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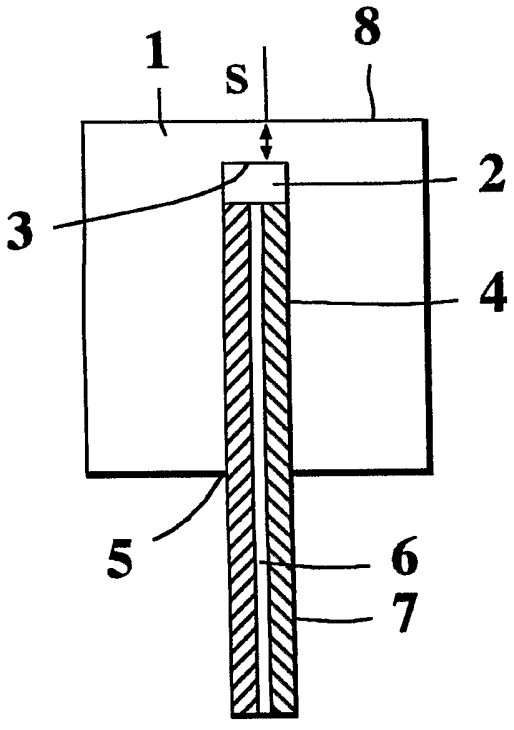
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(54) **Title:** Method and Apparatus for Monitoring a Contact between Two Surfaces



(57) **Abstract:** Method for monitoring a contact between two surfaces, particularly two surfaces moving relative to each other, which contacts between two surfaces appear in sliding and rolling bearings, in gear trains, and in other sliding or rolling contacts of a machine construction. In the method, a recess (5), which has a bottom (3), is created behind the first surface (8) in the contact, and which recess extends towards the first surface (8). A detection device (4, 10) is placed at a distance from the bottom, so that a detection space (2) is formed between the detection device (4, 10) and the bottom (3) of the recess. Now the detection device (4, 10) can be used to monitor the changes taking place in the detection space (2).

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MONITORING A CONTACT BETWEEN TWO SURFACES

The present invention relates to a method, according to the preamble of Claim 1, for monitoring a contact between two surfaces, particularly two surfaces that move relative to each other. Contacts of this kind between two surfaces typically appear in sliding and rolling bearings, in gear trains, and in other sliding and rolling contacts of a machine construction.

The invention also relates to an arrangement intended to apply the method.

It is quite difficult to measure the forces, stresses, and temperature, as well as the changes in them, which appear in contacts between two moving surfaces. Naturally, it is impossible to set conventional measuring devices in a contact point, because they would either be damaged between the surfaces, or else they would excessively affect the conditions in the contact, so that a reliable measurement result would not be obtained. However, the use of a form of measurement that would be reliable, affect the point being measured as little as possible, and would also be economical, would make it possible to obtain a considerable amount of new information on the operations of tribologic contacts. The use of a combination of a sufficiently cheap sensor and a measuring system would make it possible to gain considerable advantages in maintenance and the availability of different kinds of machine, as the real need for maintenance could be evaluated more accurately than at present.

Sliding bearings are a particularly interesting subject. Sliding bearings are components that are widely used in machine construction. They support and guide rotating machine components and are typically used in, for instance, motors and engines, turbines, and generators. In sliding bearings there is a liquid film, for example an oil film, between the moving machine component, for example a shaft, and a fixed machine component, for example the bearing shell, on which the moving machine component can move. As the movement takes place on the liquid film, the loadbearing capacity of the bearing is good and its wear is small. From the point of view of the operation of rolling bearings, the lubricant film is the central factor, through which the forces are transmitted from the

shaft to the bearing. Failure of the lubricant film leads to an increase in the temperature of the bearing, the destruction of the bearing surfaces, and finally to damage of the entire bearing. Monitoring of bearings is important, in order to predict possible damage, but at the present moment extensive condition monitoring is restricted to either the measurement of temperature from the outer surface of the bearing metal, or to the measurement of vibrations from the outer casing of the bearing shell. If it is wished to measure the parameters that are vital to the operation of a sliding bearing, such as the pressure or temperature of the lubricant film, the sensor must be taken directly to the tribologic point of contact. This is a challenging task, as there is a high pressure at the tribologic point of contact, the loading state is dynamic, and the contact is affected by vibrations. In addition, the sensor must not interfere with the operation of the lubricant film and the bearing, nor must it detrimentally affect the service life of the bearing. Due to its challenging nature, the development of sensor arrangements of this type has previously been impossible.

One way to investigate the operation of the oil film of a sliding bearing is to drill a hole in the bearing metal and to place a small pressure sensor in the hole. In this case, the hole must be large enough for the sensor to fit into it and for the oil to be able to act directly on the sensor, so that the hole does not create a detrimental throttle effect. The hole must therefore be relatively large compared to the thickness of the liquid film. A hole extending to the liquid film will alter the flow of the liquid and thus the pressure at the measurement point. The sensor will thus not measure the real pressure in the film and so that a reliable picture will not be obtained of the real situation at the measurement point. The movement of the liquid film and the flow at the hole may also cause rapid wear in the very soft bearing metal at the location of the hole.

In laboratory conditions, attempts have been made to manufacture thin-film sensors for measurement of the tribologic contact. In these, attempts have been made to use thin-film technology to manufacture a sensor directly on the bearing surface, by using surfacing and texturing technique. The technology has been researched at Tokyo University in Japan, where sliding bearings and the parameters affecting them have been measured (Someya, T., Mihara, Y., New thin-film sensors for engine bearings. In:

Proceedings of CIMAC Congress 2004, Kyoto. Paper No. 19, 16 pp.). In this solution, the sensor is formed on the surface of the bearing metal and the actual sensor component, i.e. a reactive film, is under a protective layer. By using different kinds of reactive films, it is possible to measure the oil pressure, the temperature, and strain from the surface of a sliding bearing. This approach opens new possibilities of monitoring the conditions prevailing in a real tribologic contact. In principle, the use of this sensor construction could permit reliable measurement of a tribologic contact, at least in sliding bearings. However, this technique is still being developed and there are no experiences of its application to continuous industrial use. One possible problem may be the detaching of the sensor structure from a surface under pressure. This could be a problem at least when measuring a rolling or an unlubricated sliding contact.

The invention is intended to create a reliable and economical manner of measurement, by means of which it will be possible to measure the conditions in a contact between two surfaces moving relative to each other, in such a way that the object being measured is affected as little as possible.

The invention is based on making a recess, which extends towards the surface in contact, behind the surface in contact in the immobile piece of two pieces moving relative to each other or in a piece at rest. At a distance from the bottom of the recess a detector is fitted, which is used to monitor the space between the detector and the bottom of the recess, in order to detect a desired variable.

According to one preferred embodiment of the invention, in the construction the position of the bottom of the recess is measured.

According to one particularly preferred embodiment of the invention, the position of the bottom of the recess is measured with the aid of optical measurement.

More specifically, the method according to the invention is characterized by what is stated in the characterizing portion of Claim 1.

The arrangement according to the invention, is in turn characterized by what is stated in the characterising portion of Claim 17.

Considerable advantages are gained with the aid of the invention.

The most important advantage of the invention is that the surface in the contact remains completely intact, so that the properties of the object being measured do not substantially change, nor does the measurement affect the phenomena taking place in the object. In objects operating on a liquid film the liquid film remains intact and the flows in it remain unaltered. In a rolling contact or dry sliding contact fracturing of the surface can be avoided, because flaws that will start a fracture are not formed in the surface. If an optical fibre is used in the measurement and the measurement is performed with the aid of light, the noise appearing in the measurement can be easily minimized by rapid sampling and, for example, sliding averaging. In addition, the powerful electrical interference that appears in an industrial environment cannot affect an optical measurement, thus facilitating the processing of the measurement data and avoiding the need for complicated and expensive interference protection. Optical detection is extremely reliable and stable. Thus, a manner of measuring that is reliable and cheap in price is achieved. The construction according to the invention is reasonable easy to implement with the aid of known techniques used in machine construction and optical fibres. In some cases, it is possible to use other forms of detection too to measured the distance between the bottom of the recess formed behind the surface and the detector. Possible forms of detection that can be mentioned include capacitive and inductive measurement. However, these forms of detection have the weakness of being sensitive to interference and unstable, compared to optical measurement.

Optical measurement is preferably implemented as a simple measurement of the intensity of reflected light. In this way a quite high degree of accuracy will be achieved. In applications demanding very high accuracy, it is possible to form a Fabry-Perot interferometer, operating with the aid of monochromatic light, from the recess created and the optical fibre fitted to it, in which case the measurement accuracy in the case of the distance will be a fraction of the wavelength used.

In the following, the invention is examined with the aid of examples and with reference to the accompanying drawings.

Figure 1 shows a schematic diagram of one embodiment of the mechanical construction of the invention.

Figure 2 shows an alternative embodiment of the invention.

Figures 3 - 5 show schematic diagrams of the principle of the intensity measurement.

Figure 6 shows a schematic diagram of the measurement arrangement of the intensity measurement.

Figure 7 shows one shape of the recess required in the invention.

In the following, the term tribologic contact refers to a contact between two surfaces, in which the surfaces act on each other either directly or by means of a liquid film. Such contacts are, among others, a sliding movement dry, a sliding movement on a liquid film, and a rolling movement, a contact between two surfaces that are immobile relative to each other, such as compression between the surfaces, and combinations of these.

Figure 1 shows one construction according to the invention, in a highly simplified view. In it, a recess 5 is made in the bearing metal 1, which extends to close to the surface 8 in tribologic contact. In this example, the surface is the surface of a bearing strip. The bottom 3 of the recess 5 is preferably a polished or an otherwise sufficiently reflectively finished surface. The need for polishing or surface treatment depends on the method of manufacturing the hole and addition treatment of the bottom of the hole will not necessarily always be required. In the following, the bottom is referred as the mirror surface 3. An optical fibre 4, which is formed of a core 6 and a casing layer 7, is fitted inside the recess. The end of the fibre is at a distance from the mirror surface 3, so that the an observation space, i.e. an etalon 2 is created between the end of the fibre and the

mirror surface. The distance between the bottom of the recess and the surface in the contact is *s*.

In the alternative solution of Figure 2, the etalon 2 is filled with a thermochromatic material 9, for example, with a thermochromatic polymer, the colour of which changes when the temperature changes. One example of such a material is acryl mixed with a thermochromatic pigment. In the solution according to this embodiment, the temperature of the sliding bearing or other surface is measured by measuring the radiation reflected from the mirror surface 3. Because the colour of the thermochromatic material changes when the temperature changes, the colour of the light reflected back to the optical fibre changes at the same time, and the temperature can be detected by detecting the colour of the light. The detection can be performed with the aid of a colour filter, by measuring the amount of light of each separate colour passing through the filter. An optically active substance, the polarization of which changes according to the temperature, can also be used to detect temperature, in which case the temperature can detected with the aid of the rotation of the polarization. The advantage of this solution is that the temperature measurement can be brought close to the object being measured. An optical fibre will also require a much smaller hole or recess than a thermo-element, for example.

Figures 3 - 5 show the principle for the measurement of the distance of the mirror surface. Because the mirror surface 3 moves due to the effect of the pressure acting on the surface 8 in the contact, the movement of the mirror surface can be used to measure, for example, the pressure acting on the bearing from the oil film in the sliding bearing. The measurement of the movement of the mirror is implemented as a measurement of the distance between the end of the optical fibre 4 and the mirror surface 3. The end of the fibre 4 is placed at a precisely defined distance *l* from the mirror surface 3. There is a lens 10 at the end of the fibre 4, which can be manufactured advantageously by shaping the end of the fibre. Thus no separate components will be required; instead the fibre with the lens is a unified piece. The fibre lens 10 focuses the beam 13 of light coming from the fibre to the focal length 11 of the focussing point. The focal length 11 is between the end of the fibre and the mirror surface 3. Figures 4 and 5 show the effect of altering the distance between the mirror surface 3 and the fibre lens 10. When the mirror surface 3 is

in the extreme position as far as possible from the focal length 11, the light coming from the core 6 of the fibre 4 is dispersed as a wide beam 12 onto the mirror surface 3. The mirror surface will now reflect a wide return beam 14 towards the end of the optical fibre and most of the reflected light will strike the casing layer 7 of the fibre 4 and the intensity of the light striking the core 6 will be low. If the mirror surface 3 is moved closer to the focal length according to Figure 5, more of the reflected light 14 will strike the core 6 of the optical fibre. Thus by measuring the intensity of the reflected light it is possible to measure the change in the distance between the mirror surface and the end of the optical fibre. If this change in distance is calibrated to suit each application, it will be possible to detect the absolute or relative pressure acting on the surface being measured.

In principle, the mirror surface can also be between the optical fibre and the focal length. In that case, when the distance of the mirror surface changes, a change corresponding to that in the example described above will take place. The intensity of the change will, however, be lower, so that it is preferable for the mirror surface to be farther than the focal length.

Figure 4 shows by way of illustration a surface 8 in the bearing contact, the rotating shaft 15 in the bearing, and the oil layer 16 separating them.

Figure 6 shows a schematic view of one way of implementing the distance measurement described above. In it, a light source 17 directs light to a fibre 18, by means of which the light is directed on over the fibre 19 to a sensor 20. For detecting the reflected light, a fibre 21 leading to an intensity detector 22 branches from the joint between the light source fibre 18 and the sensor fibre 19. The light source used can be a superbright led, or some other sufficiently strong light source. Conventional light detectors are suitable as the detector 22. Because in the invention the intensity change is great, high sensitivity is not required in the detector.

If particularly great measurement accuracy is needed, monochromatic or wide-band light and the Fabry-Perot principle can be used to measure the distance between the mirror surface and the optical fibre. This form of measurement is based on the interference

between the sent light and the reflected light in an etalon. The phase of the reflected light always coincides with the opposite phase between the wavelength and the distance form the light source, and with the same phase as the wave of the incoming light, so that the reflected light alternately extinguishes and amplifies the incoming light. This can be detected in the fibre as dark and light spots and with their aid the distance of the mirror surface from the source of incoming light can be calculated.

Figure 7 shows one mechanical solution for implementing the sensor. In it, a shoulder 23 is formed in the recess 5 in the bearing metal, against which the jacket 7 of the fibre can be pushed. Thus the distance between the end of the fibre and the mirror surface 3 can be easily set. An annular groove 24 is machined in the edges of the mirror surface 3. Thus narrow necks 25 are formed in the bearing metal 1 at the sides of the mirror surface 3. Deflection will now take place at the necks 25 and the mirror surface will remain straight. It should be noted that the shapes of the recess, shoulder, and groove are shown here as rectangular and sharp for reasons of simplicity. In reality, the corners are, however, preferably rounded or otherwise shaped in such way that their fracturing effect is as small as possible. This will then minimize the possibility that the structure will form a start for a possible fracture. This shaping comes within the scope of conventional mechanical engineering.

The dimensioning of the actual sensor construction depends partly on the dimensions of the optical fibre and partly on the actual object being measured. The diameter of the core of the optical fibre is about 10 - 50 μm and of the jacket about 125 μm. The fibre is surrounded by a protective collar, the diameter of which is about 0.5 - 2 mm. The diameter of the collar of course determines the diameter of the hole made in the bearing metal. The thickness s of the membrane between the mirror surface 3 and the surface 8 in the contact depends on the thickness of the oil layer in the bearing, the bearing material, and, when the question is of a bearing other than a sliding bearing, also on the type of contact. For conventional sliding bearings the thickness of the bearing-metal membrane is a few hundred μm, when the greatest distance of movement of the mirror will be a few μm. The accuracy achieved with the intensity measurement will be about one-hundredth of the distance of movement of the mirror. As has been stated above, the mirror surface

should be preferably farther than the focal length of the fibre lens from the end of the fibre. A suitable focal length is a few hundred μm while slightly inaccurate focussing can be used, nor is focussing to a precise point necessary. In the invention it is not necessary to measure the exact intensity, but the change in the intensity. In that case allowance must be made for, among other factors, the running in of the bearing and the wear of the bearing in long-term operation.

The properties of optical fibre includes the dispersion of light in a fan shape from the end of the fibre, unless the fibre ends in a lens. This phenomenon can be exploited in the measuring method described above. If the distance between the end of the fibre and the mirror is small, the amount of light reflected from the mirror and leaving the end of the fibre will change according to how close the mirror is to the end of the fibre. The closer the mirror is to the end of the optical fibre the narrower will be the light beam striking the mirror and the greater the proportion of light reflected back to the fibre. In this case the distance between the end of the fibre and the mirror must be in the order of the thickness of the fibre. The distance is defined more precisely according to the properties of the end of the fibre, i.e. mainly according to great the angle is of the light beam leaving the end of the fibre. With a narrower exit angle the mirror can naturally be farther away than with a larger angle. In this embodiment, the construction and manufacture of the actual sensor are simpler than those described above, because a lens need not be created. This sensor too must be calibrated for its application, just like the constructions described above.

Embodiments differing from those disclosed above, can also be envisaged within the scope of the invention. The distance of the mirror surface and changes in the distance can also be measured using capacitive and inductive sensors or other detection devices. The pressure acting on this surface can also be measured in principle with the aid of a piezoelectric material. However, these measuring procedures have the weakness of the signal being difficult to process in interfering factory conditions and the expense of the necessary equipment. The space required in these measurement applications may also limit the use of these methods. One way to measure the pressure in the etalon is to use a

capillary fibre and an etalon filled with liquid. The pressure can then be measured at the end of the capillary fibre, for example, using a silicon micro-mechanical sensor. Because in a silicon micro-mechanical sensor a change in pressure can be detected with the aid of a very small movement of the sensor, with the aid of it it is possible to detect pressure changes due to even the smallest movement of the mirror membrane of the etalon.

The recess required by the sensor according to the invention need not necessary be made as a blind hole like that described above. The hole required by the sensor can also be made through the bearing material and then covered with a membrane made from a suitable material. The recess can also be made in a separate piece, which is set into the bearing material. What is important is that the shape of the bearing's or other measuring surface and preferably also its elasticity are as precisely as possible the same as those of the actual bearing material. Of course, the most preferable case is for the possible surface membrane or separate piece to be made from the same material as the surface of the bearing. In other applications, the material must of course be adapted according to the construction material in question.

By changing the shape of the mirror surface it is possible to affect its reflective properties. The surface can be made either convex or concave according to whether it is wished for the light beam striking it to be focussed or refracted when it is reflected from the surface. If the edges of the bottom of the recess are shaped according to Figure 7, the shape of the mirror surface will remain essentially unchanged, because the deflection at the edges will be considerably greater than the deflection at the relatively thick centre. On the other hand, it may be preferable to made the bottom of the recess flat. Such a shape will be simpler in terms of manufacturing technique. Now the distance of the end of the optical fibre and the mirror can be set to be correct by shaping a collar from the protective casing of the fibre, which extends beyond the end of the fibre. Thus the end of the fibre, the hole of the collar, and the mirror surface will form the measuring space, i.e. the etalon. Single or multimode fibre can be used for the measurement, or even two fibres, one of which transmits light to the etalon while the other receives it. The light used can be wideband, polarized, monochromatic, or otherwise processed, nor need its wavelength coincide with the wavelength of visible light.

The sensor is placed in the sliding bearing at the point of the greatest pressure in the oil film, unless for some reason it is necessary to investigate the pressure of the film elsewhere on the circumference of the bearing. For example, in a ball or roller bearing the sensor would be situated on the rolling groove.

Claims:

1. Method for monitoring a tribologic contact between two surfaces moving relative to each other, in which method

- a recess (5), which has a bottom (3) and which extends towards the first surface (8), is created behind the first surface (8) in the contact,

- a detection device (4, 10) is placed at a distance from the bottom, so that a detection space (2) is formed between the detection device (4, 10) and the bottom (3) of the recess, and

- the changes taking place in the detection space (2) are monitored using the detection device (4, 10).

2. Method according to Claim 1, **characterized** in that change being monitored is the distance between the detection device (4, 10) and the bottom of the recess, and on the basis of the distance measurement value the pressure acting on the first surface is determined.

3. Method according to Claim 2, **characterized** in that

- a light beam (13) is directed from at least one optical fibre (4) towards the bottom (3) of the recess, in such a way that, when the bottom (3) is closer to the end of the fibre, most light is reflected to the core of at least one optical fibre and, when the bottom (3) is farther from the end of the fibre the least light is reflected to the core of the optical fibre,

- the position of the bottom (3) is defined on the basis of the reflected light intensity, and

- the pressure acting on the bottom (3) is defined on the basis of the position of

the bottom (3).

4. Method according to Claim 2, **characterized** in that

- a focussed light beam (13) is directed from at least one optical fibre (4) towards the bottom (3) of the recess, in such a way that, when the bottom (3) is closer to the focal length (11), the most light is reflected to the core of at least one optical fibre and, when the bottom is farther from the focal length (11), the least light is reflected to at least one optical fibre,

- the position of the bottom (3) is defined on the basis of the reflected light intensity, and

- the pressure acting on the bottom (3) is defined on the basis of the position of the bottom (3).

5. Method according to Claim 4, **characterized** in that the focussed light beam (13) is aimed from the optical fibre (4) towards the bottom (3) of the recess, in such a way that the focal length is shorter than the distance (*l*) between the end of the fibre and the bottom.

6. Method according to Claim 2, **characterized** in that monochromatic light is used in the optical fibre and a Fabry-Perot interferometer is formed from the optical fibre (4) and the bottom (3) of the recess (5).

7. Method according to Claim 2, **characterized** in that an inductive sensor is used to measure the distance.

8. Method according to Claim 2, **characterized** in that a capacitive sensor is used to measure the distance.

9. Method according to Claim 2, **characterized** in that a piezoelectric sensor is used to

measure the distance.

10. Method according to Claim 1, **characterized** in that the detection space (2) is filled with a thermochromatic material and the temperature of the space is defined on the basis of the change in the colour of the light reflected through the material.

11. Method according to Claim 1, **characterized** in that the detection space (2) is filled with an optically active material and the temperature of the space is defined on the basis on the change in the polarization of the light reflected through the material.

12. Method according to any of the above Claims, **characterized** in that the recess (5) is formed by machining the first surface (8) in the contact from the rear, in such a way that the surface (8) remains intact.

13. Method according to any of the above Claims 1 - 12, **characterized** in that the recess (5) is formed by making a hole through the first surface (8) in the contact and covering it with a membrane that closes the recess.

14. Method according to any of the above Claims 1 - 12, **characterized** in that the recess (5) is formed in a separate piece, which is sunk into the first surface.

15. Method according to any of the above Claims, **characterized** in that the first surface is a bearing surface of a sliding bearing.

16. Method according to Claim 1, **characterized** in that the detection chamber (2) is filled with a liquid and the change in pressure in the detection space is expressed by connecting the detection space (2) to a pressure sensor with a capillary fibre.

17. Arrangement for monitoring a contact between two surfaces, which arrangement comprises

- a recess (5) behind the first surface (8) in the contact, which extends towards

the first surface (8) and which has a bottom (3),

- a detection device (4, 10) arranged at a distance from the bottom,

- a detection space (2) between the detection device (4, 10) and the bottom (3) of the recess, and

- elements (4, 10, 22) for detecting the changes taking place in the detection space (2).

18. Arrangement according to Claim 17, **characterized** in that the detection device is a device for measuring distance or the change in the distance between the detection device (4, 10) and the bottom of the recess.

19. Arrangement according to Claim 17, **characterized** by

- at least one optical fibre (4), by means of which a light beam (13) can be directed towards the bottom (3) of the recess, in such a way that, when the bottom (3) is closer to focal length (11), the most light is reflected to the core of at least one optical fibre and, when the bottom (3) is farther from the focal length (11), the least light is reflected to the core of at least one optical fibre,

- elements (4, 10, 22) for defining the position of the bottom (3) on the basis of the intensity of the reflected light.

20. Arrangement according to Claim 17, **characterized** by

- at least one optical fibre (4), by means of which a focussed beam of light (13) can be aimed towards the bottom (3) of the recess, in such a way that, when the bottom (3) is closer to the focal length (11), the most light is reflected to the core of at least one optical fibre and, when the bottom is farther from the focal length (11), the least light is reflected to at least one optical fibre,

- elements (4, 10, 22) for defining the position of the bottom (3) on the basis of the intensity of the reflected light intensity.

21. Arrangement according to Claim 20, **characterized** in that the light beam (13) focussed from the optical fibre (4) is aimed towards the bottom (3) of the recess, in such a way that the focal length is shorter than the distance (*l*) between the end of the fibre and the bottom.

22. Arrangement according to Claim 20, **characterized** in that monochromatic light is used in the optical fibre and a Fabry-Perot interferometer is formed from the optical fibre (4) and the bottom (3) of the recess (5).

23. Arrangement according to Claim 18, **characterized** in that an inductive sensor is used to measure the distance.

24. Arrangement according to Claim 18, **characterized** in that a capacitive sensor is used to measure the distance.

25. Arrangement according to Claim 18, **characterized** in that a piezoelectric sensor is used to measure the distance.

26. Arrangement according to Claim 17, **characterized** in that the detection space (2) is filled with a thermochromatic material and the temperature of the space is defined on the basis of the change in the colour of the light reflected through the material.

27. Arrangement according to Claim 17, **characterized** in that the detection space (2) is filled with an optically active material and the temperature of the space is defined on the basis on the change in the polarization of the light reflected through the material.

28. Arrangement according to any of the above Claims 17 - 27, **characterized** in that the recess (5) is formed by machining the material of the first surface (8) in the contact, in

such a way that the surface (8) remains intact.

29. Arrangement according to any of the above Claims 17 - 27, **characterized** in that the recess (5) comprises a hole through the first surface (8) in the contact and a membrane closing it.

30. Arrangement according to any of the above Claims 17 - 27, **characterized** by a separate piece, which is sunk into the first surface and in which the recess is formed.

31. Arrangement according to any of the above Claims, **characterized** in that the first surface is a bearing surface of a sliding bearing.

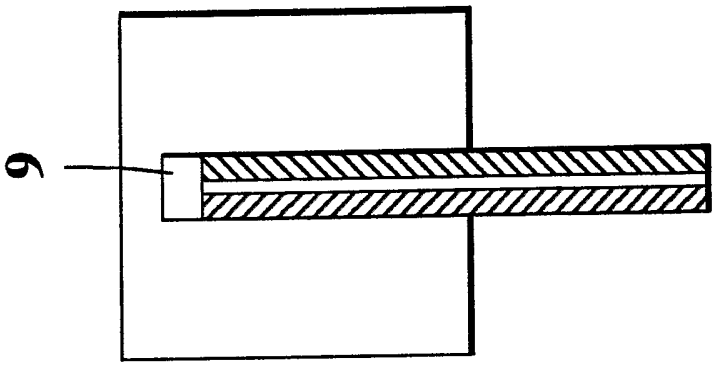


Fig. 2

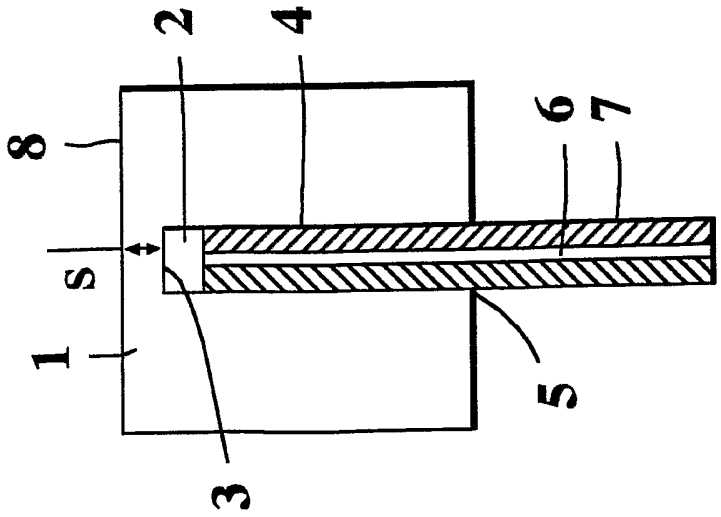


Fig. 1

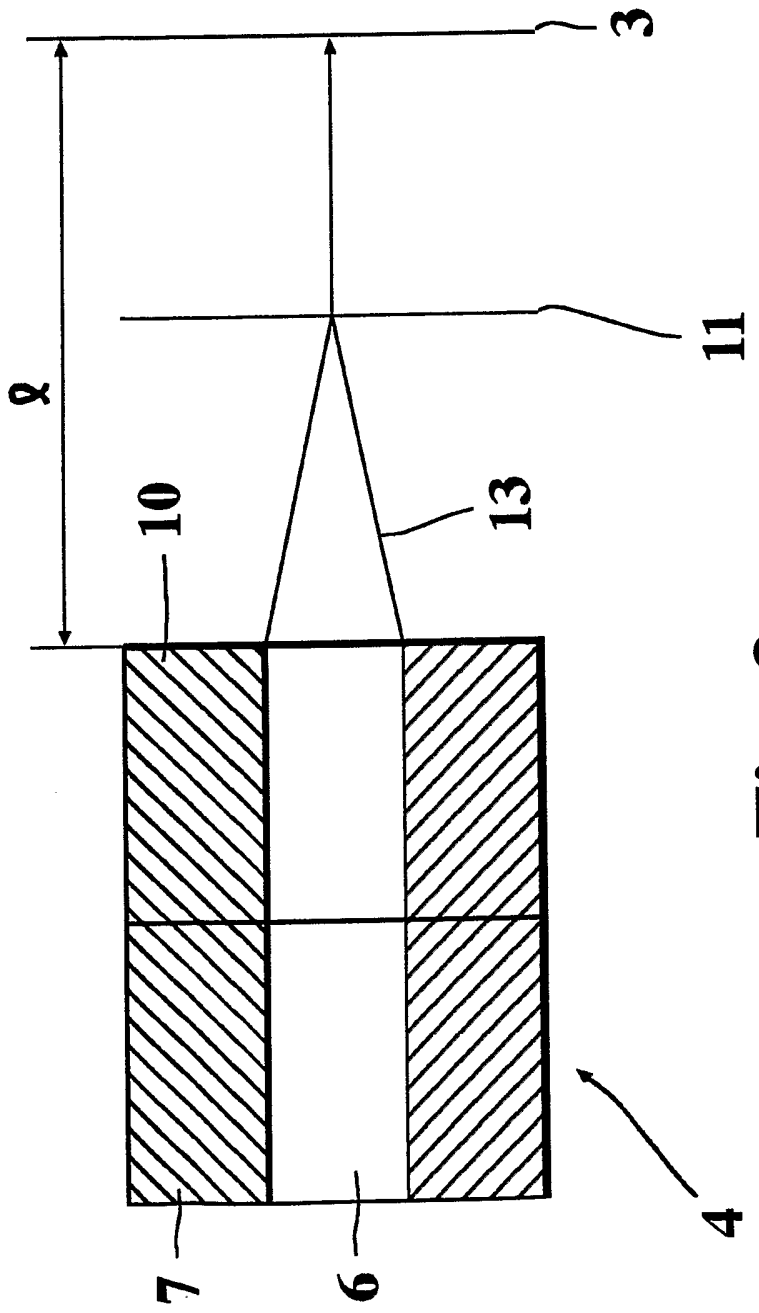


Fig. 3

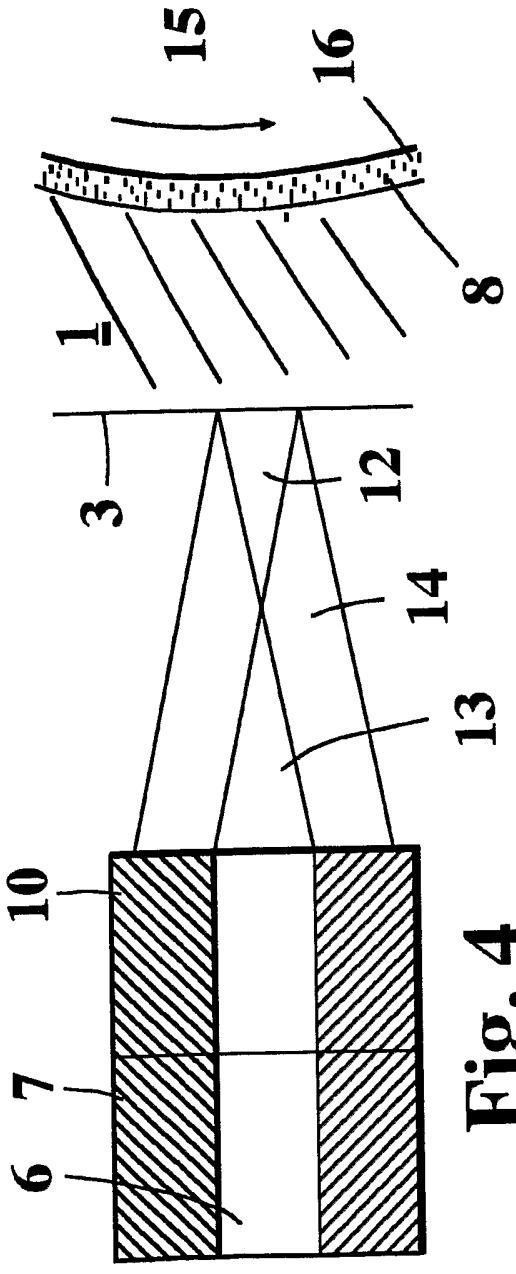


Fig. 4

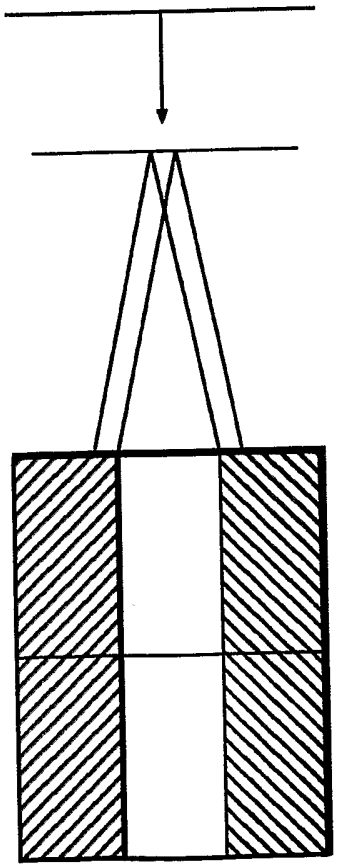


Fig. 5

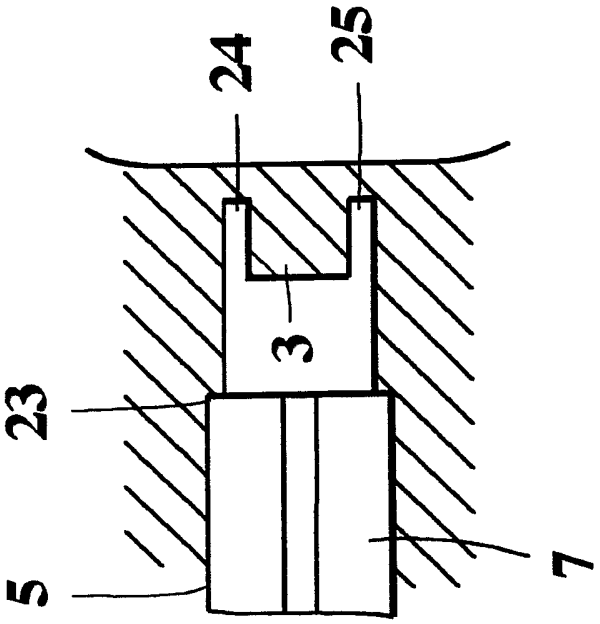


Fig. 7

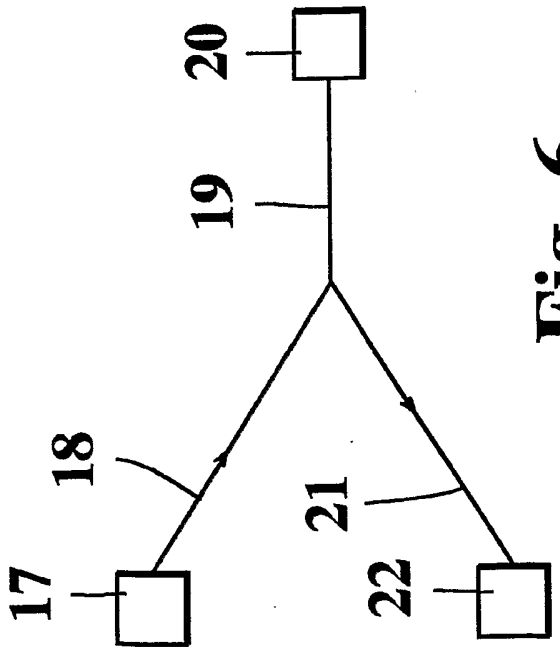


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/FI2005/000534

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01L5/00 G01L9/00 G01K11/12

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)
G01K G01L G01M F16C G01B G01D

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, PAJ, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 196 629 A (PHILIPS, GERALD J) 8 April 1980 (1980-04-08) column 3, line 41 - column 4, line 31 figure 3	1-31
X	US 4 870 271 A (PHILIPS ET AL) 26 September 1989 (1989-09-26) column 3, lines 17-30 column 5, lines 45-57 figure 5	1,13,17, 29
A	US 6 766 697 B1 (PEREZ ROBERT X ET AL) 27 July 2004 (2004-07-27) column 2, line 66 - column 3, line 5	1,6,17, 22

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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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

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"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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Date of the actual completion of the international search	Date of mailing of the international search report
7 April 2006	19/04/2006

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	de Bakker, M

INTERNATIONAL SEARCH REPORT

International application No
PCT/FI2005/000534

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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