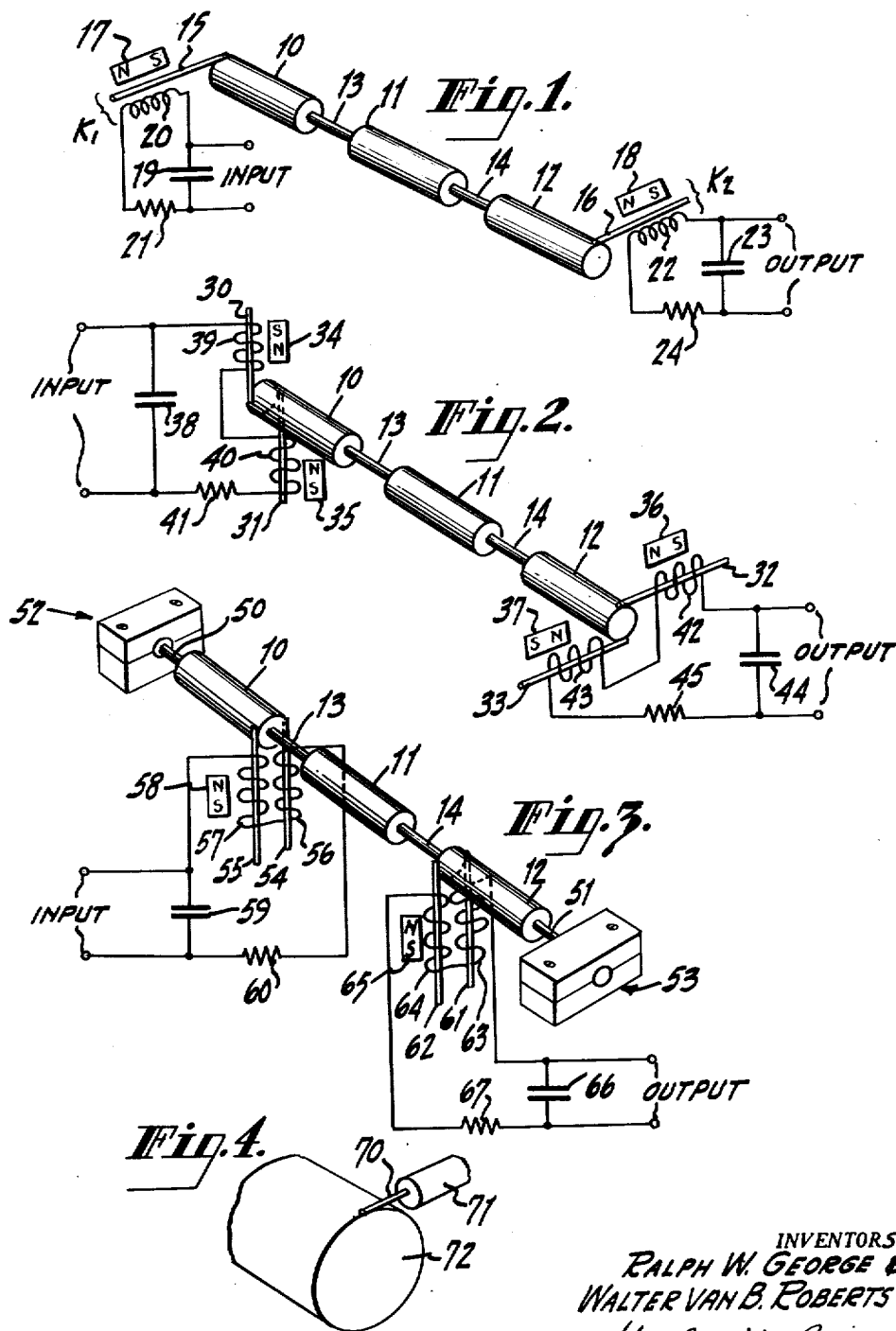


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ELECTROMECHANICAL FILTER

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ELECTROMECHANICAL FILTER

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The invention relates to electromechanical filters and particularly to electromechanical filters operating in a torsional mode.

One type of torsional electromechanical filter uses magnetostrictive end resonators as a means for coupling the filter to electrical circuits. When the radio frequency (R. F.) coils are wound around cylindrical magnetostrictive resonators, a circular magnetic bias is required to operate the resonators in a torsional mode. One way of obtaining this magnetic bias is to use a permanent or residual circular magnetic field that is induced by passing a fairly heavy current axially through the resonators. However, the coercive force in currently used magnetostrictive materials is weak, with the result that the demagnetizing effect of the R. F. input field permanently reduces the magnetic bias when the R. F. input field exceeds a certain critical value. Further, optimum bias cannot always be obtained with residual circular magnetic bias. Thus, operating limitations are imposed which are not acceptable in many cases.

Accordingly, it is an object of the invention to provide a torsional electromechanical filter that does not have the limitations imposed by torsional filters which utilize magnetostrictive end resonators and a circular magnetic bias.

Another object of the invention is to provide an improved torsional electromechanical filter.

The invention provides an electromechanical filter having a plurality of interconnected resonators designed to operate in a torsional mode. Magnetostrictive transducers designed to operate in a longitudinal mode are tangentially fastened on the end resonators, so that longitudinal vibrations of the transducers are converted to torsional vibrations of the resonators, and vice versa. Magnetic bias for the transducers is provided by small external permanent magnets, and radio frequency energy is applied to and derived from coils wound around the transducers. The input and output transducers are respectively positioned in spaced planes that form angles of substantially 90 degrees with the longitudinal axis of the filter. The respective transducers may be positioned in parallel relation, or they may be in some relation other than parallel. Since the magnetic bias provided by an external magnet is not affected by excessive radio frequency energy applied to the coils, the limitations imposed by transducers that operate in the torsional mode and that use residual circular magnetic bias are eliminated.

The invention is explained in detail in the following specification with reference to the accompanying drawing, in which like reference numerals in the figures refer to the same parts. In the drawing:

Figure 1 illustrates a torsional electromechanical filter

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having longitudinal transducers and associated circuitry constructed in accordance with the invention;

Figures 2 and 3 show other embodiments of torsional electromechanical filters constructed in accordance with the invention; and

Figure 4 shows a practical method of fastening ferrite transducers on the resonators.

Referring first to Figure 1, the basic elements of a torsional electromechanical filter are shown. Such a filter comprises a plurality of cylindrical resonators 10, 11, 12 coupled together or interconnected along their longitudinal axes by coupling necks 13, 14. Although the drawing shows only electromechanical filters having resonators that are interconnected by coupling necks, the invention is equally applicable to filters having resonators that are interconnected by coupling slugs, that is, coupling elements whose diameter is greater than the diameter of the resonators. Rod-shaped magnetostrictive transducers 15, 16 are tangentially fastened on the circumferential surfaces of the end resonators 10, 12 respectively. The transducers 15, 16 operate in the longitudinal mode and have substantially the same resonant frequency as the resonators 10, 11, 12 which operate in the torsional mode. These transducers 15, 16 are each substantially a half-wave long or some multiple of a half-wave long at the mid-band frequency of the filter. The ends of the transducers 15, 16 are maximum motion points, and it is preferred that they be fastened to maximum motion points of the end resonators 10, 12 respectively. When operating in the torsional mode, the resonators 10, 11, 12 are each a half-wave long or some multiple of a half-wave long at the mid-band frequency of the filter, and have maximum motion at their ends, which rotate in opposite directions. The coupling necks 13, 14 are a quarter-wave long at the mid-band frequency of the filter.

Magnetic bias for the transducers 15, 16 is provided by permanent magnets 17, 18 respectively. The use of such external bias magnets provides a permanent bias which is not reduced by excessive signal input. While shown beside the transducers, these magnets may be moved closer or farther from the transducer, rotated, or placed at the free end of the transducer, to give any desired magnetic bias in the transducer. The R. F. input signal is applied to one transducer 15 through a tuned circuit comprising a capacitor 19 connected in parallel with a coil 20. A damping resistor 21 may also be added to the input circuit if desired. The coil 20 is wound and positioned to give the desired electromechanical coefficient of coupling K_1 between the coil 20 and the transducer 15. When an input signal is applied to the input circuit, a longitudinal vibration is set up in the input transducer 15, and this vibration causes a torsional vibration in the resonators 10, 11, 12. The torsional vibration in the end resonator 12 causes a longitudinal vibration in the output transducer 16. An output coil 22, wound and positioned to give the desired electromechanical coefficient of coupling K_2 between the coil 22 and the output transducer 16, is connected in parallel with a capacitor 23 to form an output tuned circuit. A damping resistor 24 may also be connected in the circuit if desired. The output is derived across the terminals of the capacitor 23.

As shown in Figure 1, the input and output transducers 15, 16 are positioned in a single plane that is tangential to the end resonators 10, 12. The transducers 15, 16 extend in parallel but opposite directions from their points of fastening on the end resonators 10, 12

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respectively. From the standpoint of convenience and efficient use of space, it may be desirable that the transducers be positioned in a single tangential plane but extend in the same parallel direction from their points of fastening. In either case, the maximum conversion of longitudinal to torsional vibrations occurs when the transducers 15, 16 lie in planes that form an angle of substantially ninety degrees with the longitudinal axis of the filter. When a single transducer is employed to drive a torsion resonator, as shown in Figure 1, the unbalanced driving force applied to the resonator may set up undesired bending modes of vibration in addition to the desired torsional vibration. To reduce the transmission in such undesired modes, the transducers may be tangentially fastened at circumferential points on their respective resonator radii, one of which lies in a plane that forms an angle of substantially ninety degrees with respect to the other radius. In this way, a minimum of such spurious vibrations caused by one transducer would be set up in the other transducer. Such spurious vibrations may also be reduced to some extent by a lossy mechanical terminating line and by the use of rigid or damping supports, including mounting means, placed at points of minimum motion of the filter. These vibrations may also be reduced by using resonators having different dimensional proportions with appropriate changes in the dimensions of the coupling means between the resonators. And, these vibrations may be reduced by using a combination of two or more of the above mentioned ways of reducing such vibrations.

Another embodiment of a torsional electromechanical filter having longitudinal transducers is shown in Figure 2. Instead of one magnetostrictive transducer being fastened to each of the end resonators 10, 12 as shown in Figure 1, two transducers 30, 31 are tangentially fastened at diametrically opposite points on the circumference of one end resonator 10 to extend in parallel and opposite directions, and two transducers 32, 33 are tangentially fastened at diametrically opposite points on the circumference of the other end resonator 12 to extend in parallel and opposite directions. It is preferred that the transducers be fastened on each of the end resonators at diametrically opposite points on the resonators so that the transducers balance each other. And although the transducers 30, 31 on one end resonator 10 and the transducers 32, 33 on the other end resonator 12 are tangentially fastened at circumferential points on their respective resonator diameters, one of which lies in a plane that forms an angle of substantially ninety degrees with respect to the other diameter, they may be tangentially fastened at circumferential points on diameters that are parallel. In either embodiment, all the transducers should lie in planes that form an angle of substantially ninety degrees with the longitudinal axis of the filter.

Magnetic bias for the transducers 30, 31, 32, 33 is provided by four permanent magnets 34, 35, 36, 37. The R. F. input signal is applied to the input transducers 30, 31 through an input tuned circuit comprising a capacitor 38 connected in parallel with two serially connected coils 39, 40 coupled to the two input transducers 30, 31 respectively. A damping resistor 41 may be connected into the circuit. The coils 39, 40 are wound and positioned with respect to the input transducers 30, 31 to give the desired electromechanical coefficient of coupling between each coil and its respective transducer. The input coils 39, 40 and the associated bias magnets 34, 35 have polarities so related to each other that the ends of the transducers 30, 31 fastened to the resonator 10 move in opposite directions, thus producing a couple on the input end resonator 10. This couple produces a torsional vibration in the resonators 10, 11, 12, which in turn produces longitudinal vibrations in the output transducers 32, 33. Two serially connected output coils 42, 43 are wound and positioned with respect to the output

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transducers 32, 33 to give the desired electromechanical coefficient of coupling between each coil and its respective transducer. The output coils 42, 43 and the associated bias magnets 36, 37 have polarities so related to each other that the longitudinal vibrations of the output transducers 32, 33 induce voltages of adding polarities in the output coils 42, 43. A capacitor 44 is connected in parallel with the coils 42, 43 to form a tuned circuit from which the output is derived. A damping resistor 45 may be serially connected into the circuit as shown.

While the filter shown in Figure 2 operates satisfactorily, it may be inconvenient to assemble because the transducers at respective ends of the filter extend in opposite directions. This inconvenience is eliminated by the embodiment shown in Figure 3. In Figure 3, a torsional electromechanical filter is shown mounted by quarter-wave long necks 50, 51 which are fastened in some manner as by the supports 52, 53. The input transducers 54, 55 are tangentially fastened at diametrically opposite points on the circumference of the interior end of one end resonator 10. The input transducers 54, 55 are positioned so that they are parallel with each other and so that they extend in the same direction from their points of fastening. For this reason, only one bias magnet 58 is needed for the input transducers. Further, by placing the transducers on the interior ends of the end resonators, final tuning checks are easily made by placing test coils over the end resonators. In some cases, this may be more convenient than utilizing the longitudinal transducers to make the final tuning check. The R. F. input signal is applied to the input transducers 54, 55 through a tuned circuit comprising a capacitor 59 connected in parallel with two serially connected coils 56, 57 coupled to the two input transducers 54, 55 respectively. A damping resistor 60 may be connected into the circuit as shown. The coils 56, 57 are wound and positioned with respect to the input transducers 54, 55 to give the desired electromechanical coefficient of coupling between each coil and its respective transducer. The input coils 56, 57 and the associated bias magnet 58 have polarities so related to each other that the ends of the transducers 54, 55 fastened to the resonator 10 move in opposite directions, thus producing a couple on the input end resonator 10. This couple produces a torsional vibration in the resonators 10, 11, 12 which in turn produces longitudinal vibrations in the output transducers 61, 62.

The output transducers 61, 62 are tangentially fastened at diametrically opposite points on the circumference of the interior end of the other end resonator 12. The output transducers 61, 62 are positioned so that they are parallel with each other and with the input transducers 54, 55, and so that they extend in the same direction from their points of fastening as do the input transducers 54, 55. Two serially connected output coils 63, 64 are wound and positioned with respect to the output transducers 61, 62 to give the desired electromechanical coefficient of coupling between each coil and its respective transducer. The output coils 63, 64 and the associated bias magnet 65 have polarities so related to each other that the longitudinal vibrations of the output transducers 61, 62 induce voltages of adding polarities in the output coils 63, 64. A capacitor 66 is connected in parallel with the coils 63, 64 to form a tuned circuit from which the output is derived. A damping resistor 67 may be serially connected in the circuit as shown. As in the input circuit, only one bias magnet 65 is needed.

While the input transducers 54, 55 and the output transducers 61, 62 may be tangentially fastened at circumferential points on their respective resonator diameters, one of which lies in a plane that forms an angle of substantially ninety degrees with respect to the other diameter, the filter arrangement shown in Figure 3 is preferable from the standpoint of convenience and ease of assembly. Once the input coils 56, 57 and output coils

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63, 64 have been wound and assembled, the resonators with the transducers previously attached are easily placed in position. The arrangement shown in Figure 3 also reduces the stray R. F. field and improves the electromechanical coefficient of coupling between the transducers and the associated coils. In the embodiments shown or mentioned in connection with Figure 3, all the transducers should lie in planes that form an angle of substantially ninety degrees with the longitudinal axis of the filter.

Figure 4 shows a practical method of fastening rod-shaped ferrite transducers on the resonators to give some flexibility between the transducers and the resonators. Ferrite transducers are easily broken in handling, especially when rigidly cemented or soldered to the resonator. To eliminate this difficulty, a short piece of small diameter wire 70 is soldered or cemented to one end of the transducer 71. The dimensions of the transducer 71 with the attached wire 70 are adjusted so that the assembled unit is mechanically resonant at the desired frequency. The free end of the wire 70 is then spot-welded to the resonator 72. The solder and wire have little effect on the behavior of ferrite transducers because they are located near a point of high motion or very low stress in the transducer. Small changes in the resonant frequency of the resonator resulting from attaching the assembled transducer 71 and wire 70 may occur. These changes may be compensated for by re-tuning either the resonator 72 or the transducer 71.

When a mechanical filter is constructed, the end resonators have a certain value of mechanical Q or damping which is required for the resonator to terminate the filter. Mechanical damping can be obtained, for example, by the use of a long mechanically lossy line of the proper motional impedance which imparts the required damping to the end resonator.

Part or all of the required damping can also be obtained from electrical circuits, such as the input and output circuits shown in Figure 1, to which there is suitable electromechanical coupling, K₁ and K₂ in Figure 1. Such circuits are preferably tuned and relatively broad-band. Such an electrical circuit from which all of the required mechanical damping is obtained is usually desirable. It results in negligible electrical insertion loss because the mechanical losses in the filter are usually insignificant. When damping obtained only and directly from mechanical means is used, the transducers must have relatively small electromechanical coupling so as to introduce negligible damping from electrical circuits, with the result that the electrical insertion loss is quite appreciable. Damping obtained from a combination of both electrical and mechanical means can be used to obtain reasonable values of insertion loss, and a means of adjusting the final terminations of the filter electrically.

Broad-band electrical terminations require that the electromechanical coefficient of coupling be large compared with the fractional bandwidth of the filter. The electromechanical coefficient of coupling obtainable with Ni-Span-C at radio frequencies is very small because of its high eddy current losses, so that electrical termination is possible only with very narrow band filters. Eddy current losses may be reduced by using transducers of thin wall-tubing or very thin wire.

Relatively large electromechanical coupling coefficients in the order of 10% to 20% can be realized by the use of magnetostrictive ferrites which have negligible eddy current losses. It is also possible to reduce the effects of mis-tuning and frequency-temperature characteristics of the transducer by keeping the physical size of the transducers small in comparison with the resonators. Even though the transducers are made relatively small as shown in the drawing, it is possible to obtain broad-band electrical terminations for filters having a fractional bandwidth as high as 3% or more.

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An example of a filter having nine neck-coupled resonators constructed as shown in Figures 3 and 4 follows:

Mechanical filters:

Material	Ni-Span-C, one piece.
Resonators	0.240" diameter, 0.558" length.
Coupling necks (end)	Tuned to 101.540 kc. 0.103" diameter, 0.279" length.
Coupling necks (interior)	0.095" diameter, 0.279" length.

Transducers:

Material	Nickel ferrite.
Diameter	0.036".
Length	31/32".
Length with attaching wire	1 1/8".

Attaching wire:

Material	Nickel or Ni-Span-C.
Diameter	0.015".
Length	3/32".

Coils:

Inside diameter	0.1".
Winding length	1/2".
Turns No. 36 enamel	850 each.

Approximate tuning capacity for 2 coils----- 1200 mmfd.

A filter with the above characteristics has a bandwidth of about 3% with a mid-band frequency of 101.540 kc. The termination is adjusted by tuning the electrical circuits, moving the bias magnets, and adding resistance damping to the electrical circuits. Proper termination will give as little as one-half db variation of response in the passband and an output voltage that is about 90% of the input voltage in the passband.

The invention claimed is:

1. An electromechanical filter, comprising an elongated resonator having a substantially uniform cross-section throughout, having a curved outer surface and being adapted to operate in the torsional mode, and a rod-like magnetostrictive transducer adapted to operate in the longitudinal mode fastened to said curved surface of said resonator along a line forming a tangent with said surface, said transducer being positioned so that it lies in a plane which forms an angle of substantially ninety degrees with the longitudinal axis of said resonator.

2. An electromechanical filter, comprising at least one substantially cylindrical resonator of substantially uniform cross-section throughout and being adapted to operate in the torsional mode, and a rod-shaped magnetostrictive transducer adapted to operate in the longitudinal mode fastened to and effectively terminating at a point on the circumferential surface of said resonator along a line forming a tangent with said surface, said transducer being positioned so that it lies in a plane that forms an angle of substantially ninety degrees with the longitudinal axis of said resonator.

3. An electromechanical filter, comprising at least one cylindrical resonator adapted to operate in the torsional mode, a first rod-shaped magnetostrictive transducer adapted to operate in the longitudinal mode tangentially fastened to said filter near one end thereof for converting longitudinal motion of said transducer to torsional motion of said filter, and a second rod-shaped magnetostrictive transducer adapted to operate in the longitudinal mode tangentially fastened to said filter near the other end thereof for converting torsional motion of said filter to longitudinal motion of said second transducer, said transducers being positioned so that they lie in planes that form an angle of substantially ninety degrees with the longitudinal axis of said resonator.

4. An electromechanical filter, comprising a plurality of cylindrical resonators interconnected along a longi-

an angle of substantially ninety degrees with said longitudinal axis, said first and second diametrically opposite points lying on respective diameters that are substantially parallel with each other.

11. An electromechanical filter, comprising a plurality of cylindrical resonators interconnected along a longitudinal axis and adapted to operate in the torsional mode, a first pair of rod-shaped magnetostrictive transducers adapted to operate in the longitudinal mode tangentially fastened at diametrically opposite points on the circumferential surface near one end of one end resonator for converting longitudinal motion of said transducers to torsional motion of said resonators, said transducers being positioned so that they extend in the same and substantially parallel directions from their points of fastening and so that they lie in a plane that forms an angle of substantially ninety degrees with said longitudinal axis, and a second pair of rod-shaped magnetostrictive transducers adapted to operate in the longitudinal mode tangentially fastened at diametrically opposite points on the circumferential surface near one end of the other end resonator for converting torsional motion of said resonators to longitudinal motion of said second pair of transducers, said second pair of transducers being positioned so that they extend in the same and substantially parallel directions from their points of fastening as said first pair of transducers.

12. An electromechanical filter, comprising a plurality of cylindrical resonators interconnected along a longitudinal axis and adapted to vibrate in the torsional mode, a first pair of rod-shaped magnetostrictive transducers adapted to vibrate in the longitudinal mode tangentially fastened at diametrically opposite points on the circumferential surface near one end of one end resonator for converting longitudinal vibrations of said transducers to torsional vibrations of said resonators, said transducers being positioned so that they extend in the same and substantially parallel directions from their points of fastening and so that they lie in a plane that forms an angle of substantially ninety degrees with said longitudinal axis, first means coupled to said first pair of transducers for exciting said longitudinal vibrations therein, a second pair of rod-shaped magnetostrictive transducers adapted to vibrate in the longitudinal mode tangentially fastened at diametrically opposite points on the circumferential surface near one end of the other end resonator for converting torsional vibrations of said resonators to longitudinal vibrations of said second pair of transducers, said second pair of transducers being positioned so that they extend in the same and substantially parallel directions from their points of fastening as said first pair of transducers, and second means coupled to said second pair of transducers for detecting said longitudinal vibrations therein.

13. An electromechanical filter, comprising a plurality of cylindrical resonators interconnected along a longitudinal axis and adapted to operate in the torsional mode, a first pair of rod-shaped magnetostrictive transducers each having a short, small diameter attaching wire fastened to one end thereof tangentially fastened by their respective attaching wires at diametrically opposite points on the circumferential surface near one end of one end resonator for converting longitudinal motion of said transducers to torsional motion of said resonators, said transducers being adapted to operate in the longitudinal mode and being positioned so that they extend in the same and substantially parallel directions from their points of fastening and so that they lie in a plane that forms an angle of substantially ninety degrees with said longitudinal axis, and a second pair of rod-shaped magnetostrictive transducers each having a short, small diameter attaching wire fastened to one end thereof tangentially fastened by their respective attaching wires at diametrically opposite points on the circumferential surface near one end of the other end resonator for con-

verting torsional motion of said resonators to longitudinal motion of said second pair of transducers, said second pair of transducers adapted to operate in the longitudinal mode and being positioned so that they extend in the same and substantially parallel directions from their points of fastening as said first pair of transducers.

14. An electromechanical filter, comprising a plurality of cylindrical resonators interconnected along a longitudinal axis and adapted to vibrate in the torsional mode, a first pair of rod-shaped magnetostrictive transducers adapted to vibrate in the longitudinal mode tangentially fastened at diametrically opposite points on the circumferential surface near one end of one end resonator for converting longitudinal vibrations of said transducers to torsional vibrations of said resonators, said transducers being positioned so that they extend in the same and substantially parallel directions from their point of fastening and so that they lie in a plane that forms an angle of substantially ninety degrees with said longitudinal axis, a pair of serially connected input coils coupled to said first pair of transducers, a first capacitor connected in parallel with said pair of input coils, magnetic biasing means coupled to said first pair of transducers, means coupled to said first capacitor and said input coils for applying a varying electrical signal thereto and causing said first pair of transducers to vibrate in said longitudinal mode, a second pair of rod-shaped magnetostrictive transducers adapted to vibrate in the longitudinal mode tangentially fastened at diametrically opposite points on the circumferential surface near one end of the other end resonator for converting torsional vibrations of said resonators to longitudinal vibrations of said second pair of transducers, said second pair of transducers being positioned so that they extend in the same and substantially parallel directions from their points of fastening as said first pair of transducers, a pair of serially connected output coils coupled to said second pair of transducers, a second capacitor connected in parallel with said pair of output coils, magnetic biasing means coupled to said second pair of transducers, and means coupled to said second capacitor and said output coils for deriving an electrical signal therefrom.

15. An electromechanical filter comprising a plurality of cylindrical resonators interconnected along a longitudinal axis and adapted to vibrate in the torsional mode, a first rod-shaped magnetostrictive transducer adapted to vibrate in the longitudinal mode tangentially fastened on the circumferential surface on one radius of one of said resonators for converting longitudinal vibrations of said transducer to torsional vibrations of said resonators, and a second rod-shaped magnetostrictive transducer adapted to vibrate in the longitudinal mode tangentially fastened on the circumferential surface on a second radius of another of said resonators for converting torsional vibrations of said resonators to longitudinal vibrations of said second transducer, said second radius lying in a plane that forms an angle of substantially ninety degrees with respect to said first radius, and said first and second transducers being positioned so that they lie in planes that form an angle of substantially ninety degrees with said longitudinal axis.

16. An electromechanical filter comprising a plurality of cylindrical resonators interconnected along a longitudinal axis and adapted to vibrate in the torsional mode, a first pair of rod-shaped magnetostrictive transducers adapted to vibrate in the longitudinal mode tangentially fastened on the circumferential surface at opposite ends of one diameter of one end resonator for converting longitudinal motion of said transducers to torsional motion of said resonators, said transducers being positioned so that they extend in opposite and substantially parallel directions from their points of fastening and so that they lie in a plane that forms an angle of substantially ninety degrees with said longitudinal axis, and a second pair of rod-shaped magnetostrictive

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transducers adapted to vibrate in the longitudinal mode tangentially fastened on the circumferential surface at opposite ends of a second diameter of the other end resonator for converting torsional motion of said resonators to longitudinal motion of said second pair of transducers, said second pair of transducers being positioned so that they extend in opposite and substantially parallel directions from their points of fastening and so that they lie in a plane that forms an angle of substantially ninety degrees with said longitudinal axis, and said second diameter lying in a plane that forms an angle of substantially ninety degrees with respect to said first diameter.

17. An electromechanical filter comprising a plurality of cylindrical resonators interconnected along a longitudinal axis and adapted to vibrate in the torsional mode, a first pair of rod-shaped magnetostrictive transducers adapted to vibrate in the longitudinal mode tangentially fastened on the circumferential surface at opposite ends of one diameter of one end resonator for converting longitudinal motion of said transducers to torsional motion of said resonators, said transducers being positioned so that they extend in opposite and substantially parallel directions from their points of mounting and so that they lie in a plane that forms an angle of substantially ninety degrees with said longitudinal axis, and a second pair of rod-shaped magnetostrictive transducers adapted to vibrate in the longitudinal mode tangentially fastened on the circumferential surface at opposite ends of a second diameter of the other end resonator for converting torsional motion of said resonators to longitudinal motion of said second pair of transducers, said second pair of transducers being positioned so that they lie in a plane that forms an angle of substantially ninety degrees with said longitudinal axis and so that they extend in opposite and substantially parallel directions from their points of fastening as said first pair of transducers.

18. An electromechanical filter comprising a plurality of elongated resonators each having a curved outer surface and being adapted to vibrate in the torsional mode, means connecting said resonators end-to-end along a

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longitudinal axis, a first rod-shaped magnetostrictive transducer adapted to operate in the longitudinal mode fastened to said curved surface of one of said resonators along a line forming a tangent with said surface, said transducer being positioned so that it lies in a plane which forms an angle of substantially ninety degrees with said longitudinal axis, and a pair of rod-like magnetostrictive transducers adapted to operate in the longitudinal mode fastened to said curved surface of another of said resonators at opposite points on said curved surface along lines forming tangents with said surface, said pair of transducers being positioned so that they lie in a plane which forms an angle at substantially ninety degrees with said longitudinal axis.

19. An electromechanical filter comprising a plurality of torsional resonators coupled end-to-end in a straight line by one or more torsional coupling elements, said resonators and said elements being symmetrically positioned about a common longitudinal axis, and an electromechanical resonant transducer adapted to operate in the longitudinal mode fastened to a point on one of said resonators along a line forming a tangent with the surface of said one resonator for converting longitudinal motion of said transducer to torsional motion of said resonators or for converting torsional motion of said resonators to longitudinal motion of said transducer, said transducer being positioned so that it lies in a plane which forms an angle of substantially ninety degrees with said longitudinal axis.

References Cited in the file of this patent

UNITED STATES PATENTS

1,689,339	Harrison	Oct. 30, 1928
1,852,795	Wegel	Apr. 5, 1932
1,933,306	Berry et al.	Oct. 31, 1933
2,318,417	Phelps	May 4, 1943
2,495,740	Labin et al.	Jan. 31, 1950
2,656,516	Doelz	Oct. 20, 1953
2,667,621	Burns et al.	Jan. 26, 1954