



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : G01P 3/26	A1	(11) International Publication Number: WO 91/01008 (43) International Publication Date: 24 January 1991 (24.01.91)
(21) International Application Number: PCT/GB90/01035 (22) International Filing Date: 5 July 1990 (05.07.90) (30) Priority data: 8915673.1 7 July 1989 (07.07.89) GB (71)(72) Applicant and Inventor: DWYER, Douglas, Frank, George [GB/GB]; Hillsview, Aller Road, Dolton, Devon EX19 8QP (GB). (74) Agent: GEE, David, W.; Farmhouse Court, Marston, Sutton Coldfield, West Midlands B76 ODW (GB). (81) Designated States: AT (European patent), BE (European patent), CH (European patent), DE (European patent)*, DK (European patent), ES (European patent), FR (European patent), GB (European patent), IT (European patent), JP, KR, LU (European patent), NL (European patent), SE (European patent), US.		Published <i>With international search report.</i>
(54) Title: ANGULAR RATE SENSOR. 		
(57) Abstract An angular rate sensor for measuring angular velocity about a cavity sensitive axis which includes a fluid filled cavity, means to cause rotation of the fluid in the cavity about an axis perpendicular to said sensitive axis, the fluid having parallel to said rotation axis a flow rate gradient, and means to sense a change in the flow rate gradient with rotation of the cavity about said sensitive axis. The means can be electrical, as by measuring the change in electrical potential or electrical resistance or electrical current across the flow path, or optical by measuring the change in distribution of a neutrally buoyant material in an optically transparent fluid.		

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ANGULAR RATE SENSOR

This invention relates to an angular rate sensor, and in particular to an angular rate sensor employing gyroscopic principles.

Sensor arrangements are known which utilise a body of
5 electrically conductive liquid which is displaced along a confined path through a magnetic field to induce in the liquid an electric current reflective of the motion of the sensor body.

Sensors of such magneto-hydrodynamic type are generally used to measure angular acceleration, an example being disclosed in
10 Laughlin US patent 4,718,276; with a prolonged uniform angular rate the fluid will adopt a flow rate similar to that of the cavity and no angular rate measurement will be given. A sensor of that general type but constructed to measure angular velocity is disclosed in U.S. Patent 4,188,576 to Jacobs, which however
15 teaches ejecting a free flowing fluid jet from a rotating nozzle through a transverse magnetic field to induce current in the flow direction of the jet; the resultant electric current is measured between pick-ups rotating with the jet and spaced apart along the flow path of the fluid, and is proportional to the angular rate.

20 I now propose an alternative arrangement to that of Jacobs U.S.

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patent 4,188,576 which I believe has certain advantages, of size, simplicity and rugged construction. My arrangement uses only one fluid (in a cavity) rather than a first fluid passing through a second fluid. I am also proposing embodiments which do not
5 require the use of an electrically conductive fluid.

Although I do not discount the use of a gas, for instance a gas plasma, my preferred embodiments will use a liquid.

In particular I propose an arrangement utilising a fluid caused to flow around an annular cavity, with therefore angular
10 momentum, and I then measure the change in the fluid velocity gradient across the flow path when the cavity is subjected to rotation perpendicular to the effective axis of fluid rotation.

Thus I propose a rotation sensor for measuring angular velocity about a cavity sensitive axis which includes a fluid-filled
15 cavity, energising means to effect rotation of the fluid in the cavity about a rotation axis perpendicular to the sensitive axis, the fluid having parallel to said rotation axis a flow rate gradient, and sensor means to sense a change in said flow rate gradient with rotation of the cavity about said sensitive axis.

20 Usefully I will additionally provide external means to indicate the rate of rotation of the cavity about said sensitive axis, said indication being derived from a measurement of the change in

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said flow-rate gradient.

The change in velocity gradient is usefully measured by a comparison of the electrical signals developed to either side of a centre tapping, measured by sensors positioned within the fluid. In a particularly advantageous embodiment, in use a body of electrically conductive liquid is in movement along a confined path through a magnetic field; the potential difference at spaced points across the fluid flow path is reflective of the transverse forces acting on the liquid, which affect the liquid velocity profile, and so result in different rates of cutting of the lines of magnetic force.

A non-invasive means of measuring the flow rate of the conductive fluid can be used, employing for instance two AC powered solenoids as disclosed in Mittelman US Patent 3,566,687.

It will be understood that rotation of the cavity in which the fluid is confined, said rotation being about a sensitive axis perpendicular to the effective axis of spin (fluid rotational axis) will give rise to forces acting on each element of the moving fluid in proportion to the angular momentum of that element of the moving fluid and the rate of cavity rotation about the sensitive axis, and that this will alter the velocity flow rate gradient i.e. the velocity profile across the fluid.

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Preferably the cavity is a closed cavity, so that if for example the fluid is an electrically conducting liquid positioned within a magnetic field, the liquid can be energised into motion, and caused to rotate about the measurement axis, by the application of a current through the liquid. Alternatively, the fluid can be in an "open" cavity, and energised and caused to rotate by an external impeller, suitably with a fluid exhausting means to ensure continued fluid flow, usefully by circulation of the exhausted fluid back to the impellor input.

10 The invention will be further described by way of example with reference to the accompanying schematic drawings in which:-

Fig.1 is a perspective view of a rotatable housing locating two pairs of magnets, and internal sensors, and including an annular cavity filled with mercury;

15 Fig.2 is a schematic sectional view of an annular cavity located in a housing, such as the housing of Fig.1;

Fig.3 is a graph showing the fluid velocity distribution with the housing stationary, and with the housing rotating about a sensitive axis perpendicular to the rotational axis of the fluid;

20

Fig.4 is a schematic diagram of electrical connections from the cavity, and an amplifier used to increase the output from the sensor, suitably to operate indicating

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means for the rate of rotation of the cavity about the sensitive axis;

Fig.5 is of modified cavity arrangement; and

Fig.6 is a section on the line VI-VI of Fig.5.

5 In the embodiment according to Fig. 1, the housing or container 10 is constructed of an electrically-insulating material, conveniently a plastics material, and has an annular internal recess 13 (Fig.2) which is filled with mercury; in an alternative embodiment another homogeneous electrically conducting liquid is
10 used. Secured to the container 10 at diametrically opposed positions are a first pair of permanent magnets 11 (seen more clearly in Fig.2) and a second pair of permanent magnets 12, the magnets being positioned so that the magnetic lines of force from both pairs flow across the housing walls in the same sense. The
15 radially inner of each magnet of a pair is embedded in the plastics material of forming housing 10, whilst the radially outer of each magnet pair is secured to the exterior of the housing.

Input electrodes 14 project into the mercury so that an
20 electrical current from current generator 9 can flow within the mercury, at the position of permanent magnets 11, and when this occurs the mercury is energised to move (into or out of the paper) until the body of mercury is rotating about the axis of

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rotation RA. The shaped cross-section of the cavity is selected so that in conjunction with the frictional resistance at the walls of the container, the flow rate of the mercury across the flow path will decrease to either side away from the cavity radial centre line, as shown in the full-line graph of velocity gradient of Fig.3. Perpendicular to the rotational axis RA i.e. horizontally as viewed in Fig.2, cavity 13 has its largest diameter 19; for a hypothetical liquid front moving around the cavity 13 about axis RA, the angular rate of the radially outer elements will be greater than that of radially inner elements, it being understood however that those elements in frictional contact with the cavity wall may be slowed relative to those spaced therefrom.

In alternative embodiments to that of Fig.2, the cavity can have a different shape, for instance both at the position of the electrodes 14a,14b and at the position of pick-ups 15a,15b; the pick-ups 15a,15b need not be spaced diametrically opposite electrodes 14a,14b; and the cavity 13 need not be of uniform cross-section around its circumference, having for instance a necked portion in order to increase the fluid angular rate. Furthermore the cavity 13 may not be of constant radius about the rotational axis RA, nor need the outer part-circumference seen in Fig.2 and formed about sensitive axis SA be of this same radius.

In a further embodiment, to increase the liquid mass for a

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given housing volume, instead of cavity 13 being an annular recess formed or cut from the solid electrically-insulating plastics block 10 forming the housing, housing 10 is hollow and (except for one magnet of each magnet pair 11,12 and the sensors 5 and pick-ups) is filled with liquid e.g. mercury, the velocity profile of only part of which is sensed. Perhaps also only part of the body of liquid is energised by electrodes 14a,14b, for instance to create laminar flow (as a liquid stream within the liquid body), the velocity profile of part or all of the liquid 10 stream being sensed by pick-ups 15a,15b.

When the moving mercury cuts the lines of magnetic force from magnet pair 12, an electrical current is induced in the mercury and this can be measured, as by the electrodes or pick-ups 15a,15b; as seen in Fig.4, electrodes 15a,15b are centre tapped 15 to ground electrode 16. In the neutral condition, when the mercury is at rest, or when the mercury is rotating about axis RA without rotation of the housing about the sensitive axis SA, then the velocity gradient will be symmetrically disposed about ground electrode 16 and the voltages appearing at electrodes 15a,15b 20 will be equal and opposite and so cancel out each other; with the cavity rotating about axis SA, anti-clockwise as viewed in Fig.2, effectively a torque will be applied to the rotating mercury, so that the mercury will tend to be displaced relative to the cavity

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in dependence upon its instantaneous flow rate along the cavity, as indicated in the dotted-line graph of Fig 3, and so there will result an unbalanced electrical output from electrodes 15a,15b.

The unbalanced electrical output will be in proportion to the rate of rotation of the cavity about axis SA, and can be a measure thereof. Amplifier 17 is used to raise this electrical difference output to a useful level, to operate indicating means 30.

In an alternative embodiment, resistors R1,R2 (of resistance in this embodiment of 10 ohms), can be replaced by a potentiometer, centre tapped to amplifier 17.

We have therefore provided means to cause the mercury to flow around the cavity by the conjunction of a magnetic field and an imposed electric current; the second set of magnets 12 and electrodes 15a,15b are used to measure the electrical potentials generated as a result of the instantaneous flow of the conductive fluid. I can dispose and shape the magnets 11,12 and the housing so that the measurements of the velocity assymetry are made across a flow path of desired configuration e.g. as shown by lead-line 13. I can arrange electrodes 14a,14b so that the imposed electrical current passes wholly therebetween i.e. so that container 10 need not be an insulating container.

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For liquid energisation, it may be desirable to use alternating current excitation, and consequently an alternating magnetic field, particularly if direct current excitation is found with less conductive fluids to lead to excessive ion build up at an electrode 14. In an alternative embodiment, the rotation of the conductive fluid e.g. mercury, can be by means of alternating electro-magnetic fields with a controlled phase relationship such as to generate energising eddy currents in the conductive fluid; typically two AC fields side-by side and shifted in phase.

10 An AC field can also be used to sense the velocity gradient. Thus an AC magnetic field can provide small but measurable alternating voltages or current in an external circuit, using electrodes in the conductive fluid and a synchronous detector preferably outside the housing; this arrangement can be used for
15 applications where thermal EMF's are considered a problem.

I foresee that the cavity 13 can be one of a number of shapes, each providing a distinct velocity profile when the housing is at rest i.e. a varied flow rate across the flow path. Furthermore the cavity may be spherical, or it can be the space between two
20 spheres, in both cases with the advantage that outputs are possible for rotation about a second sensitive axis perpendicular to the first sensitive axis (and of course with each perpendicular to the rotation axis RA). The cavity shape should be such that the rate of flow of the rotating fluid varies in

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accordance with the radius from axis RA, and is selected to optimise the flow profile for a particular application.

In an alternative embodiment, the permanent magnets 12 used for sensing the electrical gradient can be replaced by solenoids energised by an alternating current. The electrodes 15a, 15b immersed in the conducting fluid can be replaced by coils, arranged to sense the field generated by the electrical currents induced in the conducting fluid. The relative amplitude and phase of the electrical currents in the sensor coils will provide information on the relative flow of velocity in the conducting fluid. e.g. mercury.

If the cavity is electrically conducting, then I foresee that the electrical potentials derived from the rotating conducting fluid can be measured on the surface of the conducting container.

In an alternative embodiment, where the assymetric velocity is again to be sensed by electrical means, I can inject neutrally buoyant material into the rotating fluid, the neutrally buoyant material having a different electrical resistance to that of the fluid. Thus the electrical resistance across the flow path will change in accordance with the distribution of the neutrally buoyant material, and thus with the velocity profile.

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I also foresee that I can use non-electrical means to sense the assymetric velocity profile. Thus if the rotating fluid is transparent, then the rate of rotation can be sensed from the variation in the optical reflection or transmission due the
5 presence of a neutrally buoyant opaque or reflecting material capable of rotation with and within the rotating fluid. Thus I deliberately introduce inhomogenities into the transparent rotating fluid. It will be understood that the "optical" sensor does not require the rotating fluid to be electrically
10 conductive.

An advantage of using liquid as the rotating medium is that it is substantially incompressible, and so does not introduce discomformity errors into the velocity distribution when the cavity is subject to high rotational forces.

15 A modified arrangement is shown in Figs. 5,6. A single large permanent magnet 111 is located in housing 110. Housing 110 is of high permeability (to magnetic flux) material, so that the lines of force travel from the north pole N across cavity 113, and then travel around the container until opposite the south pole S where
20 they then travel (radially) inwardly across cavity 113 to the south pole, to effect rotation or continued rotation of the mercury in cavity 113 in conjunction with the applied electrical current from co-axial cable 114 to terminals 114a,114b. The assymetric electrical distribution is sensed at the

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diametrically-opposed position, being sensed by pick-ups 115a,115b, and fed to amplifier/comparator 118 as is the signal from centre sensor 116, with the net current being taken to an indicator (not shown) by line 121.

5 In this embodiment, the mercury is confined within the thin annular cavity 113 defined by magnet 113 and housing 110, having respective outer and inner part-spherical surfaces coated with a thin layer of an insulating material 150,152. Thus in this embodiment, cavity 113 is formed between two truncated spheres,
10 because as viewed in Fig.5 the upper and lower terminal edges the cavity 113 are respectively defined by insulating supports 140,142; the maximum effective diameter 119 of the cavity 113 is the horizontal line which cuts centre tapping 116 since the measurement axis between pick-ups 114a,114b is vertical, the
15 fluid rotational axis is also vertical intersecting the mid-point of diameter 119 and coincident with the axis of hollow neck 144, and the sensitive axis projects out of the paper also from the mid-point of diameter 119. The cables 114,121 are located within the upper 140, and lower 142 closure members (as viewed in Fig.5)
20 prior to emerging through hollow neck 144, but in a less preferred embodiment can be located external thereto. Hollow neck 144 is externally threaded at 146 for mounting in a parent body (not shown) whose angular rate (clockwise or anti-clockwise as seen in Fig.5) is to be measured, by the difference between
25 the outputs of pick-ups 115a,115b.

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In alternative embodiments to those of Figs 2 and 5, the pick-ups 15a,15b; and 115a,115b are not diametrically disposed with respect to energising electrodes 14a,14b; and 114a,114b respectively. The flow conditions can thus and otherwise be
5 varied around the circumferential length of the cavity to achieve maximum assymetry of the velocity profile for minimum rotational rate about the sensitive axis i.e. maximum sensitivity, in particular for low angular rates. Low angular rate changes can also be noted, and separately from the new rate being measured,
10 the acceleration i.e. the rate of change of angular rate, can be computed if desired, usually by external instrumentation. The circumferential position around the cavity (in the direction of fluid flow) at which the maximum change in velocity profile (across the flow) occurs can readily be checked by the use of
15 additional pick-ups, circumferentially-spaced. The terminals 114a,114b are connected to separate but wound leads rather than to co-axial cable 114.

A major factor limiting the wider use of inertial sensors is I believe their cost, resulting from their internal complexity and
20 the number of precision parts needed; I have tackled both problems. Furthermore, as above described, the (fluid-filled) cavity I propose is not necessarily of electrically insulating material.

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CLAIMS

1. An angular rate sensor for measuring angular velocity about a cavity sensitive axis (SA) which includes a fluid filled cavity (13,113), energising means to cause rotation of the fluid in the cavity about a rotation axis (RA) perpendicular to said sensitive axis (SA), the moving fluid having parallel to said sensitive axis a flow rate gradient characterised by sensor means (15a,15b; 115a,115b) to sense a change in said flow rate gradient with rotation of the cavity about said sensitive axis.
2. An angular rate sensor according to claim 1 characterised by indicator means (30) external to the cavity to indicate the rate of rotation of the cavity about said sensitive axis (SA).
3. An angular rate sensor according to claim 1 characterised in that said sensor means includes electrically conductive probes (15a,15b;115a,115b) immersed in the fluid, and in that said energising means includes permanent magnets (11,111) secured to the cavity and located adjacent electrically conductive input electrodes, to effect rotation of the fluid both around the cavity and between the probes.

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4. An angular rate sensor according to claim 1 characterised by alternating current means to provide alternating magnetic fields to cause rotation of the conductive fluid.
5. An angular rate sensor according to claim 1 characterised by impellor means external to the cavity to effect rotation of the fluid around the cavity.
6. An angular rate sensor according to claim 1, characterised in that the cavity is a closed annulus, with a crown (19,119) at the annulus mid-position, the crown extending radially outwards from the fluid rotation axis (RA).
7. An angular rate sensor according to claim 1 characterised in that the cavity is the space between an inner sphere and an outer sphere, and in that means are provided to rotate the cavity about two axes, each perpendicular to the said fluid rotation axis (RA).
8. An angular rate sensor according to claim 1 characterised in that the cavity is electrically conducting, in that the sensor means records electrical potentials, and in that an electrical potential is measured on the surface of the container.
9. An angular rate sensor according to claim 1 characterised

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in that neutrally buoyant particulate material is located in the fluid, and in that means responsive to a change in the spatial position of the material is used to indicate a change in the velocity distribution of the fluid.

10. An angular rate sensor according to claim 1 characterised in that the rotating fluid is optically transparent, and characterised in that neutrally buoyant particulate material is present in the fluid, and means to determine the velocity profile by observation of the optical reflection and transmission index for the material.

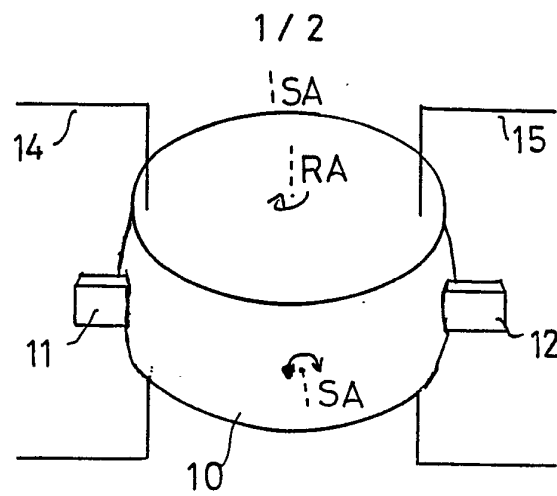


FIG 1

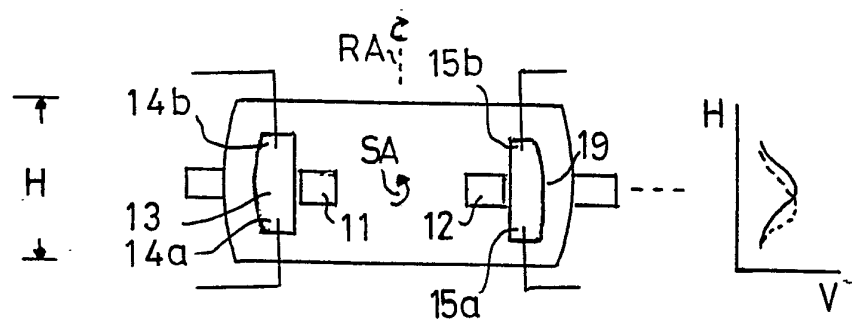


FIG 2

FIG 3

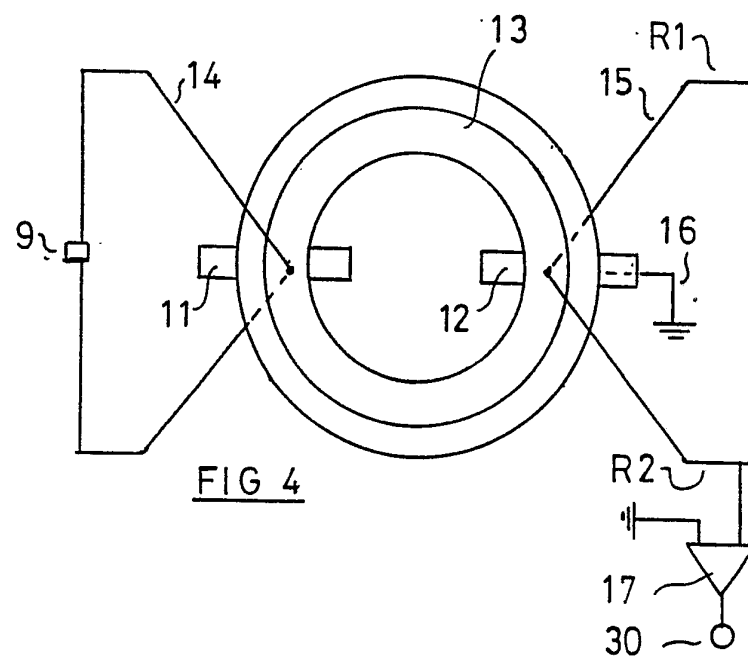
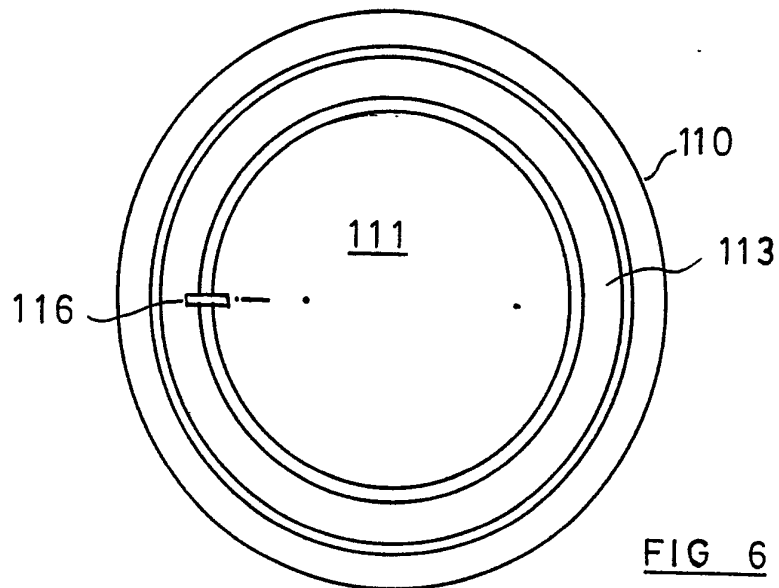
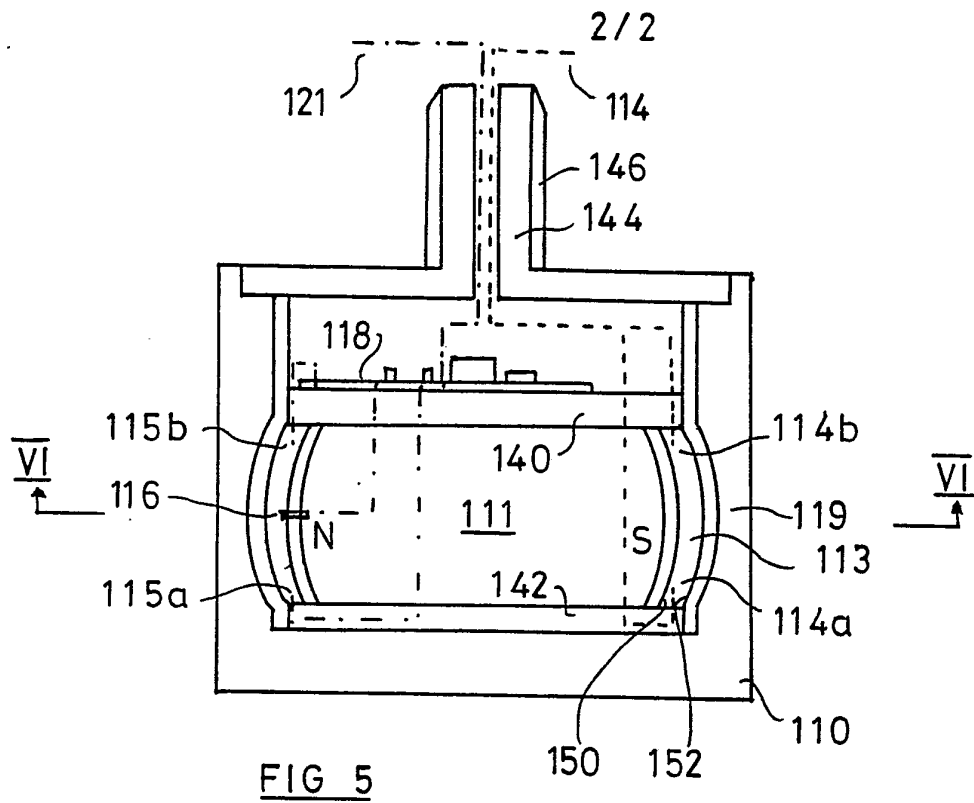
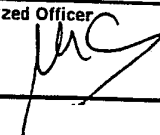


FIG 4



INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 90/01035

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁶ According to International Patent Classification (IPC) or to both National Classification and IPC IPC5: G 01 P 3/26		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁷		
Classification System	Classification Symbols	
IPC5	G 01 P	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in Fields Searched ⁸		
III. DOCUMENTS CONSIDERED TO BE RELEVANT⁹		
Category *	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
A	US, A, 4718276 (D.R. LAUGHLIN) 12 January 1988, see column 2, line 41 - line 46 --	1-10
A	US, A, 4188576 (P.L. JACOBS) 12 February 1980, see claim 1 --	1-10
A	Derwent's abstract No. K11 08 D/39, SU 794 515, publ. week 8139 UFA MINE EQUIPT WKS --	1-10
A	Derwent's abstract No. B30 048 C/06, SU 662 862, publ. week 8006 BELYAEV V S --	1-10
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IV. CERTIFICATION		
Date of the Actual Completion of the International Search		Date of Mailing of this International Search Report
31st August 1990		12. 10. 90
International Searching Authority		Signature of Authorized Officer
EUROPEAN PATENT OFFICE		 M. SOTELO

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
A	Derwent's abstract, No. 84-100 219/16, SU 1 029 086, publ. week 8416 MOSCOW BAUMAN TECH COLL --	1-10
A	Derwent's abstract, No. 85-163 577/27, SU 1 080 083, publ. week 8527 ZOLOTOV A D --	1-10
A	Derwent's abstract No. A15 08 E/01, SU 815 629, publ. week 8201 BELYAEV VS -- -----	1-10

**ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO.PCT/GB 90/01035**

SA 38022

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 02/08/90
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 4718276	12/01/88	NONE	
US-A- 4188576	12/02/80	NONE	

For more details about this annex : see Official Journal of the European patent Office, No. 12/82