Sept. 17, 1935. H. W. AUGUSTADT 2,014,514

MECHANICAL WAVE FILTER

Filed Feb. 28, 1933 2 Sheets-Sheet 1

FIG. 1

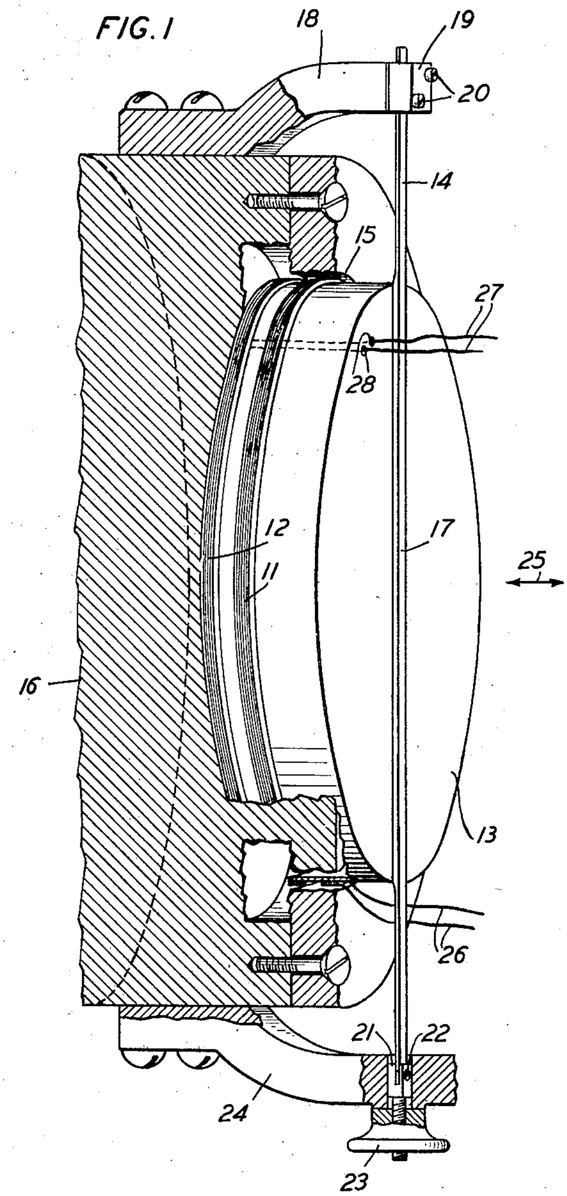


FIG. 5

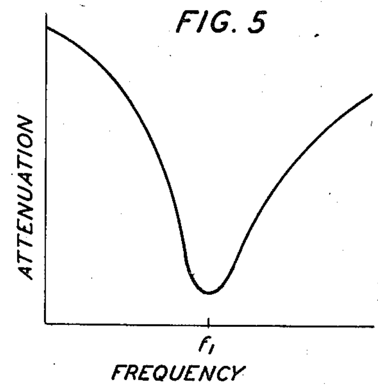
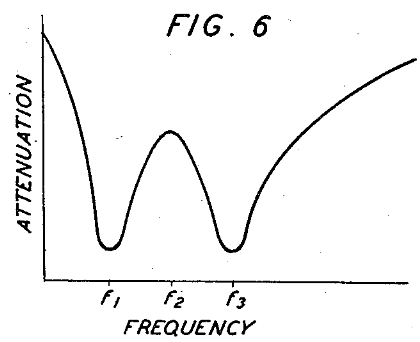


FIG. 6



INVENTOR
H. W. AUGUSTADT

BY E. V. Griggs

ATTORNEY

Sept. 17, 1935. H. W. AUGUSTADT 2,014,514
MECHANICAL WAVE FILTER
Filed Feb. 28, 1933 2 Sheets-Sheet 2

FIG. 2

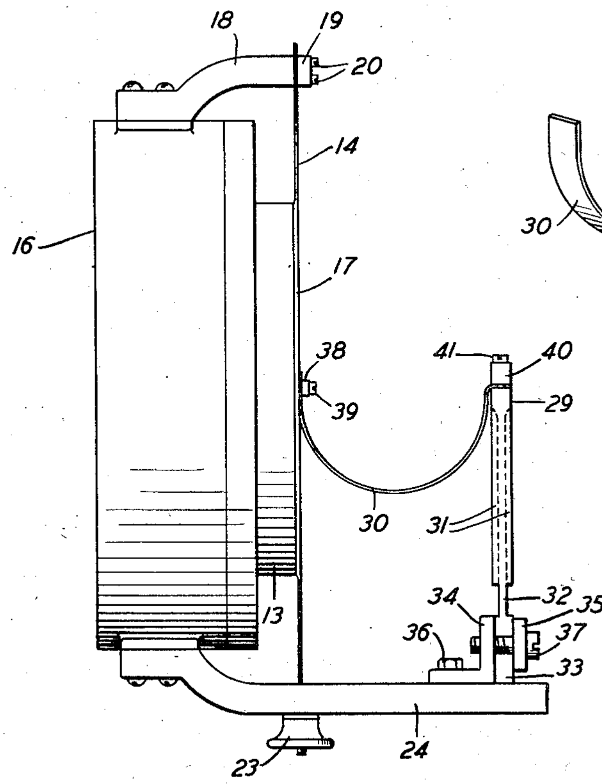


FIG. 3

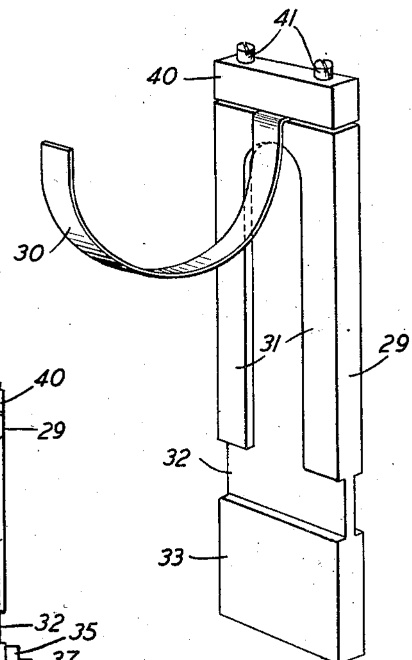
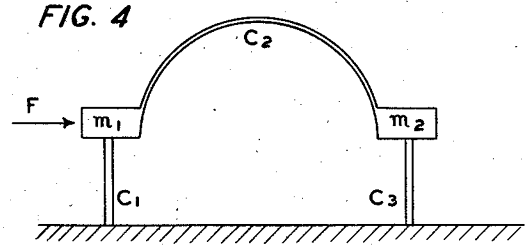


FIG. 4



INVENTOR
H. W. AUGUSTADT
BY E. V. Griggs
ATTORNEY

Patented Sept. 17, 1935

2,014,514

UNITED STATES PATENT OFFICE

2,014,514

MECHANICAL WAVE FILTER

Herbert W. Augustadt, New York, N. Y., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application February 28, 1933, Serial No. 658,929

11 Claims. (Cl. 178—44)

This invention relates to frequency selective systems and more particularly to mechanical wave filters, that is, mechanical systems for selectively transmitting vibratory wave motion.

An object of the invention is the selective transmission of a single frequency or a narrow band of frequencies.

Another object is to improve the attenuation characteristics of mechanical wave filters.

Another object is to select mechanically two or more narrow frequency bands and at the same time to attenuate strongly one or more intermediate frequencies.

A further object is to simplify the coupling between a mechanical filter and the associated electrical circuit.

Still another object of the invention is to reduce the weight and cost of mechanical wave filters used in connection with electrical circuits.

A feature of the invention is a wave filter adapted to be inserted in an electrical circuit, but the filtering action of which is dependent upon mechanical means.

Another feature is a filter in which electrical energy is converted into mechanical and the mechanical energy is reconverted into electrical by means of a single magnetic field structure.

When a mechanical filter is used as a component part of an electrical transmission system it is, of course, necessary in some manner to couple the mechanical to the electrical circuit. Heretofore, two separate field structures have been employed for this purpose, one for converting the electrical energy into mechanical energy and the second for reconverting the mechanical back into electrical energy. In accordance with the present invention this energy conversion is effected with a single magnetic field, in which both the input and the output coils of the filter are constrained to vibrate. In this way the coupling arrangement between the mechanical filter and its associated electrical circuit is simplified with a consequent reduction in the required weight and cost of the filter, due to the complete elimination of one field structure. If a single frequency or narrow band of frequencies is to be transmitted the mechanical system may be given a single resonant frequency. If two or more frequencies are to be passed the mechanical system may be provided with the requisite number of resonances, and the intermediate anti-resonant frequencies may be so placed as to attenuate strongly undesired frequencies. An application of the invention has been found in connection with navigation aids for aircraft where, for example, it is required to separate frequencies of 65 and 86 cycles per second, respectively. For a description of an aircraft radio beacon system to which the invention is applicable reference is made to an article by J. H. Dellinger and H. Pratt, in the Proceedings of the Institute of Radio Engineers, Vol. 16, page 890, July, 1928. In accordance with the invention a pair of mechanical filters may be provided to accomplish this frequency separation. One of the filters is designed to transmit a frequency of 86 cycles while having a peak of attenuation at 65 cycles; the other filter is designed to transmit a frequency of 65 cycles, with an attenuation peak at 86 cycles. In this way a large amount of discrimination between the two frequencies may be provided. The filter of the invention is particularly adapted for use on aircraft because of its simple, compact construction, lightness of weight and reliability of operation.

The invention will be more clearly understood from the following detailed description and the accompanying drawings, of which:

Fig. 1 is a perspective view, partially cut away, of a mechanical filter embodying the invention;

Fig. 2 illustrates a modified form of the filter shown in Fig. 1;

Fig. 3 is a detailed view of an element used in the filter of Fig. 2;

Fig. 4 represents diagrammatically the mechanical system of Fig. 2; and

Figs. 5 and 6 are attenuation characteristics obtainable with the filters shown, respectively, in Figs. 1 and 2.

Referring especially to Fig. 1, one form of the mechanical filter of the invention comprises an input coil 11 and an output coil 12 wound on a light form or drum 13 which is mounted on a metal band 14 and constrained to vibrate in the airgap 15 of the permanent magnet 16. The central portion 17 of the band 14 is enlarged or reinforced in order to add rigidity to the coil form 13. Duralumin has been found to be a satisfactory material from which to make the band 14 as it is light in weight and has small internal dissipation losses. One end of the band 14 is clamped to the bracket 18 by means of the block 19 and the screws 20. The other end of the band 14 fits into a slot in the square block 21 and is held by the screw 22. The outer end of the block 21 terminates in a rounded portion which is threaded to receive the thumb nut 23. The block 21 has a sliding fit in a square hole in the bracket 24. The coil form 13 is carefully centered in the airgap 15 and may be secured in place on the band 14 by means of shellac, glue or the like. The two coil windings 11 and 12 are thus free to vibrate in and out of the airgap 15 in a direction parallel to the axis of the coil form 13, as indicated by the double-pointed arrow 25. The mechanical system will have a natural frequency of vibration f_1 which will depend upon the effective mass m of the vibrating element at the point of drive, and the compliance c of the supporting band measured at the same point. In equation form

$$f_1=\frac{1}{2\pi\sqrt{mc}}, \qquad (1)$$

where f_1 is the frequency in cycles per second, m is the mass in grams and c is the compliance in centimeters per dyne. For a given mass m it is apparent that the frequency of resonance may readily be adjusted by increasing or decreasing the tension of the band 14, which may be accomplished by tightening or loosening the thumb nut 23. The natural frequency of the mechanical system is in this way set at the frequency to be transmitted by the filter. In operation, the alternating electromotive force is impressed upon the terminals 26 of the input coil 11 and if frequency f_1 is present, the mechanical system is set into vibration by the action of the alternating current flowing in the coil winding 11. The vibratory motion of the output coil 12 in the field of the magnet 16 induces an alternating electromotive force of corresponding frequency in the coil winding 12 which is effective at the output terminals 27. The lead wires from the coil winding 12 to the terminals 27 may be placed inside the drum 13 and brought out through the hole 28 as shown in Fig. 1. Due to the unavoidable mutual inductance between the two coils 11 and 12 there will be a small direct transfer of energy of frequencies other than f_1, if present, but due to the small number of turns required for these coils they act very inefficiently as a transformer, and therefore this by-passing of undesired frequencies may safely be ignored. Thus, the filter will pass freely currents of frequency f_1 but will greatly attenuate all frequencies slightly removed to one side or the other of this frequency. A possible attenuation characteristic of the filter shown in Fig. 1 is given by the curve of Fig. 5, in which frequency in cycles per second as abscissae is plotted against the attenuation in decibels as ordinates, with the frequency of resonance denoted by f_1. Attenuations as high as 45 decibels are obtainable with the filter shown in Fig. 1. If coils 11 and 12 each have the same number of turns of wire there will be no impedance transformation within the filter. If desired, however, an impedance transformation may be introduced by a proper choice of the turns ratio between the two coil windings.

A modification of the invention is shown in Fig. 2, in which a tuned reed 29, clamped at its base to an extension of the bracket 24, is coupled to the band 14 by the spring 30. The reed 29, as shown in detail in the perspective view of Fig. 3, has flanges 31 along the sides, with the exception of the narrowed portion 32, so that bending will be confined to this latter region. The motion of the reed is to and fro, in the same direction as that of the band 14. The end portion 33 of the reed 29 is clamped between the two blocks 34 and 35, as shown in Fig. 2. The block 34 is secured to the bracket 24 by the bolts 36, the reed 29 fitting into a recessed portion of the block 34 and being clamped in place by means of the block 35 and the two screws 37. One end of the spring 30 is clamped to the band 14 at the center by means of the block 38, which is held by the two screws 39. The other end of the spring 30 is clamped to the end of the reed 29, the end of the spring being held by the block 40 and the two screws 41.

The mechanical system shown in Fig. 2 is represented diagrammatically by Fig. 4, in which m_1 is the effective mass of the band 14 and associated coils at the point of drive, c_1 is the compliance of the band 14, m_2 is the effective mass of the reed 29 at its point of drive, c_2 is the compliance of the spring 30 and c_3 is the compliance of the reed 29. The arrow F indicates the point of application of the driving force. In such a system there will, in general, be two frequencies of resonance or low impedance f_1 and f_3, and an intermediate frequency of anti-resonance or high impedance f_2. An attenuation characteristic obtainable with the filter of Fig. 2 is shown in Fig. 6, where it is seen that the resonant frequencies f_1 and f_3 correspond with pass-bands, and the anti-resonant frequency f_2 coincides with a peak of attenuation. The critical frequencies f_1, f_2 and f_3 may be placed as desired provided the three compliances c_1, c_2 and c_3 are proportioned according to the following equations:

$$c_1=\frac{c_2}{4\pi^2 f_1^2 m_1 c_2-1} \qquad (2)$$

$$c_2=\frac{1}{4\pi^2\sqrt{(f_1^2-f_2^2)(f_3^2-f_1^2)m_1 m_2}} \qquad (3)$$

$$c_3=\frac{c_2}{4\pi^2(f_2^2+f_3^2-f_1^2)m_2 c_2-1}. \qquad (4)$$

It will be noted that the masses m_1 and m_2 are not uniquely determined in the above three equations. The values of m_1 and m_2 may be assigned arbitrarily, or they may be so chosen that the filter will present a desired impedance at some specified frequency. If a sharp resonance curve is desired, that is, a steeply rising attenuation characteristic, then the ratio of m_1 to c_1 should be made large; if, on the other hand, greater maximum losses are desired, and a wider transmission band is permissible, then the ratio of m_1 to c_1 should be small.

The filter illustrated in Fig. 2 is particularly adapted for use in transmitting one or two single frequencies, or narrow bands, while effectively excluding a third frequency. For example, two frequencies f_A and f_B, both present on a transmission line, may be separated by means of a pair of such filters connected in parallel across the line. In the filter which is to pass the frequency f_A the first resonance f_1 may be placed at the frequency f_A, and the peak of attenuation at f_2 may be chosen to coincide with the frequency f_B. In the other filter, which is to transmit the frequency f_B, the resonance f_3 is set at the frequency f_B while the anti-resonance f_2 is placed at the frequency f_A. The first filter will then pass freely the frequency f_A but will exclude effectively the frequency f_B, and the second filter will pass f_B while stopping f_A.

It is readily apparent that a filter having any desired number of pass-bands, with the attendant intermediate peaks of attenuation, may be obtained simply by providing the requisite number of additional reeds and connecting springs. In general, each addition of a reed and spring adds another transmission band and another attenuation peak.

What is claimed is:

1. In a wave filter, means for converting electrical energy into mechanical energy and for reconverting the mechanical energy into electrical energy, comprising a magnetic circuit having an air gap, a non-dissipative vibratory member resonant to the frequency of the signal energy to be passed, an input coil and an output coil carried by said vibratory member and constrained to vibrate in said air gap, whereby a narrow band of frequencies corresponding to the resonant frequency of said vibratory member is freely transmitted while frequencies lying outside of said band are highly attenuated.

2. Apparatus for the selective transmission of vibratory energy comprising a vibratory member sharply tuned to be resonant to the same frequency as that of a periodic signal current to be transmitted, a magnetic circuit providing an air gap, an input coil constrained to vibrate in said air gap for actuating said member under the control of said signal current, and an output coil, also constrained to vibrate in said air gap under the control of said member for producing a vibratory current of the same frequency of said signal current, whereby the frequency corresponding to the resonant frequency of said vibratory member is freely transmitted, while frequencies lying to either side of said frequency are highly attenuated by said apparatus.

3. A wave filter comprising a vibratory member having a natural frequency of vibration, means for producing a magnetic field, an input coil and an output coil, said coils being mounted on said vibratory member, and said coils being constrained to vibrate in said magnetic field, whereby a current having a frequency corresponding to the natural frequency of said vibratory member, when impressed upon said input coil, will induce in said output coil a current of corresponding frequency, whereas currents of other frequencies, when impressed upon said input coil, will be effectively blocked by said wave filter.

4. A wave filter comprising a plurality of vibratory members coupled by means of springs, said connected system of vibratory members having a plurality of natural frequencies of vibration, means for producing a magnetic field, and an input coil and an output coil mounted on one of said vibratory members, said coils being constrained to vibrate in said magnetic field, whereby the said filter will freely transmit currents corresponding in frequency to the natural frequencies of said system of vibratory members but will greatly attenuate currents having frequencies slightly removed from said natural frequencies.

5. A frequency selector comprising a non-dissipative vibratory member resonant to the same frequency as that of a periodic signal current, means for producing a magnetic field, an input coil and an output coil, said coils being associated with said vibratory member and moving therewith, and said coils being constrained to vibrate in said magnetic field, whereby the said signal current is freely transmitted from said input coils to said output coil but other frequencies are effectively excluded by said selector.

6. A wave filter comprising a vibratory member resonant to the same frequency as that of a periodic signal current and anti-resonant to an undesired frequency present with said signal current, means for producing a magnetic field, an input coil and an output coil, said coils being associated with said vibratory member and moving therewith, and said coils being constrained to vibrate in said magnetic field, whereby said filter is adapted to pass freely said signal current from said input coil to said output coil while substantially stopping the current of said undesired frequency.

7. A wave filter comprising a vibratory member sharply resonant to the same frequency as that of a periodic signal current to be transmitted, means for adjusting the resonant frequency of said member, means for producing a magnetic field, an input coil and an output coil, said coils being physically associated with said member and being adapted to vibrate at the same frequency as said member, and said coils being constrained to vibrate in said magnetic field, whereby said signal current is passed by said filter with comparatively small loss but currents of frequencies lying slightly to either side of the frequency of said signal current are greatly attenuated by said filter.

8. A wave filter comprising a magnetic circuit having an air gap, a band the resonant frequency of which may be sharply tuned, a coil form mounted on said band and extending into said air gap, an input coil and an output coil both carried by said coil form, whereby a current having a frequency corresponding to the resonant frequency of said band will be freely transmitted from said input coil to said output coil, whereas currents of other frequencies will be effectively blocked by said filter.

9. A wave filter comprising a magnetic circuit providing an air gap, a band having an adjustable tension, a coil form mounted on said band and extending into said air gap, two windings carried by said coil form, and a tuned reed mechanically coupled to said band by means of a spring.

10. A wave filter comprising means for producing a magnetic field, a vibratory member having a natural frequency of vibration, an input and an output coil both mounted on said member and constrained to vibrate in said magnetic field, and a second vibratory member mechanically coupled to said first member by means of a spring.

11. A wave filter comprising means for producing a magnetic field, a vibratory member having a natural frequency of vibration, means for adjusting the frequency of vibration of said member, an input coil and an output coil both mounted on said member and constrained to vibrate in said magnetic field, and a second vibratory member mechanically coupled to said first member by means of a spring.

HERBERT W. AUGUSTADT.