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Declaration under Rule 4.17:

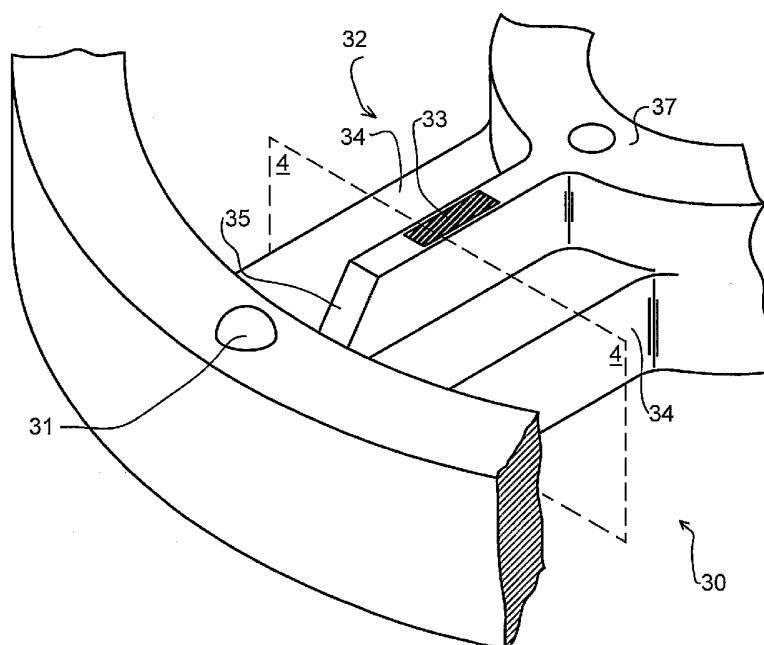
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[Continued on next page]

(54) Title: MEASUREMENT PROBE



(57) Abstract: A probe for position determining apparatus has a probe body (18) and a workpiece-contacting stylus (14). A strain sensitive structure connects the probe body and the stylus, and includes bendable members (32). The bendable members have an asymmetric cross-section, e.g. "T" shaped. A strain gauge (33) is mounted to the stem of the "T" to detect the bending caused when the stylus contacts a workpiece. This enables the strain sensitive structure to be both robust and sensitive to the bending.

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- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*
- For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

MEASUREMENT PROBE

The present invention relates to a measurement probe for use in determination of dimensions of articles like workpieces on positioning determining apparatus such as machine tools, coordinate measurement machines and other machines using coordinate positioning.

The probe may include a workpiece contact element such as a stylus which is urged out of a rest state when contact with the workpiece is made. This urging can be detected and a signal indicating the said workpiece contact may be generated to provide an indication of the workpiece position according to the coordinate positioning system used.

Many different types of probes as described above are known. Ideally such probes should be very sensitive to force acting on the probe's stylus or other contact element, and yet be reasonably robust to prevent damage to the probe e.g. when the probe is dropped or accidentally driven into the workpiece violently.

Typically contact measurement probes fall into two categories: those that produce a trigger signal very quickly when workpiece contact is made (so called "touch trigger probes"); and those which have a variable signal indicative of the amount of deflection of the stylus relative to the probe body (so called "analogue probes" "or scanning probes").

Analogue probes are used generally in a manner such the stylus moves across the workpiece and the probe generates many data points corresponding to the profile

of the workpiece. Analogue probes are necessarily sensitive and consequently are generally not suited to rugged use.

5 Touch trigger probes are simpler and better suited to applications such as use on a machine tool, where adverse conditions such as knocks and vibration are encountered. Touch trigger probes conventionally have an electrical switch type arrangement which is opened
10 (or closed) on workpiece contact.

Touch trigger probes are generally mechanical in nature and have moving parts which can become worn or damaged.

15 In order to overcome the above disadvantages probes which employ strain gauges have been developed. One such probe is shown in US Patent No. 5,327,657. Fig 9 of that document shows a strain gauge cell 334 which is strained in use by the stylus shown at the lower part
20 of Fig 9. The cell 334 has three legs extending toward the stylus. Whilst this probe is sensitive it is not particularly robust, particularly if the stylus is knocked. A similar probe is shown in EP 68899.

25 Another strain gauge probe is shown in International Patent Application No. WO01/96809A1, Fig 3 of which shows a strain gauge support structure 34 having three legs. In order to provide more robustness an additional stylus support 42 is provided. This
30 additional support allows the strain gauge support structure 34 to be reduced in stiffness and thus made more sensitive. Overall, the probe structure is not compact.

The inventor of the present invention has proposed a sensitive touch trigger probe which is robust which in the embodiments described herein negates the requirement for additional stylus support.

5

The present invention provides a measurement probe, the probe comprising a probe body, a workpiece contacting stylus, and a strain sensitive structure connecting the body and stylus, the stylus extending generally along
10 an axis, the structure having a plurality of members connecting the stylus to the body extending substantially in one plane, at least one of the members having a strain sensing element associated therewith, wherein the at least one of the members has a cross-
15 section in a direction perpendicular to the plane, which is asymmetrical.

Thus embodiments of the invention provide a strain sensing probe which has at least one strain sensing
20 element associated with a strain sensing member. The member may have a neutral bending axis (i.e. an axis which is neither compressed nor stretched), which is closer to one side of the member than an opposite side by virtue of the member's asymmetry.

25

The result of this arrangement is that the strain sensing element can be placed further from the neutral axis on one side of the member than the opposite side of the member so, for the same member stiffness a
30 greater strain sensitivity can be achieved.

It is possible that composite members could be produced, as described below, which whilst being symmetrical in cross-section, have a neutral axis which

is closer to one side of the member than the other. Such members can be employed also for increased sensitivity and robustness, and are considered to be asymmetric for the purposes of the paragraphs above.

5

Embodiments of the invention will now be described with reference to the accompanying drawings, wherein:

Fig 1 shows a measurement probe employing the invention;

10 Fig 2 shows details of a strain sensing member shown in Fig 1;

Fig 3 shows further details of the strain sensing member shown in Fig 2;

15 Fig 4 shows a cross-section through the member in the plane 4-4 shown in Fig 3;

Figs 5a,b,c and d show alternative cross-sections to the cross-section shown in Fig 4;

Fig 6 shows an alternative measurement probe;

20 Fig 7 shows a detail of components of the probe shown in Fig 6;

Fig 8 shows a further alternative strain sensing member; and

Figs 9 and 10 are cross-sections of still further alternative strain sensing members.

25

A dimensional measurement probe 10 is shown in Fig 1 which is attachable to a machine 5 via a boss 12. The machine is typically one which can determine the coordinates of the probe e.g. in xy and z planes.

30

The probe has a stylus 14 including a tip 16 for contact with a workpiece or other artefact 50 to be measured. The probe is moved by the machine relative to the artefact 50 and contact of the stylus tip with

the artefact 50 is sensed by the mechanism within the probe 10. The probe produces a signal which is sent to the machine in order to determine the probe's coordinates. In this way the coordinates of the surface of the artefact can be obtained.

The probe 10 includes a main body 18, a circuit board 20, a spring cage 22, a compression spring 24, upper member 26 of stylus 14 and a strain sensing element 30. For clarity the view of the probe is a part-section in the sectional plane shown as 1-1 in Fig 2. This plane is not completely flat but includes two planes at 120° to each other.

In operation force is exerted on the stylus tip in the x,y or z directions or combinations of these directions. The force causes flexing of the radially extending arms 32 of the sensor element 30 relative to the body 18 to which the sensor element is fixed at central portion 37. Excessive force on the stylus in the x or y directions, or pulling the stylus in the z direction away from the probe body, will result in closing of the gap 28 between the sensor element 30 and the body 18. Thus excessive strain on the sensor element 30 cannot take place. Further force on the stylus causes the compression of spring 24 resulting in the disconnection between the stylus upper member or stylus holder 26 and the sensor element 30 against the force of the compression spring 24. Removal of the further excessive force allows the stylus to reseat against the sensor element 30. The contact between this upper member 26 and the sensor element 30 is in the form of a kinematic location having a total of six points of contact. In this instance the kinematic

location is formed from three balls 31 on the sensor,
each one nesting between a pair of rollers 27 on the
member 26. Thus advantageously, reseating is possible
into a repeatable rest position if excessive force is
5 exerted on the stylus.

Fig 2 shows the sensor element 30 in more detail. The
element 30 is produced as one piece, e.g. of machined
metal. Each of the three balls 31 affixed to the
10 surface of the element 30 has in use force exerted on
them. When the stylus tip 16 contacts the workpiece
the force exerted on the balls is altered. This in
turn causes strain to be induced in radial arms 32. A
semiconductor strain gauge 33 is secured to each of the
15 arms 32. Each strain gauge provides a change in output
if the strain in the arm is altered. Thus stylus
contact with article 50 can be detected. Circuit board
20 enables such detection. An example of a circuit
suitable for use in this invention is described in US
Patent No. 5,228,352.

There are three radially extending arms 32 shown,
although other numbers of arms may be employed. Fig 3
shows an arm 32 in more detail. The area shown in Fig
25 3 is that inside the cut line 3 in Fig 2. The
preferred sectional shape of the arm is an upside down
"T" as shown in Fig 3. However, other sections are
envisaged e.g. as shown in Figs 5a,b,c and d. A strain
gauge 33 is mounted to the uppermost surface of the
30 flange which forms the stem of the "T" by means of two-
part adhesive. The "T" shape of the arm improves
responsiveness of the strain sensing member 30.

It would be possible to use a regular thin section e.g.

rectangular in place of the "T" section shown to provide the required sensitivity of the strain sensing member. However, such a section will be lacking in stiffness or if made thicker will then become
5 insensitive. It has been found by the inventor that the "T" section is both stiff for robustness and sensitive to forces acting on the stylus. For a given stiffness, more bending is experienced at the locations of the strain gauges 33 than would otherwise be the
10 case. This also leads to an improved signal to noise ratio.

Also it has been found that a notch 35 formed in the upper flange forming the stem of the "T" shape produces
15 a better resultant strain reading. This modifies the bending of the arm 32, causing the arm to deflect in use in the manner of a cantilever. The arm would be forced into an "S" shape under load if no notch were present, and this would produce less resultant strain
20 at the position of the strain gauge.

Fig 4 shows a section of the arm 32 in the plane 4-4 shown in Fig 3. The relative sizes of the section are shown. It has been found that a suitable size if "a" is equal to 1 then "b" should be in the range of about
25 1-2, "c" should be in the range of about 3-6 and "d" should be in the range of about 0.5-1.5. Axis n.a shows the neutral or bending axis. It can be seen that the distance Z1 between the strain sensitive element 33 and the neutral bending axis is greater than the
30 distance Z2 between the neutral axis and the fair line of the arm's surface opposite to the element 33.

Figs 5a,b,c and d show examples of other sectional

shapes for the arm 32 usable in place of the T section shown in Fig 4. Fig 5a shows a trapezoidal section, the strain gauge 33 being mounted to the top face as shown. Fig 5b shows a U shaped section, the strain gauge 33 being mounted to one of the upper edges of the U as shown. Fig 5c shows a composite structure having an upper section 52 which is less stiff than a lower section 54. The strain gauge is mounted as shown. The materials could be aluminium or fibreglass (52) and steel (54). Alternatively, the two sections in Fig 5c could be of the same material but perforated with holes at different densities such that they have different stiffnesses. Or the density of such perforation could vary gradually from top to bottom of a single section. Fig 5d shows a base 60, two spacers in the form of pillars 56, a strain gauge support 58, and strain gauge 33 mounted to the support 58.

In each of Figs 5,a,b,c and d the respective neutral axis n.a is shown. It will be noted that each strain gauge 33 is mounted further from the neutral axis n.a than the distance between the neutral axis and the face of the arm 32 opposite to the face where the strain gauge is mounted. As stated above, this results in a structure the strain of which can be measured readily but which can be made relatively stiff, and therefore robust. Notches can be provided, in a similar manner and for the same reason as the notch 35 in Figs 1-3.

Fig 6 shows a measurement probe 10' of similar construction to that shown in Fig 1. Again a true section is not shown, rather a section having a 120° angle is shown as for Fig 1. In Fig 6 the upper member 66 of stylus 64 bears on an inner portion of strain

sensing structure 61. In turn strain is exerted in radial arms 62. Strain sensing element 70 is fixed at its periphery to housing 78. Other details, and the functioning of the probe, are similar to the probe of Fig 1.

Fig 7 shows assembly detail of the probe shown in Fig 6. The securement of strain sensing structure 61 to housing 78 is by means of three fixings 68. The position of these fixings is such that neither compression nor tension of arms 62 is induced when housing 78 expands or contracts, due for example to thermal effects.

Fig 8 shows a strain sensitive structure 70, which may be used in place of the sensor structure 30 in Figs 1-2. Instead of the three radial arm members 32, strain gauges 33 are affixed to three members 80, which extend generally circumferentially around a generally triangular ring. A cup 82 in the middle of each member 80 holds a respective one of the balls 31 shown in Figs 1-2, against which the stylus holder 26 bears. The members 80 have "T" shaped cross-sections and notches 35, as previously. A complete ring structure is not essential to this embodiment: three separate members 80 could be used, extending generally circumferentially. Or the balls 31 could be located at the ends of each arm, instead of in the middle.

Fig 9 shows an alternative arm member 90 for use instead of the arm members 32 of Figs 1-4. It is shown in cross-section as in Fig 4, but has a thin rectangular cross-section instead of "T" shaped. Two strain gauges 33 are mounted on opposing short edges of

the rectangular cross-section, and are therefore well spaced apart. The electrical outputs of the two strain gauges are taken to the positive and negative inputs of a differential amplifier 92, which combines them
5 differentially. Because of the thin rectangular cross-section, and the differential processing, good sensitivity to bending is achieved in a reasonably robust structure.

10 Fig 10 shows a variant of the arm member of Fig 9. Here, a lateral member 94 augments the rectangular cross-section 90, so that the overall cross-section is in the shape of a cross. The lateral member 94 increases the stiffness of the member in the region of
15 the neutral bending axis. The resulting structure can be thought of as similar to two of the "T" shaped arm members of Figs 1-4, back-to-back.

Several embodiments employing the invention have been
20 disclosed. However, many variants and modifications to those embodiments will be readily apparent to the skilled addressee. Examples of such variants or modifications are described in the following paragraphs.

25 Three radially extending arms are shown in each embodiment, but fewer or more arms may be used. The arms, whilst having a radial extent may extend in an axial manner also.

30 A kinematic support for stylus 14/64 is shown which acts as a safety mechanism to prevent undue strain on element 30/60. However, this feature is not essential or could be replaced or supplemented by another feature

which operates in a similar manner.

The sections shown in Fig 4 and Figs 5 are not exhaustive. Other sections could be used provided they
5 produce the desired result i.e. a strain sensitive structure which is relatively stiff and therefore robust.

The strain gauges have been shown mounted to the face
10 of each arm opposite the tip of the stylus 64. It is possible to invert the arms 30/62 and mount the gauges on the underside of the element. It will be appreciated that terms used in this description such as "upper", "lower" etc relate to the orientation of the
15 probes shown in the drawings, and that in use the probes shown can be used in any orientation including having the stylus directed upwardly.

CLAIMS

1. A probe for position determining apparatus,
comprising:
 - 5 a probe body,
a stylus holder, connected or connectable to a
workpiece-contacting stylus,
at least one bendable member, connected between
the probe body and the stylus holder, which bends when
10 the stylus contacts a workpiece,
the bendable member having a neutral axis which is
not subject to tension or compression during such
bending, and at least one portion of the member lying
off the neutral axis, said portion being subject to
15 tension or compression during the bending,
a strain-sensing element located on said portion
which lies off the neutral axis, so as to produce an
output signal when the stylus contacts a workpiece,
the bendable member having a further portion which
20 is closer to the neutral axis than the portion on which
the strain-sensing element is located, said further
portion having a greater stiffness than the portion on
which the strain-sensing element is located.
- 25 2. A probe according to claim 1, wherein the bendable
member has a cross-section in a direction transverse to
the neutral axis which is asymmetrical.
3. A probe for position determining apparatus,
30 comprising:
 - a probe body,
a workpiece-contacting stylus,
a strain sensitive structure connecting the body
and the stylus, the strain sensitive structure

including at least one member which has an axis and which is bendable relative to the axis when the stylus contacts a workpiece,

a strain sensing element associated with said
5 bendable member, so as to provide a signal upon bending thereof,

wherein the bendable member has a cross-section in a direction transverse to the axis which is asymmetrical.

10

4. A probe according to claim 2 or claim 3, wherein said cross-section is "T" shaped, and the strain sensing element is mounted to the stem of the "T" shape.

15

5. A probe according to claim 2 or claim 3, wherein the cross-section is trapezoidal.

6. A probe according to claim 2 or claim 3, wherein
20 the cross-section is "U" shaped.

7. A probe according to claim 1,2 or 3, wherein the bendable member has a composite structure having a cross-section transverse to the axis, the composite
25 structure having a greater stiffness in one part of the cross-section than in another part of the cross-section.

8. A probe according to any one of the preceding
30 claims, wherein the bendable member has a notch at a position along its length, which modifies its bending.

9. A probe according to claim 1, 2 or 3 wherein the bendable member comprises a base and a support for the

strain sensing element, the base and the support being separated from each other by spacers.

10. A probe according to any one of the preceding
5 claims, wherein there is a plurality of said bendable members, extending substantially in a plane.

11. A probe according to claim 9, wherein the bendable members extend in a radial direction relative to the
10 probe body.

12. A probe according to claim 9, wherein the bendable members extend generally circumferentially around an axis of the probe body.

15

13. A probe for position determining apparatus, comprising:

a probe body,

a workpiece-contacting stylus,

20 a strain sensitive structure connecting the body and the stylus, the strain sensitive structure including at least one member which has an axis and which is bendable relative to the axis when the stylus contacts a workpiece,

25 a pair of strain sensing elements mounted on opposing sides of said bendable member, so as to provide respective signals upon bending thereof, and

a circuit which receives said signals and processes them differentially to produce a combined
30 output signal.

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Fig 1

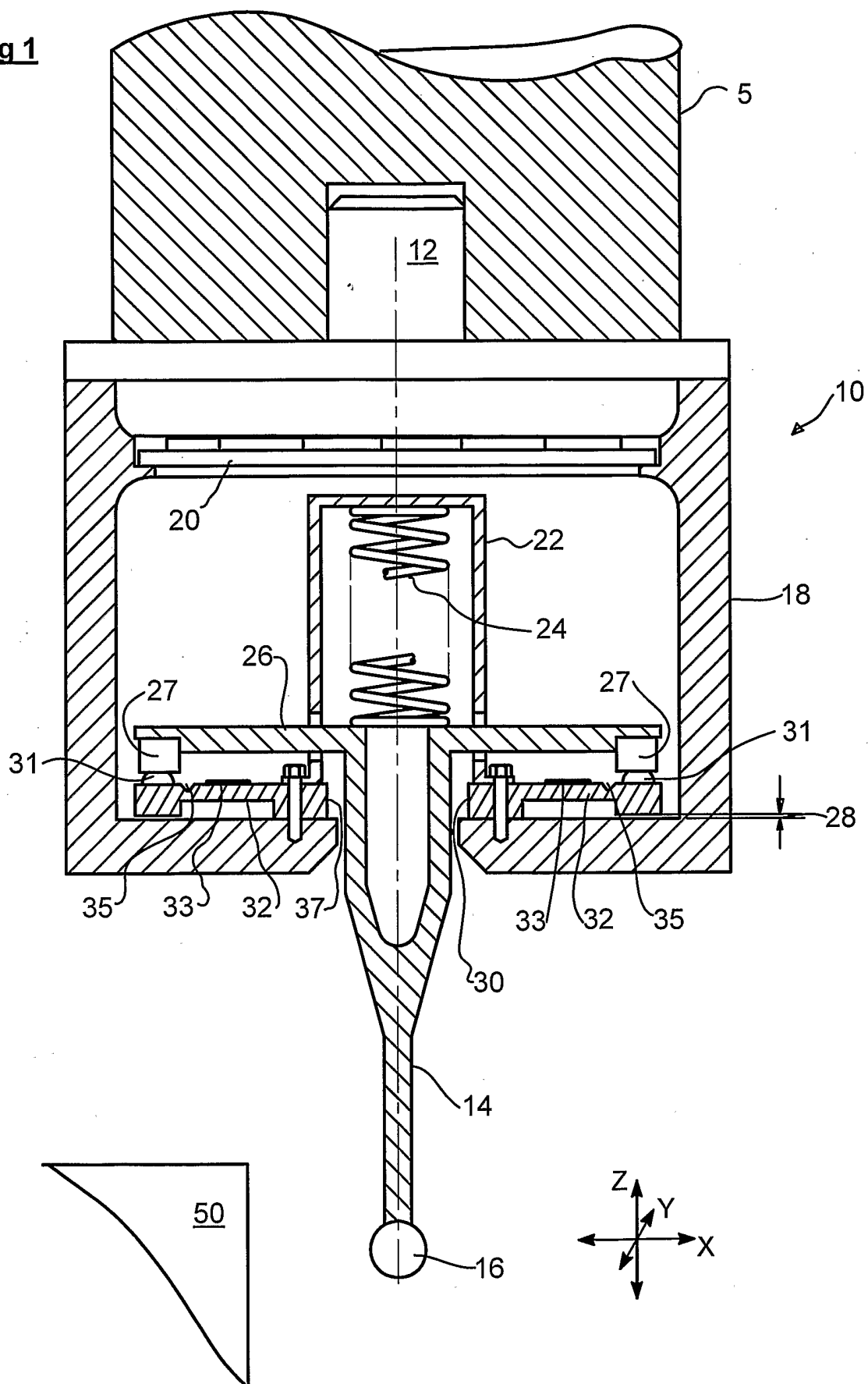
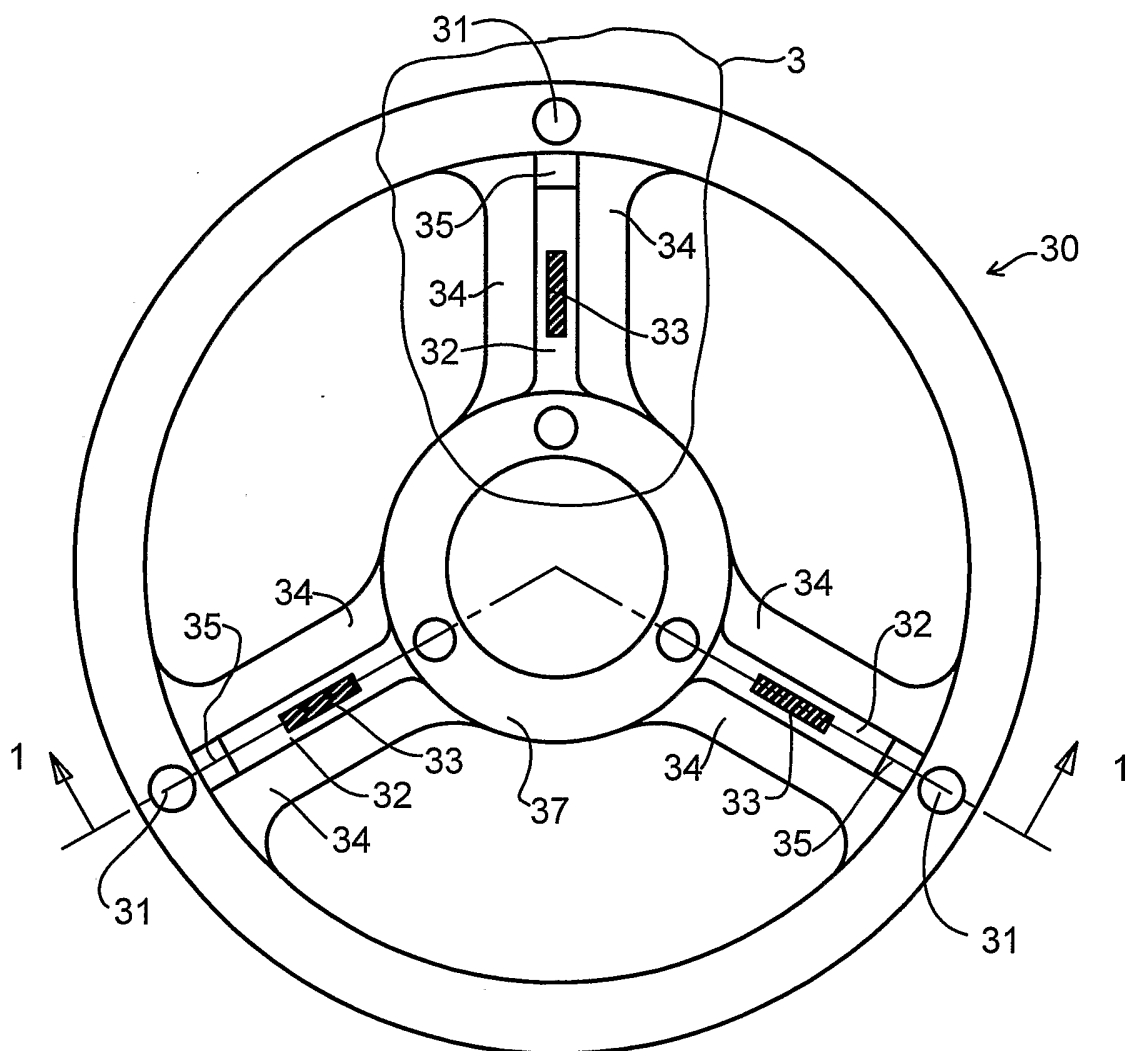
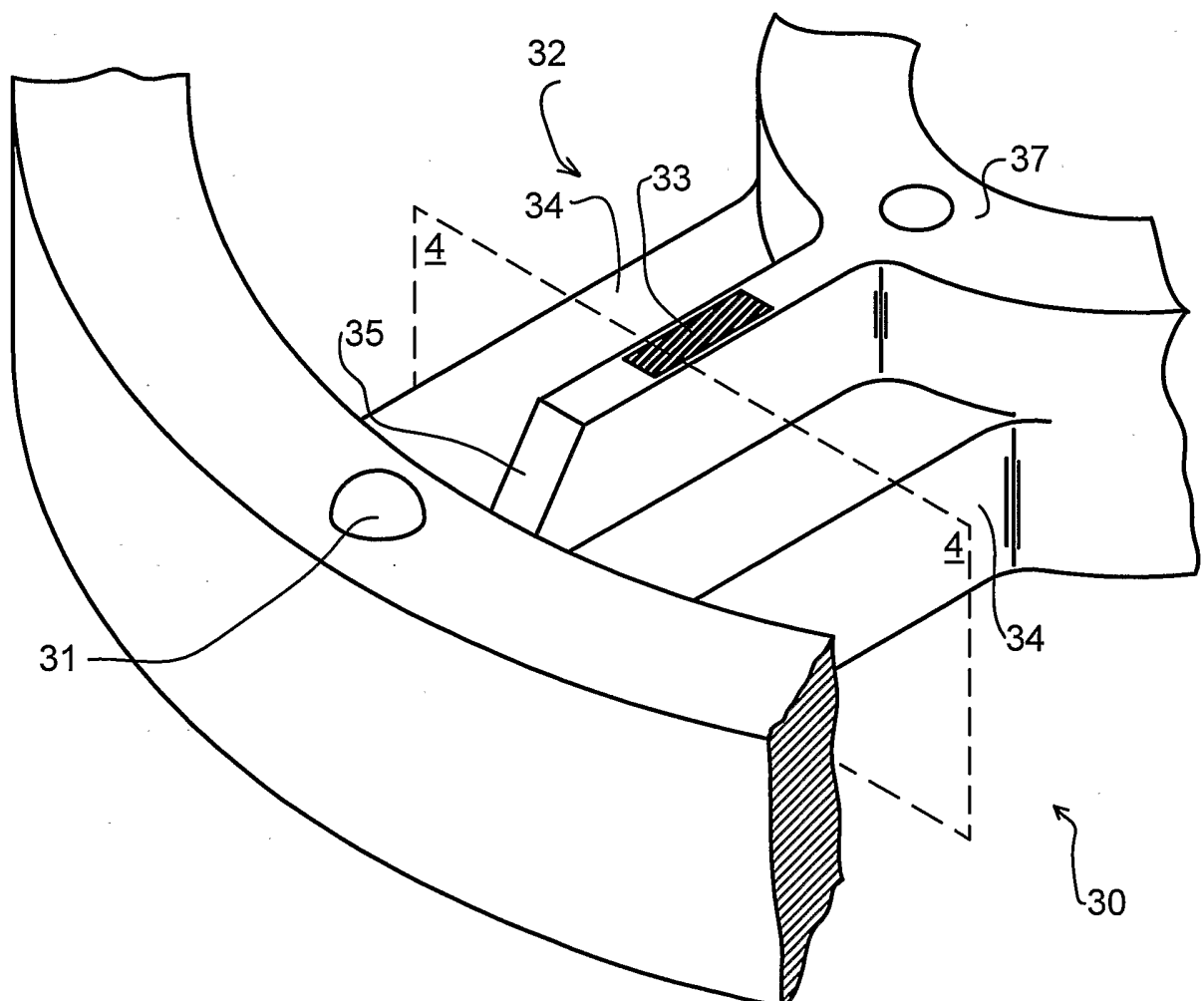
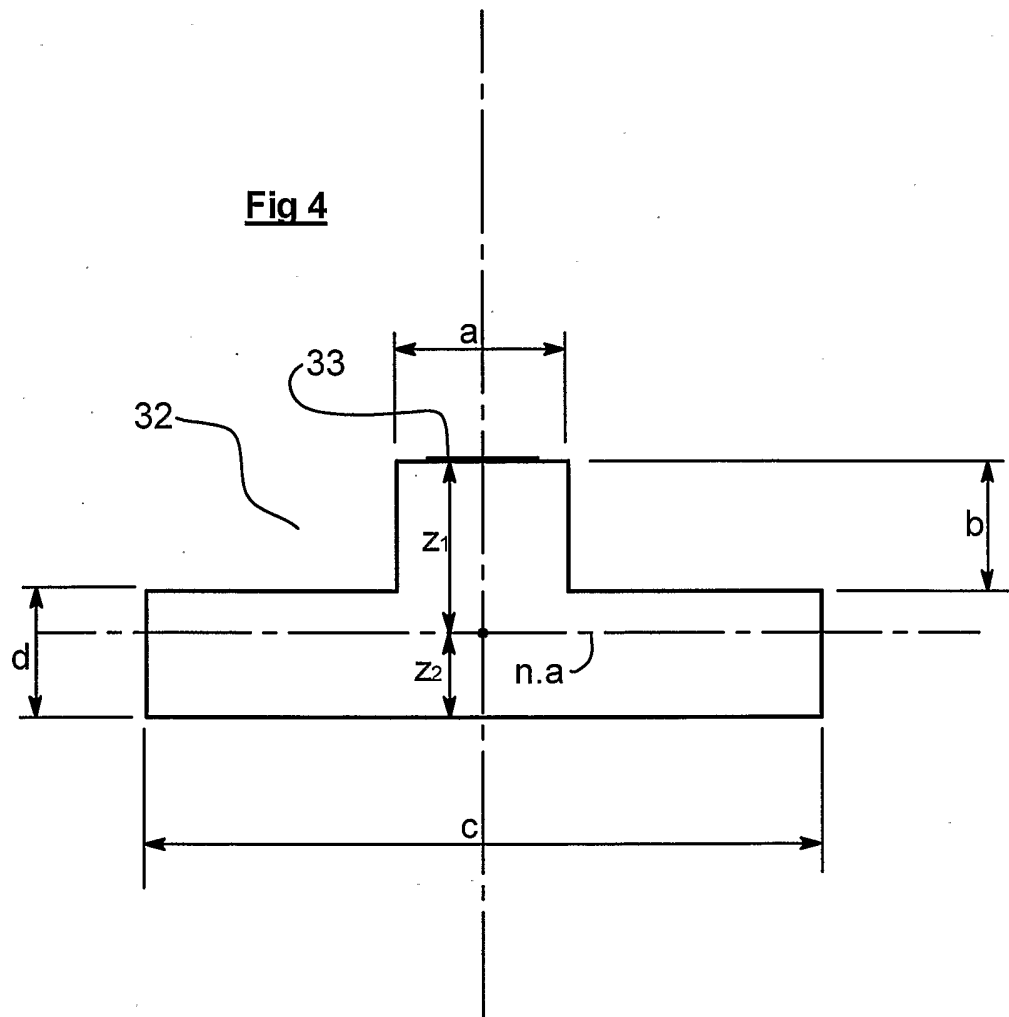


Fig 2

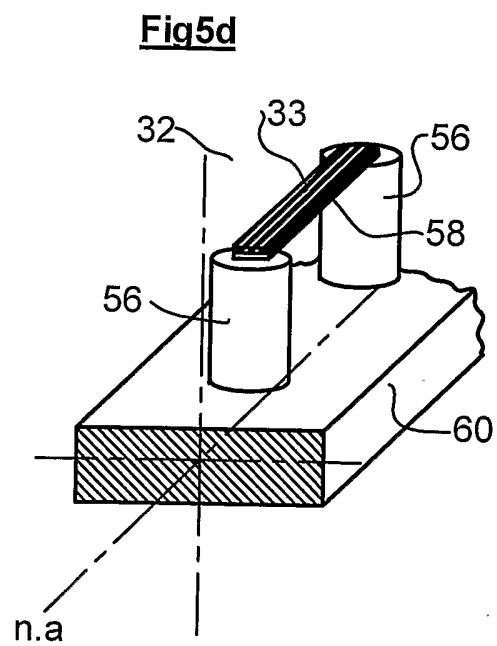
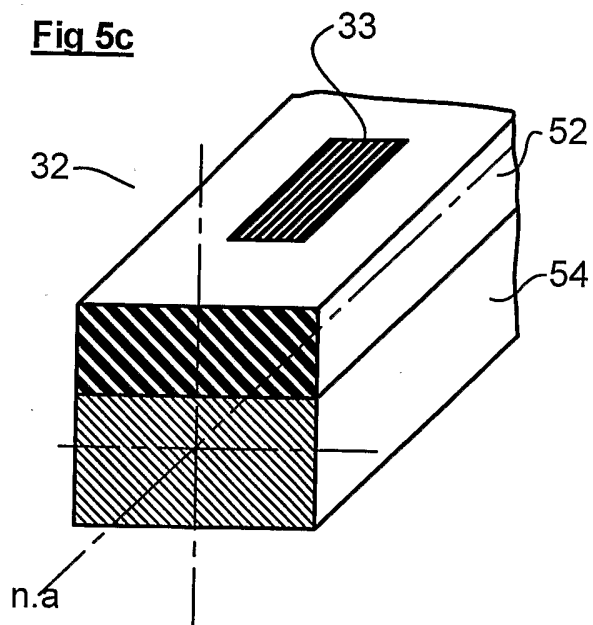
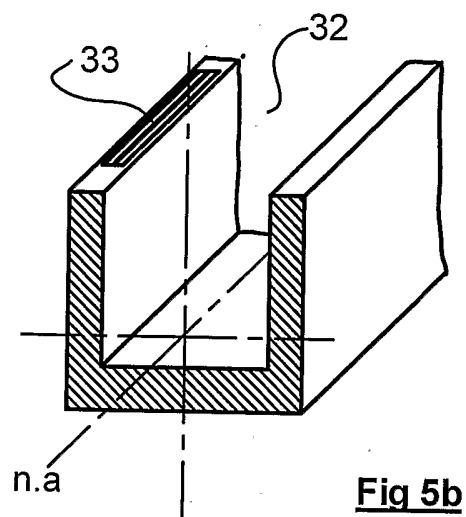
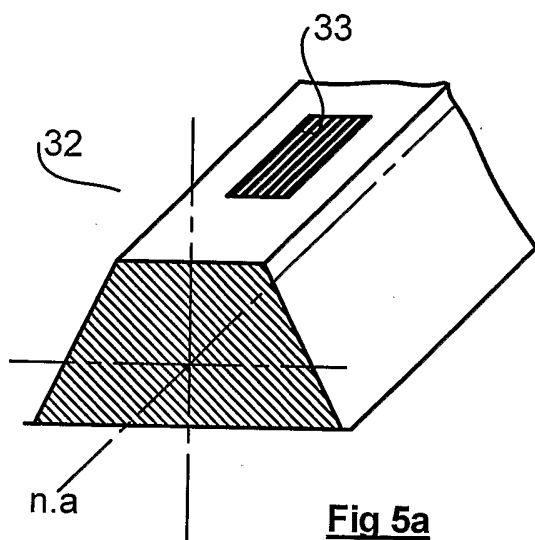
3/7

Fig 3

4/7

Fig 4

5/7



6/7

Fig 6

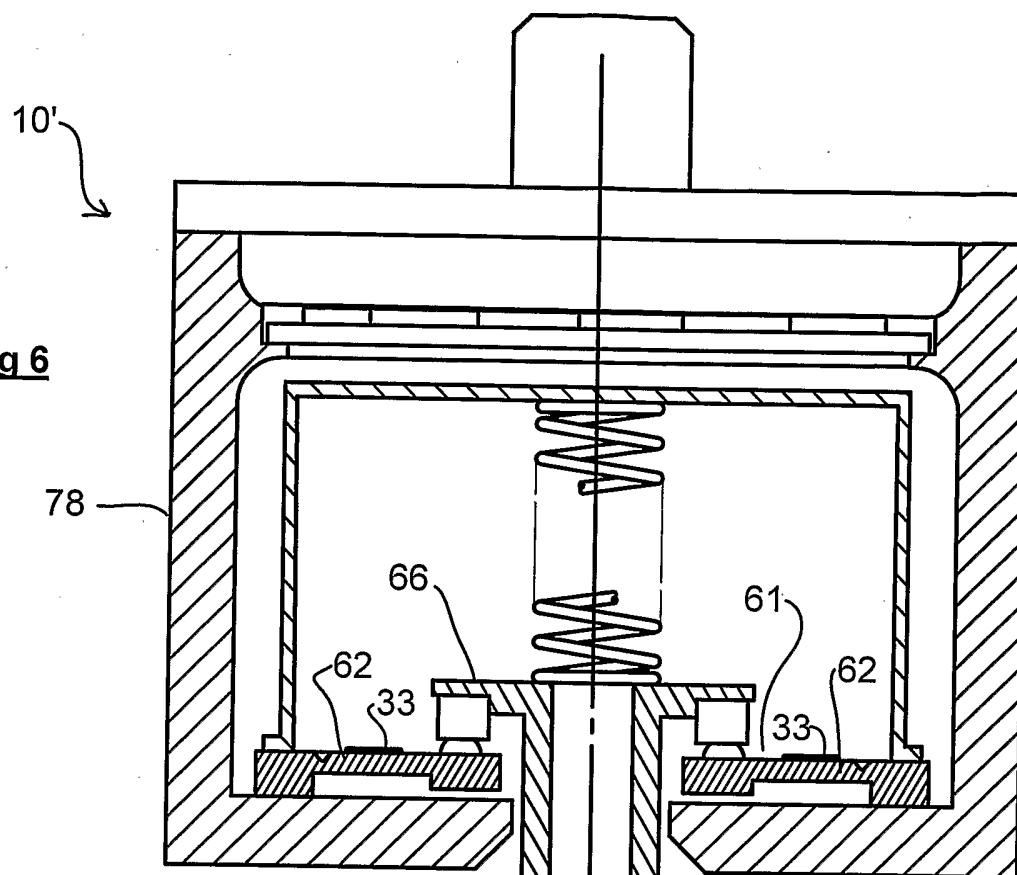
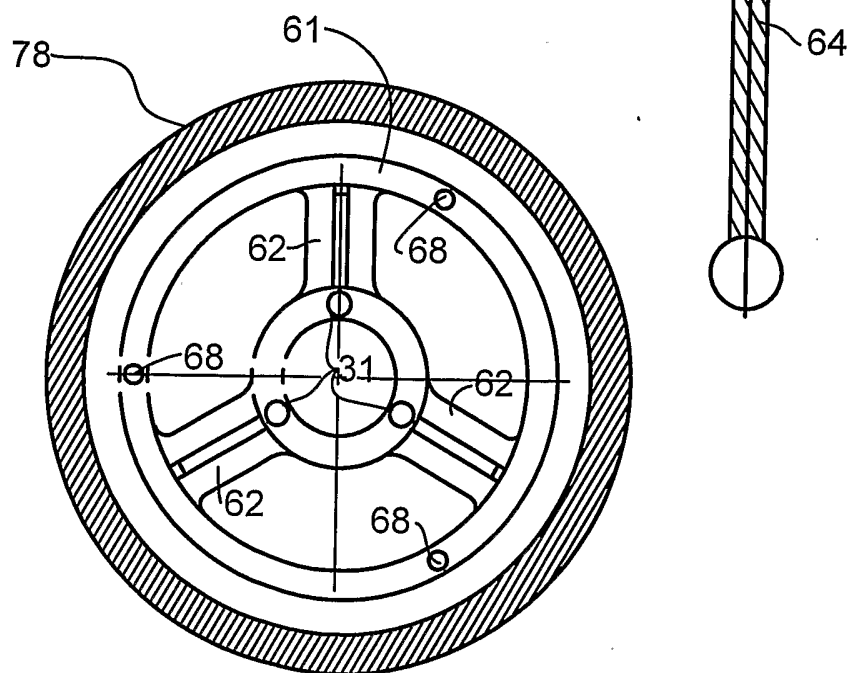


Fig 7



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FIG 8

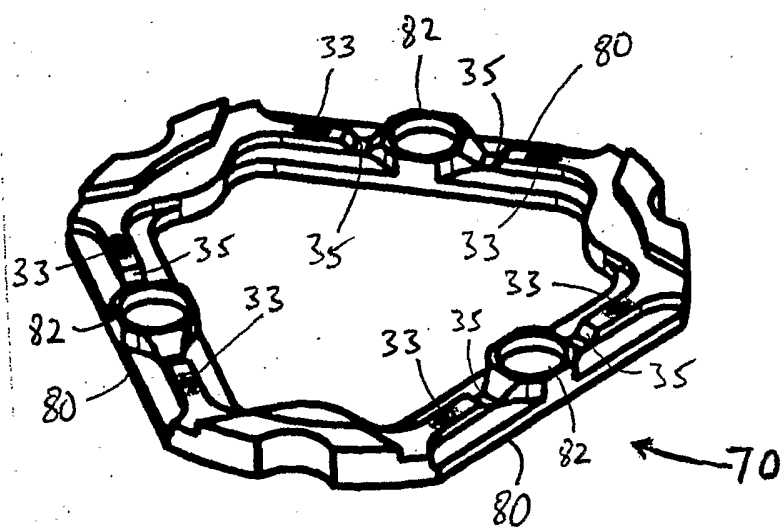


FIG 9

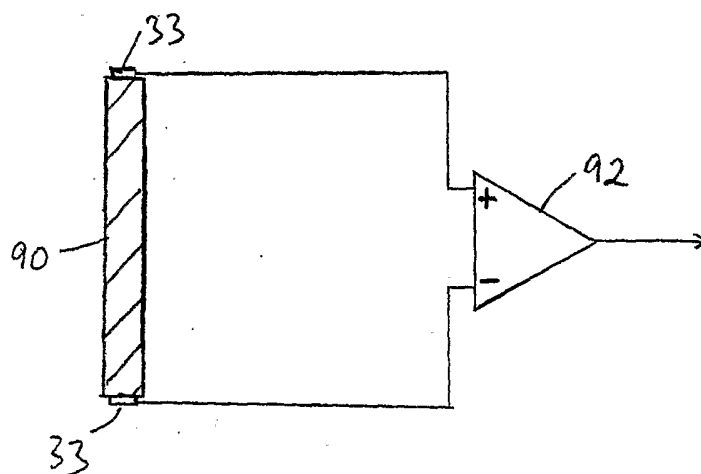
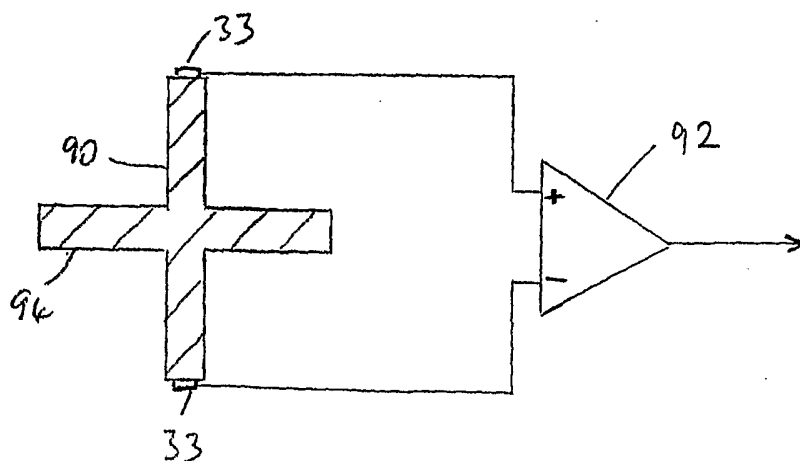


FIG 10



INTERNATIONAL SEARCH REPORT

International application No

PCT/GB2006/001095

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01B7/012

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)

G01B

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

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

EPO-Internal, WPI Data, PAJ, INSPEC, COMPENDEX, IBM-TDB

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2004/051181 A (RENISHAW PLC; MCMURTRY, DAVID, ROBERTS; MCFARLAND, GEOFFREY) 17 June 2004 (2004-06-17) page 11, line 27 - page 13, line 19; figures 2-6	1-12
A	WO 02/068904 A (CARL ZEISS; CARL-ZEISS-STIFTUNG TRADING AS CARL ZEISS; ROTH, ROLAND; S) 6 September 2002 (2002-09-06) page 13, line 5 - page 16, line 16; figures 4-8	1-12



Further documents are listed in the continuation of Box C.



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 document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *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
- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- *G* document member of the same patent family

Date of the actual completion of the international search

7 August 2006

Date of mailing of the international search report

24/08/2006

Name and mailing address of the ISA/

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Authorized officer

Kunz, L

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB2006/001095

Box II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☒ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

1-12
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☒ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claim: 1 and 2

Touch probe with a bendable member carrying strain gauges and connecting the stylus to the holder, wherein the bendable member is formed from specific materials.

2. claim: 3 to 12

Touch probe with a bendable member carrying strain gauges and connecting the stylus to the holder, wherein the bendable member has a specific shape.

3. claim: 13

Touch probe with a bendable element carrying strain gauges and connecting the stylus and the holder with a specific arrangement of the strain gauges on the bendable member.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2006/001095

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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