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[33] **Great Britain**

[31] **19,889/69**

[54] **INDUCTIVE TRANSDUCERS**
14 Claims, 10 Drawing Figs.

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174/65 R, 324/34, 336/179, 336/192, 336/212,
336/219

[51] Int. Cl. **H01f 27/02,**
H01f 27/24

[50] Field of Search **336/212,**
219, 234, 179, 83, 215, 92, 192, 210; 174/65;
324/34, 41

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ABSTRACT: An inductive displacement transducer comprising a hollow cylindrical coil and a plurality of flat U-shaped core pieces spaced from one another around the coil each with one leg within the coil and the other leg outside the coil with the free ends of their legs all at the same end of the coil. Also a compound transducer comprising two such inductive displacement transducers arranged coaxially in a common housing with one transducer serving as the active transducer and the other providing compensation for temperature changes.

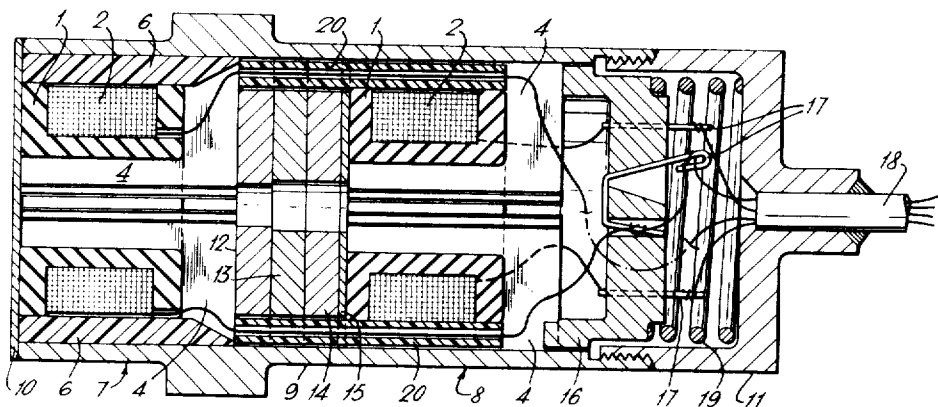


Fig. 1a.

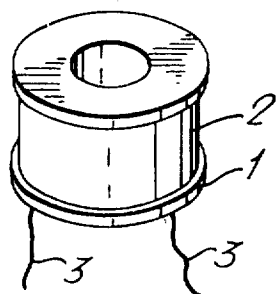


Fig. 1b.

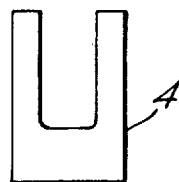


Fig. 1c.

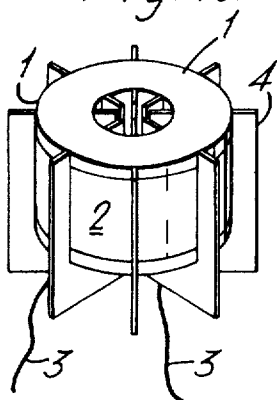


Fig. 1d.

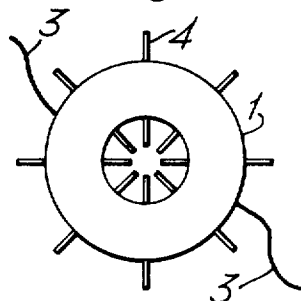


Fig. 1e.

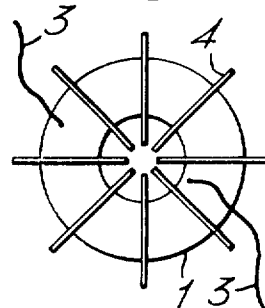


Fig. 1g.

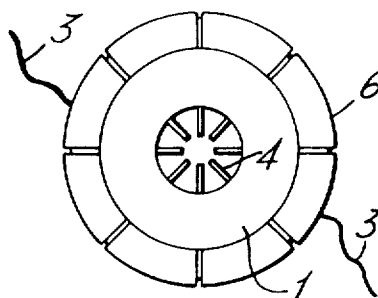
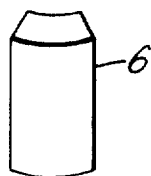
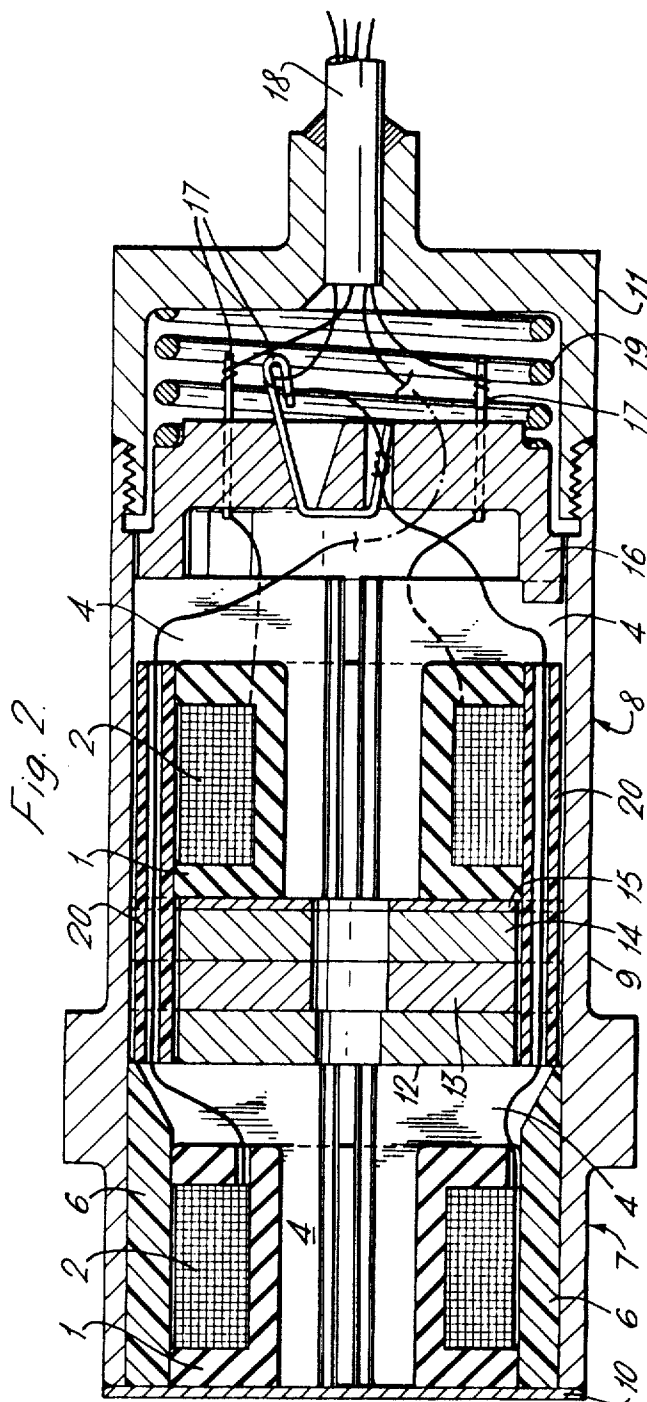


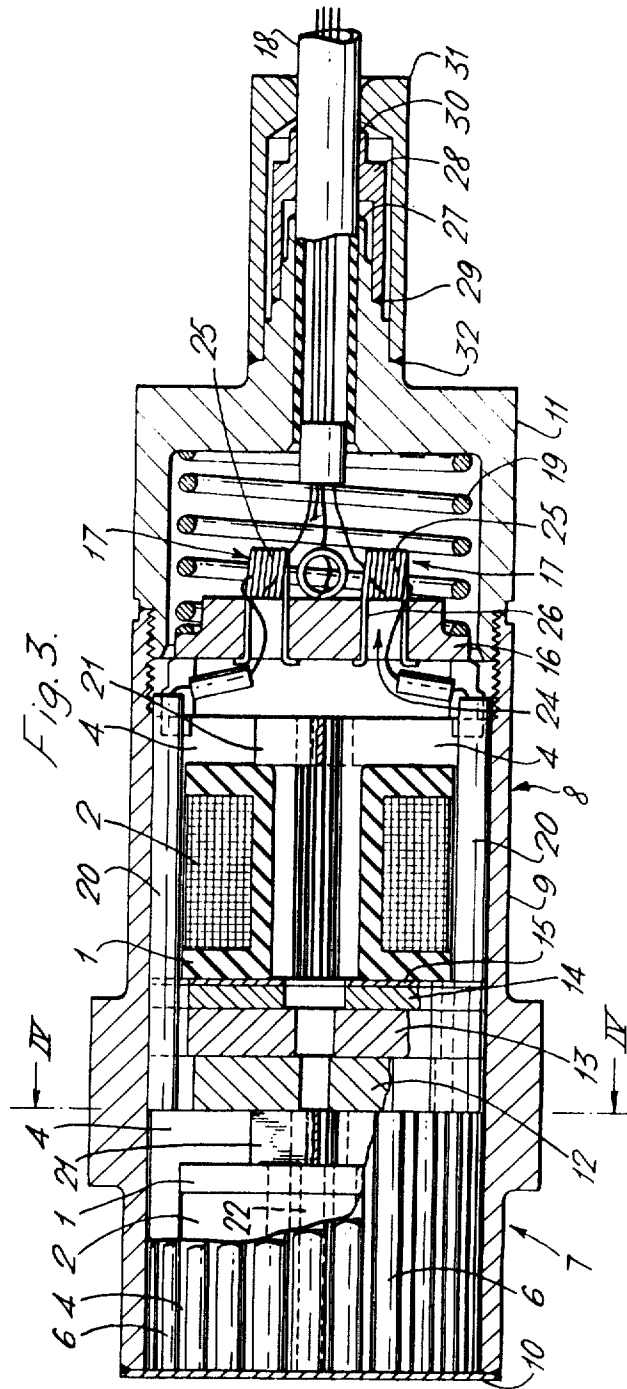
Fig. 1f.



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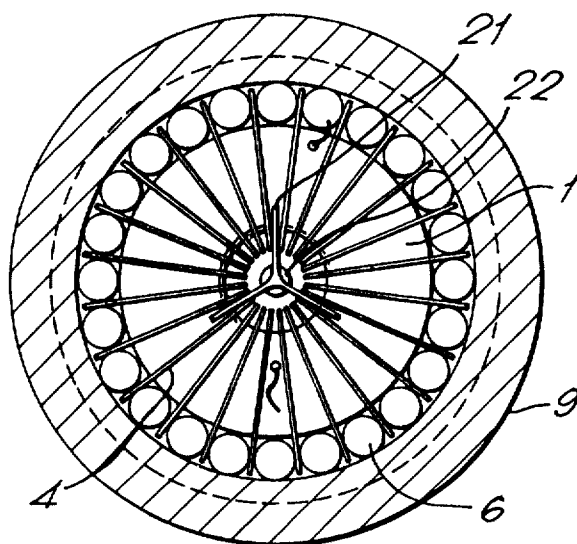
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Fig. 4.



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INDUCTIVE TRANSDUCERS

This invention concerns improvements in inductive transducers and more particularly is concerned with the form of construction of such inductive transducers.

According to this invention there is provided an inductive transducer including a hollow cylindrical coil and a plurality of flat U-shaped core pieces disposed each with one leg within the hollow of the cylindrical coil and the other leg outside of the coil, the core pieces being spaced from one another around the coil and having the free ends of their legs all at the same end of the coil.

In a particularly convenient form of transducer according to this invention the coil is wound upon a right circular hollow cylindrical coil former and the U-shaped core pieces extend radially of the coil former. The core pieces are maintained in spaced-apart relationship with one another by means of spacers which may be in the form of sectors of an annulus disposed around the outside of the coil former or may simply be cylindrical rods, and the whole assembly is cemented within a housing of nonmagnetic material.

To enable the transducer according to the invention to be used in a high-temperature environment, it is preferred that the wire of which the coil is wound has a high-temperature resistant insulation and that the U-shaped core pieces are formed of a material (such as a nickel-iron alloy) having a high permeability and a high curie point.

The transducer according to the invention can be used alone, or alternatively and preferably two substantially identical transducers units can be disposed together in a common housing, one of the transducers being the active transducer for sensing changes in inductive coupling and the other for compensating for temperature or other changes in the environmental conditions of the transducer.

In order that this invention might be understood more clearly three embodiments thereof will now be described by way of example only with reference to the accompanying drawings wherein:

FIGS. 1a to 1g illustrate the components of and stages in the assembly of a simple transducer according to the present invention;

FIG. 2 is an axial sectional view of a compound transducer employing two of the simple transducers shown in FIGS. 1a to 1g;

FIG. 3 is a view similar to that of FIG. 2 of a modified form of the compound transducer of FIG. 2; and

FIG. 4 is a cross-sectional view taken on the line IV—IV of FIG. 3.

FIG. 1a shows a hollow cylindrical coil former 1, formed of alumina, sintered alumina or silicon nitride and having flanged end faces, having wound thereupon a single coil 2 of nonmagnetic wire capable of withstanding high temperature and having high-temperature resistant ceramic or glass insulation. The coil ends are designated by the reference numeral 3.

FIG. 1b shows one of the nickel-iron U-shaped core pieces 4 of which eight are employed in the transducer of FIGS. 1a to 1g. The core piece 4 has a thickness of no more than 0.25 mm. to permit the use of high carrier frequencies without appreciable eddy current loss.

FIGS. 1c, 1d and 1e respectively show perspective, top plan and bottom plan views of the coil former 1 and coil 2 assembly of FIG. 1a assembled with eight of the U-shaped core pieces 4 of FIG. 1b. It will be appreciated that more or less core pieces 4 can be used depending upon the inductance which it is desired that the transducer should present. As shown in the Figures each core piece 4 is disposed radially of the coil 2 with the free ends of the legs of all the core pieces 4 all at the same end of the coil 2.

FIG. 1f is a perspective view of a spacer 6 fashioned in the shape of a sector of an annulus and of the same material as the coil former 1, and FIG. 1g shows eight such spacers 6 disposed around the outside of the assembly shown in FIGS. 1c, 1d and 1e so as to maintain the spacing apart of the core pieces 4. As can be seen, the spacers 6 extend further radially outward

than do the core pieces 4 so that when the assembly shown in FIG. 1g is inserted into a housing the core pieces 4 will not make contact with the walls of the housing.

The assembly shown in FIG. 1g is conveniently cemented by means of a highly temperature-resistant cement, such as a ceramic cement, in a housing formed of austenitic steel.

It can be seen from FIG. 1d for example that the core pieces 4 do not contact one another which reduces eddy current losses and avoids having to provide an insulation layer on the core pieces 4 such as by oxidation. Furthermore the assembly has a central hole 5 which facilitates potting of the assembly and is useful in the construction of the compound transducer shown in FIG. 2.

As shown in FIG. 2 the compound transducer incorporates two of the basic transducer units just described with reference to FIGS. 1a to 1g, such units being designated in FIG. 2 by the reference numerals 7 and 8, within a cylindrical housing 9 of austenitic corrosion-resistant steel which is closed at one end by means of a heat shield 10 also of austenitic steel and at the other end by means of a screw-on end cap 11.

In the transducer of FIG. 2 the transducer unit 7 is the active transducer whereas transducer unit 8 serves as a dummy compensatory or reference transducer. Thus the end face of the transducer which is closed by heat shield 10 is the active end of the transducer.

The housing 9 has an integrally formed partition 12 which separates the two transducer units 7 and 8 and acts as a buffer to prevent the transfer of any pressure acting on the active face of the transducer from the active transducer unit 7 to the dummy transducer unit 8. Disposed between buffer 12 and transducer unit 8 is a reference plate 13 formed of the same material as the material of the target to be monitored (for example, in the particular application where the transducer is designed to measure the displacement of a turbine shaft the plate 13 would be made of turbine shaft material), a ceramic disc 14 of such a thickness as to simulate a working gap, e.g., an air gap, for transducer unit 8 of substantially the mean displacement to be measured at the active face of the compound transducer, and a metal disc 15 of the same material and dimensions as the heat shield and closure member 10 for compensating for changes in the permeability of closure member 10 resulting from temperature variations.

A ceramic termination ring 16 having terminations 17 of temperature-resistant steel wire is provided within the housing 9 for making connection between the ends of the coils 2 of the two transducer units 7 and 8 and a mineral-insulated cable 18 which is hermetically sealed into the end cap 11, the termination ring 16 being held between the transducer unit 8 and the end cap 11 by means of a spiral spring 19 which permits expansion and contraction of the internal transducer assembly with temperature variations. Ceramic tubes 20 convey the ends of the coil of transducer unit 7 past transducer unit 8 to the termination ring 16.

In assembly of the transducer of FIG. 2, having inserted all the component parts of the transducer into the housing 3 and having attached the screw-on end cap 11, alumina powder is inserted into the still open active end of the transducer through the center of transducer unit 7, buffer 12, reference plate 13, ceramic disc 14, metal disc 15 and the center of transducer unit 8 until all body cavities have been filled, the whole being vibrated constantly to ensure that no cavity remains unfilled. The center of transducer unit 7 is then closed with high-temperature cement and the heat shield and end closure 10 and the end cap 11 are electron beam welded in place under high vacuum.

In use the transducer of FIG. 2 can with advantage be employed as two arms of a bridge circuit and will provide a degree of temperature compensation so long as the two transducer units 7 and 8 are in the same temperature environment. By virtue of the construction of the transducer with high-temperature resistant components it can withstand continuous temperature of the order of 600° C. and peak temperatures up to 650° C.

It will be appreciated that a single transducer unit such as shown in FIGS. 1a to 1g can be encapsulated in the same manner as the two transducer units 7 and 8 of FIG. 2, the component parts 7, 12, 13, 14 and 15 of the transducer of FIG. 2 being omitted.

FIGS. 3 and 4 show a modified form of the compound transducer of FIG. 2 and in these three figures the same reference numerals are used to designate like parts. In view of the similarity of the two devices, the following description of the transducer of FIGS. 3 and 4 will relate only to the features of the transducer which differ from corresponding features in the transducer of FIG. 2.

As may be seen clearly from FIG. 4, one respect in which the modified form of the transducer differs from the original form shown in FIG. 2 is in the cross-sectional shape of the spacers 6 which, in both units of the modified transducer, are merely cylindrical rods of circular section, such spacers being more simply manufactured than the spacers shown in FIG. 1f.

In operation of the transducer of FIG. 2 in certain high-pressure environments, the pressure acting on the front face (i.e., the heat shield 10) of the transducer could result in longitudinal compression of the core pieces 4 with consequent variation in the transducer characteristics. To avoid such an effect, the modified transducer of FIGS. 3 and 4 incorporates a star-piece 21 of nonmagnetic steel capable of withstanding high temperatures, the star-piece 21 being in the form of three flat rectangular limbs radiating from a central axis with the limbs lying in planes including the axis and being angularly spaced from each other by 120°, and a support rod 22 of the same material as the spacers 6. The star-piece 21 is designed to sit, in the finished transducer, upon the innermost (with respect to the operative end face of the transducer) end of the coil former 1 of active transducer unit 7 with the limbs of the star-piece 21 disposed between the ends of the core pieces 4 as shown clearly in FIG. 4. The support rod 22 is disposed axially of the active transducer unit 7 with one end bearing on the rear face of the heat shield 10 and the other end bearing against one end of the star-piece 21, the other end of which bears against the partition 12 formed integrally with the housing 9 of the transducer. The core pieces 4, coil former 1, star-piece 21 and support rod 22 are so dimensioned that, in the completed transducer, the core pieces 4 do not feel any pressure exerted on the front face of the transducer such pressure being taken by the support rod 22 and star-piece 21 which together are some two or three thousandths of an inch longer than the core pieces 4. It is preferred also to provide a star-piece 21 in the dummy compensatory transducer unit 8 for the purpose of maintaining the two transducer units as similar one to the other as possible although this is not essential since the dummy transducer unit 8 is not subject to pressure exerted upon the front face of the transducer to the same extent as the active transducer unit 7 by virtue of the intermediate buffer wall 12 which protects it. The star-piece 21 in the dummy transducer unit 8 is cemented in position on top of the coil former of that transducer.

Referring now more closely to the form of the termination ring 16 and the terminals 17 fitted thereto in the modified transducer of FIGS. 3 and 4, it will be seen that these also have been modified. The basic cup-shaped form of the termination ring 16 is maintained, with the rim of the cup pressing upon the ends of the core pieces 4 as in the transducer of FIG. 2 to maintain the dummy compensatory transducer unit in position, but the termination ring now has four holes 24 (two of which are visible in FIG. 3) each of which accommodate a terminal in the form of a close-wound spiral spring 25 of nonmagnetic material which has been compressed so as to permit its ends 26 to be lodged in the hole in the termination ring, the extremities of the spring ends 26 being turned away from one another as shown in FIG. 3 so as to lock the spring 25 in the hole. The resilience of the springs 25 ensures that they are retained in the holes 24 in the termination ring 16. By forcing the leadout wires of the two transducer, i.e., the active transducer and the dummy compensatory transducer, between the

turns of the terminal springs 25 a mechanical contact is obtained which is not susceptible in high-temperature environments to deterioration or failure as are the welded or brazed contacts of the transducer of FIG. 2.

Finally, the transducer of FIGS. 3 and 4 differs from that of FIG. 2 in respect of the fitting to the transducer of the mineral-insulated cable 18. As shown in FIG. 3, the screw-on end cap 11 of the transducer has a hollow protrusion into which the cable 18 is fitted and a first electron-beam weld of the protrusion to the metallic sleeve of the cable 18 is formed at 27. A sleeve 28 is then fitted over the cable 18 and the end of the protrusion and is electron-beam welded to the protrusion and to the cable at 29 and 30 respectively, and finally an outer sleeve 31 is fitted and is electron-beam welded to the end cap protrusion at 32. By this means, the sealing of the cable to the transducer is made extremely secure.

If desired the space within the end cap 11 may be filled with high-temperature ceramic wool before the end cap is fitted to the transducer. Furthermore, if the component parts of the transducer are manufactured to sufficiently high tolerances, it is no longer necessary to fill the internal cavities of the transducer with alumina powder though, if desired, this can be done.

There have thus been described inductive transducers of particularly advantageous construction which can be used in high-temperature environments. By virtue of the construction of the core of the transducer in the form of a number of spaced flat U-shaped core pieces parallel eddy currents are reduced which enables the transducer to be used with a high carrier frequency.

I claim:

1. An inductive displacement transducer comprising a hollow cylindrical coil; a magnetic core associated with said coil, said magnetic core being formed as a plurality of U-shaped core pieces disposed each with one leg within the hollow of said coil and the other leg outside of the coil, the said U-shaped core pieces each comprising a single nonlaminated wafer having parallel flat faces and being disposed spaced apart from one another around the coil and having the free ends of their legs all at the same end of the coil; a plurality of nonmagnetic electrically insulating spacers fitted between the outermost legs of adjacent ones of said U-shaped core pieces around the outside of the coil, the thickness of said spacers in the radial direction with respect to the axis of said core being greater than the width of the outermost legs of said U-shaped core pieces in said radial direction whereby the spacers extend outwardly beyond the U-shaped core pieces in the radial direction; a cylindrical nonmagnetic housing into which said coil, said core and said spacers are fitted, the coil extending coaxially with the housing and the spacers contacting the inner cylindrical surface of the housing; and terminals in said housing coupled to said coil.

2. A transducer according to claim 1 wherein said cylindrical housing is closed at both ends and pressure-resisting support means extend between the housing end closures within the housing, said pressure resisting support means serving to prevent compression of the said U-shaped core pieces in the direction of the axis of the said coil as the result of pressure induced forces applied to one of the said housing end closures.

3. A transducer according to claim 2 wherein said pressure-resisting support means comprises a nonmagnetic support rod disposed to extend coaxially through the said coil, and a nonmagnetic star-piece disposed between the end face of the coil remote from the free ends of the legs of the said U-shaped core pieces and the adjacent end closure of the said housing, the said star-piece having at least three limbs which extend in different directions between the parts of said U-shaped core pieces which traverse said end face of the coil and serve to space said end face of the coil from the adjacent end closure of the housing, and the said support rod bearing against the said star-piece and against the other end closure of the housing, the said star-piece and support rod together being longer in the axial direction than the said U-shaped core pieces.

4. A compound inductive displacement transducer comprising a cylindrical housing; an active transducer unit within said housing; a compensatory transducer unit within said housing; said active and compensatory transducer units being substantially identical to each other and each comprising, in combination, a hollow cylindrical coil disposed coaxially with said housing, a magnetic core associated with said coil, said magnetic core being formed as a plurality of U-shaped core pieces disposed each with one leg within the hollow of said coil and the other leg outside of the coil, the said U-shaped core pieces each comprising a single nonlaminated wafer having parallel flat faces and being disposed spaced apart from one another around the coil with the free ends of their legs all at the same end of the coil, a plurality of nonmagnetic electrically insulating spacers fitted between the outermost legs of adjacent ones of said U-shaped core pieces around the outside of the coil, the thickness of said spacers in the radial direction with respect to the axis of said coil being greater than the width of the outermost legs of said U-shaped core pieces in said radial direction whereby the spacers extend outwardly beyond the U-shaped core pieces in the radial direction into contact with the inner cylindrical surface of the housing; and terminals in said housing coupled to the coils of the two transducer units.

5. A compound transducer according to claim 4 wherein a reference plate formed of the same material as a target to be monitored by the transducer is disposed between the active and the compensatory transducer units to provide compensation for variation of the magnetic permeability of the target with ambient temperature variation, and a ceramic spacer disposed between said reference plate and the compensatory transducer to simulate, for the compensatory transducer, a working gap substantially equal to the mean operational working gap at the active face of the active transducer unit.

6. A compound transducer as claimed in claim 4 further including a heat shield at one end of said housing in front of the active face of the active transducer unit, and a compensating shield formed of the same material and in the same dimensions as said heat shield disposed in front of the compensatory transducer unit to provide compensation for variation with temperature of the magnetic permeability of the heat shield.

7. A compound transducer as claimed in claim 4 wherein said terminals comprise close-wound spiral springs fitted to a ceramic terminal block secured within the housing.

8. A compound transducer as claimed in claim 4 wherein said housing has an integrally formed internal partition which divides the interior of the housing into front and rear sections, said active transducer unit being disposed in the section and said compensatory transducer unit being disposed in the rear section, and wherein pressure-resisting support means extend through the coil of the active transducer, from a closure member at the active face of the transducer to said partition.

9. A compound transducer as claimed in claim 8 wherein said pressure-resisting support means comprises a nonmagnetic support rod extending coaxially through the said coil, and a nonmagnetic star-piece disposed between the end face of the coil remote from the free ends of the legs of the said U-shaped core pieces and the adjacent end closure of the said housing, the said star-piece having at least three limbs which extend in different directions between the parts of said U-shaped core pieces which traverse said end face of the coil from the adjacent end closure of the housing, and the said support rod bearing against the said star-piece and against the other end closure of the housing, the said star-piece and support rod together being longer in the axial direction than the said U-shaped core pieces.

10. A compound transducer as claimed in claim 8 wherein the said compensatory transducer unit is disposed next to said

partition in the rear section of the housing, wherein a substantially cylindrical terminal block carrying said terminals is disposed next to the said compensatory transducer unit in the rear section of the housing, and wherein a compression spring member is disposed next to said terminal block, said spring member being compressed between a closure member of the housing and said terminal block to maintain the compensatory transducer unit and the terminal block in position.

11. A compound inductive displacement transducer comprising a cylindrical housing; an active transducer unit fixed within said housing; a compensatory transducer unit fixed within said housing; said active and compensatory transducer units being substantially identical to one another and each comprising a hollow cylindrical coil disposed coaxially with said housing and a plurality of flat U-shaped core pieces spaced from one another around the coil and each having one leg within the hollow of the coil and the other leg outside of the coil with the free ends of their legs all at the same end of the coil; terminals in said housing coupled to the coils of the two transducer units; a heat shield at one end of said housing in front of the active face of the active transducer; and a compensating shield of the same material and dimensions as said heat shield disposed in front of the compensatory transducer unit to provide compensation for variation with temperature of the magnetic permeability of the heat shield.

12. A compound inductive displacement transducer comprising a cylindrical housing having an integrally formed internal partition which divides the interior of the housing into front and rear sections, an active transducer unit fixed within the front section of said housing; a compensatory transducer unit fixed within the rear section of said housing; said active and said compensatory transducer units being substantially identical to one another and each comprising a hollow cylindrical coil disposed coaxially with said housing and a plurality of flat U-shaped core pieces spaced from one another around the coil and each having one leg within the hollow of the coil and the other leg outside of the coil with the free ends of their legs all at the same end of the coil; terminals in said housing coupled to the coils of the two transducer units; and pressure-resisting support means extending through the coil of the active transducer and extending between a closure member at the active face of the transducer and said partition.

13. A compound transducer according to claim 12 wherein said pressure-resisting support means comprises a nonmagnetic support rod extending coaxially through the said coil, and a nonmagnetic star-piece disposed between the end face of the coil remote from the free ends of the legs of the said U-shaped core pieces and the adjacent end closure of the said housing, the said star-piece having at least three limbs which extend in different directions between the parts of said U-shaped core pieces which traverse said end face of the coil and serve to space said end face of the coil from the adjacent end closure of the housing, and the said support rod bearing against the said star-piece and against the other end closure of the housing, the said star-piece and support rod together being longer in the axial direction than the said U-shaped core pieces.

14. A compound transducer according to claim 12 wherein the said compensatory transducer unit is disposed next to said partition in the rear section of the housing, wherein a substantially cylindrical terminal block carrying said terminals is disposed next to the said compensatory transducer unit in the rear section of the housing, and wherein a compression spring member is disposed next to said terminal block, said spring member being compressed between a closure member of the housing and said terminal block to maintain the compensatory transducer unit and the terminal block in position.

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