-tube oscillator, such as is disclosed in the said Letters Patent of the United States 1,750,124 and illustrated in the accompanying drawing. Alloys of such composition are useful in the form of tuning forks to serve as low, audio-frequency standards, as well as for magnetostriction oscillators, to stabilize higher frequencies.

The following considerations will help to an understanding of the present invention.

Let l be the length of the vibrator, D the density of the material of which the vibrator is constituted, a the temperature coefficient of linear expansion of this material, b the temperature coefficient of Young's modulus E, and g the temperature coefficient of frequency of longitudinal vibration. By using well known equations for the velocity of sound v in an elastic medium:

$$v=2lf=\sqrt{E/D}.$$

If the temperature be permitted to change slightly, it can be shown that

$$b=2g-a, \text{ or } g=\frac{a+b}{2}.$$

It is obvious from this equation that one way to get a small temperature coefficient of frequency is to make alloys for which b is opposite

in sign, and nearly equal in magnitude, to a. Since a is always positive, in metals, and varies in value from 1×10^{-6} to $12+10^{-6}$ for alloys of iron, nickel and chromium, it is desirable to make alloys for which b will be negative in sign and of this order of magnitude.

In an alloy containing 36 per cent nickel, 8 to 10 per cent chromium, and the balance iron, the value of g can be made vanishingly small, under suitable magnetic and thermal conditions. It is likewise true, as I have found, that the 8 per cent and 10 per cent chromium alloys are very powerful magnetostrictive vibrators. The addition of about 13 per cent of cobalt to the iron nickel alloy containing 36 per cent nickel, reduces g to zero.

The temperature coefficient of frequency g, for any given alloy of this series, may vary with temperature, and with the steady magnetic field applied to the rod. For all these alloys, g can be changed by heat treatment, such as quenching or annealing. g is thus primarily a function of composition, although it is, to some extent, influenced by heat treatment, magnetization, and temperature.

All of the alloys may contain about 1 per cent of manganese as deoxidizer, which facilitates forging. The impurities should be low, so high-grade materials are desirable; for example, electrolytic nickel, cobalt, chromium, and Armco iron.

If the natural frequency of vibration of a specimen rod is measured as a function of temperature, and the frequency is plotted in a curve against temperature, the temperature coefficient of frequency is the slope of this curve.

In the experimental work on which this invention is based, the natural frequency of the rod was measured by placing it in the coils of a magnetostriction oscillator, such as is illustrated in the accompanying drawing, the frequency of which oscillator the rod was allowed to control. Some harmonic of this frequency (usually the seventh) was made to produce beats with some harmonic (usually the fifth) of the fifty kilocycle output from a General Radio, Class C-21-H, crystal-controlled standard-frequency assembly. The difference frequency was amplified and then measured by an audio-frequency meter. The natural frequency of the rod could thus be ascertained with high accuracy.

Measurements were made with the temperature of the rod at any desired value between room temperature and 130° C.

Each rod was measured at four or five different temperatures, and with a series of various polarizing fields, so that curves were obtained, giving the natural frequency as a function of the magnetic field, and of the temperature. From these curves, temperature coefficients could be computed under various conditions of temperature and magnetization for each specimen.

The following were found to be favorable alloy compositions of nickel, chromium and iron: Cr 8 per cent, Ni 37 per cent; Cr 8 per cent, Ni 38 per cent; and Cr 10 per cent, Ni 36 per cent. The balance is iron, in each case.

To show the effect of heat treatment on the variation of frequency with magnetic field, samples cut from the same rod were measured in the quenched, annealed, and forged conditions. The annealed sample showed 0.6 per cent frequency change, the forced sample 0.2 per cent change, and the quenched sample 0.1 per cent change, as the magnetic field was increased to saturation. This behavior with heat treatment is typical of most of these alloys.

The tests showed that there is less frequency variation with field as the temperature rises.

The tests showed further that the addition of more than 10 per cent of chromium or of cobalt to the iron-nickel series (30 per cent to 40 per cent nickel) reduces the dynamic magnetostriction effects.

Heat treatment is another factor which may cause marked changes in the properties of these alloys. A sample was annealed by heating to redness and allowing it to cool slowly in the furnace. It was demonstrated that there is a critical magnetizing field, for each specimen, where the temperature coefficient changes from positive to negative values, passing through zero. The amount of change in the temperature coefficient, as the field varies, was shown to be large for the annealed and forged samples and very small for the quenched sample. By proper choice of composition, the temperature coefficients can be made too small to measure, or less than one part in a million per degree centigrade, by careful adjustment of magnetic field and heat treatment. Without such adjustment, the coefficient may be counted upon to be less than 20 cycles in a million per centigrade degree.

This research shows that, while the temperature coefficient may be made negligible, the magnetic field applied to the rod may cause considerable variation of the rod frequency. It thus appears that variations in magnetic field may, in some cases, be more objectionable than temperature changes. When the frequency change with field is large, as for the annealed sample of alloy containing 8 per cent Cr, 37 per cent Ni, and balance Fe, there may be 50 parts in a million frequency variation for a field change of one oersted. It can be seen that the fluctuations of the earth's magnetic field would give a frequency variation of a few parts in a million. This is for the alloy which shows the largest effect of this kind, and the same composition when quenched has this frequency variation reduced to about three parts in a million for one oersted field change. If fields larger than 170 oersteds are applied, the variation is further reduced to one part in a million per oersted.

As the temperature coefficient varies somewhat with temperature, heat treatment, and magnetic field, it is possible, by arranging the thermal and magnetic conditions, to obtain practically zero temperature coefficient with any of the above compositions. Other compositions close to these will have very small coefficients. For example, any composition in the range from 36 per cent to 40 per cent nickel 8 per cent chromium, and the balance iron in each case, should have a temperature coefficient less than ten parts in a million, under suitable conditions.

The desirable characteristics for frequency standards to control magnetostrictive oscillators are, of course, excellent stabilization and small effect of magnetic field on frequency, in addition to low-temperature coefficient. The alloys above enumerated are all excellent vibrators. These alloys are practical compositions for applications requiring low-temperature coefficient, low magnetic-field coefficient, and excellent stabilizing power, or large dynamic magnetostriction. By quenching these alloys, the magnetic-field coefficient can be still further reduced without affecting the other desirable properties.

With chromium, iron and nickel, the best al-

loys, according to this invention, for the purpose of magnetostrictive frequency standards are those containing from eight to ten percent of chromium, thirty-six to thirty-eight per cent of nickel, and the balance iron, together with one per cent of manganese to facilitate forging. With such alloys, properly heat treated and magnetized, one may obtain temperature coefficients of frequency of the order of one cycle in a million per centigrade degree.

Modifications may be made by persons skilled in the art without departing from the spirit and scope of the invention, as defined in the appended claims.

What is claimed is:

1. A vibrator having a substantially constant frequency with variations of temperature, and constituted of an alloy having about 8 to 10 parts chromium, 36 to 40 parts nickel, and the balance iron with a small addition of another substance or substances, and a coil cooperatively related to the vibrator, the relation between the coil and the vibrator being such that the current flowing through the coil is subjected to the reaction of the vibrator at a frequency which resonates with the vibrator.

2. A vibrator having a substantially constant frequency with variations of temperature, and constituted of an alloy having about 8 to 10 parts chromium, 36 to 40 parts nickel, and the balance iron with a small addition of manganese.

3. A vibrator having a substantially constant frequency with variations of temperature, and constituted of an alloy having about 8 parts chromium, 37 parts nickel, one part manganese and the balance substantially all iron, and a coil cooperatively related to the vibrator, the relation between the coil and the vibrator being such that the current flowing through the coil is subjected to the reaction of the vibrator at a frequency which resonates with the vibrator.

4. A vibrator having a substantially constant frequency with variations of temperature, and constituted of an alloy having about 8 parts chromium, 37 parts nickel and the balance substantially all iron.

5. A vibrator having a substantially constant frequency with variations of temperature, and constituted of an alloy having about 8 parts chromium, 38 parts nickel and the balance substantially all iron.

6. A vibrator having a substantially constant frequency with variations of temperature, and constituted of an alloy having about 10 parts chromium, 36 parts nickel, and the balance substantially all iron.

7. A vibrator having a substantially constant frequency with variations of temperature and constituted of chromium, nickel and iron, and a coil cooperatively related to the vibrator, the relation between the coil and the vibrator being such that the current flowing through the coil is subjected to the reaction of the vibrator at a frequency which resonates with the vibrator.

8. A vibrator having a substantially constant frequency with variations of temperature and constituted of chromium, nickel and iron, with a small percentage of manganese, and a coil cooperatively related to the vibrator, the relation between the coil and the vibrator being such that the current flowing through the coil is subjected to the reaction of the vibrator at a frequency which resonates with the vibrator.

9. A vibrator having a substantially constant frequency with variations of temperature, and comprising about 8 to 10 parts chromium, 36 to 40 parts nickel, and the balance substantially all iron, and a coil cooperatively related to the vibrator, the relation between the coil and the vibrator being such that the current flowing through the coil is subjected to the reaction of the vibrator at a frequency which resonates with the vibrator.

10. A vibrator having a substantially constant frequency with variations of temperature, and comprising about 8 parts chromium, 37 parts nickel and the balance substantially all iron, and a coil cooperatively related to the vibrator, the relation between the coil and the vibrator being such that the current flowing through the coil is subjected to the reaction of the vibrator at a frequency which resonates with the vibrator.

11. A vibrator having a substantially constant frequency with variations of temperature, and comprising about 8 parts chromium, 38 parts nickel and the balance substantially all iron, and a coil cooperatively related to the vibrator, the relation between the coil and the vibrator being such that the current flowing through the coil is subjected to the reaction of the vibrator at a frequency which resonates with the vibrator.

12. A vibrator having a substantially constant frequency with variations of temperature, and comprising about 10 parts chromium, 36 parts nickel, and the balance substantially all iron, and a coil cooperatively related to the vibrator, the relation between the coil and the vibrator being such that the current flowing through the coil is subjected to the reaction of the vibrator at a frequency which resonates with the vibrator.

13. A magnetic material having a substantially constant frequency with variations of temperature, and comprising about 8 to 10 parts chromium, 36 to 40 parts nickel, and the balance substantially all iron.

14. A magnetic material having a substantially constant frequency with variations of temperature, and comprising about 8 parts chromium, 37 parts nickel and the balance substantially all iron.

15. A magnetic material having a substantially constant frequency with variations of temperature, and comprising about 8 parts chromium, 38 parts nickel and the balance substantially all iron.

16. A magnetic material having a substantially constant frequency with variations of temperature, and comprising about 10 parts chromium, 36 parts nickel, and the balance substantially all iron.

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