The present invention relates to the construction and spring mounting of a vibratable armature in a magnetically energized transducer. Magnetically energized transducers of the type here specifically involve dare typically used for underwater sound propagation and detection. They comprise a housing (usually defining the vibration-producing piston) which contains an electromagnet. When the transducer is used for transforming electrical vibrations into mechanical vibrations, the energization of the electromagnet is varied in accordance with the mechanical vibrations to be produced. An armature is resiliently mounted on the housing in magnetically attractive relationship with the electromagnet, and the armature is therefore caused to vibrate mechanically in accordance with the variations of the electrical signals applied to the windings of the electromagnet. The vibrating armature resists with the housing, causing the latter to vibrate correspondingly.

The vibrations in question are usually at a relatively high rate, such as 500–2000 cycles per second. These vibrations may be produced for an appreciable period of time, either intermittently or continuously. It is imperative that the armature vibrations reflect the electrical signal variations as accurately as possible. This involves a very complex dynamic designing problem. The armature itself must be rigid in order that internal vibrations will not adversely modify the vibration of the armature as a whole. Moreover, the armature should move evenly, without twisting or tipping. The natural resonant frequency of the armature, combined with its spring mounting, must not interfere with the accurate following of the electrical signals by the armature. This in turn is controlled by the mass of the armature and the stiffness of the spring which supports it; the mass of the armature may not be too large nor may the spring stiffness be too small. The spring must permit sufficient amplitude of movement of the armature during its vibrations as to provide a desired power output. The spring must be able to withstand a very large number of flexures without significant fatigue or deterioration. The greater the amplitude of movement permitted the armature, the greater are the stresses exerted on the spring and hence the greater is the tendency for fatigue and deterioration to occur.

The prime object of the present invention is to devise an armature construction and mounting which satisfies all of the above requirements, and in particular which provides an armature construction of optimum magnetic properties yet with a high degree of rigidity, and a spring mounting for that armature which provides the required spring stiffness and amplitude of armature motion, while at the same time minimizing the stresses exerted on the spring, thereby maximizing spring life and minimizing the possibility of fatigue or deterioration. Further, the construction is such that the parts of the transducer can be readily assembled and disassembled. Provision is also made for substantially eliminating the production of unwanted vibration in the assembly.

From a magnetic point of view, the armature is desirably made of thin laminations of magnetic steel sandwiched between non-magnetic laminations. In accordance with the present invention a series of inner and outer clamping rings are associated with the said laminations in order to produce a firmly rigidised armature assembly.

The armature is mounted in the support housing by means of a spring structure of novel design, comprising sinusoid spring lengths extending between the armature and that portion of the spring assembly which engages the housing, the thickness of those sinusoid lengths varying from point to point in a predetermined fashion in order to produce the desired optimum stress distribution when the spring lengths are deformed. The armature construction and the spring construction are closely structurally coupled, so as to produce a rigidised subassembly, thereby to ensure uniform movement of the armature within the housing without appreciable twisting or tilting. The housing and those portions of the spring unit which engage the housing to mount the spring-armature subassembly in place are cooperatively constructed so that vibration of the armature does not adversely affect the housing or give rise to any appreciable undesirable vibrations in the housing.

While the operation of the device of the present invention is described in terms of transducing electrical signals into physical vibration in the nature of sound, it will be understood that the frequency of the vibrations involved is not limited thereto, and that the transducer is equally applicable to a reverse action, changing mechanical vibrations of the armature into fluctuating electrical signals in the magnet windings.

To the accomplishment of the above, and to such other objects as may hereinafter appear, the present invention relates to the construction and arrangement of a magnetotactic transducer, and in particular to the armature construction thereof and the manner in which that armature is spring mounted in the housing, all as defined in the appended claims, and as described in this specification, taken together with the accompanying drawings, in which:

FIG. 1 is a diametrical cross sectional view of a typical embodiment of the present invention;
FIG. 2 is a fragmentary cross sectional view thereof taken along the line 2–2 of FIG. 1; and
FIG. 3 is a cross sectional view, on an enlarged scale, of a portion of the armature and of the spring unit assembled therewith.

For purposes of exemplification the instant invention is here disclosed as embodied in a magnetotactic transducer of the type employed in underwater sonar work, in which transduction is effected between fluctuating electrical signals in the windings of an electromagnet and mechanical vibrations of a spring-mounted armature. As here specifically disclosed, the transducer comprises a housing generally designated 2 defining a vibration-producing piston which is adapted to be immersed in or exposed to a body of water. The housing 2 is formed of two halves 2a and 2b which meet annular surface 4 and which are held in assembled position by split clamp 6. A sealing ring 8 is compressed between the housing halves 2a and 2b at the surface 4 in order to prevent the entry of undesired fluid into the interior of the housing 2. The housing halves 2a and 2b are provided with opposing annular recesses 10a and 10b within which magnetic cores 12a and 12b respectively are received, those cores having
3 a U-shaped cross section. Windings 14a and 14b are received between the legs of the U's in the cores 12a and 12b respectively. The cores 12a and 12b are sealed in place within the respective recesses 10a and 10b by sealing and securing material 16. The end surfaces of the arms of the U's of the cores 12a and 12b respectively are spaced from one another, and define pole faces between which the armature, generally designated 18, is adapted to be received. Electrical connections to the windings 14a and 14b are made in known fashion through the body of the housing 2 from an external electrical connector generally designated 20.

The armature 18, which is of ring shape and which is received in the annular space between the pole faces of the cores 12a and 12b, is designed to be acted upon upon a fluctuating magnetic field. It therefore is desirable, in order to minimize the formation of eddy currents, that the armature be formed of a plurality of alternating magnetic laminations 22 and non-magnetic spacer laminations 24. The magnetic laminations 22 may, for example, be formed of silicon steel, and the non-magnetic spacer laminations 24 may be formed of aluminum. These elements 22 and 24 are, in accordance with the present invention, provided with registering radially inner and outer recesses 26 and 28 respectively.

For clamping the elements 22 and 24 together to produce a rigidified structure, and for connecting the rigidified armature mounting means provided therefor, a composite ring assembly is utilized in accordance with the present invention, as follows: A radially inner ring 30 formed of some suitable structural material such as steel is provided, that ring having a wall 32 with a radially outwardly directed projection 34 extending therearound, the projection 34 fitting snugly within the radially inner recesses 26 on the elements 22 and 24. A radially outer metal ring 36, which may be split rather than continuous, extends around the outer periphery of the ring defined by the elements 22 and 24. The ring 36 comprises a wall 38 having a radially inwardly directed projection 40 therearound which fits snugly into the radially outwardly directed recesses 28 of the elements 22 and 24. The entire assembly is rigidified by an outermost ring 42 which defines a heavy interference fit over the ring 36, and which may be shrunk thereto. The concentric pressure exerted by the ring 42 on the assembly comprising the ring 32, the elements 22, 24 and the ring 36, ensures that maximum structural rigidity of the assembly is obtained.

The spring unit which resiliently mounts the armature 18 between the pole faces of the cores 12a and 12b is generally designated 44. It comprises a ring 46 of appreciable structural rigidity which fits closely and rigidly over the armature ring 42. Extending from either side of the ring 46 are spring walls 48 which, as disclosed, have a sinusoidal shape in cross section and which extend to elongated mounting feet 50. The spring assembly 44 is designed to receive within an annular recess 52 formed in the housing 2, the feet 50 engaging against the axially outer surfaces 54 of the recess 52. The feet 50 are pressed against the surfaces 54, and there held in place, by a split ring 56 which extends around and bears against the radially outer surface 58 of the recess 52.

The spring walls 48 engage the mounting feet 50 at radially inner points. As may be seen from FIG. 1, the axially outer surfaces 54 of the recess 52 are recessed or relieved opposite those radial inner points, as indicated by the reference numeral 60. This permits free flexure of the mounting foot 50 as the armature vibrates without interference by any portion of the housing 2, thereby substantially preventing the production of unwanted vibrations in the housing 2.

The wall thickness of the spring wall 48 contributes in a very important fashion to the production of the desired operating characteristics of the device. As may best be seen from FIG. 3, that wall thickness is not uniform, instead, it is varied in such a fashion as to effect a substantially uniform stress distribution throughout the spring when the armature vibrates. The spring wall 48 is relatively thick where it meets the ring 46 and progressively thin in points representing one-quarter and three-quarters of its length, and is relatively thick at a point representing one-half of its length, with the thickness varying gradually between these points. The relationship between the thickness of the spring wall 48 and positions along the length of that wall from ring 46 to foot 50 may be expressed by the following formula: 

$$t = t_o (1 - \alpha \cos \theta) \frac{1}{2}$$

where \(t_o\) is the thickness at any point \(\theta\) corresponding to the angle \(\theta\) of said sinusoid, with \(\alpha = 0^\circ\) and \(\alpha = 360^\circ\) corresponding to the points where said spring meets the ring 46 and the mounting foot 50 respectively, \(t_o\) is the minimum spring thickness, and \(a\) is a tapering factor.

The following table gives typical dimensions for springs designed in accordance with the present invention, \(r\) being the radius of curvature of the spring wall, as indicated by the arrow \(r\) in FIG. 3, \(R\) being the distance between the line 51 shown in FIG. 3 and the axial center line of the spring unit, and \(t_{min}\) and \(t_{max}\) representing the minimum and maximum thicknesses respectively of the spring:

<table>
<thead>
<tr>
<th>Ring Wall, in.</th>
<th>R, in.</th>
<th>r, in.</th>
<th>t_{min}, in.</th>
<th>t_{max}, in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000</td>
<td>2.201</td>
<td>1.970</td>
<td>0.021</td>
<td>0.044</td>
</tr>
<tr>
<td>0.000</td>
<td>2.353</td>
<td>2.090</td>
<td>0.021</td>
<td>0.044</td>
</tr>
<tr>
<td>0.000</td>
<td>2.505</td>
<td>2.193</td>
<td>0.021</td>
<td>0.044</td>
</tr>
<tr>
<td>0.000</td>
<td>2.658</td>
<td>2.296</td>
<td>0.021</td>
<td>0.044</td>
</tr>
</tbody>
</table>

The amplitude of vibration of the armatures for the 500-cycle, 1000-cycle and 2000-cycle units respectively were approximately 0.021 inch, 0.008 inch and 0.006 inch respectively. Typical weights of the armatures for these three cycles are 13.3 lbs., 43.3 lbs. and 1.3 lbs. respectively.

With constructions of the type here disclosed, the requirements of mass, spring stiffness, armature motion relative to piston motion, stress development within the springs, and longevity are all achieved in a simple and efficient manner, and to a surprisingly greater degree than has heretofore been obtainable with other constructions. It is noteworthy that the armature-spring mounting sub-assembly may readily be inserted into the housing and removed therefrom, thus facilitating assembly, replacement and repair. The spring assembly is not, nor need it be, welded to the housing. The split ring 56 spring mounting foot 50 combination permits the neutral positioning of the armature with the spring wall 48 in a very nearly unbiased state, thus maximizing the life of the device and increasing its accuracy.

While but a single embodiment of the present invention has been here specifically disclosed, it will be apparent that many variations may be made therein, all within the scope of the instant invention as defined in the following claims.

We claim:

1. In an electromechanical transducer comprising a support member, an armature member, and a spring extending between said members and vibratory mounting them relative to one another, said spring being of bellows shape; the improvement which comprises the thickness of said spring being comparatively great at first and second points where said spring meets said members respectively and at a third point substantially midway between said first and second points along the length of said spring and being comparatively small at fourth and fifth points respectively substantially midway between said first and third points and said second and third points.

2. In an electromechanical transducer comprising a support member, an armature member, and a spring extending between said members and vibratory mounting them relative to one another, said spring being of bellows shape; the improvement which comprises the thickness of said spring being comparatively great at first and second points where said spring meets said members respectively and at a third point substantially midway between said first and third points and said second and third points.
ness of said spring being comparatively great at first and second points where said spring meets said members respectively and at a third point substantially midway between said first and second points along the length of said spring and being comparatively small at fourth and fifth points respectively substantially midway between said first and third points and said second and third points, the thickness of said spring varying substantially smoothly between said points.

3. In an electromagnetic transducer comprising a support member, an armature member, and a spring extending between said members and vibratory mounting them relative to one another, said spring being of substantially sinusoidal shape; the improvement which comprises the thickness of said spring being comparatively great at first and second points where said spring meets said members respectively and at a third point substantially midway between said first and second points along the length of said spring and being comparatively small at fourth and fifth points respectively substantially midway between said first and third points and said second and third points, the thickness of said spring varying substantially smoothly between said points.

4. In an electromagnetic transducer comprising a support member, an armature member, and a spring extending between said members and vibratory mounting them relative to one another, said spring being of substantially sinusoidal shape; the improvement which comprises the thickness of said spring being comparatively great at first and second points where said spring meets said members respectively and at a third point substantially midway between said first and second points along the length of said spring and being comparatively small at fourth and fifth points respectively substantially midway between said first and third points and said second and third points, the thickness of said spring varying substantially smoothly between said points.

5. In an electromagnetic transducer comprising a support member, an armature member, and a spring vibratory extending between said members and mounting them relative to one another, said spring being of substantially sinusoidal shape; the improvement which comprises the thickness of said spring varying according to the formula \( t_0 = t \left(1 + a \cos \theta \right) \) where \( t_0 \) is the thickness at any point \( \theta \) corresponding to the angle \( \theta \) of said sinusoid, with \( \theta = 0^\circ \) and \( \theta = 360^\circ \) corresponding to the points where said spring meets said members respectively, \( t_0 \) is the minimum spring thickness, and \( a \) is a tapering factor.

6. In an electromagnetic transducer, an armature member, a support member having a space within which said armature member is received, said space being defined by at least one side wall, and a spring extending between said members and vibratory mounting them relative to one another, said spring being secured to said armature member, extending substantially laterally outtherefrom and terminating in a mounting portion engaging said recess at a side wall thereof, said mounting portion comprising a first part which said spring proper engages and a second part extending substantially longitudinally from said first part, said side wall engaged by said mounting portion being recessed opposite said first part of said mounting portion and physically operatively engaging said mounting portion substantially only at said second part thereof.

7. The combination of claim 6, in which said spring is of bellows shape, its thickness being comparatively great at first and second points where said spring meets said members respectively and at a third point substantially midway between said first and second points along the length of said spring and being comparatively small at fourth and fifth points respectively substantially midway between said first and third points and said second and third points, the thickness of said spring varying substantially smoothly between said points.

8. The combination of claim 6, in which said spring is of substantially sinusoidal shape, its thickness being comparatively great at first and second points where said spring meets said members respectively and at a third point substantially midway between said first and second points along the length of said spring and being comparatively small at fourth and fifth points respectively substantially midway between said first and third points and said second and third points, the thickness of said spring varying substantially smoothly between said points.

9. In the combination of claim 8, an armature comprising a first ring of spacers and magnetic leaves, a radially inner non-magnetic ring locked to said first ring, a radially outer non-magnetic ring locked to said first ring and a radially outermost non-magnetic ring closely fitted over said radially outer ring.

10. The combination of claim 6, in which said spring is of substantially sinusoidal shape, its thickness varying according to the formula \( t_0 = t_s \left(1 + a \cos \theta \right) \) where \( t_0 \) is the thickness at any point \( \theta \) corresponding to the angle \( \theta \) of said sinusoid, with \( \theta = 0^\circ \) and \( \theta = 360^\circ \) corresponding to the points where said spring meets said members respectively, \( t_0 \) is the minimum spring thickness, and \( a \) is a tapering factor.

11. In the combination of claim 10, an armature comprising a first ring of spacers and magnetic leaves, a radially inner non-magnetic ring locked to said first ring, a radially outer non-magnetic ring locked to said first ring and an outermost non-magnetic ring closely fitted over said radially outer ring.

12. In the combination of claim 6, an armature comprising a first ring of spacers and magnetic leaves, a radially inner non-magnetic ring locked to said first ring, a radially outer non-magnetic ring locked to said first ring and an outermost non-magnetic ring closely fitted over said radially outer ring.

13. In an electromagnetic transducer, an armature member, a support member having a space within which said armature member is received, said space being defined by side walls, and a spring extending between said members and vibratory mounting them relative to one another, said spring being secured to said armature member, extending substantially laterally outtherefrom in opposite directions and terminating at each end in a mounting portion engaging said recess at a side wall thereof, said mounting portion comprising a first part which said spring proper engages and a second part extending substantially longitudinally from said first part, said side wall engaged by said mounting portion being recessed opposite said first part of said mounting portion and physically operatively engaging said mounting portion substantially only at said second part thereof.

14. The combination of claim 13, in which said spring is of bellows shape, its thickness being comparatively great at first and second points where said spring meets said members respectively and at a third point substantially midway between said first and second points along the length of said spring and being comparatively small at fourth and fifth points respectively substantially midway between said first and third points and said second and third points, the thickness of said spring varying substantially smoothly between said points.

15. The combination of claim 13, in which said spring is of substantially sinusoidal shape, its thickness being comparatively great at first and second points where said spring meets said members respectively and at a third point substantially midway between said first and second points along the length of said spring and being comparatively small at fourth and fifth points respectively substantially midway between said first and third points and said second and third points, the thickness of said spring varying substantially smoothly between said points.

16. In the combination of claim 15, an armature comprising a first ring of spacers and magnetic leaves, a radially inner non-magnetic ring locked to said first ring, a radially outer non-magnetic ring locked to said first ring.
and an outermost non-magnetic ring closely fitted over said radially outer ring.

17. The combination of claim 13, in which said spring is of substantially sinusoidal shape, its thickness varying according to the formula \( t_s = t_0 (1 + a \cos \theta) \) where \( t_0 \) is the thickness at any point \( \theta \) corresponding to the angle \( \theta \) of said sinusoid, with \( \theta = 0^\circ \) and \( \theta = 360^\circ \) corresponding to the points where said spring meets said members respectively, \( t_0 \) is the minimum spring thickness, and \( a \) is a tapering factor.

18. In the combination of claim 17, an armature comprising a first ring of spacers and magnetic leaves, a radially inner non-magnetic ring locked to said first ring, a radially outer non-magnetic ring locked to said first ring and an outermost non-magnetic ring closely fitted over said radially outer ring.

19. In an electromagnetic transducer, an armature comprising a first ring comprising circumferentially arranged spacers and magnetic leaves, radially inner non-magnetic ring locked to said first ring, a radially outer non-magnetic ring locked to said first ring, and a radially outermost non-magnetic ring closely fitted over said radially outer ring.

No references cited.

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