

June 2, 1970

A. SEMMELINK

3,515,965

LOW FREQUENCY MAGNETOSTRICTIVE FLEXURAL TRANSDUCER

Filed June 30, 1969

3 Sheets-Sheet 1

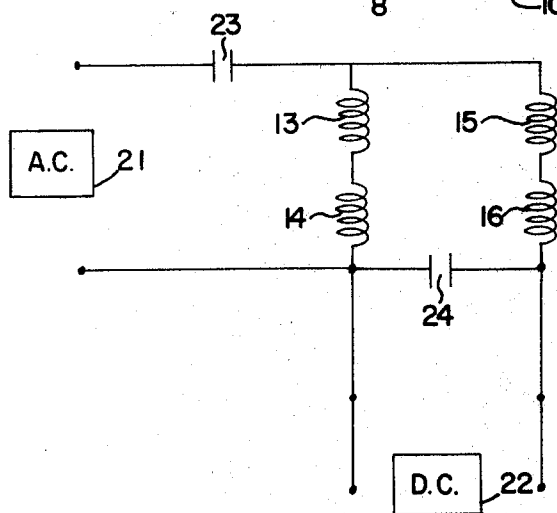
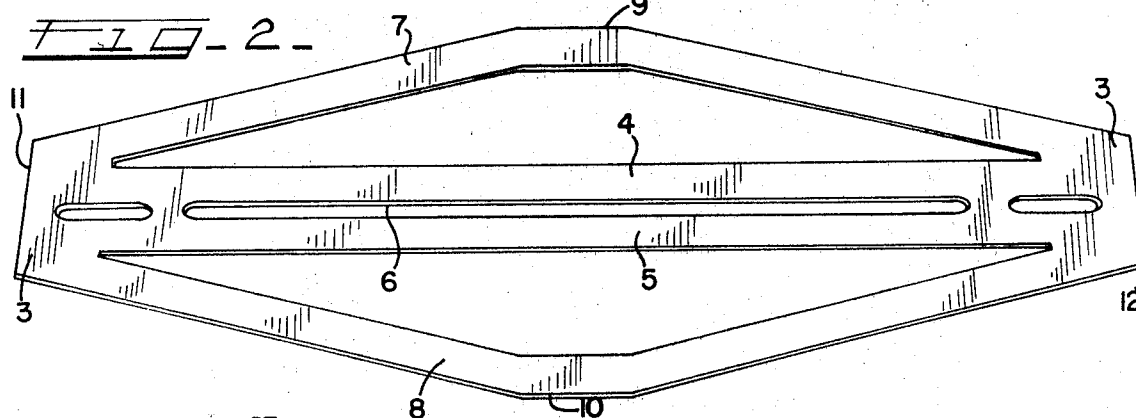
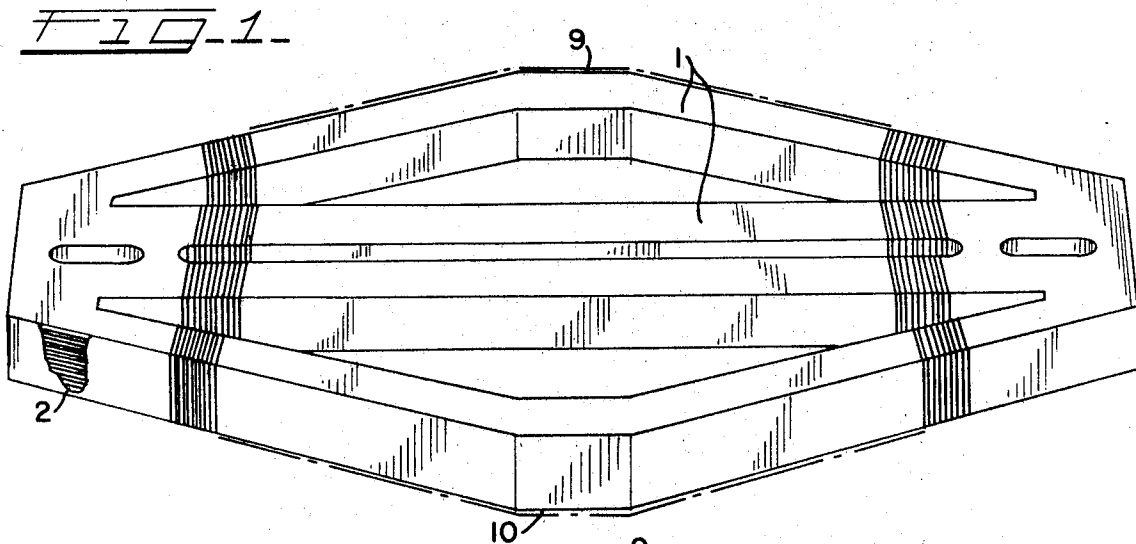


FIG-4-

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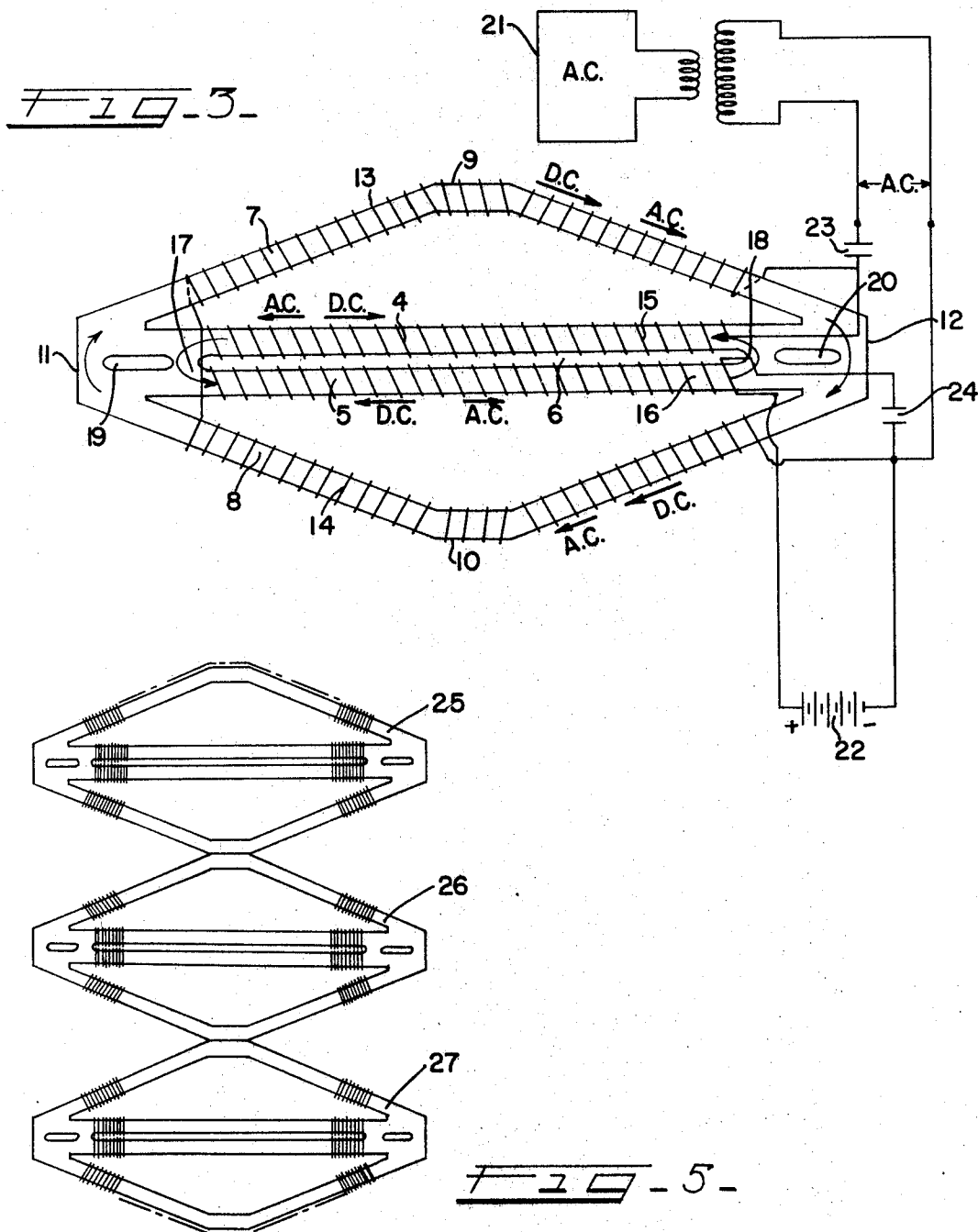
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3 Sheets-Sheet 2



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3 Sheets-Sheet 3

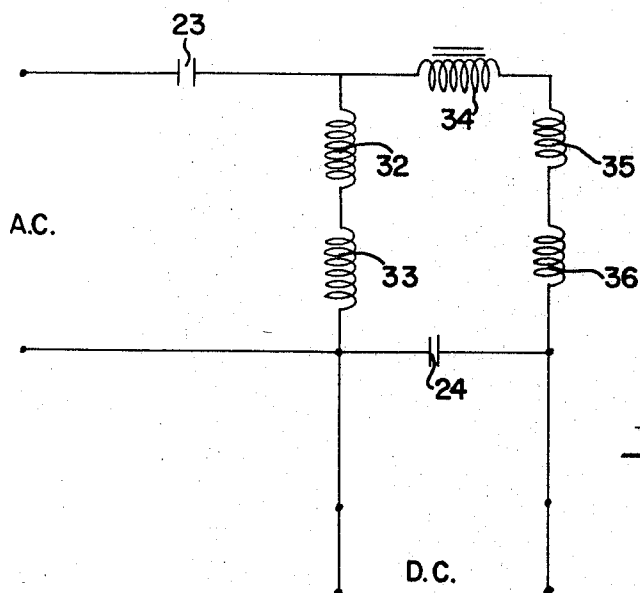
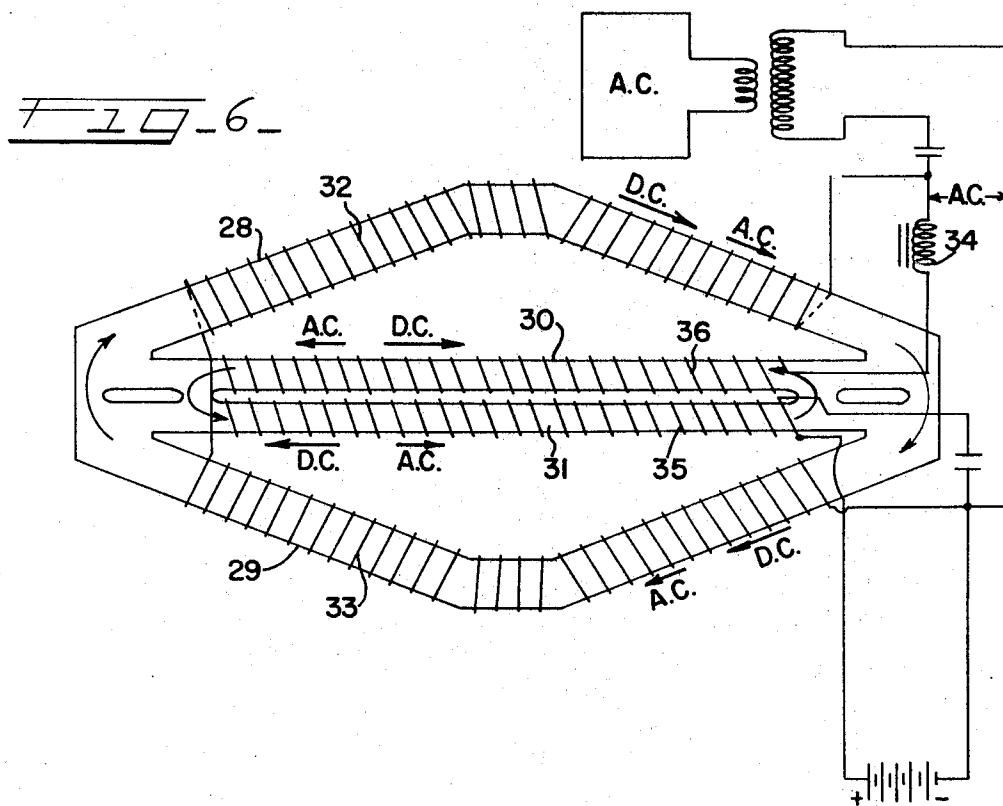


FIG - 7 -

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LOW FREQUENCY MAGNETOSTRICTIVE FLEXURAL TRANSDUCER

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10 Claims

ABSTRACT OF THE DISCLOSURE

The transducer consists of a stack of laminations of magnetostrictive material having the shape of a parallelogram with a center leg, which may be slotted, along the major axis. The major axis of the parallelogram is considerably longer than the minor axis. The four sides or outer legs of the transducer as well as its center bar are each provided with a winding of several turns. The direction of the currents in the windings is so arranged that when the outer leg expands, the center leg contracts and vice versa. The resulting motion is a large flexural vibration of the sides coupled with a small longitudinal vibration of the center leg.

My invention relates to a magnetostrictive transducer wherein electrical currents are converted into mechanical displacement.

A main object of my invention is to convert electric power into vibrations in an audible and ultrasonic range.

It is another object of my invention to generate a more efficient conversion of electric power into vibrations.

It is an object of my invention to achieve a transducer having a high power capacity.

It is another object of my invention to radiate sonic energy and ultrasonic energy with a transducer circuit appropriate to the resonant frequency of the transducer frame.

It is a final object of my invention to provide geometry to multiply motion and amplify the natural vibration of the transducer.

Other objects and advantages of this invention are readily appreciated by reference to the following detailed description in conjunction with the accompanying drawings wherein:

FIG. 1 is a perspective view of a stack of flat elements of the magnetostrictive transducer in accordance with this invention and showing a portion of the coils.

FIG. 2 is a perspective view of a single element of the stack of laminated elements shown in FIG. 1.

FIG. 3 is a schematic illustration of my invention showing the magnetostrictive transducer with electrical connections to alternating and direct current sources.

FIG. 4 is a schematic diagram showing the connections of the coils to each other and to the AC and DC generators.

FIG. 5 shows an amplitude multiplying device where a number of my devices are stacked along the minor axis to multiply the effect.

FIG. 6 is a schematic illustration of a modified form of my magnetostrictive transducer in which the legs are thickened.

FIG. 7 is a schematic diagram of the electrical circuit of the modified form of FIG. 6.

In brief, my invention combines the idea of utilizing the geometry of a rhombus as the frame of a transducer whereby a small amplitude of motion at the major axis delivers greater amplitude of motion across the minor axis. This is done by using a single material in the transducer frame and magnetostrictive effects are produced by using

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opposite sides of appropriate bias currents to develop magnetic fields in electric coils. My device proposes to use a flexural magnetostrictive transducer which is composed of a single magnetostrictive material, such as nickel or permendur.

Nickel and valadium permendur have magnetostrictive coefficients of opposite sign. Magnetization will tend to shorten the length of a nickel bar, while it will lengthen a permendur bar. Thus, the displacement effect of each of these materials is oppositely directed for a given current situation.

The illustration of FIG. 1 shows the magnetostrictive transducer with part of its windings around the core or frame 1 which extends laterally. This structure is built of laminae 2 to avoid excessive heating from eddy currents. A single one 3 of these laminae is shown in FIG. 2. Each lamina 3 is stamped from a sheet of magnetostrictive material and then stacked, one on the other, to form the structure shown in FIG. 1.

The laminations of the parallelogram or rhomboidal shape frame 1 of the transducer shown in FIG. 1 may be held together by clamping means at the ends of the structure or an epoxy resin may be used between the laminations to insulate and hold them together and may be used to coat the outer part of the transducer to make a shell, and thereby hold the laminations of the transducer together and provide a relatively smooth outer surface.

Each of the laminations shown in FIG. 2 is stamped from sheet material. The center bars 4, 5 formed along the major axis has a slot 6 down its center. The cross sectional area of each of the bars 4, 5 or legs 7, 8 is about the same. A flat section is at each end 9, 10 of the minor axis. The material of the laminations is of any of the magnetostrictive materials, such as iron-nickel, nickel, or permendur. Materials having no eddy currents, for example, ferrite may be used, but are in solid form rather than laminated to form the frame.

The electrical connections of the transducer are shown in FIG. 3, and because of the configuration of the bars 4, 5 and legs 7, 8, a small contraction of the major axis will create quite a large extension of the minor axis. This effect is amplified if at the same time that the major axis 11, 12 contracts, the legs or bars extending between the apices of the minor axes 9, 10 expand. This effect is produced by the coils 13, 14, 15, 16 and control elements shown in FIG. 3.

The electrically conductive windings are connected in such a way that the DC component in each of the coils is in the same direction in adjacent coils, such as 13 and 15. Similarly, because of the manner in which the circuit is arranged, the direction of flow of the AC current is in opposite directions in adjacent coils. At a certain point in time, the instantaneous values of the DC and AC currents in the windings of each of the legs or bars is as shown. In this situation, the magnetostrictive effect is at a maximum in the horizontal bars 4, 5, and a minimum in the angled legs 7, 8. Depending on the material, this lengthens the horizontal bars 4, 5 and shortens the angled legs 7, 8, thus shortening the minor axis 9, 10. Similarly, at the other phase of the cycle, the magnetostrictive effect is at a minimum in the horizontal bars 4, 5 and a maximum in the angled legs. In this way, the length of the legs 7, 8 encased within coil 13 and 14 is at their shortest when the bars 4, 5 encased within the coils 15 and 16 are at their maximum. This is apparent as shown in FIG. 3 because the AC current and DC current are in the opposite direction through the coils 15, 16 of bars 4 and 5 when the AC and DC current are in the same directions in the legs 7 and 8. Thus, the distance between the points 9 and 10 is minimized when the distance between elements 11 and 12 is maximized. Similarly, when the AC current is in the opposite direction, the AC and DC

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current is subtractive in the legs 7 and 8 at the point in time when the current of AC and DC in bars 4 and 5 is at a maximum because the AC current surges in phase with the DC current and thus is additive to the DC current in the coils 15, 16 surrounding the lateral bars 4, 5. At this stage, the distance of the major axis 11, 12 is maximized and the length along each of the legs 7, 8 and the distance of the minor axis 9, 10 is minimized. It is readily apparent that a greater displacement effect is created by arranging the circuit as described above. The purpose of the long slot 6 between the central bars is to provide a closed magnetic circuit through the bars. The magnetic field goes one direction in one bar 4 and the other direction in the other bar 5, and connecting pathways 17, 18 are provided at the ends of the long slot 6.

The two short slots 19, 20, which are not essential to the operation of the device, provide some isolation of the magnetic field of the center bars 4, 5 from the magnetic field generated in the side legs 7, 8. Since the magnetic induction of one of these fields is increasing when the magnetic induction of the other is decreasing, then some isolation provides mutual independence of the fields.

The simplified circuit diagram shown in FIG. 4 is drawn to show the circuit which is wound on the frame of FIG. 3. The same numbering is used in FIGS. 3 and 4 for identical parts. The objective of this circuit is to connect the windings in such a way that the direction of change of magnitude of the sum of the AC component plus the DC component of the inner windings 15, 16 is opposed to the direction of change of the magnitude of the sum of the same components in the windings 13, 14 of the outer legs 7, 8. The value of the capacitors and inductors depends on the frequency of the AC applied. The frequency of the AC component of the current should be the same as an integral multiple of the resonant frequency of the transducer frame. A pulsating current source may be used for some applications. For best operation, the frame acts in a similar manner to a tank circuit in high frequency electrical applications.

The preferred operating frequency of the transducer is the first flexural resonance frequency of the outer legs. A mounting (not shown) is provided at the ends of the major axis of the parallelogram to allow for the relatively small longitudinal vibration of the center leg. The flexural resonance of bars is proportional to the thickness of the bar in the plane of vibration and inversely proportional to the square of the length. Thus, such resonances may be varied considerably by a choice of the dimensions. Typical operating frequencies are 10 kHz. or lower. Another resonance frequency is that of the center leg, which may be considered as a mass loaded longitudinally vibrating bar. This resonance is inversely proportional to the length of the bar and to the effective mass of the load.

Most efficient operation can be expected when these frequencies, the flexural and the longitudinal, are the same. This may be achieved by the appropriate choice of the relative thickness of the inner and outer legs. Use of lower frequencies gives more efficient operation because there is lower eddy current and hysteresis loss at lower frequencies.

In any case, inner coils 15, 16 are wound in series and the outer coils 13, 14 are wound in series. Functionally, as to the AC supply 21, coils 13 and 14 are in parallel with coils 15, 16. As to the DC supply 22, all the coils are in series. The AC supply is decoupled from the DC supply by means of the capacitors 23 and 24. Capacitor 23 passes AC current and may be chosen of such value as to be useful for tuning purposes if one so desires. Since the coils are located around magnetostrictive elements along the length of the bar (FIG. 3), the multiplication factor is enhanced by the resonance effect and shape of the frame. Greater power is developed along the major axis. The smaller the spacing between the inner 4, 5 and outer 7, 8 bars, the greater is the multiplication factor. However, some spacing is necessary to avoid great strain

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upon the bars and legs with possible disruption of a bar.

The DC component is always greater than the AC component to avoid a reversal of current flow and a consequent frequency doubling. By having the DC component greater than the AC component, this possibility is avoided. In any case, the direction of flow of the DC current is in a certain direction, and the DC current does not go into the AC source because of capacitor 23.

A multiplication of effects can be obtained by stacking a number of transducers 25, 26, 27 along the minor axis (FIG. 5). In this arrangement, the transducer circuits are connected in parallel so that the effect is multiplied. A stack such as this can also be used for non-resonating impact or pulse operation to give a single short effect. In some instances, pulse operation may be preferred to continuous or damped oscillations. By stacking, an increased output may be obtained without a change in resonant frequency. If the same output were to be obtained from a single transducer, the dimensions of the transducer would have to be increased. The increase of transducer frame dimensions lowers the transducer frequency. In cases where high transducer frequency and greater output is desired, a stack is preferable to a single large transducer.

A modification of my invention is shown in FIG. 6. An advantage of this modified embodiment is that the power output of the transducer is in proportion to its size, i.e., a good measure of power output is the volume of the core. Because of its design, the embodiment shown in FIG. 6 has a substantial amount of magnetostrictive material and produces large power outputs.

As pointed out in the disclosure above, the flexural resonance of bars is proportional to the thickness of the bar in the plane of vibration and inversely proportional to the square of the length. In order to secure a maximum power output for a given power input, it is preferable that the period of response or resonance frequency of the legs be the same or nearly the same as that of the inner bars. In order for the outer legs and inner bars to have the same period of vibration, it is necessary that the outer legs 28, 29 have a greater cross-sectional area than the inner bars 30, 31. The embodiment of this improvement is shown in FIG. 6 where a structure of this sort resonates both the inner bars 30, 31 and outer legs 28, 29 at approximately the same frequency to give a maximum power output for a given power input. If the magnetostrictive materials are to be affected the same amount, these magnetostrictive materials must be subjected to the same magnetic flux concentration. The length of the legs is greater than that of the bars, and therefore, the coil windings 32, 33 on the outer legs must have more turns to cause more lines of flux to pass through them to give the same flux concentration throughout the legs 28, 29 as is found in the bars 30, 31. A series balancing reactor 34 is added to this circuit in order that the impedance of the windings about the outer legs 28, 29 are matched with the series circuit 35, 36 which is wound about the inner bars. In all other respects, coil windings 13-16 of FIG. 6 are identical to those of FIG. 4.

In FIG. 7 is seen a simplified showing of the circuit diagram of FIG. 6. This circuit is similar in all respects to that shown in FIG. 4, except a balancing reactor 34 is shown in series with coils 35 and 36 which represent the coil windings on the inner bars. The outer coils 32, 33 of FIGS. 6 and 7 have a few more turns than the corresponding coils 13, 14 of FIGS. 3 and 4.

One half of the AC current goes through coils 32, 33 and the other half goes through the balancing reactor 34 and coils 35, 36. Obviously, it may be desirable for some applications to have more or less power going through one side of the parallel circuit or the other. The value of the balancing reactor may be adjusted accordingly.

The advantages of this invention are a multiplication of displacement along the minor axis, a resonance tuned circuit for maximum response, a high electromechanical

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efficiency, a high power output, directivity of output, and possible variation of effects.

The foregoing is a description of an illustrative embodiment of the invention, and it is applicant's intention in the appended claims to cover all forms which fall within the scope of the invention.

What is claimed is:

1. A magnetostrictive transducer comprising:
an integral frame of magnetostrictive material having the shape of a rhombus with two bars of said magnetostrictive material forming a diagonal down its major axis and legs forming the sides of the rhombus between the apices of its major axis;
first means for generating a magnetic field of a certain intensity about each of said legs and bars when electric current is conducted through said means;
second means for generating a second magnetic field of a certain cyclic rate of change of intensity about each said bar and leg when alternating current is conducted through said means; and
means for supplying current to said first and second means whereby said legs are caused to expand at the time that said bars are contracting and vice versa.
2. A magnetostrictive transducer comprising:
a core of magnetostrictive material with legs having the shape of a rhombus with two adjacent bars of said material forming a diagonal member down the major axis of the rhombus;
conductor means coiled about each said leg and said bar;
a source of DC voltage;
a source of AC voltage;
means connecting said conductor means to said DC source in series whereby a magnetic field is established in said legs in opposite directions and in said bars in opposite directions; and
means connecting said conductor means to said AC source whereby said AC voltage is applied across each said leg in opposite directions and across each said adjacent bar in opposite directions whereby AC current opposes and reinforces said DC current in different legs and bars.
3. A magnetostrictive transducer as set forth in claim 2 in which:
a series of cores are placed side by side with the apices of their minor axes in contact whereby when AC and DC voltage is applied to said conductor means, the displacement of the minor axis is larger than that of the major axis.
4. A magnetostrictive transducer comprising:
a stack of identical rhomboidal shaped integral laminations of magnetostrictive material secured together; said laminations being integral and each having legs in the shape of a rhombus with two adjacent bars of said magnetostrictive material extending diagonally between the apices of its major axis;
first means for generating a magnetic field of an opposed direction and constant magnitude in each of said legs and said bars formed by said stacked strips; and
second means for generating a magnetic field of varying intensity in each of said legs and said bars, whereby said legs are caused to contract at the time that said bars are expanding and vice versa.
5. A magnetostrictive transducer as set forth in claim 4 in which said first means comprises:
conductor means coiled about each of said bars in series and about said legs in series, each conductor means series being connected to the other at one end;
a source of DC voltage; and
first electrical connecting means for connecting each other end of said conductor means to said source to

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establish a magnetic field in said adjacent bars in opposite directions and in said legs in opposite directions whereby the direction of said magnetic field in each of said bars is in the same direction as said magnetic field of said adjacent legs.

6. A magnetostrictive transducer as set forth in claim 4 in which said second means comprises:
conductor means coiled about said bars in series and said legs in series;
a source of AC voltage; and
second electrical connecting means for connecting the ends of each said coiled conductor means to different poles of said AC source whereby said AC source adds to the DC voltage across alternate coils and subtracts from the DC voltage in the other coils and vice versa.
7. A magnetostrictive transducer as set forth in claim 5 in which said second means comprises:
a source of AC voltage; and
second electrical connecting means for connecting the ends of each said coiled conductor means to different poles of said AC source whereby said AC source adds to the DC voltage across alternate coils and subtracts from the DC voltage in the other coils and vice versa.
8. A magnetostrictive transducer as set forth in claim 7 in which said first connecting means comprises:
a first electrically conductive means for electrically conducting one pole of said DC source to one end of said conductor means coiled about said bars; and
a second electrically conductive means for electrically connecting the other pole of said DC source to the other end of said conductor means coiled about said legs.
9. A magnetostrictive transducer as set forth in claim 8 in which said second connecting means comprises:
a capacitor having two terminals;
a first electrical connector connecting one terminal of said capacitor to one pole of said DC source;
a second electrical connector connecting a second terminal of said capacitor to the other pole of said DC source;
a third electrical connector connecting one terminal of said AC source to one side of said DC source;
a second capacitor having two terminals;
a fourth electrical connector connecting one terminal of said second capacitor to the electrically connected ends of said series conductor means; and
a fifth electrical connector connecting the other terminal of said capacitor to the other terminal of said AC source.
10. A magnetostrictive transducer as set forth in claim 8 in which:
said legs of said stack of laminations of magnetostrictive material are larger in cross-sectional area than said bars; and
said conductor means of said first means comprises:
a balancing reactor.

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