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(71) Applicants
Hans List,
126 Heinrichstrasse,
Graz, Austria.
(72) Inventors
Peter Krempl,
Peter Claassen,
Helmut List.
(74) Agents
Barker, Brettell & Duncan,
138 Hagley Road,
Edgbaston,
Birmingham,
B19 9PW.

(54) A transducer for measurement of mechanical values on pipes

(57) The invention provides a flexible piezo-electric transducer comprising a piezo-electric film having its opposed faces in contact with electrically conducting surfaces to form a sensor element (5). The sensor (5) is attached to an electrically insulating tape (4).

The tape (4) has a self-adhesive coating and is of sufficient length so that in use one or more turns can be wound around a pipe (8) and mounted thereon by the adhesive.

Variations in diameter of the pipe (8) due to pressure within the pipe are transmitted to the sensor (5) by friction between the pipe (8) and the piezo-electric film. The charge is taken off from terminals (6, 7).

FIG. 3

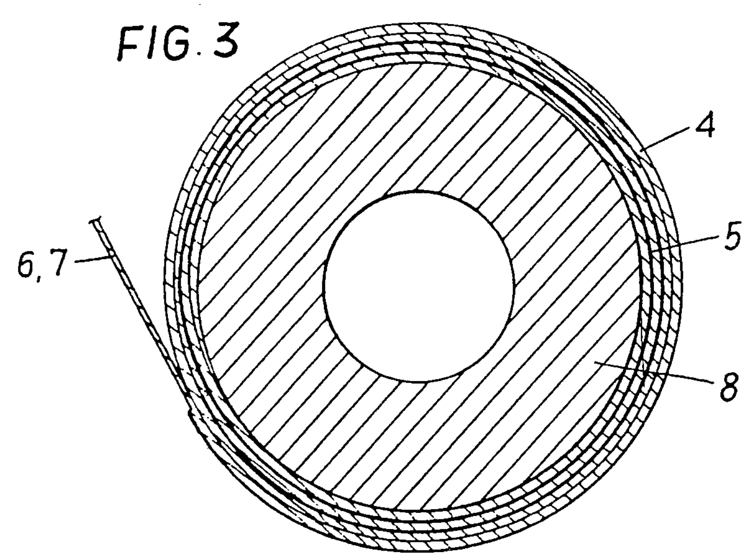

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FIG. 1

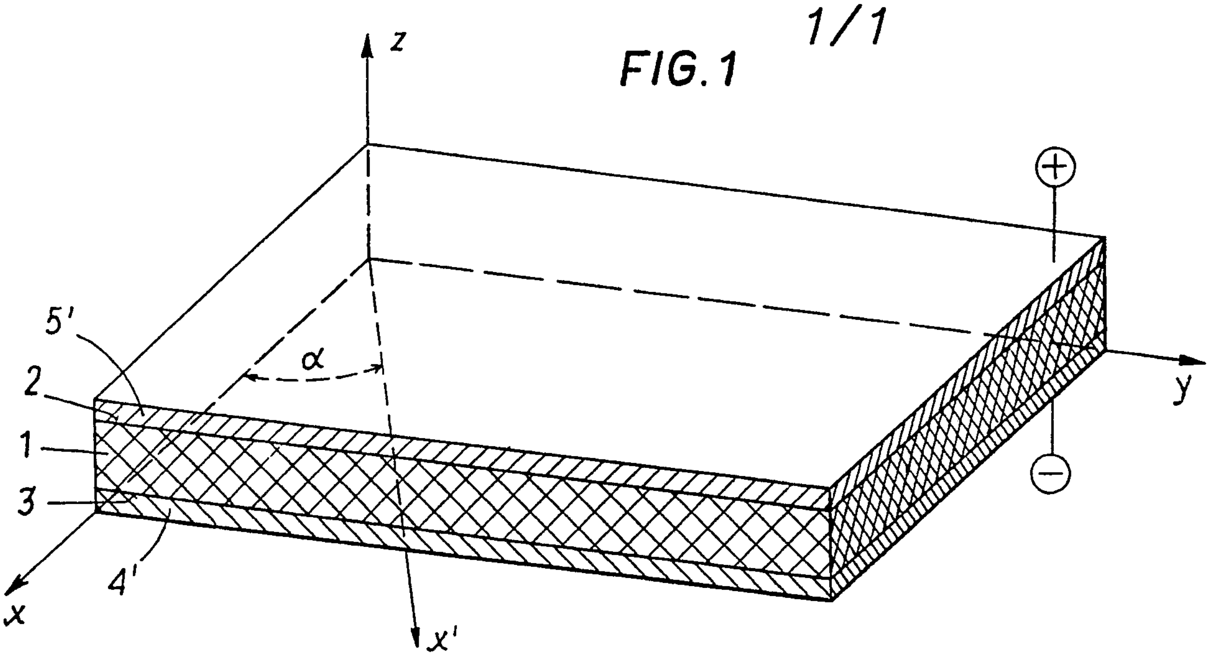


FIG. 2

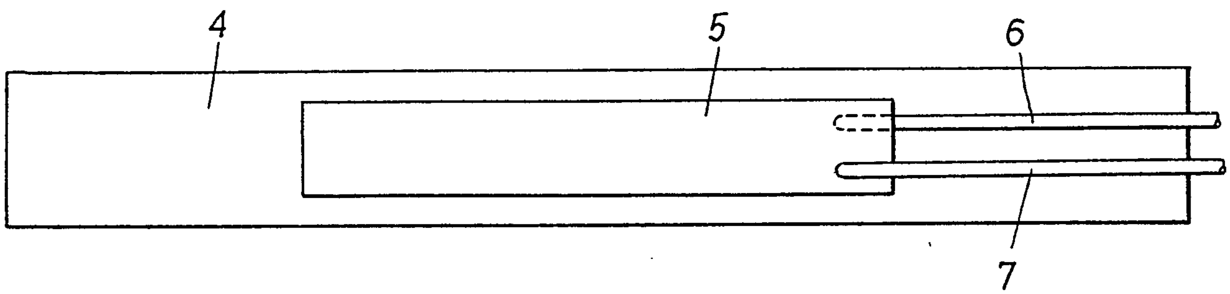
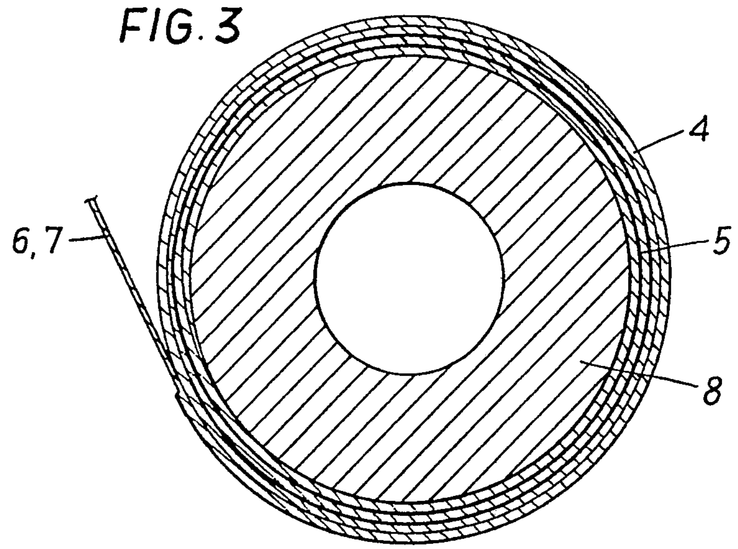


FIG. 3



SPECIFICATION

A transducer for measurement of mechanical values on pipes

This invention relates to a transducer comprising a piezo-electric measuring sensor element for measurement of pressure distribution within pipes.

Transducers of the kind referred to above are known especially for the measurement of pressure distribution in the fuel injection pipes of injection combustion engines, mainly diesel engines, whereby from the pressure trace conclusions can be drawn in regard to the function of the injection pump and the injection valves.

For the example of pressure measurements in diesel injection pipes the basic idea is that pressure within the pipe is plotted as a function of time. Pressure rise in the pipe causes an enlargement of the cross-sectional-area and therefore of the circumference of the pipe, said enlargement being measurable.

It is known to use piezo-electric transducers and to transmit the pressure pulsations of the injection pipe by means of a transmitter member to a piezo-electric disc of single crystal or ceramic. Arrangements of this kind are very expensive and have the disadvantage of having a relatively large mass which is exposed to strong acceleration forces due to vibrations of the injection pipe in a direction perpendicular to the pipe axis. Those forces can cause deformations of the pipe which are superposed to the deformations caused by the pressure pulsations transmitted to the piezo-electric disc, thereby falsifying the pressure measurement. These problems occur with all those transducers measuring pressure distribution by way of deformation of the pipe and in which the transducer mass is not small enough to avoid measurable deformation of the pipe caused by vibrations of the whole pipe. Because of this care has to be taken that vibration-caused deformations of the transducer mounting arrangement itself are not transmitted to the sensor element.

Another problem especially with pipes which are subject to strong bending vibrations is that the pipes are stretched at one part of the circumference and compressed on the opposite part. These stretches and compressions alternating with the vibration phases may be larger than the pressure-caused stretch of the pipe circumference. Locally sensing transducers which register the stretch of only a part of the circumference therefore disadvantageously also sense surface variations caused by vibrations and can give a strongly falsified measuring result.

It is also known to attach strain gauges on pipes to measure stretch of the pipe or pressure within the pipe respectively. Strain gauges have a number of advantageous properties, e.g. flexibility and little mass, and they are very well suitable for both static and dynamic measurements. However, an arrangement is necessary which guarantees a reproducible initial tension of the strain gauge. In the case where the initial tension of the strain gauge is subject to greater variations caused by mounting, thermal expansion or the like, the necessary adjustment of the expensive measuring bridge needs additional operations. Such additional work never can be avoided when the relative dynamic stretches to be measured are in the order of 10^{-5} and lower. The mentioned difficulties occur on all strain gauges the physical properties of which are used to measure vibrations of length and which depend on the absolute value of the length.

In measurements for instance on diesel injection pipes the measuring results are often strongly falsified by the already mentioned vibrations. Compensation of this influence can be achieved - if at all - only by use of expensive special strain gauges and only by assignment of skilled personnel. On grounds of the mentioned disadvantages strain gauges are, despite their merits, not practical for quick workshop diagnosis of injection systems of diesel engines, for example.

It is the aim of the invention to provide a transducer which makes possible the quick measurement of the pressure distribution within pipes, which are not provided with special arrangements for such measurements, whereby much preparatory work is avoided. For measurements on pipes disconnection of the same for application of a pressure transducer should be avoided because it is often impossible to interrupt the operation of a plant, also, disconnection of the pipe takes time, and the risk of soiling the inside of the pipe must be avoided.

The present invention consists in a transducer comprising a piezo-electric measuring sensor element for measurement of pressure distribution within pipes, wherein the piezo-electric measuring sensor element is a flexible piezo-electric film, the opposite surfaces of said film being in connection with electrically conducting contact surfaces, the measuring sensor element being mounted on a flexible insulating support extending beyond the sensor, and being closely joinable to the surface of the pipe by means of the flexible insulating support, and at least the periphery portion of said insulating support being coated with adhesive.

The flexible insulating support in use serves as an intermediate member for converting the gripping force or tension applied through the support into contact pressure relative to the pipe which is essential for the correct functioning of the sensor element.

According to another aspect, the invention includes a method of mounting on a pipe an elongate flexible piezo-electric transducer formed from a piezo-electric sensor element mounted on an insulating tape, the tape having adhesive on at least the peripheral portions of one face thereof, the steps of the method comprising frictionally pressing the sensor element against the pipe and then winding under tension one or more turns of the tape around the pipe to mount the transducer and to gain the desired initial tension during the attaching process.

The design of a transducer according to the invention enables simultaneous use of the advantageous properties of strain gauges i.e. flexibility, little mass and therefore rapid response, stretchability and stretch sensitivity - and of the advantageous properties of piezo-electric sensors i.e. direct measurement of relative variations from any given base level, compression sensitivity, simple electronic processing of the charge signals -, whereby the disadvantages of both transducer principles are avoided.

The piezo-electric film which is advantageously chosen only a few μ thick forms the dielectric of a capacitor, the electrically conducting surfaces being used as the capacitor electrodes. The sensor element therefore can be used also for capacitive measurement of pressure distribution. This is an essential advantage because static or quasi-static and low frequency processes which cannot be measured piezo-electrically due to the limited insulation resistance, can be measured capacitively. The use of a flexible, piezo-electric film as a sensor element in a pressure transducer makes it possible for the first time to apply one and the same transducer alternatively for piezo-electric or capacitive measurement of pressure distribution without the necessity of additional mounting devices.

The use of a flexible piezo-electric film as a measuring sensor element in a transducer according to the invention gives the advantage that the sensor element may be joined closely to cylindrical surfaces, so that good stretch, friction, and contact pressure between the surface of the body to be measured and the sensor element is attained whereby precise measurement is possible.

There are known a number of flexible dielectrics in the form of foils or films, most of which may be considered as electrets in the sense that they possess a semi-permanent electric polarisation, the outer field of which is compensated by surface charges which are also semi-permanent. Such piezo-electrics show a longitudinal piezo-electric effect in the direction of the Z-axis (axes according to the IRE-convention) and transversal piezo-electric effects in the direction of the X- or Y-axis respectively. Some known piezo-electrics are for instance Polyvinylidene-Fluoride (PVDF), Polyvinyl-Fluoride (PVF), Polyvinyl-Chloride (PVC), Polyacrylonitrile (PAN), Polymethyl-Methacrylate (PMMA), fluorinized Ethylene-Propylene (FEP), Polystyrene, Polyethylene (PE) and its Terephthalate, Polycarbonate, Polysulfonate, and Nylon.

The invention has the further advantage that by way of the elastic cross-contraction in the Z-direction, amplification of the piezo-electric and capacitive stretch sensitivity is obtained. Enlargement of a pipe may moreover be measured by means of a transducer according to the invention also over the longitudinal piezoeffect if the sensor element is so attached that the pipe stretch exerts pressure perpendicular to the surface of the sensor film. In many applications of the invention the piezo-electric film will be subject to forces which cause stretch in the film parallel to the surface and pressure perpendicular to the surface of the film. This combination of stretch and pressure gives rise to an especially high sensitivity.

According to a further feature of the invention it may be advantageous to provide flexible interposition layers between the piezo-electric film and the surface of the body to be measured. These layers are additional to the flexible support and may serve as an electrical insulation, as protection against mechanical damage, or for taking charge off the piezo-electric film.

It is further advantageous to provide a piezo-electric film consisting of a monoaxial-orientated polymer. Polymers of this kind have an especially high piezo-electric sensitivity, therefore they are particularly suitable for transducers in the sense of the invention.

According to the invention the piezo-electric film may consist of Polyvinylidene-Fluoride, preferably of monoaxial-orientated β-Polyvinylidene-Fluoride. Among the above-mentioned piezo-electric Polymers Polyvinylidene-Fluoride has an especially high piezo-electric sensitivity and a big dielectric constant. Ordinary PVDF is a mixed form of α- and β-PVDF. The α/β - mixed form of PVDF can be brought into the monoaxial-orientated β-form by stretching the PVDF-film inelastically, whereby the direction of the maximum sensitivity is identical with the direction of stretch. A PVDF-film pretreated in this manner has an especially high piezo-electric stretch sensitivity in X-direction which is about ten times higher than the sensitivity in Y-direction. This high piezo-electric sensitivity and the eminent chemical and physical stability makes this material particularly suitable for the use as a piezo-electric film.

It may be of particular advantage to form the aforementioned electrically conducting contact-surfaces by thin electrically conducting layers firmly connected to the surface of the piezo-electric film. Said layers may be made for instance of metal, deposited by evaporation or of an electrically conducting varnish.

According to the invention it is especially advantageous if the piezo-electric film is a strip of a monoaxial-orientated polymer under initial tension, the direction of the initial tension X′ and the direction X of the maximum piezo-electric stretch sensitivity of the film enclosing an angle of less than 45 degrees. For that purpose the film is stretched around a pipe, or pressed on it in such a manner that tangential initial tension occurs. Due to this orientation of the film radial stretch of the pipe causes stretch of the piezo-electric film predominantly in the direction of its highest piezo-electric stretch sensitivity, said direction being, in the film of monoaxial-orientated PVDF, the direction of the X-axis. By this arrangement of a sensor element embracing the pipe the radial and primarily only pressure generated stretch of the pipe is registered in an intensified measure. Parasitic stretches and compressions of the pipe parallel to the axis of the pipe and therefore parallel to the Y-axis of the film, however, can cause only little interference due to the much less piezo-electric sensitivity in this direction. By these means and the use of, for instance, monoaxial PVDF weakenening of vibration interference down to 1/10 of the interference which occurs when using piezo-electric films which are isotropic in X- and Y-direction is attainable. This advantage is still preserved if the film is so arranged that its direction of orientation encloses an acute angle with the above-mentioned direction of maximum piezo-electric stretch sensitivity.

An especially advantageous embodiment of a transducer according to the invention is achieved when the sensor element formed from the film and the electrically conducting layers is attached on an electrically insulating tape constituting the flexible support. This embodiment is particularly suitable for stretch measurement on cylindrical surfaces, above all for stretch measurement on pipes of any diameter. The tape is stuck around the pipe, the eventually desired initial tension is gained during the attaching process. In the case where stretch of an object having an electrically conducting surface is to be measured the sensor element can be attached in a manner that the electrode adjacent to the measuring surface is connected to earth. Measurement is then carried out as with a unipolar piezo-electric transducer and the insulating tape forms a protective foil for the sensor element.

It may also be advantageous if at least the periphery portions of the insulating tape have a self-adhesive coating on the side facing the sensor element. This makes the mounting of the sensor element easier and cheaper.

Transducers applied by means of adhesion have advantageously practically no vibration mass, however, application for instance for stretch measurement on badly soiled and oily pipes makes cleaning of the measuring point necessary. For this range of application the measuring strip may be stretchable at least once around the pipe and applied as a tension binder.

For measurements on pipes which are subject to heavy bending vibrations it is particularly advantageous to choose the direction of minimal piezo-electric stretch sensitivity of the film substantially parallel to the axis of the pipe. In this case the signals generated by the bending vibrations are negligibly small. According to a further arrangement such signals may be entirely compensated by attaching the piezo-electric film surrounding the pipe once or an integer multiple of one. The signals generated by the stretches and compressions at diametrically opposite points of the circumference of the pipe caused by the bending vibrations are inverse and of the same amount so that a simple compensation is attained.

The same effect is achieved if the transducer is provided with a number of sensor elements arranged symmetrically to the longitudinal axis of the pipe.

To perform measurements on pipes, it may be advantageous to stick the piezo-electric flm directly on the surface of the pipe by means of an adhesive. In this case a particularly simple and stretch-transmitting connection between the sensor element and the hollow body is achieved. This type of attachment is particularly suitable for production line testing of injection pipes of internal combustion engines.

Determination of the time response and local stretch condition of a pipe is possible if a number of measuring sensor elements according to the invention are attached to the pipe along its longitudinal axis. Said stretch condition may be caused for instance by pressure within the pipe or by a body moving within the pipe and being at least partially in contact with the inner surface of said pipe. In particular, determination of the propagation of pressure or shock waves within a pipe is possible, thereby avoiding points of disturbance caused by sensor elements arranged on the inner surface of or pressure sensing openings in said pipe. With such an arrangement it is further possible to determine movement of a body within a pipe, for instance the movement of a piston within a cylinder or the movement of a projectile within a gun barrel.

The invention will now be more specifically described by way of example with reference to a preferred embodiment depicted in the accompanying drawings wherein:

Figure 1 is a section of a sensor element used in the invention in schematic representation,

Figure 2 a strip transducer according to the invention extended longitudinally, and

Figure 3 shows a cross section of the transducer of Figure 2 attached to a pipe.

Figure 1 is a section of a piezo-electric film 1 forming a sensor element having contact surfaces 2 and 3, the crystallographical axes of the sensor element being referenced X, Y, and Z. In monoaxial-orientated polymers direction X is chosen as the direction of the maximum stretch sensitivity parallel to the surface of the film. The direction of the initial tension is referenced X′. In most applications it will be advantageous to have angle α between the direction X of maximum sensitivity and direction X′ of initial tension between zero and 45 degrees. Contact surfaces 2 and 3 of film 1 are each formed by an electrically conducting layer 4′, 5′ consisting of metal evaporated on the film or of a conductive varnish. At least one of the contact surfaces 2, 3 may be provided with an insulated electrical connection leading to a charge collector or directly to an electrical measuring circuit.

Figure 2 shows a sensor element 5 consisting of a flexible piezo-electric film attached to an electrically insulating tape 4 constituting the flexible support. For charge take off terminals or printed contacts 6 and 7 are connected to the contact surfaces of the sensor element 5. Figure 3 shows the sensor element of Figure 2 attached to a pipe 8, the free ends of the charge take off terminals 6, 7 being schematically indicated.

On the side facing the sensor element the tape 4 has a self-adhesive coating at least on the periphery portions which projects over the sensor element 5. When sticking the tape 4 on pipe 8 sensor element 5 is frictionally pressed against the pipe. Variations of the diameter of pipe 8 therefore are transmitted to sensor element 5 by friction between pipe 8 and the piezo-electric film. The sensor element itself is not stuck on the pipe.

When mounting the transducer on a pipe, the necessary gripping force or initial tension is applied to the sensor element 5 as the tape is applied to the pipe in the manner of a tension binder. Where more than one turn is applied each turn is stuck to the preceding turn. Variations in pipe dimensions are transmitted to the sensor elements by friction.

CLAIMS

1. A transducer comprising a piezo-electric measuring sensor element for measurement of pressure distribution within pipes, wherein the piezo-electric measuring sensor element is a flexible piezo-electric film, the opposite surfaces of said film being in connection with electrically conducting contact surfaces, the measuring sensor element being mounted on a flexible insulating support extending beyond the sensor and being closely joinable to the surface of the pipe by means of the flexible insulating support, and at least the periphery portions of said insulating support being coated with adhesive.

2. A transducer according to Claim 1 wherein the flexible insulating support is coated with adhesive on that side facing the sensor.

3. A transducer according to Claim 1 or Claim 2, wherein in addition to the flexible support the piezo-electric film is provided with flexible interposition layers so arranged that in use said interposition layers are disposed between the film and the surface of the pipe.

4. A transducer according the any one of Claims 1 to 3, wherein the piezo-electric film consists of a monoaxial-orientated polymer.

5. A transducer according to any one of Claims 1 to 4, wherein the piezo-electric film consists of Polyvinylidene-Fluoride.

6. A transducer according to Claim 4 or Claim 5, wherein the piezo-electric film is a strip under initial tension, the direction of the initial tension X' and the direction X of the maximum piezo-electric stretch sensitivity of the film enclosing an angle of less than 45 degrees.

7. A transducer according to any one of the Claims 1 to 6, wherein the electrically conducting contact surfaces are formed by thin electrically conducting layers connected firmly to the surface of the piezo-electric film.

8. A transducer according to Claim 7, wherein the sensor element formed by the film and the electrically conducting layers, is attached to an electrically insulating tape constituting said flexible support.

9. A transducer according to Claim 8, wherein at least the periphery portions of the insulating tape have a self-adhesive coating on the side facing the sensor element.

10. A transducer according to any preceding claim wherein only the periphery portions of the flexible support or tape are coated with adhesive.

11. A transducer according to any preceding claim wherein the sensor element is mounted on the flexible support by means of the adhesive coating.

12. A transducer according to any preceding claim, wherein the piezo-electric film is arranged and adapted so that in use on a pipe the film embraces the pipe once or an integer multiple of one.

13. A transducer as hereinbefore described with reference to and illustrated by the accompanying drawings.

14. A method of mounting on a pipe an elongate flexible piezo-electric transducer formed from a piezo-electric sensor element mounted on an insulating tape, the tape having adhesive on at least the peripheral portions of one face thereof, the steps of the method comprising frictionally pressing the sensor element against the pipe and then winding under tension one or more turns of the tape around the pipe to mount the transducer and to gain the desired initial tension during the attaching process.

New claims or amendments to claims filed on 16.12.81, 25.1.82.
Superseded claims 1-14.
New or amended claims:-

CLAIMS

1. A transducer comprising a piezo-electric measuring sensor element for measurement of pressure distribution within pipes, said sensor element being formed from a flexible piezo-electric film the opposite surfaces of which are coated with a conductive material to provide electrically conducting contact surfaces, wherein the sensor element is mounted on a flexible insulating support which extends beyond the sensor elements and the transducer is mountable on the pipe by means of the flexible support, and wherein at least the peripheral portions of the support on one side thereof are coated with an adhesive for mounting the transducer, and the arrangement being such that the support is of such length that it can be wrapped around the pipe at least once so that in use it serves as a tension binder and gives the sensor element the desired initial tension during mounting.

2. A transducer according to Claim 1 wherein the flexible insulating support is coated with adhesive on that side facing the sensor element.

3. A transducer according to Claim 1 or Claim 2, wherein in addition to the flexible support the piezo-electric film is provided with flexible interposition layers so arranged that in use said interposition layers are disposed between the sensor element and the surface of the pipe.

4. A transducer according the any one of Claims 1 to 3, wherein the piezo-electric film consists of a monoaxial-orientated polymer.

5. A transducer according to any one of Claims 1 to 4, wherein the piezo-electric film consists of Polyvinylidene-Fluoride.

6. A transducer according to Claim 4 or Claim 5, wherein the piezo-electric film is a strip under initial tension, the direction of the initial tension X' and the direction X of the maximum piezo-electric stretch sensitivity of the film enclosing an angle of less than 45 degrees.

7. A transducer according to any one of the Claims 1 to 6, wherein the electrically conducting contact surfaces are formed by thin electrically conducting layers connected firmly to the surface of the piezo-electric film.

8. A transducer according to Claim 7, wherein the sensor element formed by the film and the electrically conducting layers, is attached to an electrically insulating tape constituting said flexible support.

9. A transducer according to Claim 8, wherein at least the periphery portions of the insulating tape have a self-adhesive coating on the side facing the sensor element.

10. A transducer according to any preceding claim wherein only the periphery portions of the flexible support are coated with adhesive.

11. A transducer according to any preceding claim wherein the sensor element is mounted on the flexible support by means of the adhesive coating.

12. A transducer according to any preceding claim, wherein the piezo-electric film is arranged and adapted so that in use on a pipe the film embraces the pipe once or an integer multiple of one.

13. A transducer as claimed in claim 1 and substantially as hereinbefore described with reference to and illustrated by the accompanying drawings.

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