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(54) Abstract Title**: Movement detector apparatus and detecting method**

(57) An apparatus for detecting at least one of the motion and position of a moveable part of the apparatus., the device comprising a radiation source in combination with a radiation detector which are respectively arranged to direct radiation onto and receive radiation from the moveable part of the apparatus, the received radiation having a different wavelength from the directed radiation and the arrangement being such that the received radiation is radiation emitted from the moveable part in response to the directed radiation.

Figure 2

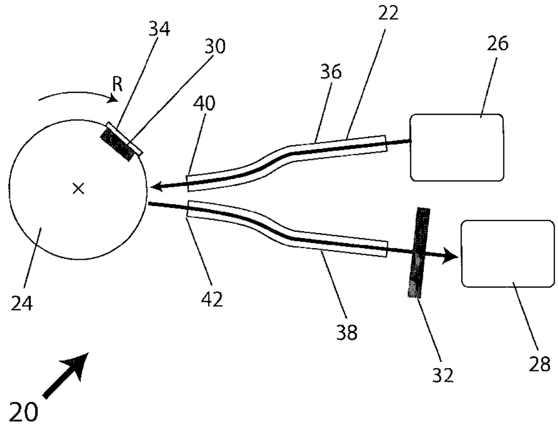

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Figure 1

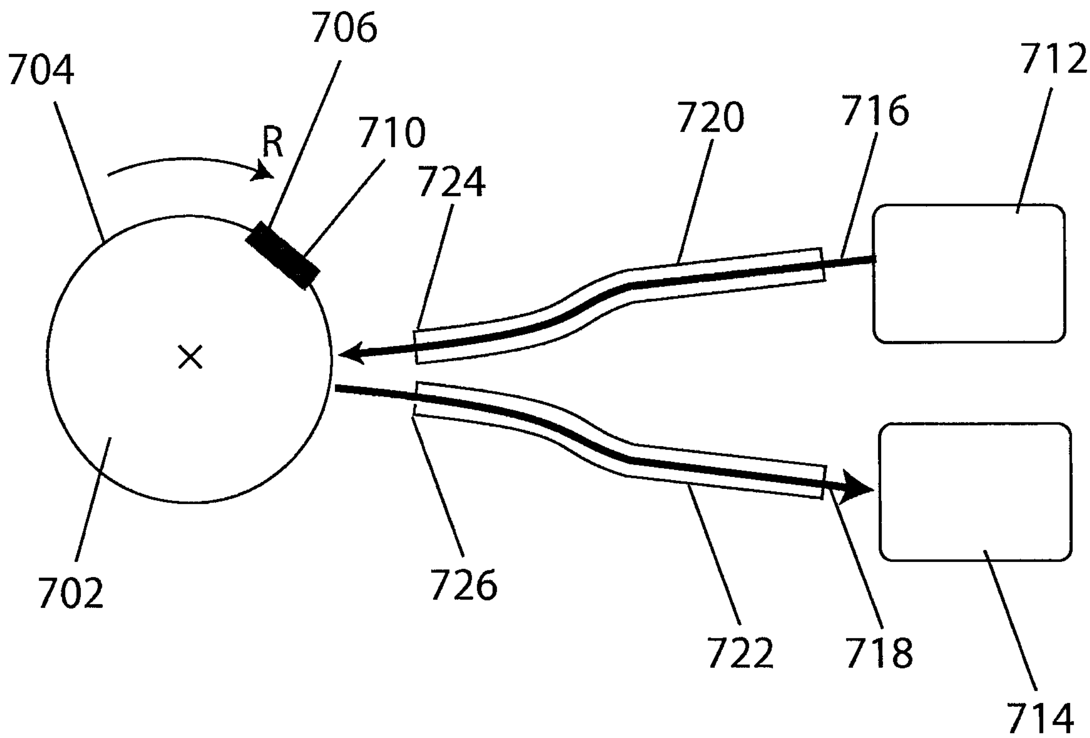


Figure 2

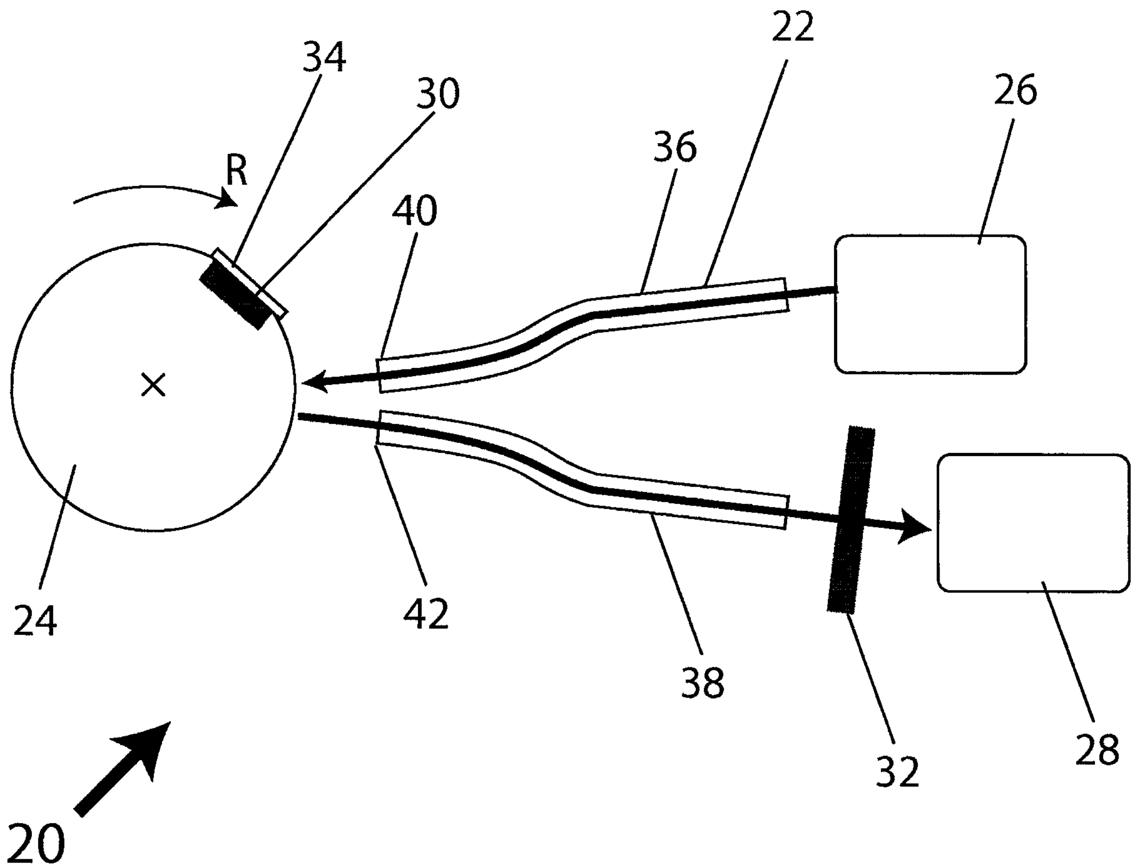


Figure 3

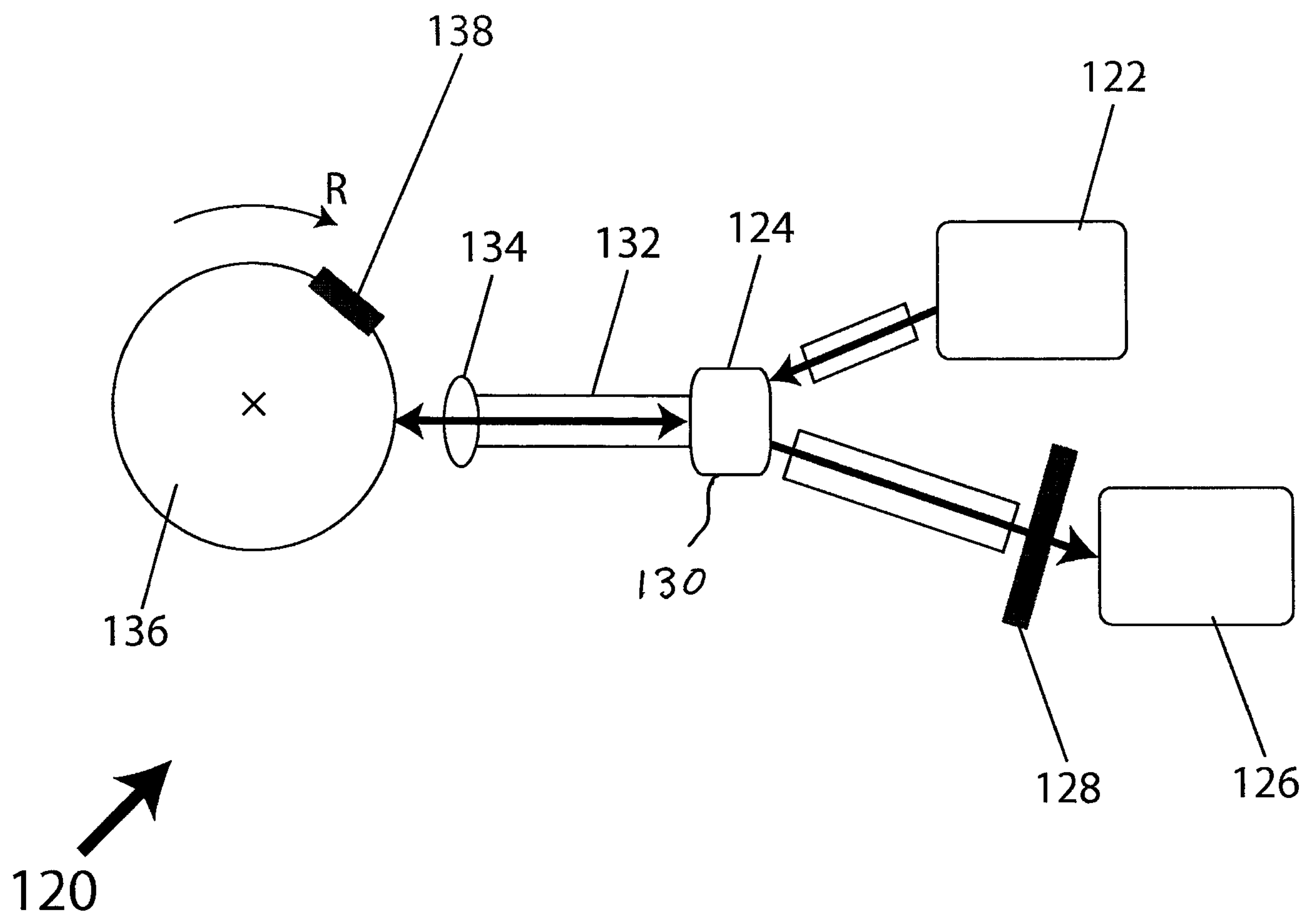


Figure 4

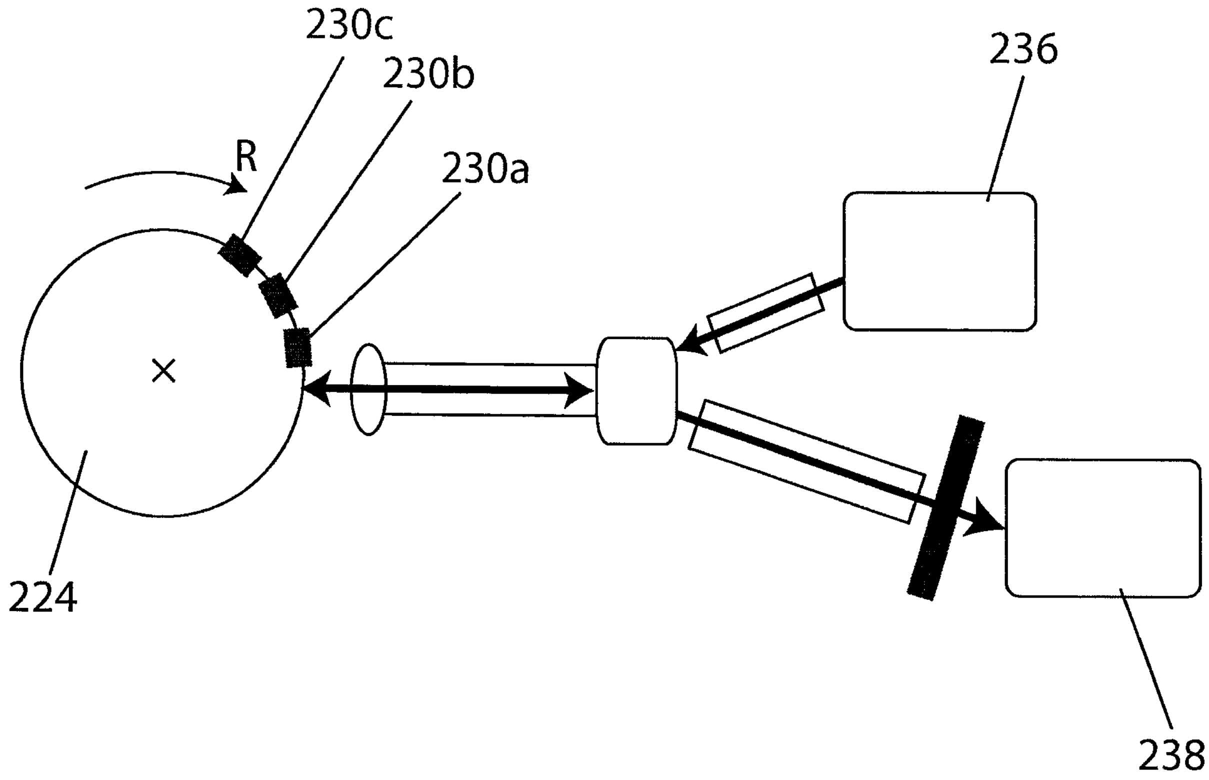


Figure 5

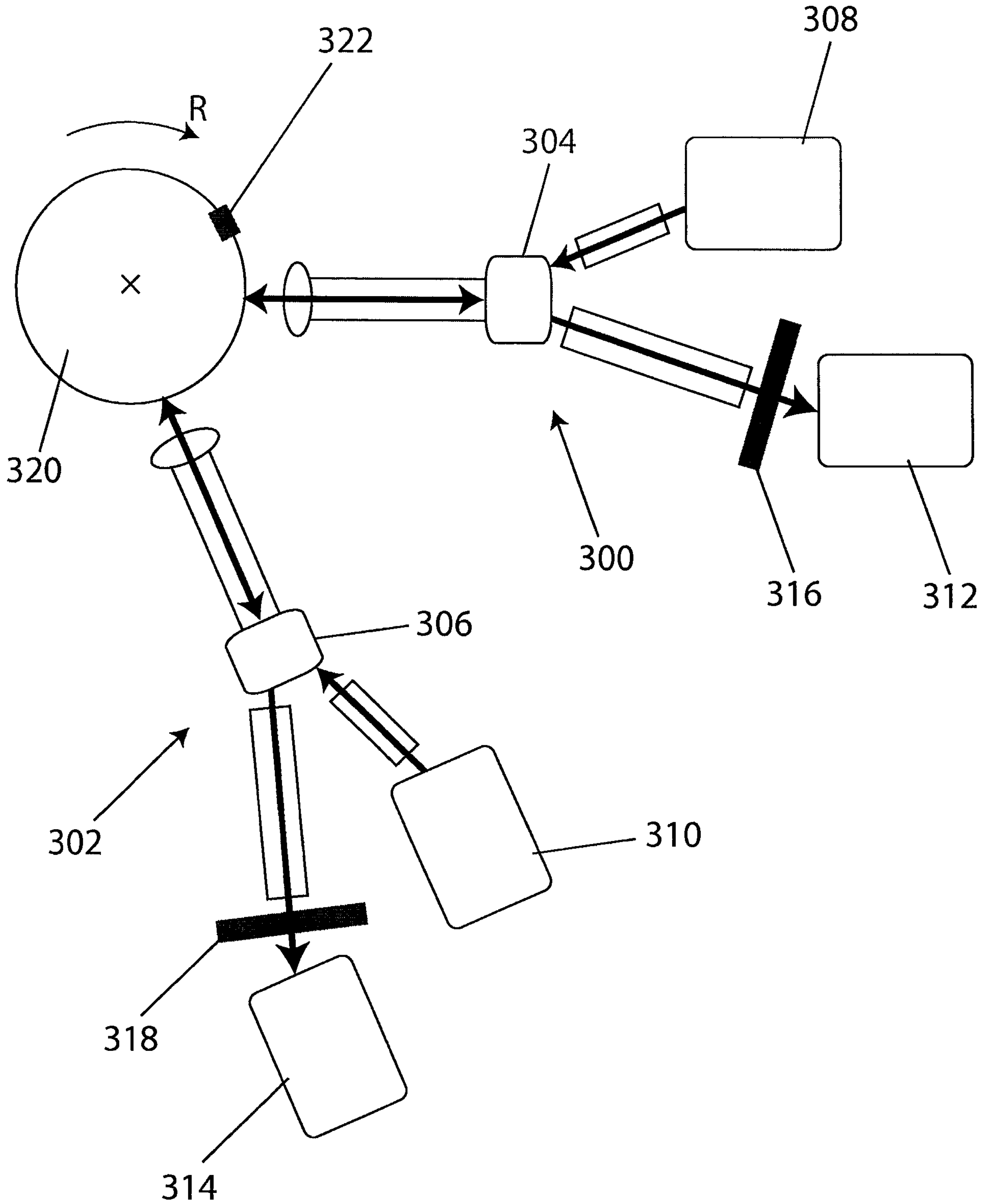
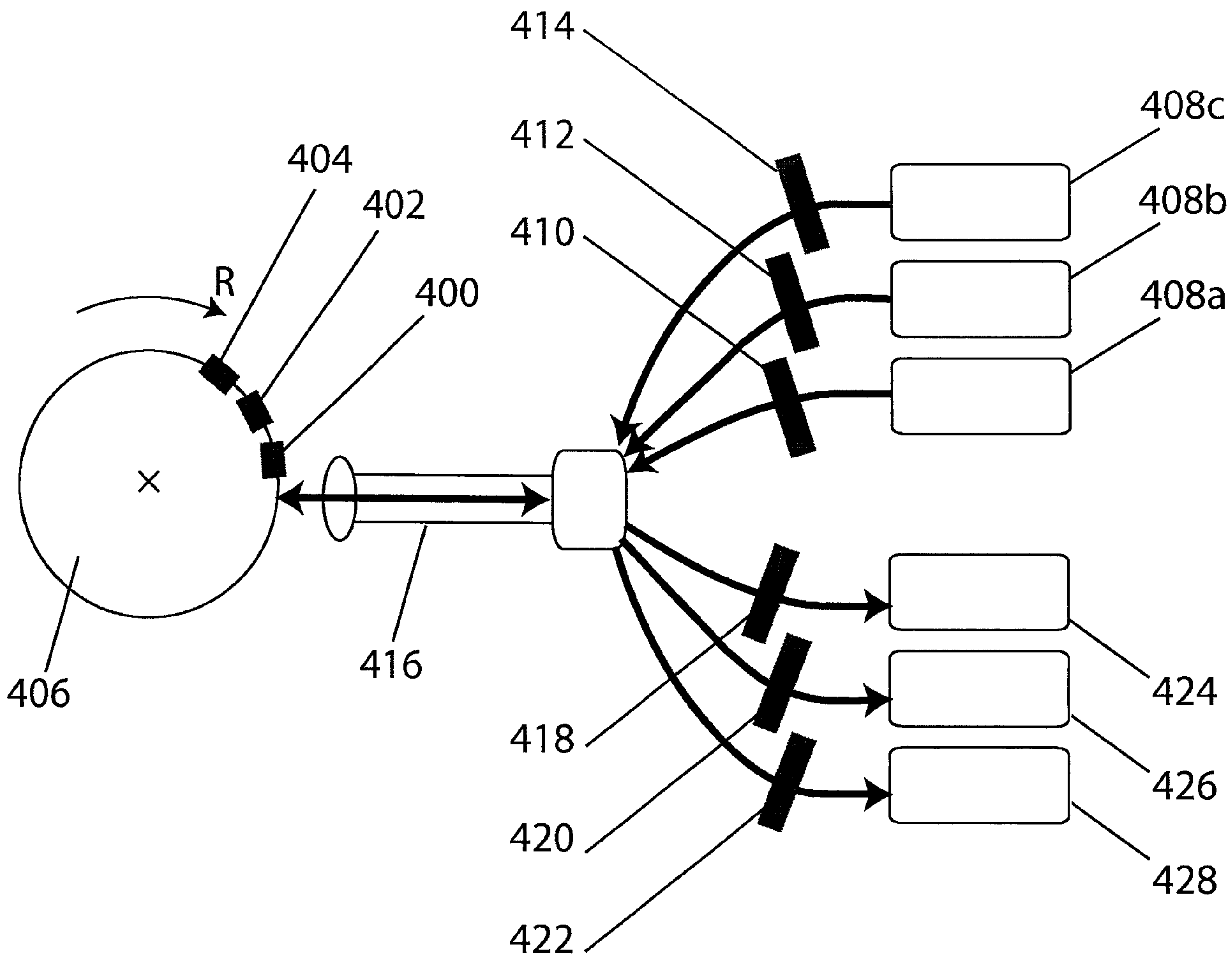


Figure 6



414
412
410
408c
408b
408a
404
402
400
R
406
416
418
420
422
424
426
428

Figure 7

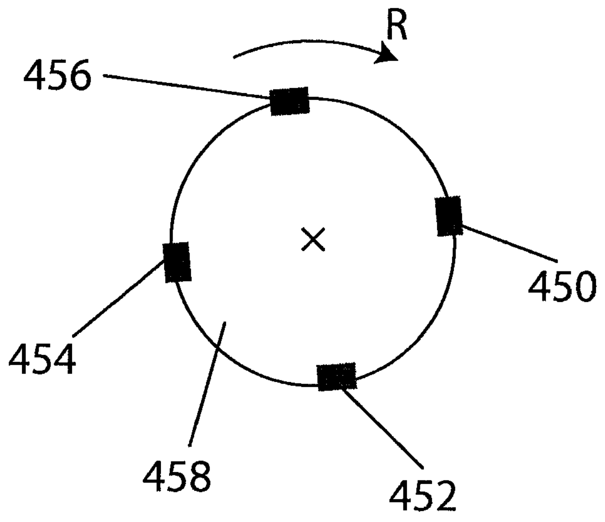


Figure 8

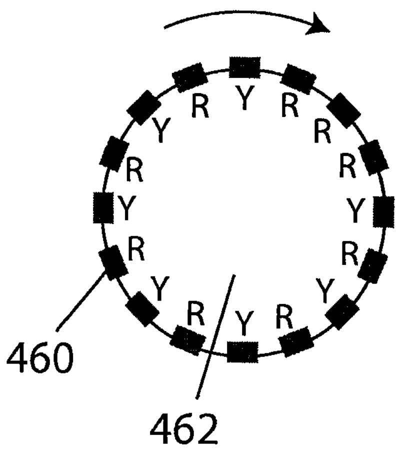


Figure 9a

Figure 9b

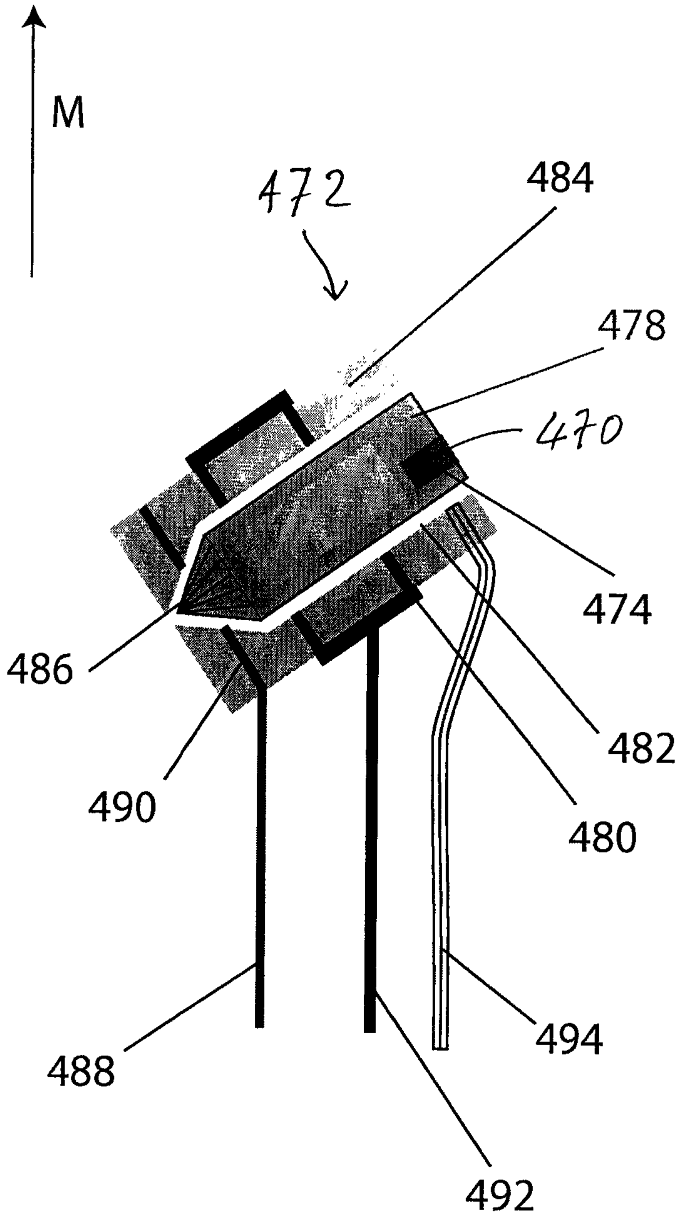


Fig.9a

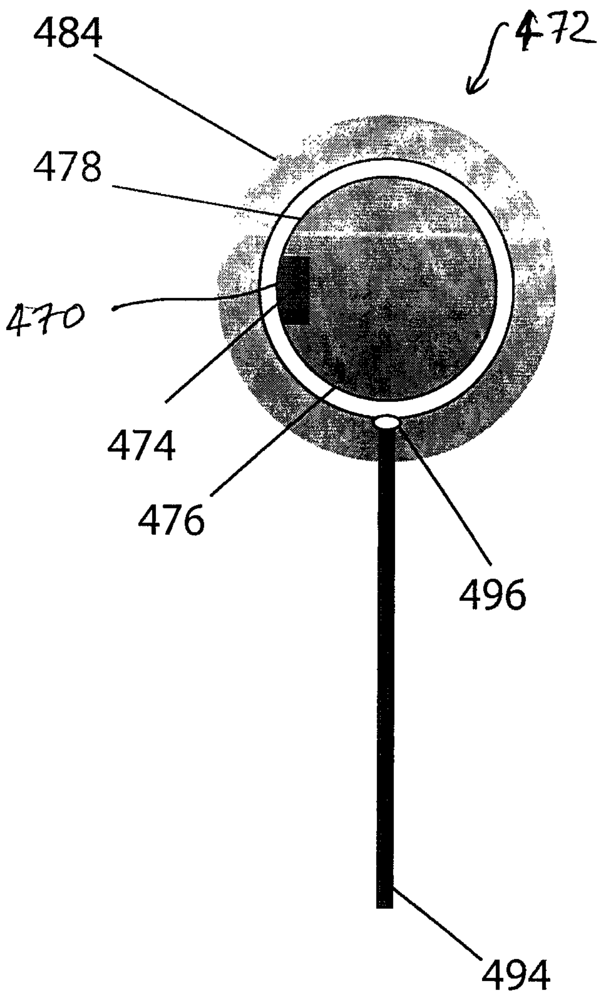
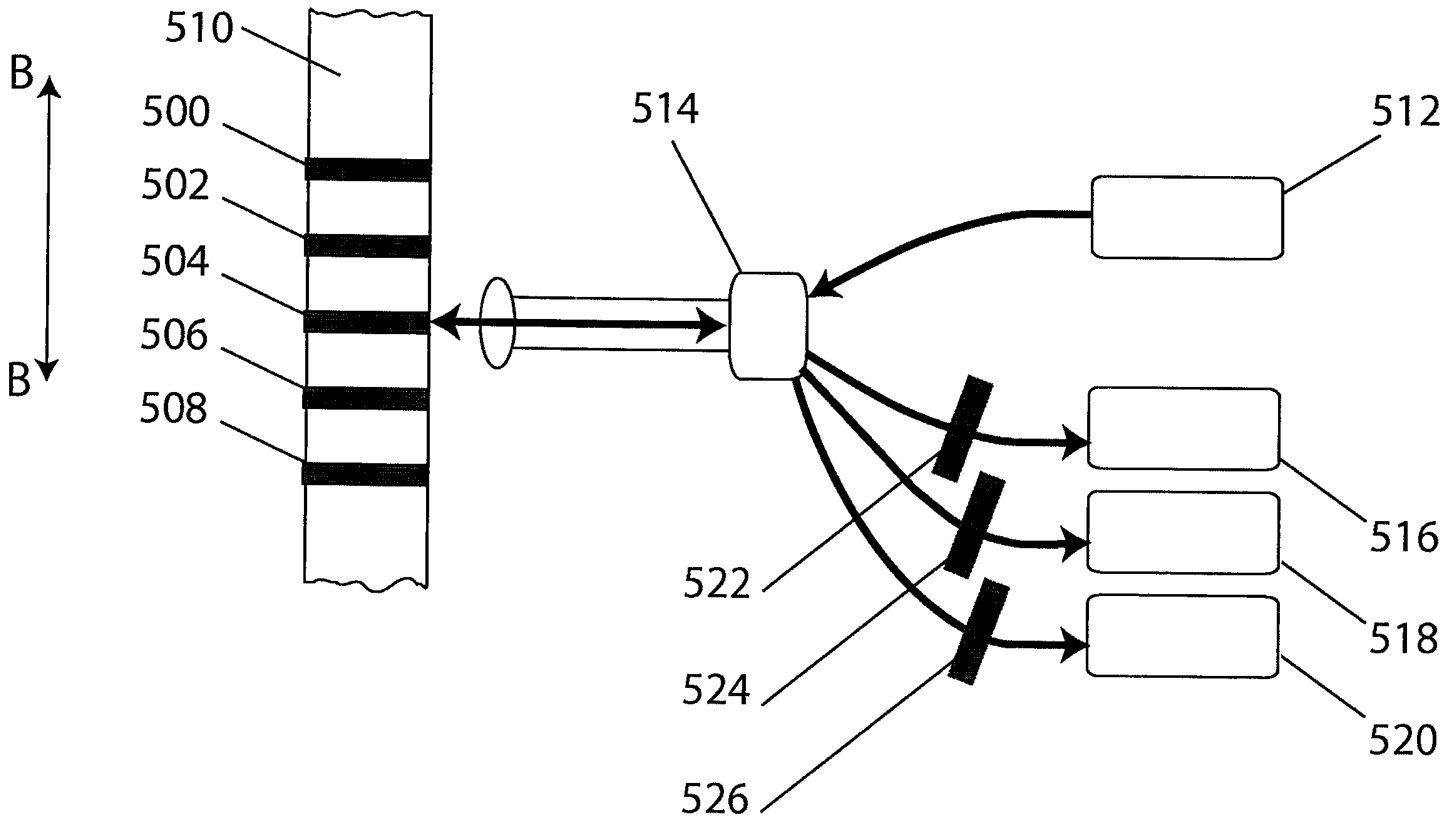


Fig.9b

Figure 10



DETECTOR APPARATUS AND DETECTING METHOD

The present invention relates to an apparatus for, and method of, detecting at least one of the motion and the position of a movable part of the apparatus. The motion may be rotational motion and/or translational, e.g. linear, motion. The position may be a static or dynamic position. The present invention has particular application in tachometers, for measuring the rotational frequency of a movable part of the apparatus, and in linear motion detectors such as flow meters, as well as in other devices. The present invention most particularly has application in nuclear magnetic resonance spectrometers, for detecting and measuring the frequency of the rotational motion of a sample holder. The present invention also has application in a position detector where the position of a movable part is detected, for example to determine the vertical position of a movable float in a liquid level detector.

A known optical tachometer, which is employed in a nuclear magnetic resonance spectrometer, has a typical construction as shown in Figure 1. A rotatable part 702, such as a holder for a sample to be subjected to nuclear magnetic resonance experiments, is provided on its outer circumferential surface 704 with a reflective region 706, such as a strip or patch. Most typically, the reflective region 706 is constituted by a reflective tape which is adhered to the surface, for example by a pressure-sensitive adhesive. Alternatively, the reflective region 6 may be a printed or painted mark. The outer surface 710 of the reflective region 706 most typically has a higher degree of optical reflectance than the surrounding outer circumferential surface 704 of the object 702. However, an alternative arrangement could be employed, where the region 706 to be detected has a lower reflectance (i.e. is duller) than the remaining surface 704.

A light source 712 and an associated light detector 714 are provided remote from the rotating part 702, and are mutually disposed so that a light beam 716 emitted from the light source 712 may be incident on the reflective region 706, when the reflective region 706 is in a particular angular orientation as a result of rotation of the object 702 about its axis X in the direction of arrow R, and then reflected off the reflective region 706 to form a reflected beam 718 which is received and detected by the light detector 714. Typically, the light is visible radiation. The detector 714, or process circuitry (not shown) connected thereto, is adapted to count the number of flashes of reflected light received by the light detector 714 per unit time (e.g. per second). This permits a rotational frequency of the object 702 to be determined.

Such a known tachometer suffers from a number of problems.

First, depending on the nature of the surface of the rotatable part, there can be a lack of contrast between the reflective properties of the reflective region, such as the tape, on the one hand and of the rotatable part on the other hand. This can cause spurious reflections from the surface of the rotatable part being incorrectly processed as reflections from the tape, and consequently an incorrectly high frequency count to be determined.

Second, in use a reflective tape or a printed or painted mark is not particularly durable or robust. The reflective region may be progressively worn down or even worn off. This would reduce or even eliminate the required contrast between the reflective region and the rotatable part. It would of course be possible to attempt to protect the outer surface of the reflective region against wear, for example by coating or covering the reflective region with a tough transparent layer, e.g. a glass, polymer or varnish layer. However, such a layer may introduce additional problems, such as secondary reflections or interference, which again could result in spurious reflections, and an incorrect frequency count to be determined.

In nuclear magnetic resonance spectrometers, the sample is rotated at high rotational velocity, for example 1 million revolutions per minute. The rotatable sample holder typically has a diameter of only a few millimetres, for example from 1 mm to 4 mm. The rotatable sample holder can inadvertently be shifted slightly in position. Dust and/or condensation or fog (as a result of the reduced temperature) can be present around the rotatable sample holder. Since the rotating sample holder is disposed within a strong magnetic field, which is required to be highly homogeneous, it is necessary to use an optical sensor to measure the rotational frequency, because a sensor incorporating electronics or a magnet in the vicinity of the rotating sample holder cannot be used. There is also a general trend to try to increase the rotational velocity and decrease the dimensions of the rotating sample holder in nuclear magnetic resonance spectrometers. All these parameters in combination tend to increase the difficulty of measuring the rotational frequency at high accuracy.

Furthermore, in such nuclear magnetic resonance spectrometers, the light source 712 and the light detector 714 are located remote from the rotating sample holder 702. The need to provide and detect incident and reflected light at a specified angle of reflection means that two optical paths are required. A first optical fibre 720 for the light beam 716 is coupled to the light source 712 and a second optical fibre 722 for the light beam 718 is coupled to the light detector 714, the free ends 724, 726 of the optical fibres 720, 722 being located adjacent the rotating sample holder 702. This gives a rather complicated construction since two separate optical paths are required extending away from the rotatable sample holder 702, and the construction is not particularly robust or durable. Furthermore, the use of elongated optical fibres 720, 722 to transmit the incident and reflected light, with free ends 724, 726 supported near the rotating sample holder 702, does not provide high detection accuracy at the rotating sample holder 702.

It is also known to use a light emitter/light detector pair to shine light onto and receive reflected light from an object to detect translational motion of the object. This also can suffer from similar problems of lack of contrast and durability.

In addition, for such known motion detectors, it would be desirable to provide increased functionality without the need for expensive and complicated hardware, control circuitry and/or software. Such functionality may comprise, for example, detecting properties of the motion and/or position of the object such as its fine position, and the direction of motion, and increased sensitivity of the motion detection, particularly under different conditions of use of in different environments.

It is an aim of the present invention at least partially to overcome these above-stated problems of known motion detectors.

It is a further aim of the present invention to provide a motion and/or position detector with increased functionality, in addition to rotational and/or translational motion detection, and/or static or dynamic position detection, without the need for expensive and complicated hardware, control circuitry and/or software.

Accordingly, the present invention provides an apparatus incorporating a device for detecting at least one of the motion and the position of a movable part of the apparatus, the device comprising a radiation source in combination with a radiation detector which are respectively arranged to direct radiation onto and receive radiation from the movable part of the apparatus, the received radiation having a different wavelength from the directed radiation and the arrangement being such that the received radiation is radiation emitted from the movable part in response to the directed radiation.

Preferably, the radiation source is adapted to emit radiation in a first wavelength band, the movable part is positioned to receive radiation from the radiation source, the movable part is provided with a radiation receiving and emitting element, and the radiation detector is adapted to detect radiation in a second wavelength band different from the first wavelength band, the radiation detector being positioned to receive radiation emitted from the radiation receiving and emitting element, wherein the radiation receiving and emitting element is arranged to emit radiation within the second wavelength band in response to incident radiation within the first wavelength band.

More preferably, the radiation receiving and emitting element comprises a fluorescent material adapted to emit radiation within the second wavelength band when incident with radiation within the first wavelength band. The fluorescence may be phosphorescence, and the fluorescent material may be a phosphorescent material, which may exhibit a significant time delay (even up to hours in some cases) between the light being absorbed and the wavelength-shifted light being emitted. In the case of phosphorescence, the object may move significantly between the absorption and emission steps, which allows the receiving and emitting element to be in a first position on absorption and in a second different position on emission.

The apparatus may further comprise a transparent protective body for the radiation receiving and emitting element.

The apparatus may yet further comprise an optical coupler providing a common optical path for at least a portion of the optical path of the radiation from the radiation source and at least a portion of the optical path of the radiation emitted from the radiation receiving and emitting element.

Preferably, the optical coupler is comprised in a common optical element, for receiving incident radiation from the radiation source and transmitting radiation to the radiation detector, and a lens is located at an free end of the common optical element, which is adapted to be focussed onto an outer movable surface of the movable part that is provided with the radiation receiving and emitting element.

Optionally, the movable part is provided with a plurality of the radiation receiving and emitting elements which are mutually spaced along a moving direction.

In one embodiment, the radiation source and the radiation detector comprise a first optical assembly, and further comprising a second optical assembly comprising a second radiation source adapted to emit radiation in the first wavelength band, and a second radiation detector adapted to detect radiation in the second wavelength band, the second radiation detector being positioned to receive radiation emitted from the radiation receiving and emitting element in response to radiation incident thereon from the second radiation source, wherein the first and second optical assemblies are mutually positioned so as to be directed at two different positions of the radiation receiving and emitting element in a moving direction thereof whereby the direction of movement of the movable part can be detected.

In another embodiment, a plurality of the radiation receiving and emitting elements is provided which are mutually spaced along a moving direction, at least one of the radiation receiving and emitting elements being adapted to emit radiation in a third wavelength band when incident with radiation in the first or a fourth wavelength band, and further comprising at least one further radiation detector adapted to detect radiation in the third wavelength band, the radiation detector being positioned to receive radiation emitted from the at least one radiation receiving and emitting element.

Preferably, the plurality of the radiation receiving and emitting elements is provided in a series of different radiation emission wavelength bands to define an origin for the movement of the movable part.

In one preferred aspect, the movable part is rotatable and the device is adapted to detect rotational motion of thc rotatable part. The movable part may be a sample holder in a nuclear magnetic resonance spectrometer.

In another preferred aspect, the movable part is translatable and the device is adapted to detect translational motion of the translatable part.

The present invention also provides a method for detecting at least one of the motion and position of a movable part of an apparatus, the method comprising the steps of:
(a) directing radiation from a radiation source onto the movable part of the apparatus; and (b) receiving emitted radiation from the movable part of the apparatus, the received radiation having a different wavelength from the directed radiation and the received radiation being emitted from the movable part in response to the directed radiation.

Preferably, in step (a) the radiation is in a first wavelength band and is directed onto a radiation receiving and emitting element on the movable part, wherein the radiation receiving and emitting element is arranged to emit radiation within a second wavelength band, different from the first wavelength band, in response to incident radiation within the first wavelength band; and in step (b) a radiation detector detects radiation in the second wavelength band.

More preferably, the radiation receiving and emitting element comprises a fluorescent material adapted to emit radiation within the second wavelength band when incident with radiation within the first wavelength band.

The directed radiation and the emitted radiation may be at least partly transmitted along a common optical path. The common optical path may be provided by an optical coupler which comprises a common optical element, for receiving incident radiation from the radiation source and transmitting radiation to the radiation detector, and a lens, located at an free end of the common optical element, which is adapted to be focussed onto an outer movable surface of the movable part that is provided with the radiation receiving and emitting element.

The movable part may be provided with a plurality of the radiation receiving and emitting elements which are mutually spaced along a moving direction. The method may further comprise analysing the emission of radiation from the plurality of the radiation receiving and emitting elements to determine a position of the movable part relative to the moving direction.

In one embodiment, the radiation source and the radiation detector comprise a first optical assembly, and the method further comprises providing a second optical assembly comprising a second radiation source adapted to emit radiation in the first wavelength band, and a second radiation detector adapted to detect radiation in the second wavelength band, the second radiation detector being positioned to receive radiation emitted from the radiation receiving and emitting element in response to radiation incident thereon from the second radiation source, wherein the first and second optical assemblies are mutually positioned so as to be directed at two different positions of the radiation receiving and emitting element in a moving direction thereof, and analysing the detected radiation to determine the direction of movement of the movable part.

In another embodiment, a plurality of the radiation receiving and emitting elements is provided which are mutually spaced along a moving direction, at least one of the radiation receiving and emitting elements being adapted to emit radiation in a third wavelength band when incident with radiation in the first or a fourth wavelength band, and further providing at least one further radiation detector adapted to detect radiation in the third wavelength band, the radiation detector being positioned to receive radiation emitted from the at least one radiation receiving and emitting element, and wherein the emitted radiation in the third wavelength band is detected.

Preferably, the detected radiation in at least the second and third wavelength bands is analysed to determine the position of the movable part in the moving direction. More preferably, the position of the movable part in the moving direction is correlated with respect to an origin for the movement of the movable part, the origin corresponding to a selected one of the plurality of the radiation receiving and emitting elements.

In one aspect, the movable part rotates at least one of the rotational frequency and the rotational velocity of the movable part is determined by analysing the frequency of the received radiation.

In another aspect, the movable part translates and at least one of the translational frequency and the translational velocity of the movable part is determined by analysing the frequency of the received radiation.

Embodiments of the present invention will now be described by way of example only with reference to the accompanying drawings, in which:

Figure 1 is a schematic plan view of a known tachometer;

Figure 2 is a schematic plan view of a tachometer in accordance with a first embodiment of the present invention;

Figure 3 is a schematic plan view of a tachometer in accordance with a second embodiment of the present invention;

Figure 4 is a schematic plan view of a tachometer in accordance with a third embodiment of the present invention;

Figure 5 is a schematic plan view of a tachometer in accordance with a fourth embodiment of the present invention;

Figure 6 is a schematic plan view of a moving part of a tachometer in accordance with a fifth embodiment of the present invention;

Figure 7 is a schematic plan view of a moving part of a tachometer in accordance with a sixth embodiment of the present invention;

Figure 8 is a schematic plan view of a tachometer in accordance with a seventh embodiment of the present invention;

Figures 9a and 9b are respectively side and end views of a tachometer in a nuclear magnetic resonance spectrometer in accordance with an eighth embodiment of the present invention; and

Figure 10 is a schematic side view of a linear motion detecting device in accordance with a ninth embodiment of the present invention.

Referring to Figure 2, there is shown a tachometer 20 in accordance with a first embodiment of the present invention. The tachometer 20 incorporates a motion detecting device 22 for detecting motion of a movable part 24 of the tachometer 20, in this embodiment a rotatable part of the tachometer 20. The rotatable part of the tachometer 20 rotates about its axis X in the direction of arrow R. The rotatable part 24 may perform other functions within the tachometer 20, or within a larger apparatus of which the tachometer 20 is a functional part. For example, in one particularly preferred embodiment the rotatable part 24 may be a sample holder of a nuclear magnetic resonance spectrometer. In alternative embodiments, the rotatable part 24 may be integral with or connected to a shaft of a machine such as a machine tool or a printing apparatus, or of a motor such as a servo motor.

The motion detecting device 22 comprises a radiation source 26 in combination with a radiation detector 28 which are respectively arranged to direct radiation onto and receive radiation from the movable part 24. The radiation source 26 is adapted to emit radiation in a first wavelength band towards the movable part 24 which is positioned to receive the radiation from the radiation source 26. The radiation source 26 is either monochromatic (comprising a single wavelength or more typically a specific wavelength band), or alternatively a filter (not shown) is provided correspondingly to filter the output radiation. The movable part 24 is provided with a radiation receiving and emitting element 30. The radiation detector 28 is adapted to detect radiation in a second wavelength band different from the first wavelength band. The radiation detector 28 is provided with a filter 32 to filter out all incoming radiation of the single wavelength, or the specific wavelength band, as the case may be, emitted from the radiation source 26 and to permit reception by the radiation detector 28 of radiation of wavelength in a different specific radiation band.

The radiation detector 28 is positioned to receive radiation emitted from the radiation receiving and emitting element 30. The radiation receiving and emitting element 30 is arranged to emit radiation within the second wavelength band when incident with radiation within the first wavelength band. In particular, the radiation receiving and emitting element 30 comprises a fluorescent material adapted to fluoresce to emit radiation within the second wavelength band when incident with radiation within the first wavelength band. The radiation receiving and emitting element 30 may comprise a self-adhesive tape or mark, for example a printed or painted mark, which incorporates a fluorescent material. A particularly preferred fluorescent material is a rhodamine dye embedded in dilute form in a stable polymer matrix. The present inventors have found that pure rhodamine or other dyes do not fluoresce well since the adjacent molecules "quench" each other. Optimal fluorescence is therefore achieved when the dye is diluted in a matrix, to space the dye molecules out. The inventors have used a commercial product (available Sigma-Aldrich) which contains polymer particles impregnated with

2.5% rhodamine-B. The polymer particles were mixed with epoxy glue to form a rapidly-hardening fluorescent material which may be painted on the rotating object.

In some embodiments, the fluorescent material is selected which absorbs and/or emits radiation at a wavelength outside the visible spectrum. For example, a fluorescent material may absorb radiation in the red part of the visible spectrum and emit radiation in the infrared part of the invisible spectrum. Alternatively, a fluorescent material may absorb radiation in the ultraviolet part of the invisible spectrum and emit radiation in the visible spectrum. The use of such fluorescent materials may increase the contrast between the directed and emitted radiation as compared to the use of visible radiation for both absorption and emission by the fluorescent material.

The fluorescence may be phosphorescence, and the fluorescent material may be a phosphorescent material, which may exhibit a significant time delay (up to hours in some cases) between the light being absorbed and the wavelength-shifted light being emitted. In the case of phosphorescence, the movable part being detected may move significantly between the absorption and emission steps. This allows the receiving and emitting element to be in a first position on absorption and in a second different position on emission. In the case of a rotor, light could be absorbed on one side and emitted on the other side of the rotor, which can have an additional advantage such as the physical blocking of scattered light by the body of the moving part.

Typically, the fluorescent radiation is emitted from the fluorescent material within an extremely short period of time after receipt of the incident exciting radiation, typically measured in nanoseconds, or even picoseconds. Such a rapid response means that such fluorescent materials can be used even to detect rotational velocities of 1 million revolutions per minute, as typically employed for a sample holder of a nuclear magnetic resonance spectrometer, with each fluorescent response being detected for each revolution, and the response being associated with that respective revolution. For example, the lifetime of the rhodamine-B fluorescence is around 4 nanoseconds. If a sample holder is spinning at 100 kHz, the rotation period is 10 μs, which is 10000 ns, longer than the lifetime.

However, to detect the motion it is not necessary to associate each response with that respective revolution. If a longer fluorescent lifetime than the rotation period is used, even phosphorescence (which is a long-lived variety of fluorescence) which can have a timescale of seconds, the method still detects the motion for each revolution, since the fluorescent radiation emitting spot still flashes by the detector every time the rotatable part turns. A long fluorescence lifetime even creates some new possibilities, since the sample may be allowed to move a considerable distance before the emission is detected.

As known to persons skilled in the art, a fluorescent material emits radiation at a longer wavelength than that of the radiation which is absorbed by the fluorescent material. In the case of rhodamine-B, green light (having a typical wavelength band of from 500 to 565 nm) is absorbed and red light (having a typical wavelength band of from 625 to 740 nm) is emitted.

The radiation receiving and emitting element 30 may be embedded in or covered by a tough and durable transparent protective body 34, for example of plastics material or glass, to protect the radiation receiving and emitting element 30 from wear and to permit the outermost irradiated surface of the resultant assembly of the radiation receiving and emitting element 30 to be readily cleaned.

Accordingly, the arrangement is such that as the rotatable part 24 rotates about axis X in direction R, each time the fluorescent radiation receiving and emitting element 30 is incident with radiation from the radiation source 26 via optical fibre 36, the fluorescent radiation receiving and emitting element 30 is initiated to emit fluorescent radiation of a different wavelength that is conveyed along optical fibre 38, passes through the filter 32 and is detected by the detector 28. One detection signal is generated for each revolution of rotational motion. The received radiation of detector 28 is non-reflective radiation emitted from the movable part 24 in response to the directed radiation from source 26. In the embodiment with rhodamine dye, the radiation detector 28 only receives non-reflective red radiation emitted from the fluorescent radiation receiving and emitting element 30, and does not receive any green radiation from the radiation source 26, either directly or indirectly by reflection. Since reflected radiation from the radiation receiving and emitting element 30 is not detected, any spurious reflections from the transparent body 34 protecting the radiation receiving and emitting element 30 would not disturb the radiation received by the radiation detector 28 because such reflections would be removed by the filter 32.

The incident radiation should be generated, or filtered, in such a way that it has negligible intensity at the sensitive wavelength of the detector 28. For example, the incident radiation could be monochromatic light generated by a laser, or could be broad-spectrum light which has been passed through a filter which suppresses light at the detector wavelength. On the detection side, the light could be filtered to pass only the desired wavelength band to a broad-spectrum detector 28, or the detector 28 itself could be sensitive to a particular wavelength band. The wavelength filtration could be accomplished using ordinary coloured filters, or by interference filters, or by diffraction gratings, prisms, etc. In addition, the optical fibres themselves can be designed to filter out or pass certain wavelengths. There are many possible structural arrangements and combinations thereof which would be apparent to those skilled in the art.

When the tachometer 20 in accordance with the first embodiment of the present invention is employed in a nuclear magnetic resonance spectrometers, the movable part 24 being a rotatable sample holder, the radiation source 26 and the radiation detector 28 are located remote from the rotating sample holder, and a first optical fibre 36 is coupled to the radiation source 26 and a second optical fibre 38 is coupled to the radiation detector 28, the free ends 40, 42 of the optical fibres 36, 38 being located adjacent the rotating sample holder 24.

As stated above, this can gives a rather complicated construction since two separate optical paths are required extending away from the rotatable sample holder. Accordingly, referring to Figure 3, there is shown a tachometer 120 in accordance with a second embodiment of the present invention. This embodiment is a modification of the first embodiment, in that because reflected radiation is not detected, there is no need to provide any angle between the incident and detected radiation, and so the emitted and detected light beams may be co-linear and, having different wavebands, may share a common optical coupler.

In Figure 3, the radiation source 122 is adapted to emit radiation in a first wavelength band towards an optical element 124 and the radiation detector 126, provided with a filter 128, is positioned to receive the radiation from the optical element 124. The optical element 124 comprises a beam splitter/combiner 130 which acts as an optical coupler, an optical fibre 132 connected thereto and a lens 134 at the free end of the optical fibre 132. The lens 134 is positioned adjacent to the rotatable part 136 of the apparatus carrying the fluorescent radiation receiving and emitting element 138. The lens 134 has an optical power to be able to focus onto the outer rotating surface of the rotatable part 136.

This embodiment provides the advantage that by providing the lens 134 focussed onto the rotatable part 136 of the apparatus carrying the fluorescent radiation receiving and emitting element 138, the spatial resolution and detection sensitivity can be greatly increased. In addition, the use of a combined optical element 124 rather than two optical fibres extending towards the rotatable part 136 provides a more robust and durable construction. A particular advantage of this embodiment is that there is no need to align separately the free ends of two different optical fibres with the reflective or fluorescent spot.

In a further embodiment of the present invention, as shown in Figure 4, which is a modification of that of Figure 3, a series of radiation receiving and emitting elements 230a, 230b, 230c is provided, circumferentially spaced, on the movable part 224. In this embodiment, three radiation receiving and emitting elements are provided but there may be two or more thereof in alternative embodiments. As the movable part 224 rotates, each of the radiation receiving and emitting elements 230a, 230b, 230c would in turn receive radiation from the radiation 236 source and fluoresce to emit radiation to provide a respective detectable radiation signal for the detector 238. This would provide fine registering of the angular position of the movable part 224.

In a yet further embodiment of the present invention, as shown in Figure 5, two optical assemblies 300, 302 are provided, the two optical assemblies 300, 302 being mutually angularly oriented by an angle not equal to 180 degrees. Each optical assembly 300, 302 incorporates a respective optical element 304, 306, for example having the construction shown in Figure 3. In this way, the optical axes of the optical elements 304, 306 are angularly offset and not co-linear. Each optical element 304, 306 is associated with a respective radiation source 308, 310 and a respective radiation detector 312, 314, the latter assembled together with a respective filter 316, 318. In a modified construction, a common radiation source is optically coupled to both optical elements 304, 306.

As the movable part 320 rotates, the radiation receiving and emitting element 322 sequentially receives radiation from a respective optical element 304, 306 and emits radiation that is detected by the respective radiation detector 312, 314. Accordingly, two detectable radiation signals are emitted, which are mutually at an angle of other than 180 degrees with respect to the angular velocity of the movable part 320. An analysis of the delay between the detection of the two signals, dependent on whether the angle therebetween is less than or greater than 180 degrees, can permit the rotational direction of the movable part 320 to be determined.

In another embodiment of the present invention, as shown in Figure 6, a series of radiation receiving and emitting elements 400, 402, 404 is provided on the rotationally movable part 406 in a circumferentially spaced manner. In this embodiment, three radiation receiving and emitting elements are provided but there may be two or more thereof in alternative embodiments. Each radiation receiving and emitting element 400, 402, 404 is adapted to emit radiation at a different respective wavelength band from the other radiation receiving and emitting elements 400, 402, 404, and to be excited by radiation in a respective wavelength band in filtered radiation emitted from a respective radiation source 408a, 408b, 408c, or a common radiation source 408, and transmitted by three separate respective source filters 410, 412, 414 and an optical element 416. Three detectors 418, 420, 422 are correspondingly respectively assembled with three detector filters 424, 426, 428, each filter 424, 426, 428 being adapted transmit radiation emitted from a respective radiation receiving and emitting element 400, 402. 404. In a modification, a single detector may be provided with three adjacent filters. In another modification, the radiation receiving and emitting elements 400, 402, 404 are adapted to be excited by radiation in a common wavelength band.

A more simplified, and therefore more practical, modified variation of this embodiment has a single radiation source 408, which has an output radiation wavelength band which is sufficiently broadband enough to excite all of the radiation receiving and emitting elements 400, 402. 404, and correspondingly only one source filter 410 is required.

As the movable part 406 rotates, each of the radiation receiving and emitting elements 400, 402, 404 would in turn receive radiation from the radiation source 408 and fluoresce to emit radiation of a respective wavelength band to provide a respective detectable radiation signal for the respective detector 424, 426, 428. Analysis of the different radiation signals would provide a definition of the angular position of the movable part 406.

In a modification, as shown in Figure 7, a series of the radiation receiving and emitting elements 450, 452, 454, 456 of different radiation emission wavelength may extend around the entire circumference, and the radiation signals would provide a definition of the angular position of the movable part 458. This would enable the angular position of the movable part 458 to be determined at any angular orientation of the movable part 458.

In another modification, as shown in Figure 8, the two or more radiation receiving and emitting elements 460R, 460Y of different fluorescent colour may be disposed as a repeat sequence, with one position of the repeat defining an origin of the movable part 462. For example, the fluorescent colours emitted may be red (R) and yellow (Y) by two different radiation receiving and emitting elements, and these may be disposed in a sequence -Y-R-Y-R-Y-R-Y-R-R-R-Y-R-Y-R-Y-R- around the movable part. The -R-R-R- section defines an origin. By counting signals detected by the detector or detectors, an angular position with respect to the origin can be determined. Other sequences will be readily apparent to those skilled in the art.

The previous embodiments may be employed as a tachometer in a nuclear magnetic resonance spectrometer. Figures 9a and 9b are respectively side and end views of a tachometer in a nuclear magnetic resonance spectrometer in accordance with an eighth embodiment of the present invention. More details of the nuclear magnetic resonance spectrometer are illustrated.

Referring to Figures 9a and 9b, the tachometer 470 in a nuclear magnetic resonance spectrometer 472 includes a fluorescent mark 474 on the outer cylindrical surface 476 of a sample holder mounted, as a rotor 478, for rotation on gas bearings 480 in a chamber 482 in a drive support in the form of a stator 484. The rotor 478 has a conical drive tip 486 and a drive gas supply 488 connects to a drive turbine 490 adjacent to the tip 486, the supply of gas causing rotation of the tip 486 by impingement thereon. A bearing gas supply 492 supplies gas to the gas bearings 480. A single optical fibre 494 has a lens 496 at an end thereof. The lens 496 is located on the inner cylindrical surface of the stator 484 so as to face the rotor 478, in particular at a location facing the locus of rotation of the fluorescent mark 474. The single optical fibre 494 supplies incident light at a first wavelength from a light source (not shown) and transmits to a detector (not shown) emitted fluorescent light at a second wavelength. As well known to those skilled in the art, the axis of rotation of the rotor 478 is tilted with respect to an applied magnetic field M at an angle of 54.7 degrees to provide optimal NMR resolution in solid-state NMR experiments.

Referring to Figure 10 there is shown another embodiment of the present invention, comprising a linear motion or position detector. As shown in Figure 10, a series of radiation receiving and emitting elements 500, 502, 504, 506, 508, is provided on a translationally movable part 510, the elements extending along the direction of motion in the direction B-B. In this embodiment, five radiation receiving and emitting elements are provided but there may be a larger or smaller number thereof in alternative embodiments. Each radiation receiving and emitting element 500, 502, 504, 506, 508 is adapted to emit radiation at a respective wavelength band, but to be excited by radiation in a common wavelength band emitted from a common radiation source 512 and transmitted by an optical coupler 514. The radiation receiving and emitting elements 500, 502, 504, 506, 508 of different fluorescent colour are disposed is a repeat sequence, with one position of the repeat defining an origin. For example, the fluorescent colours emitted may be red (R), yellow (Y) and blue (B) by three different radiation receiving and emitting elements, and these may be disposed in a sequence R-Y-B-R-Y along the movable part 510. The -B- defines an origin of the position of the movable part 510, and the -R- and -Y- permit determination of location of the movable part 510 with respect to the origin. Three detectors 516, 518, 520 are correspondingly respectively assembled with three filters 522, 524, 526, each filter 522, 524, 526 being adapted transmit radiation from a selected radiation receiving and emitting element 500, 502, 504, 506, 508.

As the movable part 510 translates, one of the radiation receiving and emitting elements 500, 502, 504, 506, 508 would receive radiation from the radiation source 512 and fluoresce to emit radiation of a respective wavelength band to provide a respective detectable radiation signal for the respective detector 516, 518, 520. Analysis of the different radiation signals would provide a definition of the translational position of the movable part 510. By detecting signals detected by the detector or detectors, a linear position with respect to the origin can be determined. Other sequences will be readily apparent to those skilled in the art.

The present invention provides an apparatus for, and method of, detecting at least one of the motion and the position of a movable part of the apparatus. The motion may be rotational motion and/or translational, e.g. linear, motion. The position may be a static or dynamic position. The embodiments of the present invention can provide that by using fluorescent materials, which may exhibit phosphorescence, that are detected on moving parts of devices, the use of reflected radiation can be avoided, which overcomes many of the problems of known motion or position detectors which employ optical systems using the detection of reflected radiation from a moving part. The embodiments of the present invention can also provide a motion and/or position detector with increased functionality, in addition to rotational and/or translational motion and/or static or dynamic position detection, without the need for expensive and complicated hardware, control circuitry and/or software. For example, fine registering of the position, a direction of motion, and determination of the position with respect to an origin can all be detected in addition to the velocity of the motion of the detected part.

Although the illustrated embodiments employ fluorescent material to provide that that the radiation detected by a detector is non-reflective radiation emitted from the movable part in response to the source radiation, in other embodiments the radiation receiving and emitting element comprises another device or material to achieve this technical effect, for example a circuit adapted to emit radiation at one wavelength when illuminated with radiation at a second wavelength.

As stated above, the present invention has particular application for detecting high velocity rotations using a solid-state optical tachometer, most particularly for incorporation into a nuclear magnetic resonance spectrometer. However, the present invention may also be employed in other rotational motion tachometers for other application, particularly for small-scale or miniaturised devices. The present invention also has application for use in linear motion detectors such as flow meters, especially in devices where the use of reflected light, as used in some known devices, is problematic with regard to optical signal detection accuracy by an optical detector.

CLAIMS

1. An apparatus incorporating a device for detecting at least one of the motion and the position of a movable part of the apparatus, the device comprising a radiation source in combination with a radiation detector which are respectively arranged to direct radiation onto and receive radiation from the movable part of the apparatus, the received radiation having a different wavelength from the directed radiation and the arrangement being such that the received radiation is radiation emitted from the movable part in response to the directed radiation.

2. An apparatus according to claim 1 wherein the radiation source is adapted to emit radiation in a first wavelength band, the movable part is positioned to receive radiation from the radiation source, the movable part is provided with a radiation receiving and emitting element, and the radiation detector is adapted to detect radiation in a second wavelength band different from the first wavelength band, the radiation detector being positioned to receive radiation emitted from the radiation receiving and emitting element, wherein the radiation receiving and emitting element is arranged to emit radiation within the second wavelength band in response to incident radiation within the first wavelength band.

3. An apparatus according to claim 2 wherein the radiation receiving and emitting element comprises a fluorescent material adapted to fluoresce to emit radiation within the second wavelength band when incident with radiation within the first wavelength band.

4. An apparatus according to claim 2 or claim 3 further comprising a transparent protective body for the radiation receiving and emitting element.

5. An apparatus according to any one of claims 2 to 4 further comprising an optical coupler providing a common optical path for at least a portion of the optical path of the radiation from the radiation source and at least a portion of the optical path of the radiation emitted from the radiation receiving and emitting element.

6. An apparatus according to claim 5 wherein the optical coupler is comprised in a common optical element, for receiving incident radiation from the radiation source and transmitting radiation to the radiation detector, and a lens is located at an free end of the

common optical element, which is adapted to be focussed onto an outer movable surface of the movable part that is provided with the radiation receiving and emitting element.

7. An apparatus according to any one of claims 2 to 6 wherein the movable part is provided with a plurality of the radiation receiving and emitting elements which are mutually spaced along a moving direction.

8. An apparatus according to any one of claims 2 to 7 wherein the radiation source and the radiation detector comprise a first optical assembly, and further comprising a second optical assembly comprising a second radiation source adapted to emit radiation in the first wavelength band, and a second radiation detector adapted to detect radiation in the second wavelength band, the second radiation detector being positioned to receive radiation emitted from the radiation receiving and emitting element in response to radiation incident thereon from the second radiation source, wherein the first and second optical assemblies are mutually positioned so as to be directed at two different positions of the radiation receiving and emitting element in a moving direction thereof whereby the direction of movement of the movable part can be detected.

9. An apparatus according to any one of claims 2 to 7 wherein a plurality of the radiation receiving and emitting elements is provided which are mutually spaced along a moving direction, at least one of the radiation receiving and emitting elements being adapted to emit radiation in a third wavelength band when incident with radiation in the first or a fourth wavelength band, and further comprising at least one further radiation detector adapted to detect radiation in the third wavelength band, the radiation detector being positioned to receive radiation emitted from the at least one radiation receiving and emitting element.

10. An apparatus according to claim 9 wherein the plurality of the radiation receiving and emitting elements is provided in a series of different radiation emission wavelength bands to define an origin for the movement of the movable part.

11. An apparatus according to any foregoing claim wherein the movable part is rotatable and the device is adapted to detect rotational motion of the rotatable part.

12. An apparatus according to claim 11 wherein the movable part is a sample holder in a nuclear magnetic resonance spectrometer.

13. A nuclear magnetic resonance spectrometer comprising the apparatus according to claim 12.

14. An apparatus according to any one of claims 1 to 10 wherein the movable part is translatable and the device is adapted to detect translational motion of the translatable part.

15. A method for detecting at least one of the motion and position of a movable part of an apparatus, the method comprising the steps of:

(a) directing radiation from a radiation source onto the movable part of the apparatus; and

(b) receiving emitted radiation from the movable part of the apparatus, the received radiation having a different wavelength from the directed radiation and the received radiation being emitted from the movable part in response to the directed radiation.

16. A method according to claim 15 wherein in step (a) the radiation is in a first wavelength band and is directed onto a radiation receiving and emitting element on the movable part, wherein the radiation receiving and emitting element is arranged to emit radiation within a second wavelength band, different from the first wavelength band, in response to incident radiation within the first wavelength band; and in step (b) a radiation detector detects radiation in the second wavelength band.

17. A method according to claim 16 wherein the radiation receiving and emitting element comprises a fluorescent material adapted to fluoresce to emit radiation within the second wavelength band when incident with radiation within the first wavelength band.

18. A method according to any one of claims 16 to 17 wherein the directed radiation and the emitted radiation are at least partly transmitted along a common optical path.

19. A method according to claim 18 wherein the common optical path is provided by an optical coupler which is comprised in a common optical element, for receiving incident radiation from the radiation source and transmitting radiation to the radiation

detector, and a lens is located at an free end of the common optical element, which is adapted to be focussed onto an outer movable surface of the movable part that is provided with the radiation receiving and emitting element.

20. A method according to any one of claims 16 to 19 wherein the movable part is provided with a plurality of the radiation receiving and emitting elements which are mutually spaced along a moving direction.

21. A method according to claim 20 further comprising analysing the emission of radiation from the plurality of the radiation receiving and emitting elements to determine a position of the movable part relative to the moving direction.

22. A method according to any one of claims 16 to 21 wherein the radiation source and the radiation detector comprise a first optical assembly, and the method further comprises providing a second optical assembly comprising a second radiation source adapted to emit radiation in the first wavelength band, and a second radiation detector adapted to detect radiation in the second wavelength band, the second radiation detector being positioned to receive radiation emitted from the radiation receiving and emitting element in response to radiation incident thereon from the second radiation source, wherein the first and second optical assemblies are mutually positioned so as to be directed at two different positions of the radiation receiving and emitting element in a moving direction thereof, and analysing the detected radiation to determine the direction of movement of the movable part.

23. A method according to any one of claims 16 to 22 wherein a plurality of the radiation receiving and emitting elements is provided which are mutually spaced along a moving direction, at least one of the radiation receiving and emitting elements being adapted to emit radiation in a third wavelength band when incident with radiation in the first or a fourth wavelength band, and further providing at least one further radiation detector adapted to detect radiation in the third wavelength band, the radiation detector being positioned to receive radiation emitted from the at least one radiation receiving and emitting element, and wherein the emitted radiation in the third wavelength band is detected.

24. A method according to claim 23 wherein the detected radiation in at least the second and third wavelength bands is analysed to determine the position of the movable part in the moving direction.

25. A method according to claim 24 wherein the position of the movable part in the moving direction is correlated with respect to an origin for the movement of the movable part, the origin corresponding to a selected one of the plurality of the radiation receiving and emitting elements.

26. A method according to any one of claims 15 to 25 wherein the movable part rotates and further comprising determining at least one of the rotational frequency and the rotational velocity of the movable part by analysing the frequency of the received radiation.

27. A method according to claim 26 wherein the movable part is a sample holder in a nuclear magnetic resonance spectrometer.

28. A method according to any one of claims 15 to 19 wherein the movable part translates and further comprising determining at least one of the translational frequency and the translational velocity of the movable part by analysing the frequency of the received radiation.

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Application No: GB0611446.6 **Examiner:** Mr Sigurd Christensen
Claims searched: 1-28 **Date of search:** 18 October 2006

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-3, 15-17	US 4880972 A (BROGARDH et al..) See in particular the Abstract, col. 5, line 19- 41, claim 1, and Fig. 3, 8.
A	-	DE 10005227 A1 (LAUZE ELECTRONIC GMBH) Abstract and Fig. 1
A	–	GB 2155619 A (PLESSAY COMPANY (UK)) Abstract and figure.
A	-	US 3954339 A (ATWOOD et al.) Abstract and Fig. 2.

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EPODOC, WPI