United States Patent

[11] 3,558,936

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420 Quigley Ave., Willow Grove, Pa. 19090
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[54] **RESONANT ENERGY-CONVERSION SYSTEM**
56 Claims, 47 Drawing Figs.

[52] U.S. Cl. 310/8.1, 310/8.2, 310/8.3, 310/8.7
[51] Int. Cl. H01v 7/00
[50] Field of Search 310/8.3, 8.7, 8.5, 8.6, 8.1, 8.2, 26; 228/1; 330/30; 73/71.5

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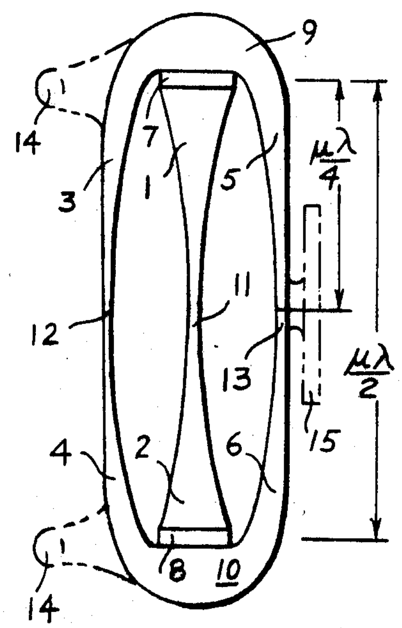
Primary Examiner—Milton O. Hirshfield
Assistant Examiner—B. A. Reynolds

ABSTRACT: A new discipline of energy conversion and transfer involving high Q, constant-frequency, mechanical apparatus, having structure and performance analogous to those of alternating current electrical networks and permitting the injection and extraction, at choice, of electrical or mechanical energy, the mechanical energy being available at a range of impedance levels, in selected phase relationships, and in a manner compatible with fluid energy systems as well.



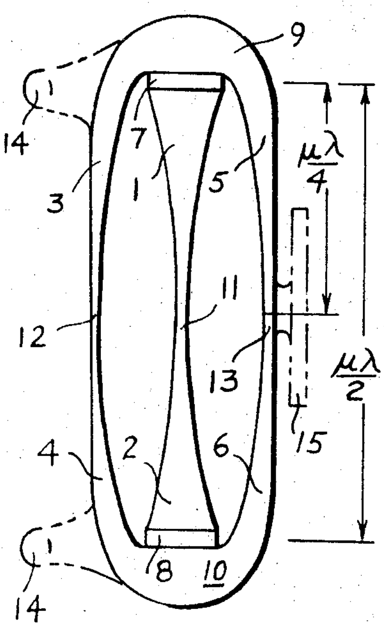


FIG. 1

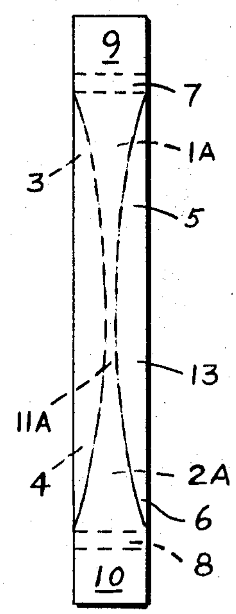


FIG. 8

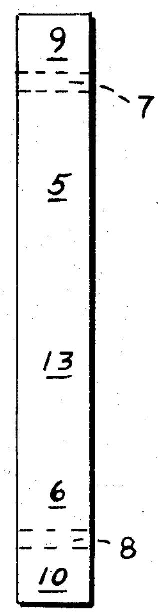
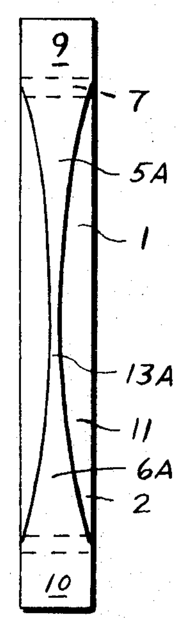


FIG. 7



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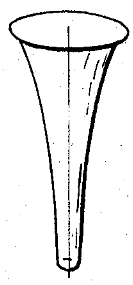

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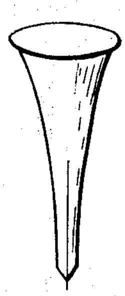

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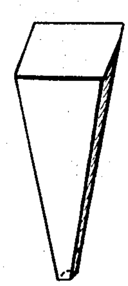

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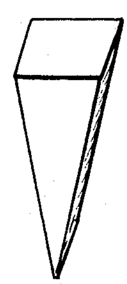

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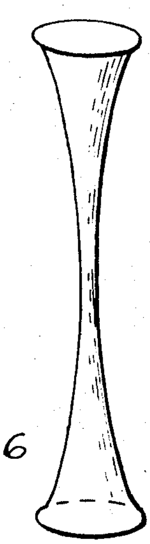

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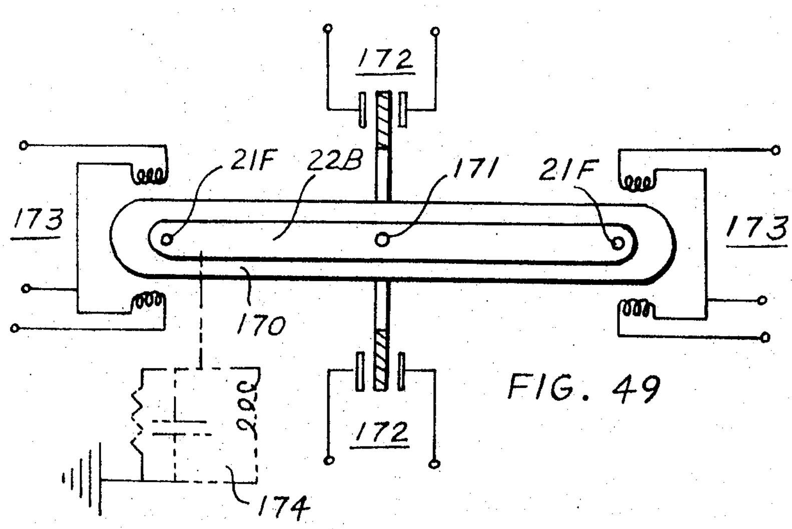

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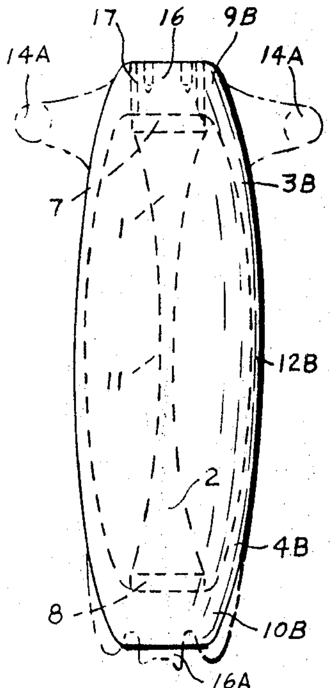

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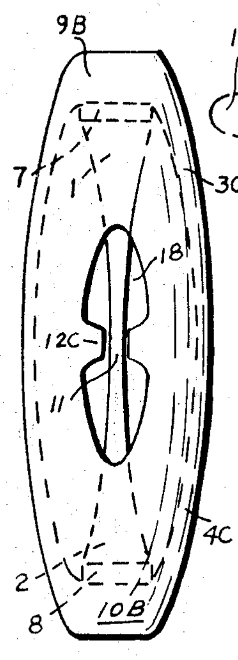

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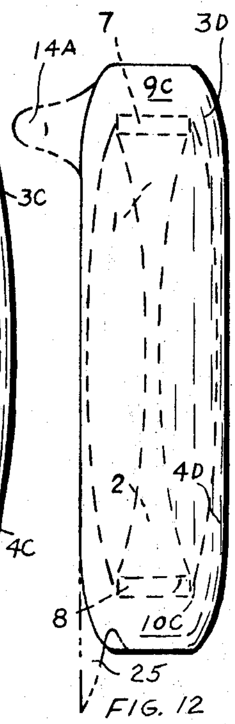

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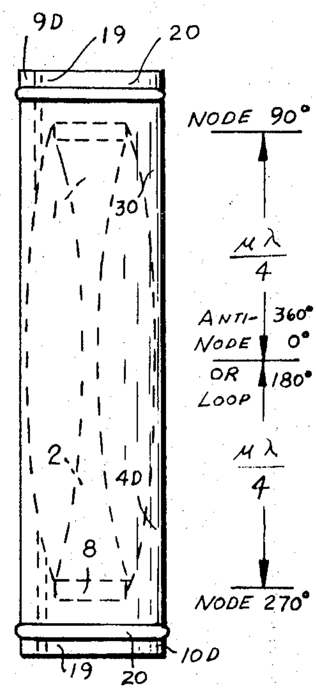

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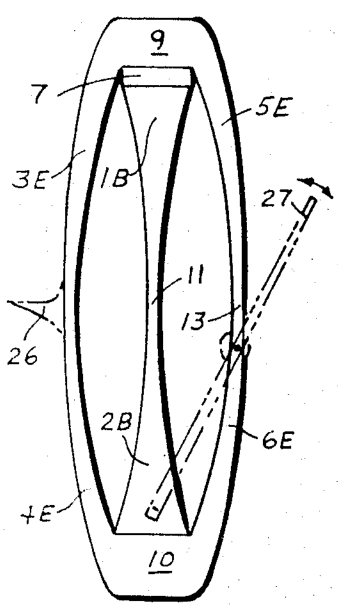

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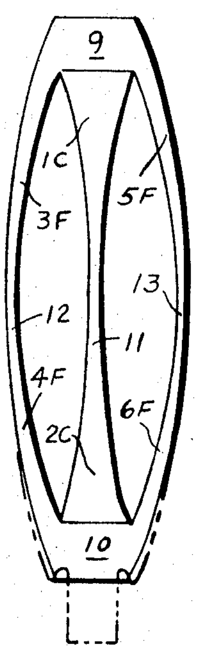

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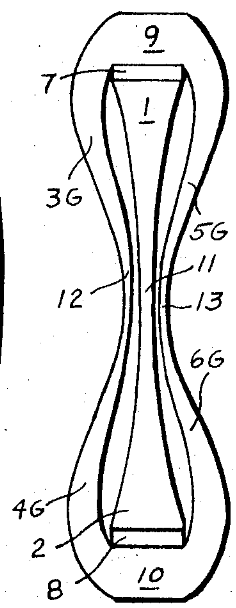

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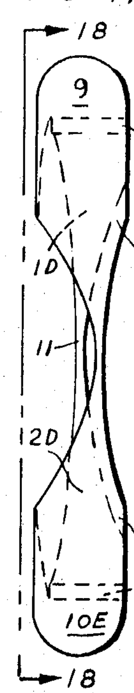

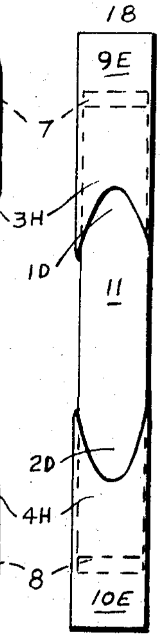

FIG. 18

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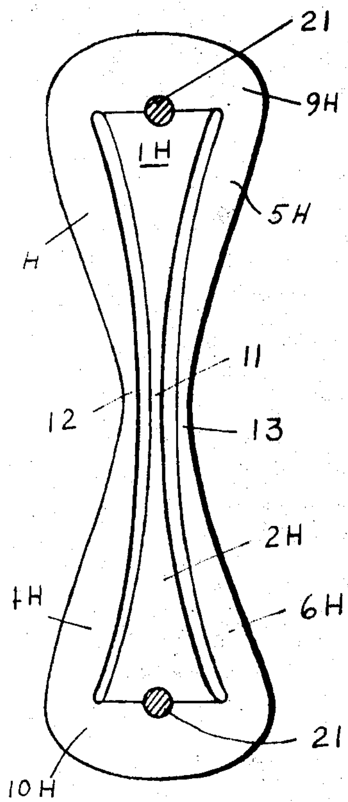

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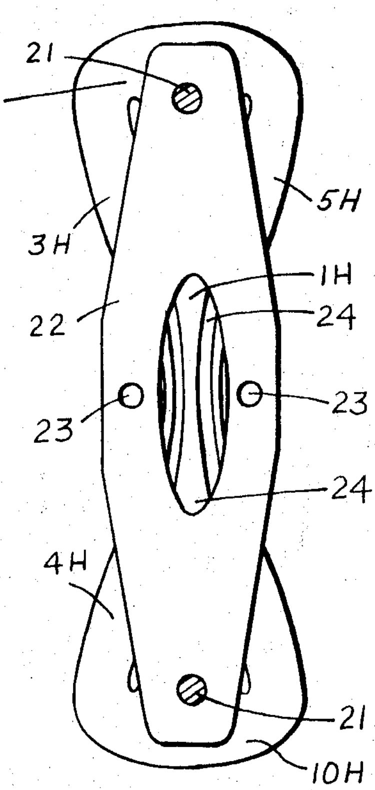

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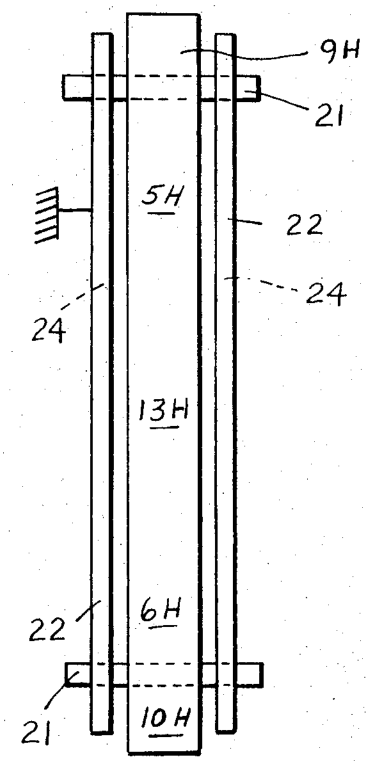

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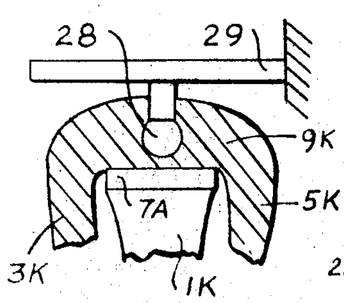

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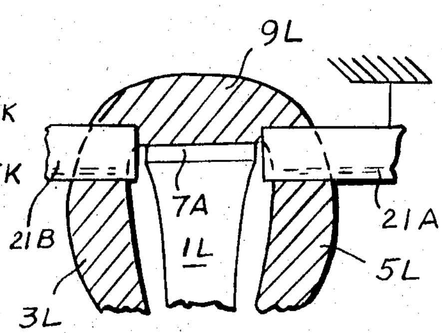

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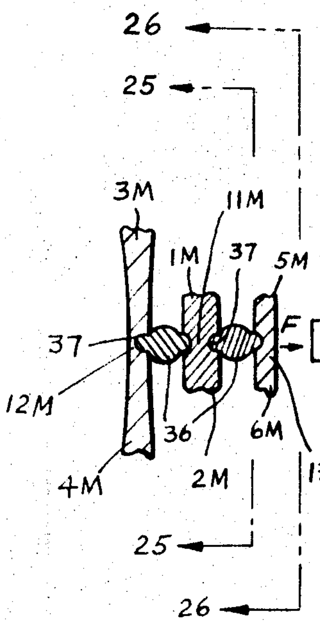

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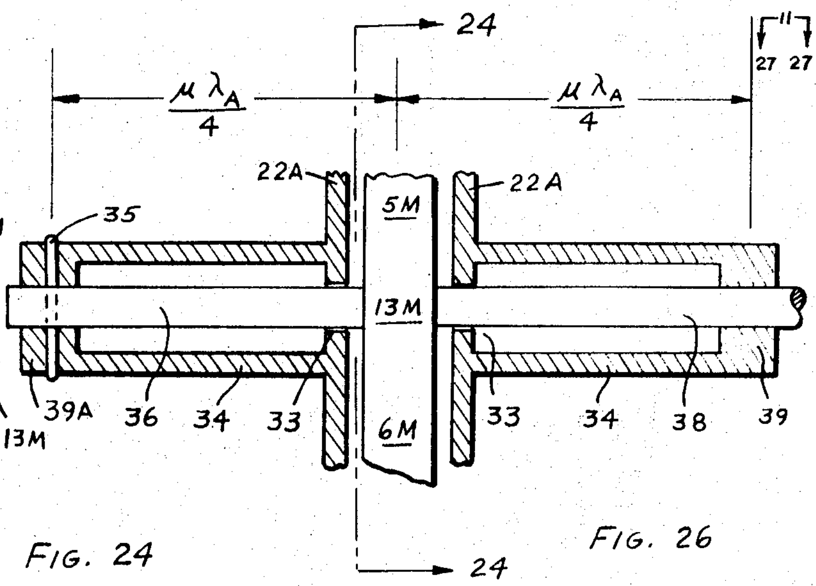

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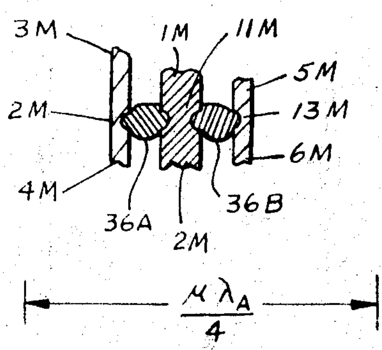

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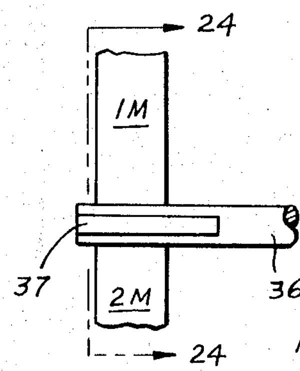

FIG. 25

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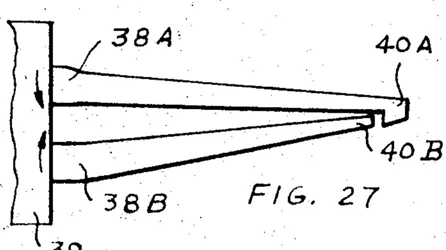

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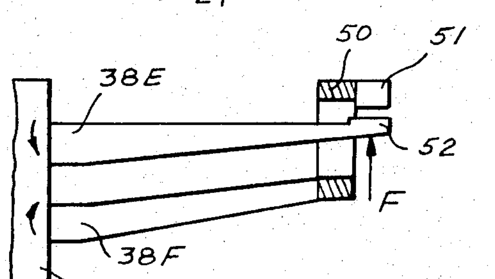

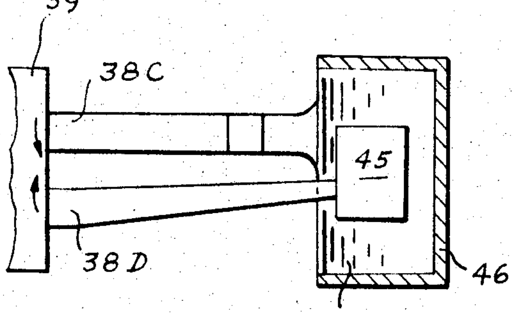

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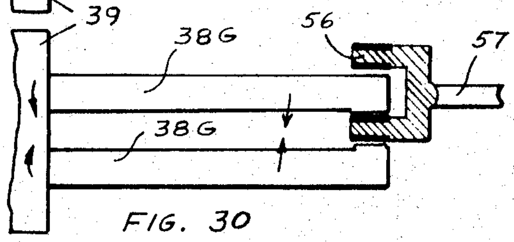

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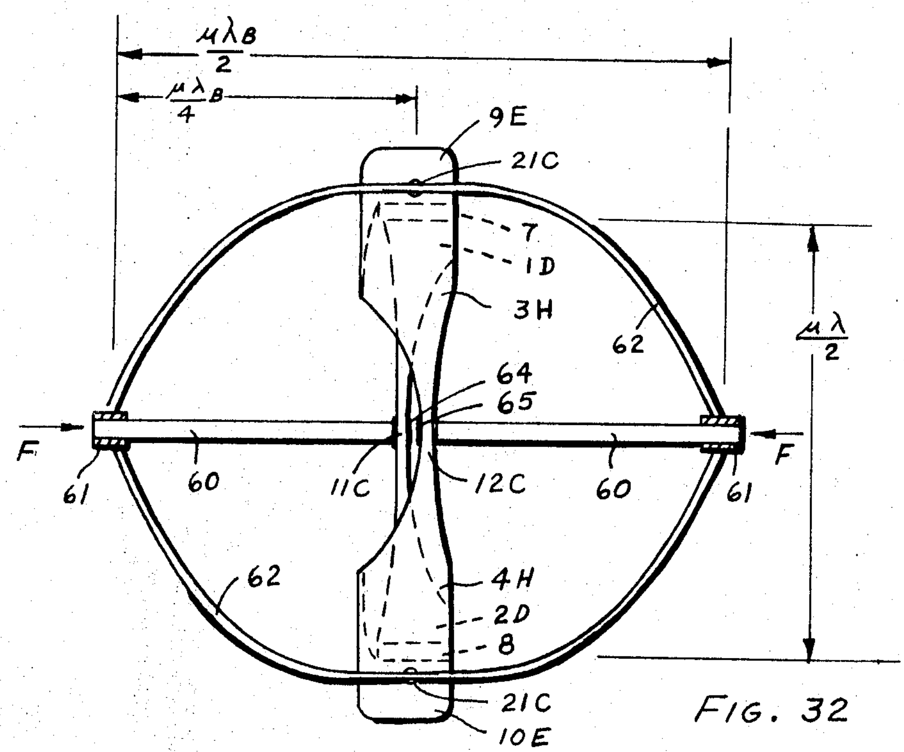

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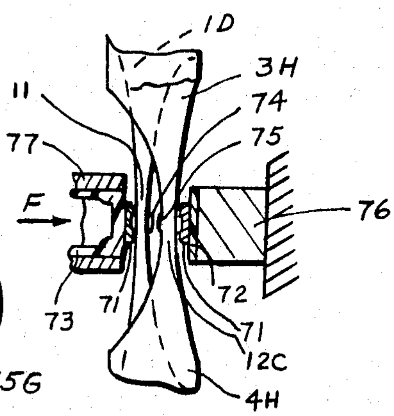

FIG. 33

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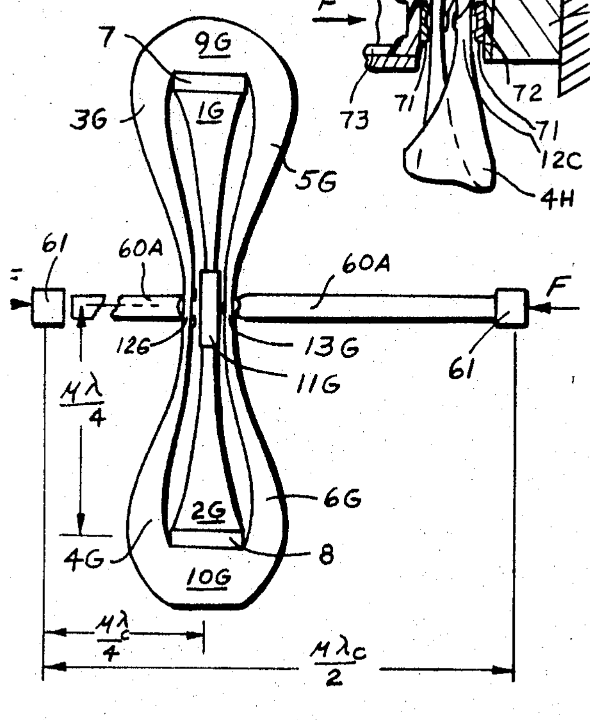

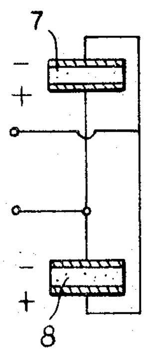

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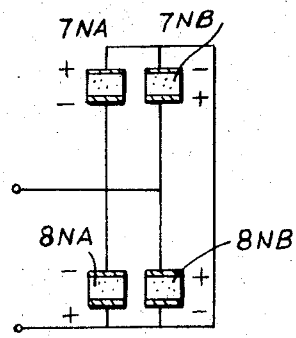

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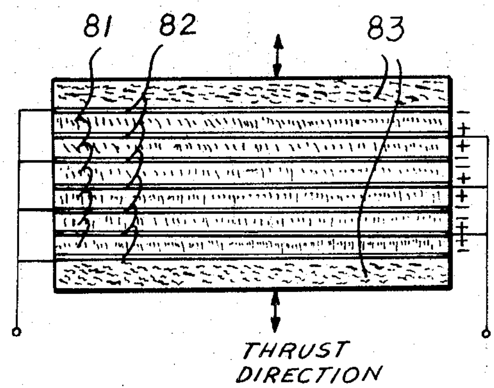

FIG. 36

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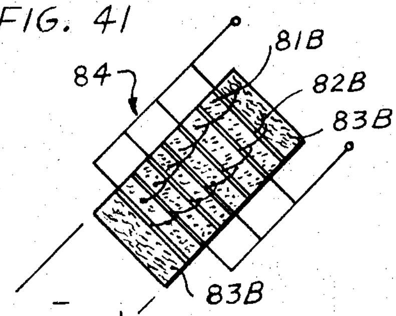


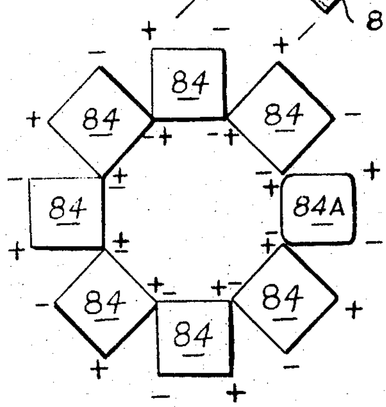
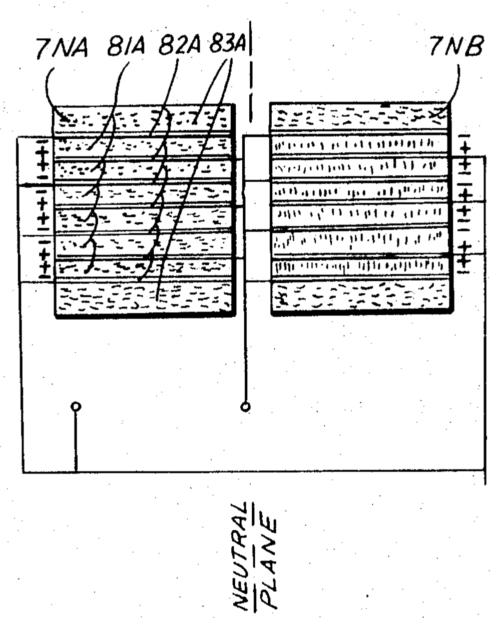


FIG. 40



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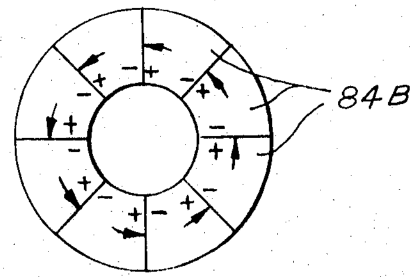

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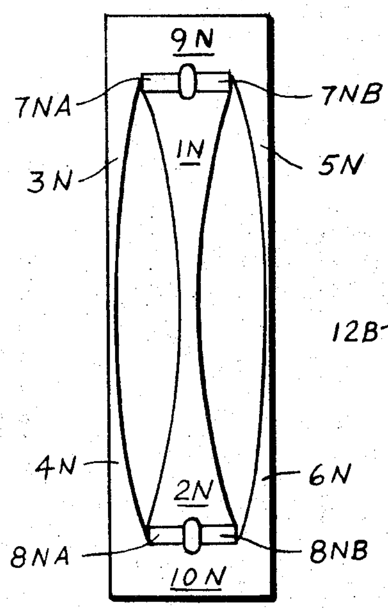

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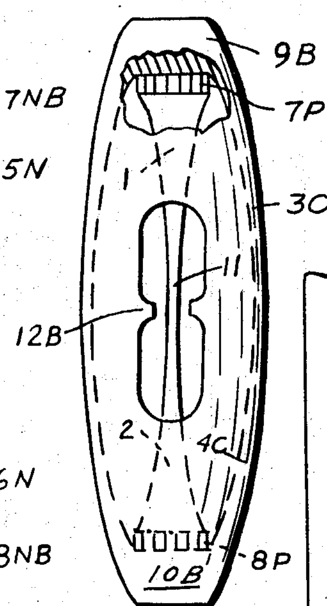


FIG. 42

FIG. 45

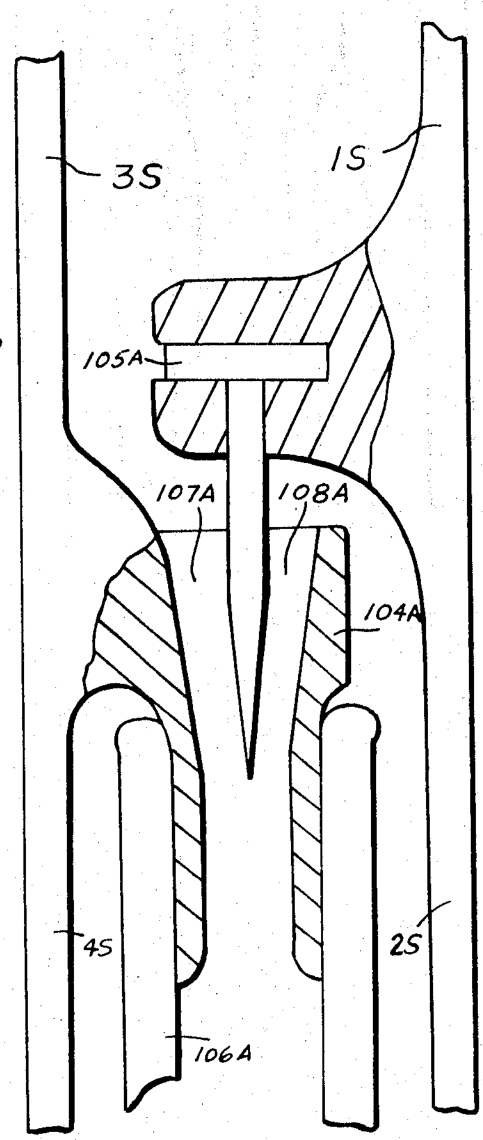
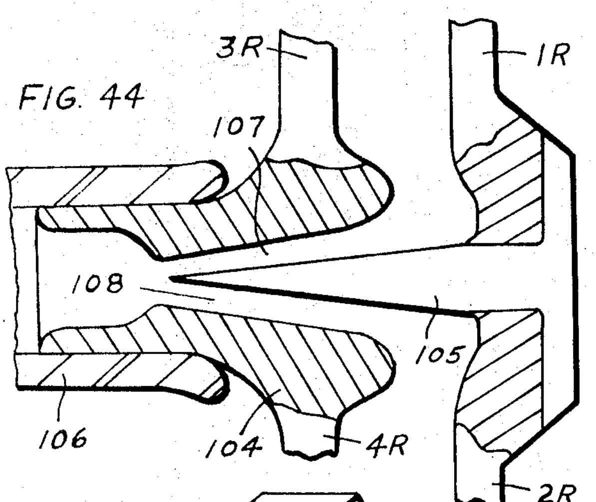


FIG. 44



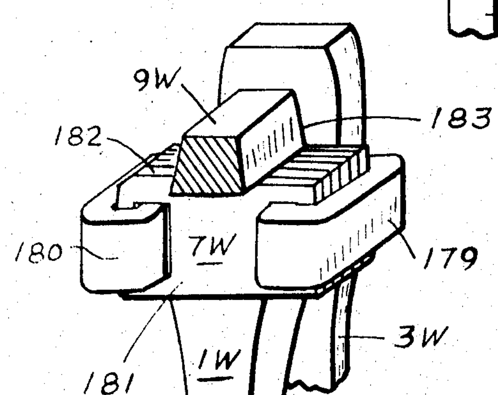


FIG. 50

RESONANT ENERGY-CONVERSION SYSTEM

RELATED APPLICATIONS

Representative references illustrating the present state of the art include the following U.S. Patents, issued to W. P. Mason: 2,514,080; 2,742,614; 2,828,470; and 2,880,334, plus a number of the patents carried in Class **228**, Subclass **1**, including cross references, contained in the Patent Office searchroom files.

BACKGROUND OF THE INVENTION

The background of the invention lies primarily in various forms of machines and energy conversion devices which, in the mechanical world, behave rather as electrical direct-current systems do. In certain areas, mechanical knowledge has followed the stimulus of electrical teachings; and the analogies to electrical quantities have become well known to those practitioners in mechanics and acoustics who have dealt with the disposition of unwanted vibrations; with the transit of sound via materials; with ultrasonic welding and processing; and with the dynamics of instrumented control. The search, if there has been one, for a mechanical or acoustic counterpart to the universal alternating-current network, fundamental to all of electricity and electronics, appears not to have evoked much discovery heretofore.

DESCRIPTION OF THE PRIOR ART

Systems of the type disclosed are believed not to exist in the art.

SUMMARY OF THE INVENTION

This invention relates to generically new forms of energy converters. Certain versions may be recognized and described in the familiar terms of "motor," "generator," "engine," etc. depending on the mode of energization and the application intended. However, much more is encompassed than is indicated by these familiar terms; and in the oscillatory regime established here old limitations disappear, sometimes being replaced by new ones. Impedance transformations become achievable without external drives or gear-reduction ancillaries; and energy may be injected or extracted in selected phase relationships. The system will often be partly electrostrictive or magnetostrictive, the former being generally superior for most purposes. There is less occasion for use of the relatively mushy, low-impedance electromagnetic-transduction processes, at least in the modal regions; in the antinodal sectors, applications will certainly develop. The mode of mechanical motion is oscillatory, in harmony with the dynamics of AC systems; but energy exchange with rotary and continuously linear systems is within the scope of the new discipline. The various mechanical (or acoustic) oscillations may be linear or longitudinal, flexural, or torsional.

Unlike electromagnetic devices of related size and/or power, optimum operating frequencies are higher, often by plural orders of magnitude, into the ranges generally labeled audio or ultrasonic; and the mechanical excursions will appear to many of those being introduced to the new regime to be uselessly small, the small excursions being in keeping with the character of deformations of materials that have normally high moduli of elasticity. Forces that are used, brought to bear, and experienced are often very high; but the simplicity of impedance control will be a welcome experience.

Since the system does not offer continuous rotation without some processing, there are no rotary bearing frictions; but friction (or resistive) loading may be applied in use; and improper design may lead to waste of energy in frictional loadings, as revealed by localized or generalized overheating.

Like the conventional rotating apparatus, converters will operate best when the balance between incoming and outgoing, or converted, energy is moderate. To work at their best, the systems should be permitted to store a large reservoir of kinetic energy in material in motion; the stored energy should

be relatively high as compared with the amount of energy being converted per cycle. The oscillating masses behave exactly as does a rapidly rotating flywheel; though it may seem difficult at first to appreciate this behavior in a device that superficially appears to be standing still.

BRIEF DESCRIPTIONS OF THE DRAWINGS

The drawings, containing 50 FIGS., illustrate the teachings of this invention and present certain representative converter forms selected from among the many possible configurations and purposes.

FIG. **1** is an elevation of a simple form of full-wave energy converter.

FIG. **2** is a pictorial view of one of the possible configurations of a horn or quarter-wave portion usable in devices of the character shown in FIG. **1**.

FIG. **3** is a pictorial view of an alternative form of quarter-wave portion which the converter of FIG. **1** might include.

FIG. **4** shows another alternative quarter-wave portion or mechanical impedance transformer which might be employed in FIG. **1**.

FIG. **5** shows still another form of horn suitable for constituent structure in FIG. **1**.

Fig. **6** is a pictorial view of a form of meridional member such as can be used in devices of the character of FIG. **1**. FIG. **7** is a side view of a converter which, if rotated 90°, would look like FIG. **1**.

FIG. **8** is a side elevation of a second converter construction which would look like FIG. **1** if rotated 90°.

FIG. **9** is a side elevation of a third form of converter which would look like FIG. **1** if rotated 90°.

FIG. **10** is a view of an alternative form of converter differing from FIG. **1** in that the outer structure is generally cylindrical.

FIG. **11** is an elevation of the converter of FIG. **10** at an angle of 90° to FIG. **10**.

FIG. **12** is an elevation of a form of converter teaching an alternative configuration of tool tip.

FIG. **13** is an elevation of a converter showing how fluid passages may be incorporated.

FIG. **14** is an elevation of a converter teaching the manner of making low and intermediate impedance energy pickoffs.

FIG. **15** is an elevation of a converter teaching that converter structure can have function even without containing transducers.

FIG. **16** is an elevation of a converter having the outer members aligned close to the inner member for convenient attachment of energy exchange means.

FIGS. **17** and **18** are elevations from two sides of a converter differing from that of FIG. **16** in being arranged to oppose its inner member with only a single outer member instead of two.

FIG. **19** is a cutaway elevation and FIGS. **20** and **21** are elevations from two sides of a converter having no transducers.

FIG. **22** is a fragmentary view of a converter combining the presence of a transducer with mounting or grounding structure at or near a node.

FIG. **23** shows another method of mounting a converter at or near a node.

FIG. **24** is a fragmentary sectional view of the loop portion of a converter.

FIG. **25** being a fragmentary view of one end of one of the shafts and FIG. **26** being taken outside the principal converter members themselves but sectionally within an external supporting structure not seen in FIGS. **25** and **26**.

FIG. **27** is a fragmentary view showing the right end of the supporting structure of prior FIG. **26**, plus the completed projecting right ends of shafts **36** and **37**, designated here as shafts **38A** and **38B**, extending to working loops a quarter wave beyond their points of emergence from structure **39**.

FIG. **28** is similar to FIG. **27**, except that the shaft ends are configured for agitating a fluid.

FIG. 29 is similar to FIGS. 27 and 28, except that the shaft ends are configured for performing an ultrasonic welding operation.

FIG. 30 is similar to FIGS. 27—29, except that the shaft ends are configured to drive a rotating body; and FIG. 31 is similar to FIG. 24 except that the driving portions of the shafts have been altered to inject an additional motional mode.

FIG. 32 is an elevation of the converter of FIGS. 17 and 18, adapted for welding and equipped with a disengaging spring means.

FIG. 33 is a fragmentary view showing an alternative welding adaptation for the converter of FIGS. 17 and 18.

FIG. 34 is an elevation of the converter of FIG. 16 adapted for welding.

FIG. 35 is a diagram for electrical connection of transducers in converters of this invention.

FIG. 36 is a diagram for assembly and electrical connection of transducers in converters of this invention.

FIG. 37 is an alternative diagram of electrical connection of transducers of this invention.

FIG. 38 is an alternative diagram for assembly and electrical connection of transducers in converters of this invention.

FIG. 39 is an elevation of a flexural converter employing transducer systems of the character described in FIGS. 37 and 38.

FIG. 40 is a plan view of a transducer array for producing torsional resonance in a converter of this invention and FIG. 41 is an elevation of one stack in the array of FIG. 40.

FIG. 42 is an elevation of a converter employing the transducer array of FIG. 40.

FIG. 43 is a plan view of a transducer array alternative to that of FIG. 40.

FIG. 44 is an elevation of a fluid motor of the type referred to in FIG. 13.

FIG. 45 shows an alternative form of fluid motor.

FIG. 49 shows an adaptation of a converter of the character of FIG. 12 for serving as a vibrator type of gyroscope.

FIG. 50 shows an adaptation of the converters of this invention adapted for coaction with a magnetostrictive transducer.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Considering FIG. 1 first, there is seen a meridional wasp-waisted central structure 1, 2, 11, flanked by what appear to be a pair of similar structures, 3, 4, 12, and 5, 6, 13. Each of the latter has a width generally half that of the first. The outer members are seen to be integral with each other and with the interconnecting bridging structures 9 and 10 at top and bottom respectively.

Intervening between the ends of the meridional column and the confining bridging structures are transducers 7 and 8, preferably ferroelectric, but permissibly magnetostrictive. The ferroelectric types are generally superior in this service because of their greater efficiency since they require no bias current and because they can be placed entirely under relatively uniform stress. Geometrically they are preferable because they can be wholly confined in compressive prestress between the heavy ends of the meridional structure 1, 2, 11 and the bridging structures 9 and 10.

For most applications, the total height of the ferroelectric transducers together will not exceed one-eighth of the length of the meridional structure and may be much shorter. Thus, they will not operate at their own resonant frequencies but rather will be compelled to behave as part of a system resonating at a much lower frequency.

The meridional structure 1, 2, 11 is preferably a symmetrical pair of interconnected integral mechanical transformers or "horns," having a small cross-sectional area at midlength. Single horns were disclosed by Mason in his U.S. Pat. No. 2,514,080 and have been widely copied since, particularly in the design of ultrasonic welding machines that populate the U.S. Patent Office searchroom files.

It may be inferred that, at some frequency f_1 having a half-wave length in the material equal to the combined length of the two horns of structure 1, 2, 11, it can be made to resonate, with a pair of nodes at the top and bottom extremities and a loop at midlength. It will be recalled from the prior art of single horns that, where the large-diameter base of such a mechanical transformer has an area S and the small-diameter tip has an area s, the resonant longitudinal excursion at s is S/s times the excursion imparted to the larger end, while the force deliverable at the smaller end is of the order of s/S times that imparted to the base.

However, when the meridional member is confined as seen in FIG. 1, and particularly when, as seen in subsequent FIG. herein, it is exchanging energy at its midpoint 11, the resonant frequency will be affected, as will the excursions and forces available.

Experience has shown that, while similar configurations at both base and tip and an area progression from base to tip in accordance with an exponential taper are generally satisfactory, the designer has a much wider choice, fourier progressions, conical progressions, and even stepped progressions having been resorted to, though the last-named type suffers most from energy reflections.

Likewise, a horn having an oblong or square base may, by judicious calculations, be made to conform to a smooth transition FIG. it a circular, elliptical or other tip shape, while even a circular base may terminate in a tip shaped like a blade. Momentary reference is here made to the series of illustrations in FIGS. 2, 3, 4, and 5. FIG. 6 is a pictorial view of a meridional member that might be assembled into a structure like that seen in FIG. 1. As illustrated in FIG. 6, the length of a meridional member is approximately $\mu\lambda/2$, where μ is any odd integer and λ is the wavelength corresponding to the resonant frequency in the material of which the member is made. Usually, but not necessarily, μ will have a value of one. When μ exceeds unity, the principal loop may be closer to one end.

Except for such discontinuities, not seen in FIG. 1, as may be caused by the location of tool bits or energy-exchange devices at 11, there is a smooth energy transition along the length of half-wave member 1, 2, 11 from its heavy, high-impedance upper end, past the minimum-impedance central portion 11, to the high-impedance bottom end. The high-impedance ends provide suitable energy matching surfaces for the transducers 7 and 8, which, like the metals that are preferred for the horns (though they may be of other materials in certain instances), have a relatively high Youngs Modulus. In English units, the Youngs Modulus in tension/compression of high dynamic strain types of lead titanate-zirconate ferroelectric ceramic, such as "PZT-4," and of barium titanate ranges from 7 or 8 to to 12 times 10^6 psi, while Youngs Moduli for representative metals range upwardly from these values to 30 times 10^6 psi for steel and even higher for tungsten, molybdenum and beryllium.

Examining the flanking members in turn, it is seen that the total width of the front faces of members 3, 4, 12 and 5, 6, 13 appears about equal to the width of member 1, 2, 11 at all common levels. If, for the moment, we assume that the same materials are used, that there is no front to back taper, and that the depths of all members in a direction perpendicular to the paper are equal, the masses at all levels of the meridional member 1, 2, 11 on the one hand and the paired flanking members, 3, 4, 12 plus 5, 6, 13 on the other, will be equal. This is not strictly true; and there will be further discussion on this point.

In the static condition, the meridional member is usually in compression, with a balanced tensile force divided equally between the flanking members. Because of the nature of the service to which the converters are subjected, structural fasteners will rarely be used since they are subjected to frictional working, especially on threaded surfaces, and will produce undesirable parasitic damping with loss of energy and evolution of heat. For this reason, assembly of the converter, with the transducers 7 and 8 to be trapped at the respective ends of the meridional member, is preferably, by stretching, aided by thermal differential expansion; however, the process must be carefully controlled because ferroelectrics will be damaged by temperatures approaching their Curie points. The static prestress values created in the members will be a function of the amount of dimensional interference between inner and outer members that must be overcome at assembly. The static prestress values are preferably sufficient to keep the transducers in compression at system resonance at power levels beyond those anticipated in service, since these brittle devices must not be permitted to develop high tensile stresses. Longer half-wavelength paths in outer members favor light metals having high sound velocity, while inner members tend to use heavier materials. The inner member need not be compressed when brittle transducers are not present. Heretofore we have considered the inner member as about a half wave in length. Preferably, however, the design half-wave length should extend from the midpoint of the upper transducer to the midpoint of the lower one. These points will then be the nodes of the converter, whose antinodes or loops will be located at midlength on all longitudinal members.

Assuming for the present that this converter will be electrically driven, we will electrically connect the transducers in phase opposition, as will be discussed in greater detail later in connection with FIGS. **35—42**. That is, we will so connect transducers **7** and **8** that the upper one will expand while the lower one contracts during the first half cycle of applied alternating current, with the upper one contracting and the bottom one expanding during the second half cycle of the first full wave, and so on alternately at frequencies up to resonance, the frequency at which the converter comes mechanically or acoustically into phase with the electrical input. At the resonant frequency, when the time required for an acoustic wave to travel from the midpoint of one transducer to the other is equal to half the duration of one electrical cycle, the system begins to store energy in mechanical force and motion, with the midpoint **11** always moving vertically in a direction exactly opposite that of midpoints **12** and **13**, which move in unison. Midpoint **11** reaches the top of its excursion when midpoints **12** and **13** reach the bottom of theirs. Full motion amplitude is not reached on the first cycle, when the system is just beginning to store energy, but it is rapidly attained, because this system is well adapted to high frequency energization and very little energy is wasted by this system on bearing friction and frictions resulting from side thrust of rotating devices, or on windage, etc. There is, in fact, the danger of overstressing and thus partly depolarizing the transducers or even of fracturing them if the input electrical energy is not limited to precalculated levels, as the system may otherwise tend to run away in amplitude. Energy may, of course, be taken out of the system most conveniently in mechanical form at low-impedance points **11**, **12**, and **13**. Mechanical energy may likewise be injected into this system also, as will be discussed at greater length in disclosures hereinafter and elsewhere.

One example of an appliance for which a converter of this type is well suited is sketched in phantom lines. A pair of handles **14** located abreast of one of the nodes or preferably opposite each of the nodes would enable an operator to exert pressure upon an oscillating sanding shoe **15** fitted at the loop **13**. There would be no need to couple midpoint loops **11** and **12** to anything.

As seen in the diagram accompanying FIG. 1, this is not a half-wave resonator but a full-wave device. If we consider the midpoint **11** of the meridional member **1**, **2**, **11** to be at the 0° or 360° position under static conditions and whenever it passes this position while oscillating, we may consider that the phase-opposed midpoints **12**, **13** of the flanking members are at a 180° interval from the position of midpoint **11** since they are always moving in the opposite direction. Correspondingly, the points of zero motion in the middle of the upper and lower transducers **7** and **8**, that is, halfway between the oscillating midpoints **12** and **13** on one hand and **11** on the other, are at quadrature, at 90° and 270°, respectively.

The question will arise in the reader's mind as to whether it is physically possible to locate the nodes within the transducers, since the path from the midpoints up through the middle of either one of the flanking members, for example **3**, **4**, **12**, via the bridging end **9** to transducer **7**, is obviously and necessarily much longer than the interval from midpoint **11** to transducer **7**. This is, of course, true; and it causes some design complication. It is necessary to select material for the flanking members and ends that has a sufficiently higher internal sonic velocity than does the meridional member to equalize the time of travel of sound between the transducers via the stress-opposed members. It is, further, necessary to modify the cross-sectional dimensions of the members so as to restore the mass balance lost in substitution of materials, remembering that the effective length of the path in the outer members is arrived at by more complex logic than for the inner one. Since, in the ultrasonic welder business, single quarter-wave horns have to be modified after fabrication to bring their resonant frequencies closer to design tolerances, and since some of the modification procedures are commonly referred to by those practicing them and holding patents as trade secrets, optimum balancing of members involves acquiring skills in cut-and-dry experimentation and measurement. This does not mean that unbalanced converters will not function. For most purposes they will serve best if their masses are symmetrical and if their current, voltage, amplitude, and force curves are maintained in a reasonable balance throughout their operating range.

Seams between the longitudinal members and/or transducers do not necessarily establish the locations of nodal planes or zones. The actual node may be a point elsewhere in the general area, depending on the mass and energy balances between the members and the energy input and extractor means; and the nodes may shift somewhat within the operating range. The tensile and compressive members may permissibly be integral. Efficiency loss when the transducer is several degrees away from the node is small if the transducer is well aligned with the forces. The end structures **9** and **10**, that bridge the outer members and apply compression to transducers **7** and **8** and to the inner member, are designed for rigidity, as evidenced by their deep crowned configurations. Preferably, they should not be excessively bowed by their loads, because such bowing can result in nonuniformity of loading across ferroelectric transducer faces, causing depolarization or breakage at the edges.

It is not essential that the individual members be similarly tapered. Thus, referring to FIGS. **7**, **8**, and **9**, showing alternative side aspects for converters in accordance with FIG. **1**, all members may have identical depth, as in FIG. **7**. If the proper mass and acoustic velocity relationships are maintained, however, the side members may be reduced in depth at the midpoint as in FIG. **9** or the inner member may be so reduced, as in FIG. **8**. To compensate for reductions in depth, material substitutions may be made; or the widths, as viewed in FIG. **1**, may likewise be varied. The foregoing sentences in this paragraph describe optional approaches to the tailoring of the loop portions of the horns or mechanical transformers arranged in quadrature in the converters of this invention.

Referring now to FIG. **10**, the first, or inner, or meridional member **1**, **2**, **11** is hidden within the second member, a single cylindrical outer member **3B**, **4B**, **12B**, which completely encloses it. To permit assembly of a device of this character, a closure is desirable, in this case plug **16**, which may be pinned or have tight-fitting acme or buttress threads **17** to minimize frictional working of thread surfaces, perhaps aided by infiltrated solders or firm cements. The ideal nodal position is within the transducers **7** and **8**; however, as long as the quality of workmanship is such there is no marked deviation of the nodes away from the transducers and the zone immediately endwise of them, the device will usefully convert power. Such a converter, with handles **14A** opposite one node and a riveting or hammering die **16A** below the other node (handles and die seen in phantom lines), would take advantage of high force values and low amplitudes. Refer again to the second-last, third-last, and the fourth-last paragraphs containing a discussion of nodes.

When one member is enclosed within the other, it may be desirable to have a window **18**, as seen in FIG. **11**. Window **18** affords visual and tactile access to loop **11** and permits coupling energy pickoffs between loops **11** and **12C**.

Referring to FIG. **12**, otherwise similar to FIG. **10**, the sides are now straight to give the converter a cylindrical form. Handles **14A**, again seen in phantom, permit the user to employ a chisel or scraper **25** at the lower end, where an intermediate amplitude and force can be obtained beyond transducer **8**, especially if mass unbalance between inner and outer members is designed in as per the discussion in the third-last, fourth-last, and fifth-last paragraphs. By investing greater mass in the meridional member, the node is shifted toward it. If the outer cylinder is of much lighter-weight material than the meridional member this may be possible here, though more difficult than in the prior instances where the outer members were not complete cylinders. Otherwise, in this instance, the nodes will move endwise and may become diffuse, with some of the effective stroke and power being lost.

Referring now to FIG. **13**, O-ring seals have been installed in grooves at each end, permitting the converter to serve also as a piston, with end openings **19**, which may optionally be valved, for fluid access to whatever hydraulic energy pickoffs or motors are to be installed therein.

One transducer has been eliminated in FIG. **14**, otherwise similar to FIG. **1**, permitting inner member **1B**, **2B**, **11** to interface directly against bridge **10** at the lower node. Tiny, hermetically sealed, converters may be equipped with a tiny blade **26** (in phantom), enabling a surgeon to cut tissue effortlessly and precisely with the blade oscillating at tens of thousands of cycles per second. The ferroelectric should be capable of withstanding heat of sterilization.

Alternatively, if visualized as an open structure like that of FIG. **1**, the converter of FIG. **14** optionally can include lever **27**, of lesser stiffness than the longitudinal members **2B** and **6E**, to which it is secured, whipping in a reciprocating arc at its tip, as shown by the double arrowhead. Depending on motional considerations and relative component stiffness, the mounting points of lever **27** may or may not permit swiveling that is to say, compensatory provisions for synchronous angular reorientation during resonant excursions can optionally be introduced here. In FIG. **15**, which otherwise resembles FIG. **1**, there are no transducers at all. The inner member **1C**, **2C**, **11** abuts directly at the nodes at both ends against bridges **9** and **10**. The difference between this form of resonant energy converter and the other forms seen heretofore is that there is no provision for electrical input or output. This structure will still store energy in resonant resilient deformation of its mass; but both input and pickoff will necessarily be mechanical. Although high-impedance mechanical pickoffs have been illustrated hereinbefore, in most cases the mechanical input and output energies will be exchanged at the midpoints or loops where motion reaches a maximum. Thus, an internal-combustion piston or cylinder located and axially reciprocating there can directly drive an adjacent or coaxial hydraulic pump of related or complementary design, with the balance of the sizable mass of a heavy resonant converter structure serving as an energy reservoir in a manner analogous to that of a conventional rotating flywheel.

Moreover, it is not at all unreasonable, with such an energy source as a reciprocating internal-combustion device, located and fitted to drive between loops **12** and **13** on one hand and **11** on the other, or between any of the loops and a stationary support, to utilize the graduated impedance of this mechanical transforming structure in the same manner as a complex and costly gear reduction might be employed upon the shaft of a conventional rotating power plant.

One might, of course, expect to find transducer-driven resonant energy converters of this invention adapted to serve as welders, mixers, etc., and operating at relatively high frequency and in relatively small sizes, as in certain prior-art devices not adapted to store energy. It may then come as somewhat of a shock to envision the wholly mechanical resonant energy converter of FIG. **15** to be built so large as to store piston-type combustion energy in such frequency ranges as 300—400 c.p.s., or upward of 24000 2-stroke cycles per minute per cylinder. Such energy would be delivered from simple slender tube-shaped devices upwards of 30 feet long adapted to power vessels, etc. Energy from these oscillatory devices can be employed to drive rotary propulsion means; but the direct application of oscillatory energy to the water may prove more feasible. For many important applications, there is a growing tendency to take advantage of frequencies well above the conventional 60-cycle regime established by banks of large electromagnetic generators at power stations. In aircraft, for example, the standard minimum frequency was long ago established at 400 H. It is not unreasonable, therefore to visualize large converters powered at the loops by resonant combustors and electrostrictive (or possibly magnetostrictive) transducers at the nodes serving as high frequency power stations for industry.

Referring now to FIG. **16**, it departs from FIG. **1** in that the flanking members **3G**, **4G**, **12** and **5G**, **6G**, **13** are brought closer to the meridional member for convenient attachment of energy-exchange means. It is appropriate to mention that such energy-exchange means are preferably made integral when possible with the members to which they are to be coupled, although the requirement for integral structure is less rigorous at these loops than near the nodes where the forces are so much higher. It is, of course, necessary that parts subject to wear and frequent breakage be detachable; but avoidance of any longitudinal motion between parts is again essential in FIG. **16**.

Referring now to FIGS. **17** and **18**, the converter has been reconfigured to distribute its structure so as to oppose the midpoint or loop of the meridional member with only a single other member instead of two as in FIG. **16**.

Referring in turn to FIGS. **19** through **21**, the converter seen in FIG. **19** has no electrical transducers. Instead, there is seen located at each of the nodal interfaces in FIG. **19** a snugly fitted connecting pin **21**. In FIGS. **22** and **23**, these pins will be seen to be tightly fitted in turn into holes in a pair of support plates **22**, equipped with windows **24** and mounting holes **23**, to which may be attached any mounting or cooperative structure or apparatus that is not intended to be part of the reciprocating, energy-conversion, resonating array. Then the low-impedance energy exchange loops or midpoints **11**, **12**, **13** may each, or any of them may, be applied to develop or deliver, as the case may be, such energy as may be available to it against ancillary apparatus borne on its nonmoving support plate **22** reference. Referring to FIG. **22**, it is seen that, even though there is a transducer in place, it is possible to locate a point near the node at which the resonant energy converter may be attached via a rod **28** to a bracket **29**, which in turn may be supported on grounded, nonmoving structure.

Referring to FIG. **23**, it is seen that mounting pins **21A** and **21B**, which may be attached to or supported on extraneous structure, such as the plates **22** seen in FIGS. **20** and **21**, may be installed with their centerlines intersecting the node where transducer **7A** is located.

Referring now to FIGS. **24** and **25**, the fragmentary midportion **11M** of the meridional member **1M**, **2M** is seen coupled to the loops **12M** and **13M** of the flanking members **3M**, **4M** and **5M**, **6M** by a pair of shafts, each of which has a pair of ear splines that mesh, somewhat in the manner of gear teeth, with corresponding pockets at the loops of the reciprocally oscillating members. This coupling arrangement enables the shafts **36** to rotate in oscillation in opposite directions.

In FIG. **26**, drawn at a right angle to FIG. **25**, the shafts **36** are seen to pass with clearance **33** through central openings in a pair of plates **22A** resembling the plates **22** seen in FIG. **21**. At intervals of $\mu\lambda_A/4$ from their midpoint, the shafts are supported – in fact, if they are not called upon to perform axial excursions they may even optionally be pinned, as at **35**, in structure **39** and **39A** mounted on plates **22A** at each side. It is important to note that the expression $\mu\lambda_A/4$ here refers to the wave length of torsional vibration in shafts **36** and does not necessarily coincide quantitatively with other quarter-wave lengths encountered in other FIGS. heretofore. The shafts are supported at their nodes. Their loops include the points where they meet the resonant vertical members and a point at a distance $\mu\lambda_A/4$ beyond the right-hand support where they are best adapted to deliver their properly phased power. This last loop will be the subject of discussions of alternative rotary pickoffs seen in FIGS. **27** through **31** next following.

Referring now to FIG. **27**, shafts **38A** and **38B** are seen emerging from support **39** and terminating at a mean distance to the right of $\mu\lambda_A/4$. Remembering that the shafts turn in opposite directions, when viewed from above their rotation is alternately toward each other, as denoted by the arrows, and away from each other. Thus tip **40B**, being farther removed from the axis of shaft **38B**, will rotate at a somewhat greater peripheral velocity than will tip **40A**. If shaft **38A** has been pinned **35** at its left end as seen in FIG. **26**, and if shaft **38B** has not been pinned but is free to slide on splined ear **37**, seen best in FIG. **25**, under longitudinal force F, work entrapped between tips **40A** and **40B** may be welded or otherwise processed. It is emphasized that no attempt is being made here to offer pronouncements on detailed design of welding tips, which are not part of this disclosure.

Referring in turn to FIG. **28**, shafts **38C** and **38D** may be employed in ultrasound processing of fluids. For example, one may carry a container **46** holding a fluid **47**, while the second carries an agitator **45** with which to create differential motion in the fluid.

In FIG. **29**, another scheme for expending shaft oscillatory energy in various work pieces is shown. In this case, shaft **38E** and its tip **52** rotate within cylinder **50**, carried on shaft **38F**. Tip **52** is aligned for forcible lateral application against tip **51** at the underside of cylinder **50**, as would be required for welding a pair of intervening workpieces.

In FIG. **30**, identical shafts **38G** project and have their tips aligned toward each other. Intervening between them is the lip **56** of a cup clutch mounted on shaft **57**. FIG. **31**, which is superficially similar to FIG. **24**, represents the device from which tip shaft portions **38G** derive their rotation via driving portions **36A** and **55B**. Instead of being symmetrical like their predecessors, these driving portions **36A** and **55B** each have a wedging shoulder facing the loop **11M** of member **1M**, **2M** **1M**, **2M** on their upper surfaces. These wedges thus have an outwardly thrusting force imparted to their driven loops at each downward movement of member **1M**, **2M**, **11M**. Thus, a half-wavelength away, or in the vicinity of cup clutch **56**, the ends of the same shafts dance inwardly, momentarily gripping cup clutch **56** at the identical phase of every cycle, putting shaft **57** into cyclically boosted one-way spin.

Referring now to FIG. **32**, the energy converter of FIGS. **17** and **18** appears again, this time fitted with a pair of welding tips **64**, located at loop **11C**, and **65**, at loop **12C**. Tips **64** and **65** are at the inboard ends of identical shafts **60**, supported at their remote ends at appropriate quarter-wave intervals $\mu\lambda_B/4$, by soft spring **62** that are in turn supported by pins **21C**, located at or near the levels of the transducer nodes **7** and **8**. Springs **62** are much too soft (and may be damped as well) to be excited by the frequencies of the stiffer structures involved here; so they merely apply a light restoring force when axial forces F, required when welding intervening pieces, are released.

Referring now to FIG. **33**, instead of applying welding forces remotely via rods having alternate loops and nodes, the arrangement seen here may be more convenient. It consists of anvil **76**, carrying stiff rubber or plastic pad isolator **72** and die **71**, carrying button **75**. Above, pressure cylinder **77**, lined in rubber or plastic **73**, is adapted to force a similar die to depress button **74**. Button **74** is carried in member **1D**, **2D** **11** and may be forced down upon any workpiece inserted between buttons **74** and **75**, which are afforded excursions in their rubber seats to the limit of oscillatory movement of members **1D**, **2D**, **11** and **3H**, **4H**, **12C**.

Referring to FIG. **34**, which is otherwise similar to FIG. **16**, member **1G**, **2G** carries ring die **11G**, which is adapted in turn to carry therewithin a workpiece that is to be welded between two others. Dies **12G** on member **3G**, **4G** and **13G** on member **5G**, **6G** are each designed to carry one of two mating work pieces to be assembled on either side. Rods **60A**, which may be supported and force-biased at $\mu\lambda_C/4$ intervals outwardly from members **3G**, **4G** and **5G**, **6G**, deliver the required pressure to the workpieces.

Referring now to FIGS. **35** and **36**, the first shows a general schematic of one way to wire in transducers **7** and **8**, shown sandwiched in between their respective electrode surfaces. The directions of prepolarization of the transducers are denoted by the plus and minus signs. It will be noted that one side of the line is connected to the positively polarized side of the upper transducer **7** and to the negatively polarized side of the lower transducer **8**, leaving the remaining two electrodes to feed or to be sustained by the other side of the line. When the transducer needs to be composed of a plurality of assembled elements in order to hold the electrical impedance down to practicable values, electrical connections must be made between the elements. However, the surfaces must be very flat and very well finished to prevent the occurrence of bending stresses in any of the elements. In addition, the elements must be well insulated from metallic structure. The use of very hard electrode materials, particularly if thick or not well finished, tends to produce such bending stresses. Yet resorting to relatively soft electrode interlayers, particularly if they are thick or if they have Youngs Moduli that are too low, can cause loss of efficiency, power being squandered in deformation of such inert materials.

In FIG. **36**, the manner of assembly of thickness-polarized, multiple-element **81** transducers is shown, the apparent relative thickness of interelement electrodes **82** being greatly exaggerated for clarity of showing. While these interlayers will consist of two separate layers whenever fired-on electrodes have been applied to both sides of all elements, it is not essential to have more than one layer between any pair of elements. Consequently, only one layer is shown. The number of interconnections is kept to a minimum when prepolarized elements are assembled with like polarities facing like, as shown by the signs at the right of FIG. **36**. Insulation of the element stack from the structure directly above and below can be achieved with nonferroelectric-ceramic facing discs **83** of such materials as aluminum oxide. The stack should also be encased with additional insultants on its outer surfaces to keep out contamination which can electrically short-circuit the elements. Here, plastic and other organic insultants can be used freely, and should be well bonded to the sides of the aluminum-oxide discs **83**, though such materials should not be permitted to become wedged in above or below the transducers.

For simplicity of presentation, discussion of resonant electrical energy converters has thus far been confined to those having longitudinal resonance, with thickness-polarized transducers being chiefly employed. However, since the ferroelectrics generally have Poisson's ratios on the order of about 0.3, it will be obvious that elements otherwise polarized will also serve, with some loss of efficiency.

The use of magnetostrictive transducers is also contemplated where temperatures or other environmental conditions are unfavorable to ferroelectrics. Generally speaking the efficiencies will be lower for these except perhaps in very large sizes.

Referring next to FIGS. **37**, **38**, and **39**, it will be shown that the resonant energy converter system can likewise be designed to accommodate members in flexural resonance as well as in longitudinal systems.

Because of the greatly reduced stiffness of structural members in flexure, the frequency pattern of flexural resonance is far below that of longitudinal resonance and the amplitudes are correspondingly higher. This is why human experience with vibration is generally due to flexural rather than longitudinal vibration.

In order to promote flexural resonance in the converter system schematically sketched in FIG. 39, twice as many transducers are preferably employed, the pairs of transducers at each end being individually out of phase by 180°. In this case, transducers 7NA and 8NA are phased together and opposed to transducers 7NB and 8NB, which are likewise phased as one, a typically effective arrangement, but not the only possible one, being portrayed schematically in FIG. 37.

Detailed wiring of low-impedance (electrical) transducer discs can be set up, as in FIG. 38, in a manner that executes the design of FIG. 37. Mechanically, each transducer block of a pair is assembled and wired in the same manner discussed a above in connection with FIG. 36. Then the blocks are interconnected as shown.

Referring now to FIGS. 40 through 43, it will be seen that the converter system can be employed to serve directly in torsional resonance also, without going through the mechanical steps executed in FIGS. 24 through 31 above. Thus, the problem of generating continuous one-way rotation as illustrated in FIGS. 30 and 31 is also simplified.

When a ferroelectric transducer has been polarized in one direction, if its electrodes are then removed and new electrodes are applied to other surfaces aligned at an angle, often a right angle, to the formerly electroded surfaces, the energization of the transducer via the new electrodes results in a shear distortion rather than the growth or shrinkage observed when the energy is injected via the original electrodes. This was discovered and set forth by Mason in his U.S. Pats. Nos. 2,742,614, 2,828,470, and 2,880,334, wherein he was dealing with a very different kind of application, namely a delay line.

However, the achievement of effective torsional power investiture at reasonably low electrical impedances in an energy converter has required further novelty in the approach, as will be discussed.

The transducer shown in plan in FIG. 40 is seen in elevation via a sectional cutout near the top of the torsional energy converter of FIG. 42, which otherwise resembles the converter of FIG. 11. The transducer consists of a generally circular array of stacks, each of which is somewhat mindful of the stacks seen in FIGS. 36 and 38, with important differences.

FIG. 41 is an oblique elevation of one of the stacks of FIG. 40. These stacks are square in plan view, though a square plan is by no means essential or even optimum. It will be seen that the direction of polarization in FIG. 40, revealed by the plus and minus signs, is generally peripheral, all stacks being oriented in the same sequence. However, there are no existing electrodes on the surfaces in the direction of polarization. It is important that all stacks be ground precisely to the same overall compressed length, so they will share the load equally.

The driving (or driven) electrodes in each stack, again for minimum impedance, are aligned on the plan faces to drive the individual elements thickness-wise. All stacks are wired alike as seen in FIG. 41; and all those in an array are connected in parallel. The result of this mode of energization is that each of the stacks leans successively forward and backward in the direction of polarization in phase with the others with each cycle of applied electrical energy.

Thus, the stacks drive meridional member 1, 2, 11 torsionally with respect to cylindrical member 3C, 4C, 12B, with maximum torsional differential amplitude between the two members at the quarter-wave loop at midlength.

The probability of occurrence of chipped corners on the ferroelectric discs in service will be reduced if the corners are removed before assembly as in the stack designated 84A at the right of FIG. 40. The outside diameter will also be reduced appreciably if this is done.

An even better, though more costly, array is seen in FIG. 43, where all of the ferroelectric chips or elements have been ground or otherwise trimmed after polarization to a modified pie-shaped contour. With this compact arrangement, the stacks afford better support to each other and do a better job of withstanding the oblique loadings that may be produced in certain types of service.

Referring now to FIG. 44, there is seen a device for putting a mechanical energy input into a resonant energy converter. Any two differently moving longitudinal members of such a resonator, selected from among the inner, outer, and support members, may be placed in differential motion by various mechanical input means. As shown in FIG. 44, the inner and outer members, 1R, 2R and 3R, 4R, respectively, may be coupled by a pneumatic expansion nozzle 104 to a resonant-reed member 105 arranged in the manner shown. A fluid, which reasonably may be air at a suitably elevated pressure such as 30 p.s.i. with reference to atmospheric, is fed from flexible hose 106 to expansion nozzle 104 for discharge therefrom. Since the pressure differential is greater than that required for reaching nozzle velocities in the sonic region, slight variations in the input pressure will not cause serious fluctuations in the relatively constant nozzle flow.

Under the influence of the sonic flow, reed 105, which may be a relatively stiff device with a high natural frequency, begins to resonate, building up its amplitude of oscillatory motion quickly to the point at which it tends to reduce alternately the gaps 107, 108 on either side within the nozzle 104. Such partial closures of the competing passages result in cyclical pressure variations on the opposite tapered surfaces of the reed.

The effect upon the reed is that it is forced to resonate at increasingly higher amplitudes in consequence of the energy it receives from the expanding jets that rush past it alternately on either side, until it begins to rap alternately upon the opposite nozzle walls. If the resonant frequency of the reed is, say, 5KH, a regime that may be established with a properly shaped metallic reed less than 2 inches long and less than a half inch thick, and if the resonant frequency for differential longitudinal motion between members 1R, 2R and 3R, 4R has been matched to that of the reed, resulting in a half-wavelength between the nodes that may be on the order of 18 to 20 inches apart in appropriate metals, the reactions imparted by the reed will put these members into oppositely phased longitudinal resonance, causing the transducers at the nodes to feel cyclically compressive forces equal to, say, ten times the force maxima between the reed and the nozzle. This assumes that the area at the large end of the members is a hundred times the tapered down cross-sectional area immediately adjacent to the nozzle.

If we assume a 1 square inch area and the same thickness for the transducer, and if the compressive force imparted to each of the transducers at the opposite ends is to vary cyclically a total of 2000 p.s.i., the transducer deformation change that occurs is measured approximately as follows: 2000= 8,000,000 e, from the well known relationship $s = Ee$ as applied to lead titanate zirconate. The amount of compressive yield of the transducer is one-four-thousandths inches or 0.00025 inch. Part of the energy of deformation may be drawn from the transducer by a resistive electrical load.

The force change at member midlength will be 200 pounds, resulting in a stress cyclical change of 200/ 0.01 or 20,000p.s.i.

The maximum elongation produced by this stress change at the midpoint in steel would be 20,000/30,000,000 or 0.00067 inch/inch length.

The effective elongation over a 10-inch interval from node to loop in one member would be only half that ratio; but, since two side-by-side oppositely loaded members move in differential motion, one quarter-wave horn elongating while the other is foreshortening, the value is doubled back to 0.00067 inch/inch acting over the 10-inch interval for a total relative movement of 0.0067 inch.

This total movement is divided into excursions of 0.0033 inch on either side of the static position of the reed. With the horns as a consequence dancing longitudinally in matching excursions that are 180° mutually out of phase, the relative motion will be shared equally by the reed and the nozzle, both performing the full excursion.

With reference to FIG. 46, it becomes apparent that the scale of corresponding parts will change significantly if the same general type of converter input previously seen in FIG. 44 is now employed between a pair of flexural members 1S, 2S and 3S, 4S, of the type described in connection with FIG. 39, in which the flexural excursions will be of much greater amplitude relative to member length than were the longitudinal excursions previously investigated. Lesser frequencies also generally characterize the greater excursions and softer behavior of the corresponding members.

Referring now to FIG. 49, a very small, completely sealed (optional) converter 170, like that described in FIG. 12, less the phantom-lined ancillaries, may be fitted, at nodally located pins 21F, with a support 22B, which is in turn mounted at choice upon any appropriate accommodation means or structure via a pair of gimbel pins 171 situated perpendicular to the midpoint of the converter axis. This resonating converter becomes an oscillatory gyroscope, storing a great deal of energy as combined functions of the mass of its members and the cyclic excitation rate.

There is need for neither slip rings nor rotating plumbing joints, as required by conventional gyros, that would otherwise create pseudo forces, dissipate mechanical energy, and interfere, accompanied by electromagnetic noise, with the smooth inflow of electrical energy, no requirement for bearings, other contained mechanism, lubrication, etc. The gyroscope of this type can reasonably be made far smaller than can conventional gyros and can employ the heavier brittle alloys that would be highly vulnerable to catastrophic disintegration from centrifugal forces. The fact that such alloys in general have low velocities of acoustic propagation permits the use of even higher excitation frequencies than the 50 KH that might be used in a converter of 2-inch internodal length using conventional metals. The levels of storable energy permit high counterforces, thus inviting the use of extremely sensitive capacitive 172, inductive 173, which may optical, or other deflection pickoff means, which may optionally be segmentally arrayed in multiple. Mechanical restraint means 174, shown schematically in phantom, permit force coupling for rate determination and other purposes.

Referring now to FIG. 50, the nodal portion of a converter employing a very appropriate form of magnetostrictive transducer 181 is seen trapped between bridge portion 9W of outer member 3W and inner member 1W. The portion of the laminated 182 transducer core 181 directly above member 1W is seen to be of solid structure. The cutouts through which the coil assemblies 179, 180 are wound flank the compressed center portion on either side. The coil assemblies 179, 180 preferably each comprise half of the total amount of biasing and operating windings, though the biasing winding may be in one assembly 179 while the operating current passes through the other 180. The core, cutouts, and coil assemblies of these unique transducers are thus seen not to be in the line of force exertion, as is customary in magnetostrictive transducers which are on the order of a quarter wavelength or more in length. Thus they do not add undesirable length to or soften the nodally situated transducer; and they do not waste energy or interfere with the structural members of the converter.

The bridge portion 9W is seen to be a separate piece insertable in the opening 183 of member 3W. The opposite foot of bridge portion 9W that inserts in the similar opening of opposite outer member 5W (not seen in FIG. 50) has been cut off, leaving a sectioned face in order to leave a clearer view of the structure. Construction of bridge 9W as a piece separable from members 3W and 5W is not to be preferred over the forms shown hereinbefore; however, there will be occasions when this structure is resorted to on the basis of low initial cost or ease of assembly.

Obviously now, certain features of one embodiment may be combined variously with others and with certain segments of old art; and they will stimulate imitation in configurations differing in unessential detail from representative showings herein, without departing from these teachings. My invention is not to be limited to specific forms disclosed. All of the equivalent approaches to the structure, objects, and functions inferable by one skilled in the applicable arts are intended to be covered by the claims. Therefore,

I claim:

1. A mechanically resonant energy converter comprising:
an elongated first member having an acoustic termination at each end thereof;
and a balancing member array including at least one elongated balancing member, said array having acoustic terminations complementary to and exerting bearing force upon the terminations of said first member,
said members being tapered from large cross-sectional areas at said terminations to smaller cross-sectional areas at respective primary antinode regions therealong,
said first member and said balancing member together being in total effective longitudinal span approximately an integral multiple of the acoustic wavelength in them at a resonant frequency of said converter,
the complementary terminations of said first member and said array being phased substantially together at one end and out of phase at said one end with the terminations at the other end by about a half wave,
said region of said first member being out of phase with the said region of the balancing member by about a half wave and at quadrature to said terminations,
at least one of said members being adapted for coupling to means for supplying energy to said converter at said frequency, and
at least one of said members being adapted for furnishing energy at said frequency to a desired load.

2. An energy converter as in claim 1, said multiple being unity.

3. A converter as in claim 2, said array exerting longitudinal compression upon said first member.

4. A converter as in claim 3, said means being an electromechanical transducer.

5. A converter as in claim 4, said transducer being intervened in compression between the acoustic terminations at one end.

6. A converter as in claim 5, said converter including also an oppositely phased second transducer intervened in compression between the acoustic terminations at the other end.

7. A converter as in claim 5, said transducer being piezoelectric.

8. A converter as in claim 7, said transducer including a polarized ferroelectric ceramic body.

9. A converter as in claim 7, said transducer comprising alternate layers of ferroelectric material and conductive electrodes.

10. A converter as in claim 7, said converter including a layer of hard insulating material intervened between each of the opposite sides of said transducer and the respective adjacent termination.

11. A converter as in claim 4, said transducer being magnetostrictive.

12. A converter as in claim 4, said transducer having a length in the direction of compression of a minor fraction of an eighth of said wavelength.

13. A converter as in claim 4:
said transducer comprising two ferroelectric bodies of similar height;
each of said bodies having electrodes on the top and bottom faces;
said bodies being spaced apart; and
said bodies being connected to an electrical circuit in mechanical phase opposition.

14. A converter as in claim 4:
said load being an oscillating tool;
said tool being joined to a member at the antinode retention thereof;

15. A converter as in claim 14 having also means for slight movement of the relative position of said tool.

16. A converter as in claim 15 a second member thereof also having a tool joined thereto at the loop region of said second member.

17. A converter as in claim 16, said means including also a second body oscillating a half wave out of phase with said first body and mechanically coupled to a second member at the antinode region of said second member.

18. A converter as in claim 4:
said load being an oscillating tool; and
said tool being joined to a member at a portion thereof projecting endwise beyond said termination.

19. A converter as in claim 4 and including also:
a shaft located between and perpendicular to said elongated members, and
said shaft being torsionally engaged to the adjacent sides of said members.

20. A converter as in claim 19 and including also:
cooperative means for flexing said shaft cyclically; and
a rotating shaft cyclically engaged by said first shaft.

21. A converter as in claim 19 and having:
a second shaft parallel to said first shaft; and
said second shaft being torsionally engaged in opposing direction to a second side of one of said elongated members.

22. A converter as in claim 21, said shafts being coupled in mutual opposition via a load.

23. A converter as in claim 4 and including also:
a torsionally oscillating shaft; and
means for cyclically engaging said oscillating shaft against a second shaft.

24. A converter as in claim 3, having also a plurality of ferroelectric bodies intervened in compression between the complementary terminations at one end thereof.

25. A converter as in claim 24, having a plurality of ferroelectric bodies intervened in compression between the complementary terminations at the other end thereof.

26. A converter as in claim 24 the electroded surfaces of said bodies being perpendicular to the surfaces of their initial polarization.

27. A converter as in claim 26 having a second plurality of bodies as described between the terminations at the other end of said converter.

28. A converter as in claim 24:
said bodies being polarized generally parallel to the faces of said terminations and perpendicular to radii linking said bodies respectively to a common center; and
said bodies being electroded on the faces thereof parallel to said terminations.

29. The combination of a converter as in claim 1 and the said means for supplying energy at said frequency thereto.

30. A converter as in claim 29 said means being so coupled to said member as to oscillate said elongated members longitudinally in opposite directions.

31. A converter as in claim 29, said means being so coupled to said member as to oscillate said elongated members flexurally in opposite directions.

32. A converter as in claim 29, said means being so coupled to said member as to oscillate said elongated members torsionally in opposite directions.

33. A converter as in claim 29, said means being coupled also to a separate one of said members.

34. A converter as in claim 29, said means being coupled between said one member at said defined respective region and one of said members along a tapered portion thereof.

35. A converter as in claim 1, having said load secured at least to said member so adapted.

36. A converter as in claim 1, said converter including also a relatively nonresonant member joined therewith near at least one of said terminations.

37. A converter as in claim 36, said nonresonant member being joined therewith near both pairs of said complementary terminations.

38. A converter as in claim 37, said nonresonant member having low-friction guidance means for holding in alignment said means for supplying energy.

39. A converter as in claim 36;
said nonresonant member having manual gripping means thereon; and
said integral multiple being unity.

40. A converter as in claim 36, and including also:
pivotable gimbal means joined to said nonresonant member;
a frame pivotably carrying said gimbal means;
physical restraint means intervening between said array and said frame;
and means for measuring deflection of one of said members relative to said frame; and
said integral multiple being unity.

41. A converter as in claim 1, said array comprising a single principal longitudinal member.

42. A converter as in claim 41, said first member being generally contained within the contour of said array.

43. A converter as in claim 42, said array conforming generally to a right cylinder.

44. A converter as in claim 43, said array being a right circular cylinder and having a peripheral seal therearound.

45. A converter as in claim 42;
said array comprising a plurality of individual elongated members; and
said members being joined at least at one end by an integral bridging means containing said termination.

46. A converter as in claim 45.
said first member having an axis therealong; and
said individual members having generally regular angular intervals therebetween with respect to said axis.

47. A converter as in claim 42;
said array comprising a plurality of individual elongated members; and
said members being joined at least at one end by a separate bridging means containing said termination and linking said members.

48. A converter as in claim 1, said means being adapted for directly delivering said energy to said load.

49. A converter as in claim 1, said load being a fluid pressurizing means powered by the motion of said coupled member.

50. A converter as in claim 1, said means being an oscillating body mechanically coupled to said member at the antinode region thereof.

51. A mechanically resonant energy converter comprising:
elongated outer and inner members,
each of said members having tapering cross-sectional areas characterized by relatively massive endwise terminations and small midportions;
both terminations of said inner member thrusting axially outwardly against the respective terminations of said outer member;
whereby said inner member and said outer member are preloaded respectively in compression and tension; and
and means coupled to at least one of said members for exciting said converter into oscillatory resonance at a resonant frequency thereof,
at least one of said members being adapted for delivering energy at said resonant frequency to a desired load,
said inner member and said outer member together being in total effective length span an integral multiple of the acoustic wavelength therein at said resonant frequency of said converter.

52. A mechanically resonant energy converter comprising:
two principal elongated members;
said members having generally parallel axes;
each of said members constituting approximately a half-wave mechanical transformer and having varying cross-sectional areas tapering from heavy opposite ends to a light midportion of relatively low mechanical impedance;
said members being mutually coupled at their respectively mating ends;
the ends of one of said members thrusting axially outwardly in compression against the restraint imposed by the ends of the second member;

at least one of said ends being adapted for coupling to an energy-exchange device of relatively high mechanical impedance; and

at least one of said midportions being adapted for coupling to an energy-exchange device of low mechanical impedance.

53. A converter as in claim **52**:

said first energy-exchange device being an electromechanical transducer; and

said transducer being positioned between and having a compressive preload thereon applied by said ends.

54. a mechanically resonant energy converter comprising:

elongated outer and inner members;

both of said members being mechanical transformers having relatively massive ends of high mechanical impedance tapering to midportions of lesser impedance;

said members having been assembled endwise in a prestressed condition, said inner member being compressed within the stretched outer member; and

said ends and at least one of said midportions having energy-exchange media of respectively high and low mechanical impedance dynamically coupled thereto.

55. A converter as in claim **54**, both of said midportions being so coupled.

56. A converter for energy:

said converter being mechanically resonant and comprising elongated outer and inner members;

both of said members being mechanical transformers having relatively massive ends of high mechanical impedance tapering to midportions of lesser impedance;

said members having been assembled endwise in a prestressed condition;

said inner member being compressed within the stretched outer member;

said ends and at least one of said midportions having energy-exchange media of respectively high and low mechanical impedance dynamically coupled thereto; and

at least one of said members comprising a pair of separable mechanical transformers that are joined at the midpoint thereof.