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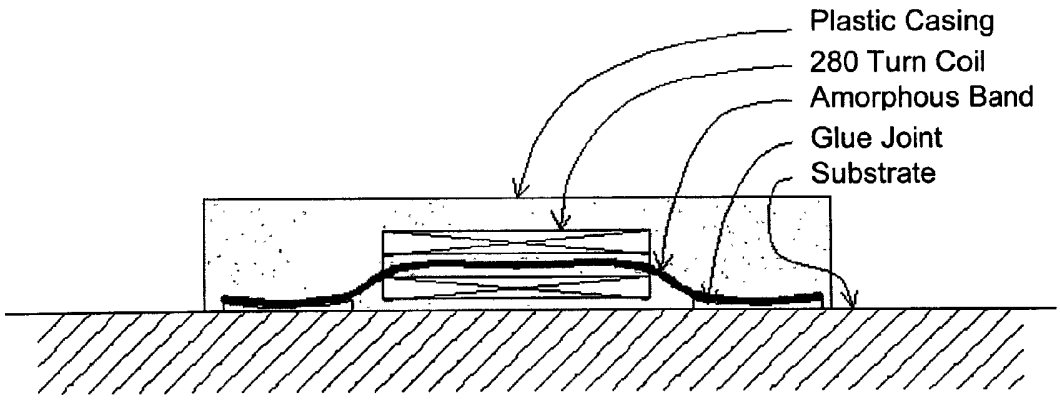
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(54) Title: SENSOR



(57) Abstract: The disclosure relates to a method and an apparatus for sensing and indicating permanent state deviations via detection of temporary inner material oscillations in real time in parts of importance for hardware design and construction, within existing production equipment, e.g. machinery, and/or monitoring of previously built-up infrastructure. One or more at least approximately 20 μm thick amorphous or nanocrystalline band elements with high permeability and relatively high magnetostriction are applied to a pertinent part, the band element or elements, respectively, being at least partially surrounded by a multi-turn coil, such atomic movements (oscillations) as occur in any optional such state deviation in the part being transferred to the band element/elements. The deviation either gives rise to a clearly measurable and detectable magnetic flow change (dB/dt) in the coil in proportion to said atomic movements, or to a similarly measurable and detectable inductance change in the coil/coils.

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Method and apparatus for sensing permanent state deviations

Technical field

The present invention relates to a method and an apparatus for sensing and indicating of permanent state deviations via detection of temporary, inner material oscillations in real time in parts of importance for hardware design and construction such as, for example, in prototype testing, in existing production equipment within industry, and/or monitoring and thereby maintaining previously constructed infrastructure.

Background art

Recent years' developments within the area of microelectronics, above all the evolution of increasingly powerful memories for computers has entailed that transducers or sensors of different types occurring on the market such as accelerometers, flexural/deformation indicators, indicators for acoustic emission and so on which are intended for measuring magnitudes of importance to the dimensioning of products in design have proved to be excessively complex in their construction and, as a result, excessively space-consuming and costly for application to the extent which modern hardware design increasingly demands and which, in particular, modern software permits.

Brief summary of the invention

One major object of the present invention is, therefore, to realise a transducer element or sensor and arrangement thereof which, in principle, are extremely simple and thereby so space-saving in their construction that previously inconceivable transducer- or sensor configurations may be realised, at the same time as the opportunity is afforded of measurement with considerably greater sensitivity and accuracy within broader ranges than has hitherto been possible, and moreover the measurement of previously almost undetectable magnitudes has been made possible.

A further object of the present invention is to realise a sensor arrangement which has a so slight inherent mass that the magnitude which it has for its object to detect cannot be affected thereby.

The above outlined objects will be attained by a method and an apparatus wherein the apparatus consists of one or more at least about 20 μm thick amorphous or nanocrystalline band elements of high permeability and relatively high magnetostriction being applied to the pertinent part, the band elements being, for attaining a desirable material structure, treated by magnetic heat treatment, the band elements being at least partly surrounded by multi-turn coils, such atomic movements as occur in an optional such state deviation being transmitted to the band element/elements either giving rise to a clearly measurable and detectable magnetic flow change (dB/dt) in the coil in proportion to said atomic movements, or to a similarly measurable and detectable inductance change in the coil/coils.

Brief description of the accompanying Drawings

The present invention will now be described in greater detail hereinbelow, with reference to the accompanying Drawings. In the accompanying Drawings:

Fig. 1 shows a sensor for acoustic emission photographed on a millimetre paper;

Fig. 2 is a schematic diagram of a sensor for detecting acoustic emission;

Fig. 3 shows the output signal as a function of load in positive and negative stretching for measurement of inductance change;

Fig. 4 shows a time signal from each respective transducer P1_1 (a. top), P1_2 (b. centre) and P1_3 (c. bottom);

Fig. 5 shows the frequency spectra over the output signals on breaking of glass for P1_1, P1_2 and P1_3 (a. top, b. centre and c. bottom, respectively);

Fig. 6 is a schematic diagram of a possible realisation of an accelerometer which is based on amorphous material;

Fig. 7 shows the connection of the accelerometer and the principle of processing of signals therefrom;

Fig. 8 shows an impulse response for the accelerometer where the signal on the Y axis is the output signal in (mV) and the X axis is the time axis;

Fig. 9 shows the results of an accelerometer measurement at 1.7 Hz;

Fig. 10 shows the results of a measurement carried out at 3.0 Hz;

Fig. 11 shows the results of a measurement carried out at 4.4 Hz;

Fig. 12 shows the result of a measurement carried out at 10.94 Hz;

Fig. 13 shows a relative frequency response for a reference accelerometer and produced accelerometer type;

Fig. 14 is a schematic diagram of a possible realisation of an accelerometer or AE sensor (AE = acoustic emission) based on amorphous material; and

Fig. 15 shows the output signal of the AE sensor in transient exiting.

Detailed description

Application as glass breakage sensor

Functional principle

The transducer or indicator consists of an amorphous ferromagnetic material which possesses the property that it may be given extremely high permeability, $5{,}000<\mu<200{,}000$, at the same time as it has, for certain alloy compositions, a relatively high magnetostriction, $5<\lambda_{sat}<40$ ppm. Taken as a whole, this gives a material with a very high magneto-elastic relationship and is therefore extremely suitable as sensor material.

By employing a band approx. 3*10 mm which is cut from a sheet of amorphous material of a thickness of 22 μm and thereafter glued on an optional material, stretching in the material can be detected. The amorphous material may be given different properties by cutting it in different directions in relation to the rolling direction, in the present case use has been made of longitudinally and transversely of the rolling direction.

The material parameters may also be modified by heat treating the material in magnetic fields in temperatures close to but below the crystallisation temperature. In the case of breaking glass and general acoustic emission, the magnetic flow change is detected in that a multi-turn coil is wound around the band, see Fig. 1 and Fig. 2.

Theory

In order to detect high frequency signals, it is advantageous and simple merely to detect the flow change and assume that it is proportional to the size of the deformation to the band. This implies that a magnetically well-defined initial state must be achieved, since an unmagnetised band gives no flow change in stretch change.

In order to attain a magnetised basic state, in principle the earth magnetic state is sufficient of 30-60 μT (20-40 A/m), but on the other hand it is unpractical to need to monitor the direction and size of the earth magnetic field when an indicator is to be mounted and calibrated.

There are two ways of attaining a satisfactory initial state:
Lightly magnetic encapsulation and direct current through the pickup coil.
Lightly magnetic encapsulation and bias magnetisation with permanent magnet.

The size of the field should be such that the magnetisation will be 0,2-0,7 T, which implies that the magnetising field in the band should be of the order of magnitude of 2-56 A/m. The size of the field may generally be calculated from the formula

$$H = \frac{B}{\mu_0 \cdot \mu}$$

where H is the magnetising field, B is the magnetic flow density, the permeability for free space $\mu_0 = 4\pi \cdot 10^{-7}$ Vs/Am and the relative permeability μ for, in this case, the amorphous band.

The measurement signal is obtained by detecting the flow change in the band because of stretching/compression. For the linear case, the following connected equation should describe the function:

$$\Delta B = d \cdot \Delta\sigma + \mu_0 \cdot \mu \cdot \Delta H$$

Where σ describes mechanical stress and d is the magneto-elastic relationship coefficient. The prefix Δ describes the change from the original value. The material parameter d may be approximated by taking maximum magnetostriction at constant mechanical stress, $\Delta\sigma = 0$, divided by magnetising field in magnetic saturation, i.e.

$$\frac{\lambda_{max}}{H_{max}} = d$$

since

$$\Delta\lambda = \frac{\Delta\sigma}{E^H} + d \cdot \Delta H$$

which, with $\lambda_{max} = 35 \cdot 10^{-6}$ and $H_{max} = 200$ A/m, gives the relationship factor d = $1.75 \cdot 10^{-7}$ m/A, a very high value for all types of magneto elastic relationship.

The output signal which may be expected is proportional to the flow change and the mechanical stress

$$U(t) = N \cdot A \cdot \frac{dB}{dt}$$

where N is the number of turns in the pickup coil and A is the cross sectional area of the amorphous band. By the assumption that $\Delta H = 0$, the following equations apply:

$$\begin{cases} \Delta\sigma = \Delta\lambda \cdot E^H \\ \Delta B = d \cdot \Delta\sigma \end{cases}$$

where E^H is the modulus of elasticity in constant magnetising field. The transition to the frequency plane and the utilisation of the above equations give:

$$\hat{U} = |N \cdot A \cdot \omega \cdot d \cdot \Delta\lambda \cdot E^H|$$

where ω is the angular frequency in rows/sec. The circumflex indicates that the amplitude value is intended. With the assumption that the modulus of elasticity is of the order of magnitude of 100 GPa, the stretching in the sensor at 100,000 kHz should be of the order of magnitude of 0,0025 ppm for the case P1_2, see Fig. 4 and Fig. 5 centre.

Measurement results

Initial experiments with sensors glued to a glass slide show that vibrations in the frequency range 40 kHz – 1 MHz can be detected.

The following comparative tests have been carried out:

Table 1, description of indicator

Sensor	Orientation of band	Number turns	Comments	Static unloaded permeability [mH]
P1_1	Transverse	280	Thick glue joint	158
P1_2	Transverse	280		60
P1_3	Longitudinal	280	Thick plastic encapsulation	32

The test was carried out in that the corner of the glass slide was broken off and the output signal registered with an amplification of approx. 100 times.

Fig. 3 shows the inductance change in different stretching for the sensors P1_, P1_2 and P1_3. Here it is clearly apparent that P1_1 and P1_2, which have bands cut out in the transverse direction, have the highest magneto-elastic relationship. These two samples also display a considerably higher permeability. This is also shown in glass breaking experiments where the signal levels in similar excitation will be higher for P1_1 and P1_2. P1_2 displays a considerably more broad band signal spectrum compared with P1_1 and P1_3. This may probably be explained by the larger glue quantities, see table 1.

Application in a developed first prototype of general accelerometer with real static measurement

Functional principle

The transducer or indicator consists of an amorphous ferromagnetic material which possesses the property that it can be given extremely high permeability, $5{,}000<\mu<200{,}000$, at the same time as, for certain alloy compositions, it has a relatively high magnetostriction, $5<\lambda_{sat}<40$ ppm. Taken as a whole, this gives a material with a very high magneto-elastic relationship and is, therefore, extremely suitable as sensor material. The transducer or indicator is composed of two amorphous bands of a size of $3 \cdot 16 \cdot 0.022$ mm. The bands are glued to a fixing block, see Fig. 1. At the fixing block, a coil is wound around each band. The coils are connected in a half bridge, see Fig. 2. By connecting the coils in such a manner that a similar change in both bands does not give a signal, a high degree of insensitivity to

temperature and other symmetric disruptions may be achieved. On flexing of the "beam" which consists of the two amorphous bands and an interjacent plastic band, a stretching in the one band will be obtained at the same time as a compression in the other band. The output signal from the coils will then be the opposite, i.e. an increase of inductance (permeability) on stretching and a reduction in compression.

The reaction mass (see Fig 14), which is located in the end of the flexural beam gives a flexing moment which is proportional to the acceleration, the length of the beam and the mass. This naturally gives the possibility of adapting the accelerometer to almost any maximum acceleration whatever. The frequency performance is substantially determined by the rigidity of the beam and the mass of the reaction mass.

Theory

Since this transducer or indicator is to have real static measurement, the measurement principle cannot be based on induced tensions as a result of flow changes. In this case, it is necessary that the relative permeability of the band is measured using a carrier wave which should have a frequency roughly 10 times higher than the expected band width of the accelerometer.

For the linear case, the following linked equation should describe the function:

$$\Delta B = d \cdot \Delta\sigma + \mu_0 \cdot \mu \cdot \Delta H$$

where H is the magnetising field, B is the magnetic flow density, the permeability for free space $\mu_0 = 4\pi \cdot 10^{-7}$ Vs/Am and the relative permeability μ for, in this case, the amorphous band.

Further, σ stands for mechanical tension and d is the magneto-elastic relationship coefficient. The prefix Δ designates change from the original value. The material

parameter d may be approximated by taking maximum magnetostriction at constant mechanical stress, $\Delta\sigma = 0$, divided by magnetising field at magnetic saturation, i.e.

$$\frac{\lambda_{max}}{H_{max}} = d$$

Since

$$\Delta\lambda = \frac{\Delta\sigma}{E^H} + d \cdot \Delta H$$

which, with $\lambda_{max} = 35 \cdot 10^{-6}$ and $H_{max} = 200$ A/m, gives the relationship factor $d = 1.75 \cdot 10^{-7}$ m/A, a very high value for all types of magneto-elastic relationship. The measurement magnitude which is of interest here is hence the permeability as a function of stretching. By assuming that a well defined magnetic state has been able to be achieved, i.e. constant and known magnetising field, the change in magnetic flow density can, with a revision of the above equations, be designated as:

$$\Delta B = d \cdot E^{H.} \cdot \Delta\lambda$$

Hence, the change in magnetic flow density is proportional to the stretching in the band with the proportional constant $d \cdot E^{H.}$ which, with $E^{H.} = 100$ GPa, will be approximately $1.75 \cdot 10^4$ T.

Assume that the coils are connected in a half bridge and that we have a stretching of 10 ppm in the one band and a compression of 10 ppm in the other band. Since the H field may be assumed to be constant and that the change in the B field is proportional to the change in permeability and naturally also to the inductance in the coils, this implies that the output signal from the balanced bridge will be

$\Delta U = 1.75 \cdot 10^{4} \cdot 2 \cdot 10 \cdot 10^{-6} \cdot = 0{,}35$ V

This is an output signal which is so powerful that it does not need to be amplified.

Measurement results

Each coil has 800 turns, which gives an inductance of 8,2 mH. The half bridge is supplied with a sinusoidal voltage of an amplitude of 4,4 V and 19,3 kHz. Since the coils are connected in series, this implies that the bridge impedance may be kept in the order of magnitude of 10 kΩ, which is a good adaptation to be driven by operational amplifier.

For calibration of the transducers, use is made of the earth's force of gravity of 9.81 G. This gives a sensitivity of 35 mV/G. The transducers appear to be saturated at approx. 1 V, which implies that the linear area is approx. ± 0.5 C which is equivalent to ± 14 G. The resonance frequency, which may be calculated as:

$$f_{res} = \sqrt{\frac{k}{m}} \cdot 2\pi$$

has, by studying an impulse response, been measured up to approx. 80 Hz, see Fig. 3.

Measurements in accelerometer test equipment

In order to examine linearity, and to some degree frequency performance, measurements were carried out in the accelerometer test equipment.

A feature common to Fig. 4, Fig. 5, Fig. 6 and Fig. 7 is that a curve with relatively large output signal variations shows the output signal from the reference accelerometer, another curve with as good as equally large output signal variations shows the signal from the prototype accelerometer, while the almost solid line continuous curve shows the analytically simulated acceleration which should be

exactly right. The scale on the axes is for the y axis acceleration in G and for the x axis time in seconds. Approximately 1,5 periods have been presented throughout.

By comparing the output signal of the accelerometers and relating them to the simulated acceleration, a frequency response can be evolved, see Fig. 8.

The developed accelerometer displays good linearity up to the expected linearity limit of 14 G. There is no reason to assume any form of frequency dependence until the frequencies begin to approach the resonance frequency at 80 Hz. The decline at 11 Hz in Fig. 8 may be explained by the fact that saturation has been reached.

Application in developed first prototype of sensor for acoustic emission

Functional principle

The indicator or transducer consists of an amorphous ferromagnetic material which has the property that it may be given extremely high permeability, $5{,}000<\mu<200{,}000$, at the same time as, for certain alloy compositions, it has a relatively high magnetostriction, $5< \lambda_{sat}< 40$ ppm. Taken as a whole, this gives a material with a very high magneto-elastic relationship and, as a result, is excellently suitable as sensor material. The indicator or transducer is composed of an amorphous band of a size of $3 \cdot 18 \cdot 0{,}022$ mm. The band is wound two turns with an insulating plastic band in between. It is vitally important that the different strata of the band do not have electric contact with each other, since the band would then function as a short-circuited secondary winding. The resulting active cylinder is glued on the measurement object with a thin glue joint and to the bottom of a bowl-shaped plastic bobbin on the other side. On the bottom of the plastic bobbin, there is secured a reaction mass, while a 1,000 turn coil is wound on its side surface. This transducer principle is best suited for detecting dynamic cycles, since there is only one coil. By using two coils coupled in a half bridge (presupposes that the coils operate differently, i.e. that for positive acceleration one coil gives a positive output signal while the other gives a correspondingly negative signal), the advantages will be afforded that the effects of all currents (air-born electromagnetic waves etc.) and

variations caused by external, global phenomena (heat, magnetic field, etc.) which occur symmetrically in relation to the coils will be reduced/eliminated.

The reaction mass (see Fig. 14) which is secured on the bottom of the plastic bobbin gives a reaction force on the active cylinder which is proportional to the acceleration and the mass. This naturally affords the possibility of adapting the accelerometer to almost any maximum acceleration and resonance frequency whatever. The frequency performance is determined substantially by the rigidity of the cylinder, as well as the mass of the reaction mass.

Theory

In order to detect high-frequency signals, it is advantageous and simple merely to detect the flow change and assume that it is proportional to the size of the deformation of the band. This implies that a magnetically well-defined initial state must be attained since an unmagnetised band gives no flow change in stretch change. In order to achieve a magnetised basic state, the earth magnetic field of 30-60 μT (20-40 A/m) is in principle sufficient, but on the other hand it is unpractical to need to monitor the direction and size of the earth magnetic field when a transducer or indicator is to be mounted and calibrated. There are two methods of attaining a good initial state:

1. Lightly magnetic encapsulation and direct current through the pickup coil.
2. Lightly magnetic encapsulation and bias magnetisation with a permanent magnet.

The size of the field should be such that the magnetisation will be 0,2-0,7 T, which implies that the magnetising field in the band should be of the order of magnitude of 2-56 A/m. The size of the field can generally be calculated from the formula

$$H = \frac{B}{\mu_0 \cdot \mu}$$

where H is the magnetising field, B is the magnetic flow density, the permeability for free space $\mu_0 = 4\pi\ 10^{-7}$ Vs/Am and the relative permeability μ for, in this case, the

amorphous band. By detecting the flow change in the band because of stretching/compression, the measurement signal will be obtained. For the linear case, the following linked equation should describe the function:

$$\Delta B = d \cdot \Delta\sigma + \mu_0 \ \mu \cdot \Delta H$$

Where σ designates mechanical stress and d is the magneto-elastic relationship coefficient. The prefix Δ designates change from the original value. The material parameter d can be approximated by taking maximum magnetostriction in constant mechanical stress, $\Delta\sigma = 0$, divided by magnetising field at magnetic saturation, i.e.

$$\frac{\lambda_{max}}{H_{max}} = d$$

since

$$\Delta\lambda = \frac{\Delta\sigma}{E^H} + d \cdot \Delta H$$

which, with $\lambda_{max} = 35 \cdot 10^{-6}$ and $H_{max} = 200$ A/m, gives the relationship factor $d = 1.75 \cdot 10^{-7}$ m/A, a very high value for all type of magneto-elastic relationship.
The output signal which may be expected is proportional to the flow change and the mechanical stress

$$U(t) = N \cdot A \cdot \frac{dB}{dt}$$

where N is the number of turns in the pickup coil and A is the cross sectional area of the amorphous band. By the assumption that $\Delta H = 0$, the following equations apply:

$$\begin{cases} \Delta\sigma = \Delta\lambda \cdot E^H \\ \Delta B = d \cdot \Delta\sigma \end{cases}$$

where E^H is the modulus of elasticity at constant magnetising field. Transition to the frequency plane and the utilisation of the above equations give:

$$\hat{U} = N \cdot A \cdot \omega \cdot d \cdot \Delta\lambda \cdot E^H$$

where ω is the angular frequency in rows/sec. The circumflex indicates that it is the amplitude value which is intended.

Measurement results

The coil which is measured has 650 turns, which gives an inductance of 3.2 mH. The resonance frequency may be calculated as:

$$f_{res} = \sqrt{\frac{k}{m}} \cdot \frac{1}{2\pi}$$

which, with the assumption that the modulus of elasticity is 100 GPa, the height of the active cylinder is 3 mm and the cross sectional area $2 \cdot 3 \cdot \pi \cdot 0{,}022$ mm^2 and the reaction mass is 4 gram, gives a resonance frequency of approx. 10 kHz. Fig. 2 shows a 50 times amplified output signal from the transducer when this has been mounted on a large iron blank and excited with a hammer blow.

A frequency analysis in the time series in Fig. 15 shows that signals up to approx. 5 kHz occur broadband, thereafter there is a distinct peak at 8 kHz and one at 60 kHz. It appears probable that the 8 kHz signal is the transducer resonance, while the 60 kHz signal is that which is traditionally called acoustic emission, i.e. transient release

of energy in, for example, material deformation. The broadband signal content below 5 kHz consists of vibrations on the test body.

WHAT IS CLAIMED IS:

1. A method of sensing and indicating permanent state deviations via detection of temporary inner material oscillations in real time in parts of importance for hardware design and construction, within existing production equipment, e.g. machinery, and/or monitoring of previously built-up infrastructure, **characterised in that** one or more at least approximately 20 μm thick amorphous or nanocrystalline band elements with high permeability and relatively high magnetostriction are applied to a pertinent part, the band element or elements, respectively, being at least partly surrounded by a multi-turn coil, such atomic movements (oscillations) which occur in any optional such state deviation being transferred to the band element/elements, the deviation either giving rise to a clearly measurable and detectable magnetic flow change (dB/dt) in the coil in proportion to said atomic movements, or a similarly measurable and detectable inductance change in the coil/coils.

2. The method as claimed in Claim 1, **characterised in that** a carrier wave (electric voltage) of slight amplitude, for example 20 kHz, is impressed over the coil/coils, for pure deformation the current across the coil being measured, or for measurement using a plurality of bridge connected coils, the voltage difference between pairs of bridge connected coils being measured, these magnitudes being substantially proportional to the mechanical stress in the bands.

3. An apparatus for sensing and indicating permanent state deviations via detection of temporary inner material oscillations in real time of importance for hardware design and construction, within existing production equipment, e.g. machinery, and/or monitoring of previously built-up infrastructure, **characterised in that** it comprises one or more at least approximately 20 μm thick amorphous or nanacrystalline band elements of high permeability and relatively high magnetostriction, which element/elements, for attaining a desirable material structure, are treated by magnetic heat treatment, which band element/elements being surrounded by multi-turn coils, such atomic movements (oscillations) as occur in any

optional such state deviation, in that they merge in the band element/elements, either giving rise to a clearly measurable and detectable magnetic flow change (dB/dt) in the coil in proportion to the atomic movements, or a similarly measurable and detectable inductance change in the coil/coils.

4. The apparatus as claimed in Claim 3, **characterised in that** the band element/elements with associated coil/coils are enclosed in an elastically deformable epoxy polymer.

5. The apparatus as claimed in Claim 3 or 4, **characterised in that** the band element/elements and the coil/coils are glued to the object whose permanent state deviations are to be indicated.

6. The apparatus as claimed in any of Claims 3 to 5, **characterised in that** the sensitivity thereof is different depending upon the orientation of the detection direction in relation to the rolling direction of the band element/elements, as a consequence of directional dependent qualities in the material.

7. The apparatus as claimed in any of Claims 3 to 6, **characterised in that** the band elements with associated coils are bridge- and amplifier connected in order to increase sensitivity and detectability, respectively.

8. The apparatus as claimed in any of Claims 3 to 7, **characterised in that** it is realised as a glass breakage indicator, accelerometer, transducer for acoustic emission or load indicator.

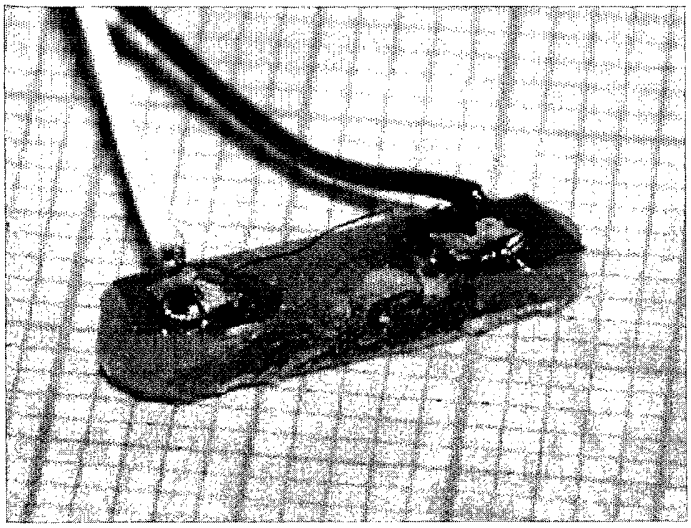


Fig.1

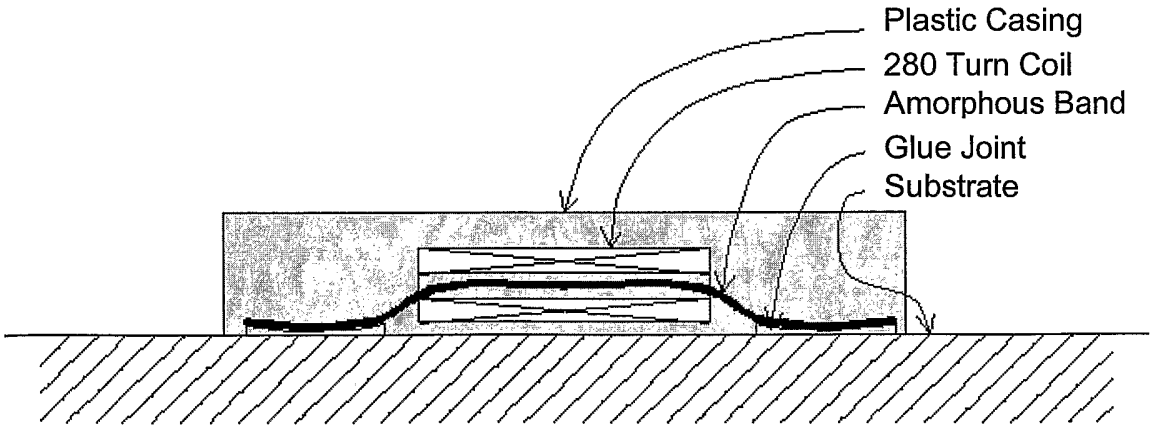

Plastic Casing
280 Turn Coil
Amorphous Band
Glue Joint
Substrate

Fig. 2

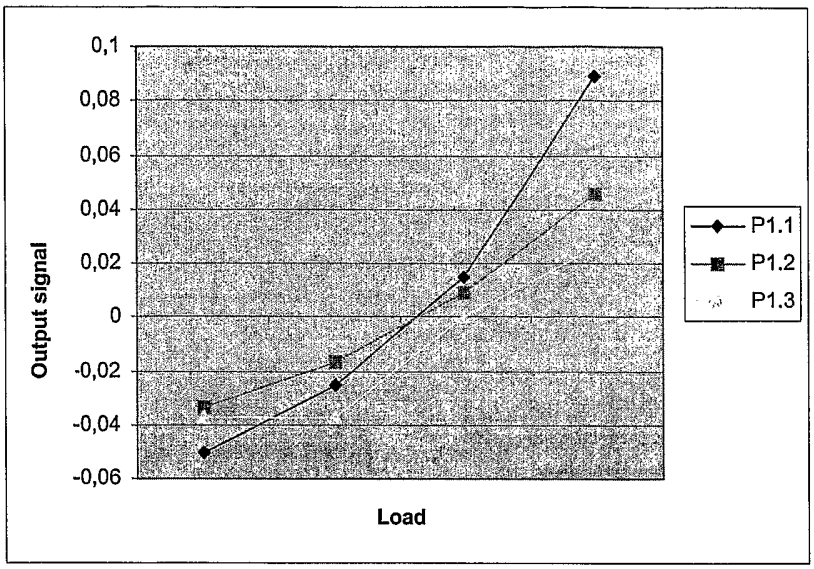


Fig.3

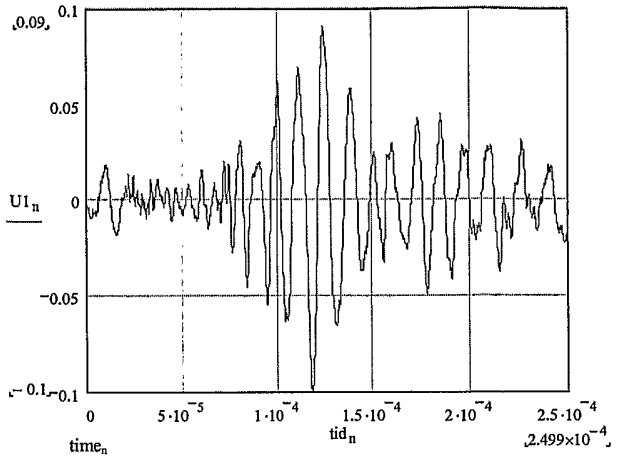


Fig.4a

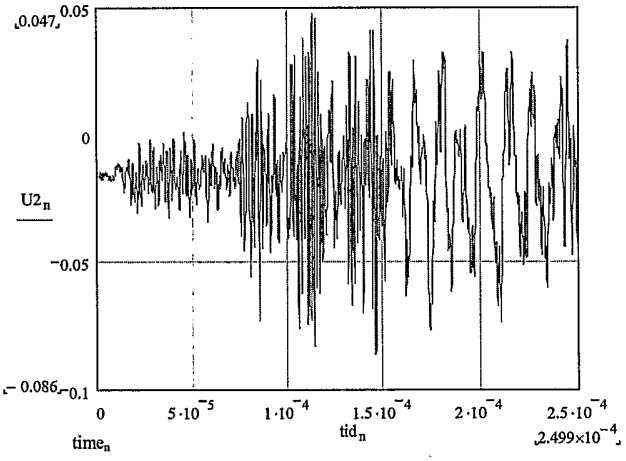


Fig.4b

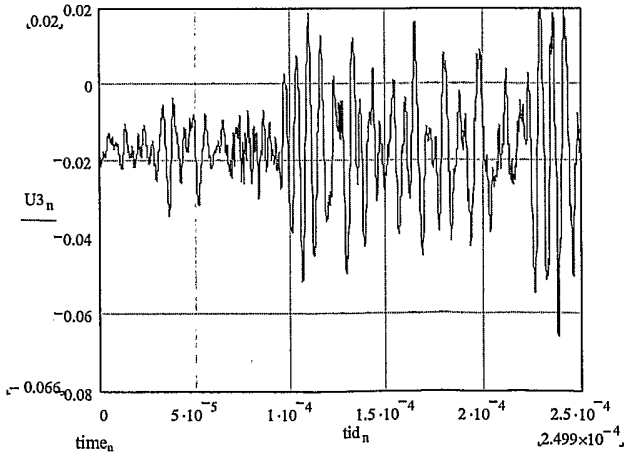


Fig.4c

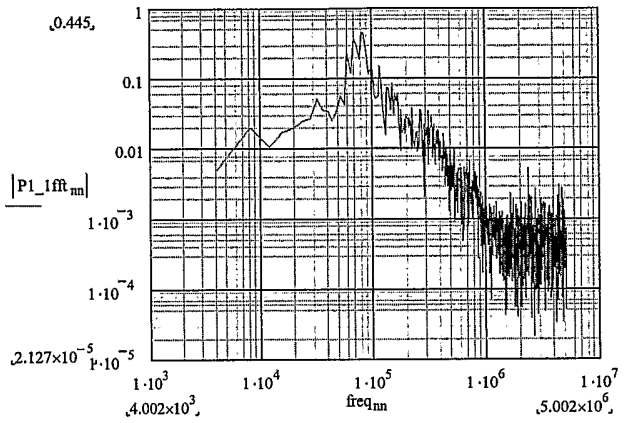


Fig.5a

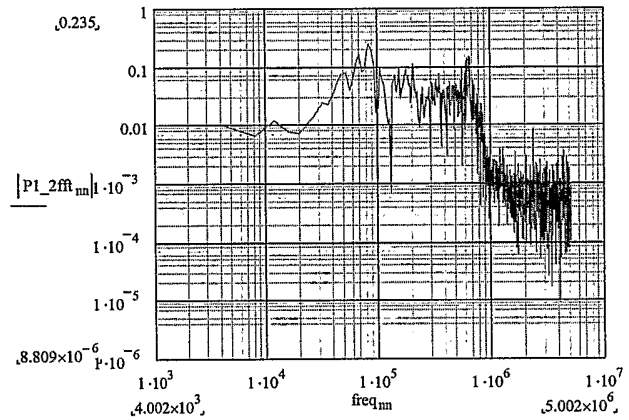


Fig.5b

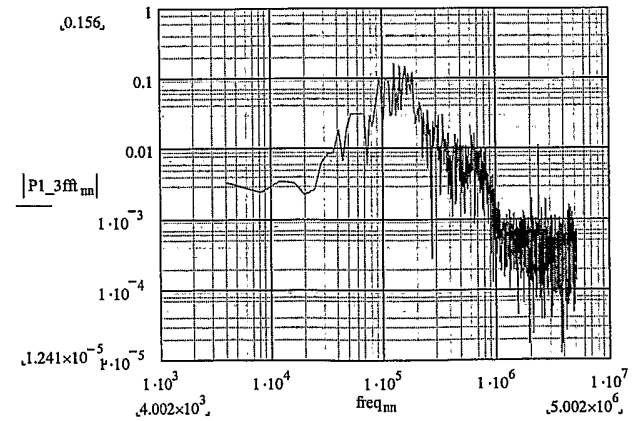


Fig.5c

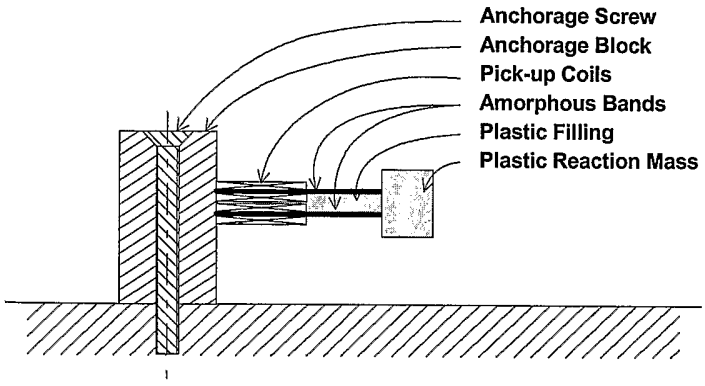

Anchorage Screw
Anchorage Block
Pick-up Coils
Amorphous Bands
Plastic Filling
Plastic Reaction Mass

Fig.6

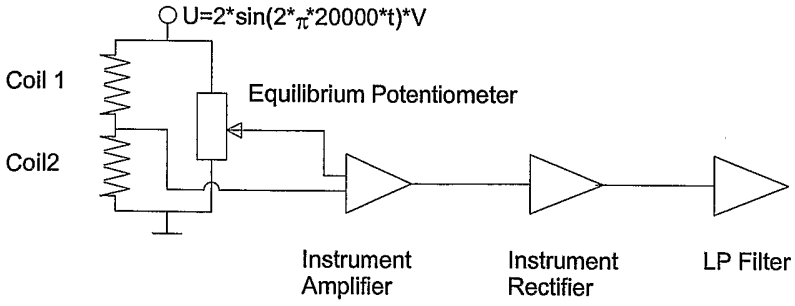

U=2*sin(2*π*20000*t)*V
Coil 1
Coil2
Equilibrium Potentiometer
Instrument Amplifier
Instrument Rectifier
LP Filter

Fig.7

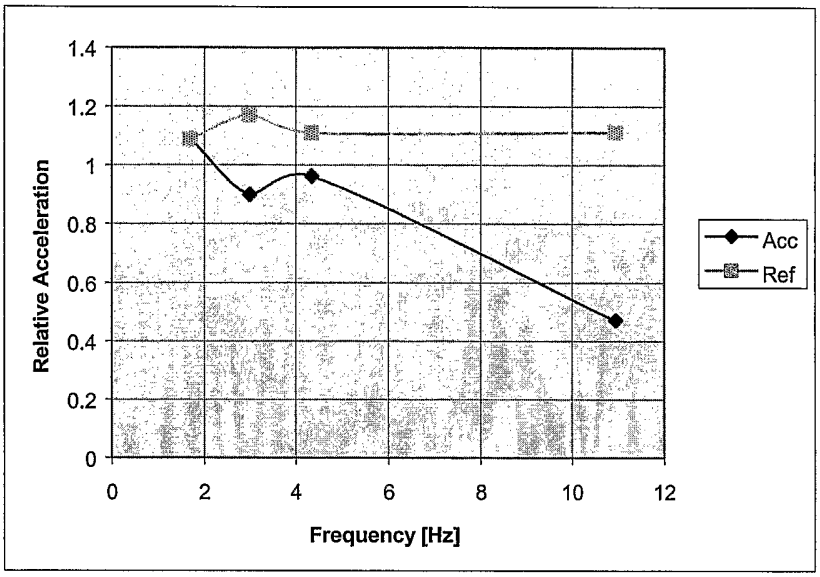

Relative Acceleration
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12
Frequency [Hz]
Acc
Ref

Fig.8

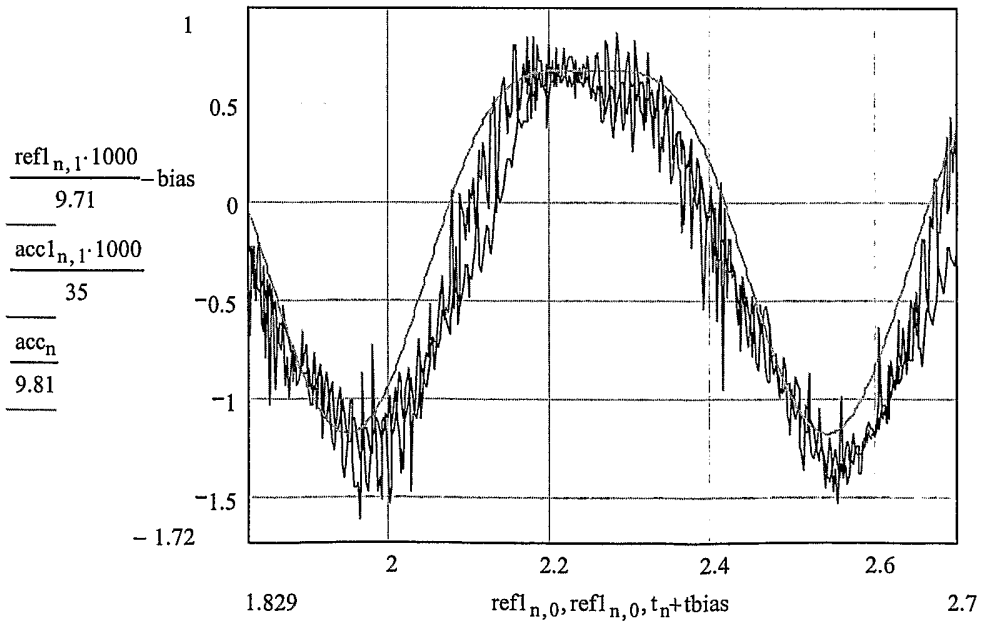

$\frac{refl_{n,1} \cdot 1000}{9.71} - bias$
$\frac{accl_{n,1} \cdot 1000}{35}$
$\frac{acc_n}{9.81}$
1
0.5
0
−0.5
−1
−1.5
− 1.72
2
2.2
2.4
2.6
1.829
$refl_{n,0}, refl_{n,0}, t_n + tbias$
2.7

Fig.9

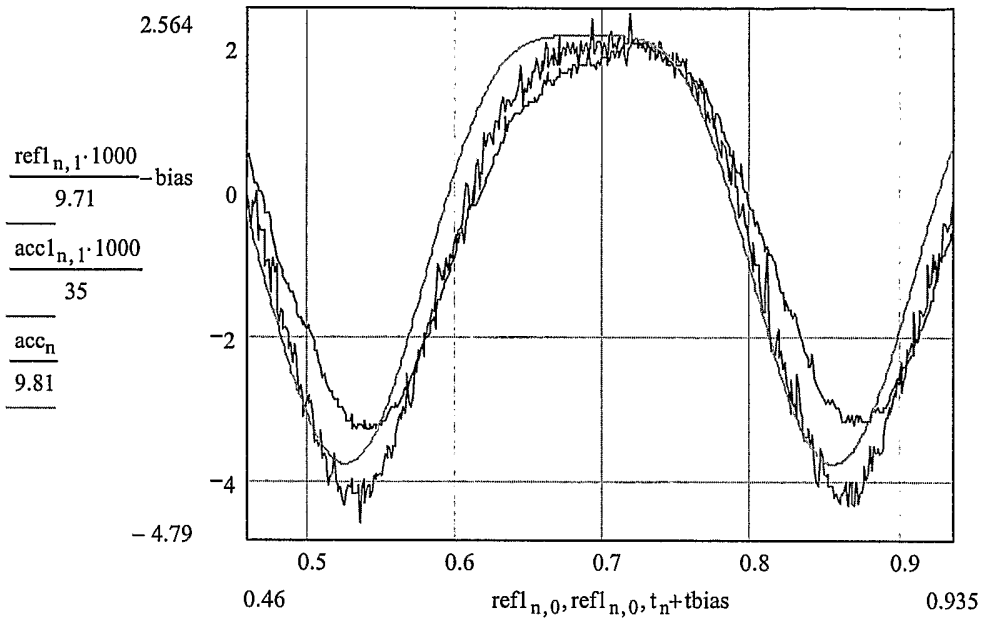

2.564
2
0
−2
−4
− 4.79
refl n,1·1000 / 9.71 − bias
accl n,1·1000 / 35
acc n / 9.81
0.5
0.6
0.7
0.8
0.9
0.46
refl n,0, refl n,0, t n+tbias
0.935

Fig.10

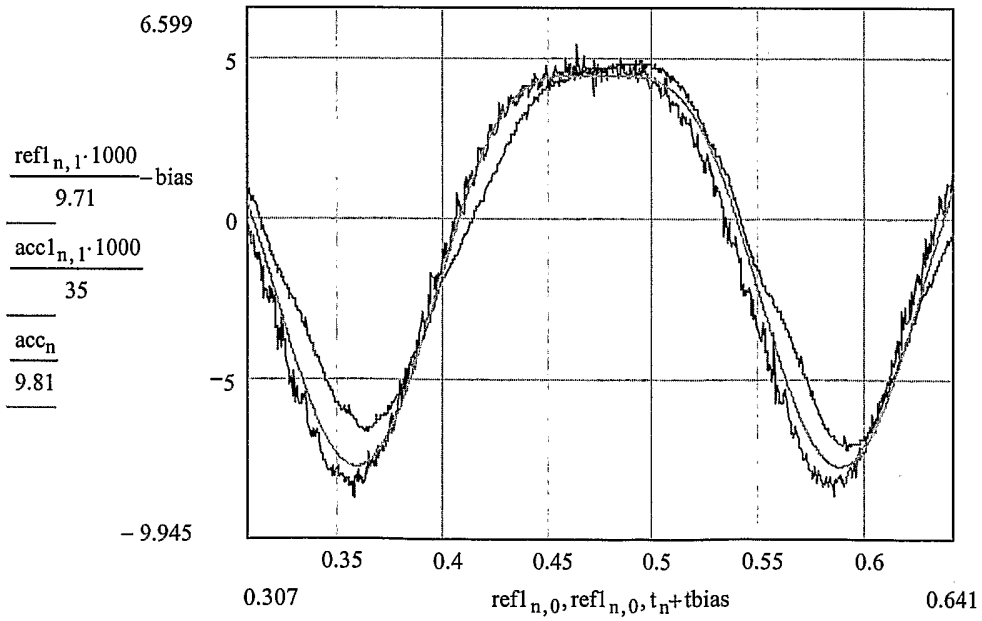

6.599
5
0
−5
− 9.945
refl n,1·1000 / 9.71 − bias
accl n,1·1000 / 35
acc n / 9.81
0.35
0.4
0.45
0.5
0.55
0.6
0.307
refl n,0, refl n,0, t n+tbias
0.641

Fig.11

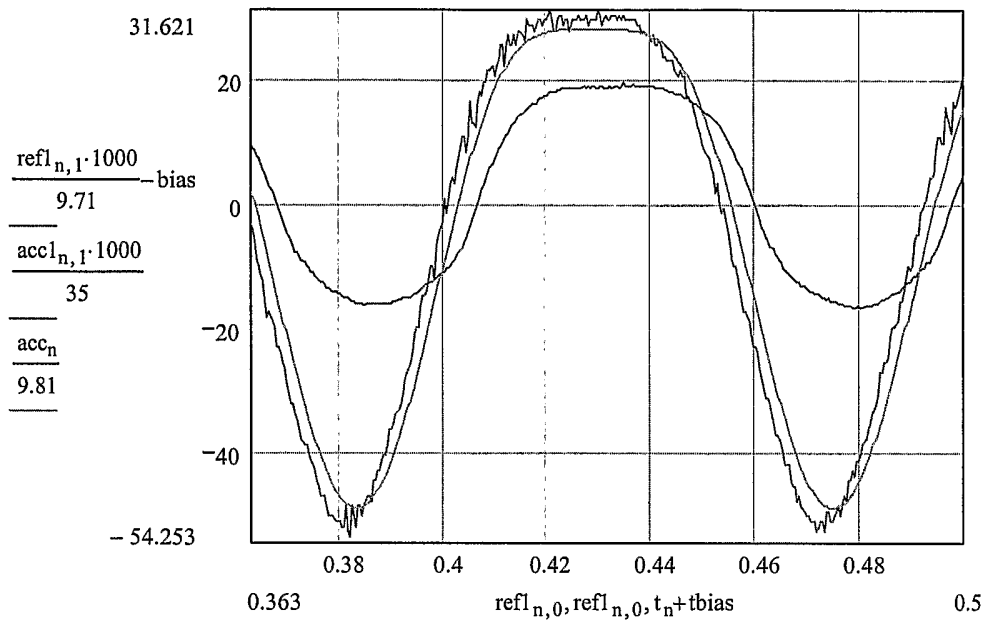

31.621
20
0
−20
−40
− 54.253
refl n, 1·1000 / 9.71 − bias
accl n, 1·1000 / 35
acc n / 9.81
0.38
0.4
0.42
0.44
0.46
0.48
0.363
refl n, 0, refl n, 0, t n+tbias
0.5

Fig.12

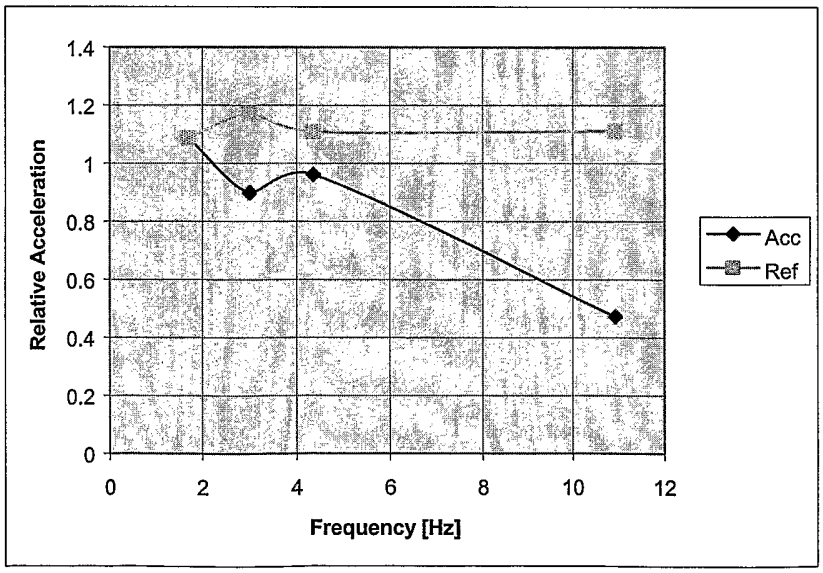

Relative Acceleration
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
2
4
6
8
10
12
Frequency [Hz]
Acc
Ref

Fig.13

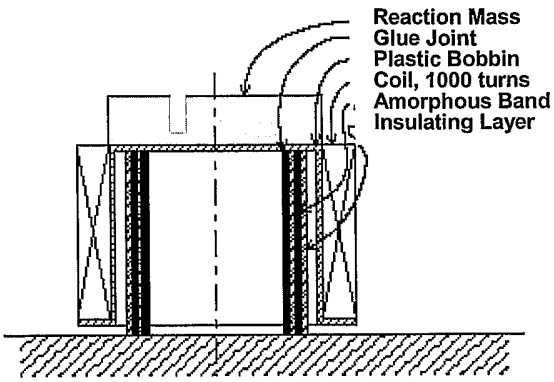

Reaction Mass
Glue Joint
Plastic Bobbin
Coil, 1000 turns
Amorphous Band
Insulating Layer

Fig.14

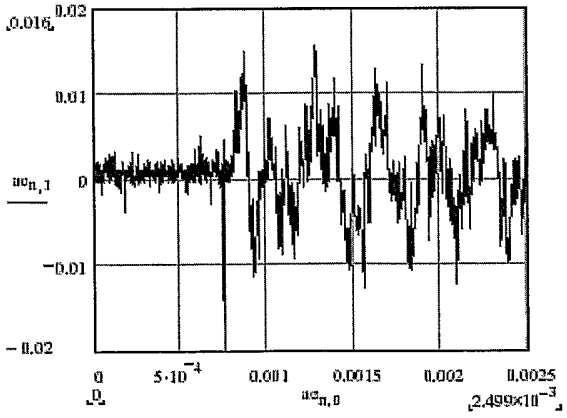

0.016
0.02
0.01
0
−0.01
−0.02
0
5·10^−4
0.001
0.0015
0.002
0.0025
2.499×10^−3

Fig.15

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 03/00871

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: G01H 11/04, G01B 7/24, G01L 1/12, G01P 15/11
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: G01H, G01B, G01L, G01P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL,WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5275049 A (E.SCHIESSLE ET AL), 4 January 1994 (04.01.94), column 2, line 45 - column 4, line 42, figure 1	1,2
Y		3-8
	--	
X	US 4463610 A (P.M.ANDERSON,III ET AL), 7 August 1984 (07.08.84), column 6, line 4 - line 30	1,2
Y		3-8
	--	

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 August 2003	08 -08- 2003
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Henrik Eriksson /itw Telephone No. +46 8 782 25 00

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Y		3-8
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X	US 5194806 A (M.OBAMA), 16 March 1993 (16.03.93), column 3, line 19 - column 5, line 33, see figures	1,2
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A	US 5321985 A (Y.KASHIWAGI ET AL), 21 June 1994 (21.06.94), abstract	1-8
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A	EP 0330311 A2 (KABUSHIKI KAISHA TOSHIBA), 30 August 1989 (30.08.89), column 4, line 33 - line 44	1,2
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A	DE 4309413 A1 (L.KIESEWETTER), 22 Sept 1994 (22.09.94), abstract	1-8
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INTERNATIONAL SEARCH REPORT

Information on patent family members

26/07/03

International application No.
PCT/SE 03/00871

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DE 4309413 A1	22/09/94	NONE	