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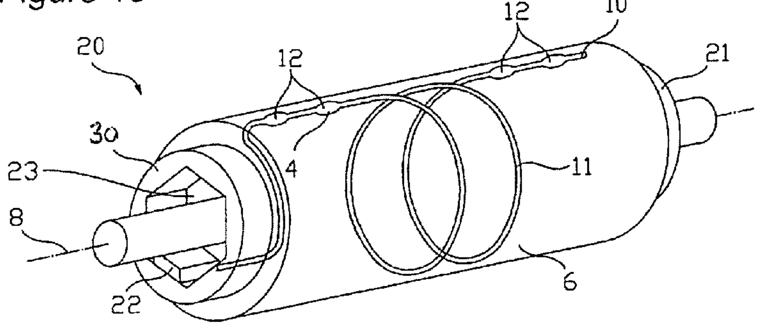
Figure 1c



(57) Abstract: An industrial roll (20) is provided, comprising a transverse force transducing fibre Bragg sensor (10) that is embedded in the roll cover (6) and/or located in-between the roll cover (6) and the roll core (21) of the industrial roll (20). The transverse force transducing fibre Bragg sensor (10) comprises a fibre optical waveguide (1) having a fibre core (2) and a fibre cladding, and a stud element (4) being nonpositively joined to a partial area of the circumferential surface of the fibre optical waveguide (1). The fibre optical waveguide (1) comprises a Bragg grating (3) located in the fibre core (2), whereby the dimension of the partial area in the longitudinal direction of the fibre (1) is longer than a grating spacing of the Bragg grating (3). The partial area is located at a section of the fibre optical waveguide housing the Bragg grating (3), and at least a first component of the stud element (4) is formed from a first material having a Young's modulus of less than 10 kN/mm^2.

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Industrial Roll with Optical Roll Cover Sensor System

The invention relates to pressure measurement in roll covers for industrial rolls and in particular to the use of fibre Bragg grating sensors for determining a pressure imposed on a roll cover.

Rolls are used in industrial papermaking for guiding, drying, and pressing the fibrous web sheet being the elementary body for the paper production. Rolls are further used in papermaking machines as guiding rollers for wet, press and drier felts. In some sections of a papermaking machine the fibre web is conveyed between two cooperating rolls, where it is pressed in the nip formed between these rolls. The properties of a paper processed from the fibre web do strongly depend on the pressure profiles present in the nip sections between the various cooperating rolls. Manufacturers of paper are therefore anxious to monitor and control the pressure profiles in these nip sections.

The nip pressure is typically monitored with sensors placed between the roll core and the roll cover or inside the roll cover. Radial forces, i.e. forces acting in the radial direction of a roll, are usually measured using piezoelectric or electro-mechanic sensors, which both produce a voltage indicative of their deformation upon being pressurised. Since paper machine rolls rotate at a high speed, the sensor signals are usually transmitted to a signal processing unit external to the roll by means of a radio transmitter.

Apart from electrical sensors also fibre optical sensors are used for monitoring the pressure conditions within a nip. Fibre optical sensors generally use a fibre optical waveguide as sensing element, whereby the strain exerted on the fibre is determined by the impact of the strain on the fibre's optical properties.

In conventional optical fibres the strain or bending induced variation in the intensity of light passing the fibre is used as a measurement signal. But since measurement signals obtained by these effects carry no information regarding the location of the signal's origin, it is not possible to determine the position where the optical properties of the fibre have been changed.

If also the point of origin of a measuring signal is of importance, optical fibres comprising several discernable measuring sections are preferred. In a fibre Bragg grating sensor a respective measuring section is formed by a Bragg grating located in the fibre core. A Bragg grating consists of a sequence of variations in the refractive index of the fibre core along the longitudinal direction of the optical fibre. Depending on the respective measurement problem, the distances between consecutive changes in the (typically two) refractive indices (so-called grating spacings) are constant or vary within one Bragg grating. Light passing the core of the optical fibre is partially reflected at each refractive index changeover, with the coefficient of reflection depending on the refractive indices involved and the wavelength of the light. Multiple reflections at a sequence of changeovers in the refractive index lead to either a constructive or destructive interference. Therefore, only one wavelength will be (at least partly) reflected, when the grating spacing of a Bragg grating measuring section is constant, and multiple wavelengths will be reflected, when the grating spacing within one measuring section varies. The wavelengths of the reflected light and the coefficient of reflectance achieved depend on the grating spacings used, the refractive indices involved and the grating length given due to the number of refractive index changeovers present in a measuring section.

When the measuring section, i.e. the section of the fibre containing the Bragg grating, is exposed to strain, the grating spacings change thereby causing a proportional shift in the wavelength of the light reflected at the grating. A measurable wavelength shift is only obtained when the Bragg grating section of an optical fibre is stretched or compressed along its longitudinal direction. Forces acting transverse to the fibre axis do not provoke a measurable change in the grating spacings but only minor Bragg wavelength shifts by photo-elastic effects. Fibre Bragg sensors are therefore primarily used as strain sensors and not as pressure or force sensors.

The pressure profile in the nip section of two cooperating rolls is practically described by the forces acting radially on the rolls. For measuring these forces directly, the Bragg grating of a fibre Bragg sensor would have to be oriented in a radial direction of the roll. A respective arrangement is not practically, since the grating length of a fibre Bragg grating is in the order of millimetres and thus too long to be used within a roll cover. Furthermore, the minimum-bending radius of an optical fibre is in the order of approximately one centimetre, thus rendering the total minimum height of the fibre with respect to the radial direction too long for practical applications. For the same reason of limited bending radius, a radial orientation of a fibre Bragg grating in the roll cover allows only one measuring section per fibre, so that a separate fibre is required for each measuring location.

Optical fibre sensors are therefore usually arranged to measure the hoop strain induced in a roll cover by the forces acting in the nip section. For detecting the hoop strain of a roll cover, the optical fibre is embedded within the roll cover or at the boundary between the roll cover and the roll core. An arrangement appropriate for determining the tangential strain in a roll cover is disclosed in European patent EP 1 392 917 B1, where preferably micro-bend fibre optic sensors are disposed along a helical, axial, circumferential, and a "somewhat random" configuration. The optical fibre configurations presented in European patent specification EP 0 809 507 B1 include spirals, waves, scattered and straight lines along the length of the roll parallel to the roll axis. When using a waveform like a wiggly line, the measuring sections of the fibre, e.g. the Bragg gratings, are oriented in the circumferential direction of the roll or have at least a component in that direction.

When using more than one measuring section within one Bragg sensor fibre, the measurement signals have to be assigned to their respective measuring section of origin. If the fibre of a fibre Bragg sensor is arranged in a helical configuration, each measuring section crosses the nip at a different angular position of the roll. The measuring section assignment may therefore be implemented using the rotation angle of the roll.

A further method of identifying the measuring section from which a certain light reflection originates is based on a determination of the time interval between the launching of a light pulse into the Bragg fibre and the detection of a light echo reflected from one of the Bragg gratings in the fibre. A respective time multiplexed fibre Bragg grating sensor arrangement is for instance disclosed in the patent specification US 4,996,419.

Instead of time multiplexing, wavelength multiplexing can be used for identifying a measuring section giving rise to a certain measuring signal. An example for such a distributed, spatially resolving optical fibre strain gauge is disclosed in document US 4,806,012. In the described Bragg fibre, the grating spacing of one Bragg grating differs to any grating spacing of another Bragg grating formed in the same fibre. Accordingly the basic wavelength of a light echo produced on one grating differs from that produced on each of the other gratings. In this context it is noted that the term "light echo" as used in this specification refers to the light reflected on a Bragg grating in a Bragg fibre. A Bragg fibre hereby refers to an optical fibre having one or more Bragg gratings formed within its fibre core. The term "basic wavelength" as used in this specification refers to the wavelength of a light echo produced with a Bragg grating not exposed to strain. The spacing between the basic wavelengths of the different Bragg gratings of a Bragg fibre is usually chosen longer than the wavelength shifts expected for the Bragg fibre when used as designed for.

Irrespective of the type of Bragg fibre used, a fibre Bragg sensor embedded in a roll cover will only allow to determine the deformation of the roll cover caused by the forces acting in the nip and not the radial forces affecting the roll within the nip area. Variations in the deformation of the cover along the length of a roll are small compared to the variation of the deformation in the circumferential direction of the roll, since the pressure difference along the length of the roll is typically much smaller than between the inside and the outside of the nip. A Bragg fibre arranged along the length of a roll and parallel to the roll axis will therefore produce only small shifts in the wavelength of light reflected at a Bragg grating if any, with the shift values being furthermore not indicative of the absolute value of the compressing forces present in the nip. To get an indication of the absolute values of the compressing forces in the nip, the Bragg gratings are oriented with a component showing towards the circumferential direction of the roll. But even this does not allow a reliable suggestion of the forces present between two corresponding rolls, since the relation between the cover deformation and the compressing forces is very complex due to the elasticity of the roll cover.

A further drawback of fibre Bragg sensors is the limited number of discernible measuring sections, which can be arranged within one fibre. A Bragg fibre sensor consists of usually not more than between ten and twenty-five gratings, which will limit the density of measuring points available for determining the pressure profile in the nip.

It is therefore an object of the present invention to provide an improved optical fibre Bragg sensing system for the characterization of pressure profiles in a nip section of two cooperating rolls.

This object is achieved by the invention as defined in the independent claims. Advantageous embodiments of the invention are the subject of other claims.

The invention comprises an industrial roll with a roll core having a section with a substantially cylindrical geometry, a roll cover sheathing the cylindrical section of the roll core at least in part, and one or more fibre optical sensors embedded in the roll cover and/or located in-between the roll cover and the roll core. One or more of the fibre optical sensors comprise at least one measuring section that is formed by a transverse force transducing fibre Bragg sensor comprising a fibre optical waveguide and a stud element, with the fibre optical waveguide comprising a fibre core and a fibre cladding, and with the stud element being nonpositively joined to a partial area of the circumferential surface of the fibre optical waveguide. The fibre optical waveguide hereby comprises a Bragg grating located in the fibre core. Further, the dimension of the partial area in the longitudinal direction of the fibre is longer than a grating spacing of the Bragg grating, and the partial area is located at a section of the fibre optical waveguide which houses the Bragg grating. Furthermore, at least a first component of the stud element is formed from a first material having a Young's modulus of less than 10 kN/mm^2 (equals 10 GPa).

An industrial roll as defined above advantageously enables a straight measurement of forces directed radially on the industrial roll.

The invention further comprises a roll cover comprising one or more fibre optical sensors embedded in the roll cover and/or located in-between the roll cover and the roll core; wherein one or more of the fibre optical sensors are formed by a transverse force transducing fibre Bragg sensor comprising a fibre optical waveguide and a stud element, with the fibre optical waveguide comprising a fibre core and a fibre cladding, and with the stud element being nonpositively joined to a partial area of the circumferential surface of the fibre optical waveguide, and wherein the fibre optical waveguide comprises a Bragg grating located in the fibre core, the dimension of the partial area in the longitudinal direction of the fibre is longer than a grating spacing of the Bragg grating, the partial area is located at a section of the fibre optical waveguide which houses the Bragg grating, and at least a first component of the stud element is formed from a first material having a Young's modulus of less than 10 kN/mm^2.

The invention also comprises a fibre optical sensor corresponding to a transverse force transducing fibre Bragg sensor as described above as part of the industrial roll and/or the roll cover.

The compressibility of the first material used for the stud element of a fibre optical sensor specified above is preferably low being characterized by a bulk modulus of preferably more than 10^{10} Pa (corresponding to 10^{10} N/m^2 equaling 10 GPa). The low compressibility guarantees an efficient transformation of transverse forces into a longitudinal deformation of the stud element.

In a preferred embodiment of an above specified fibre optical sensor, the first material has a Young's modulus of less than 1 kN/mm^2 and more preferably a Young's modulus in the range of 0.001 to 0.01 kN/mm^2.

The stud element advantageously comprises at least one second component formed of a second material and arranged on the circumferential surface of the fibre optical waveguide adjacent to the first component with respect to the longitudinal direction of the optical fibre, whereby the second material has a Young's modulus of less than 10 kN/mm^2 and a high compressibility characterized by a bulk modulus of preferably less than 106 N/m^2.

The stud element may further be implemented comprising two second components adjoining the first component on opposite sides with respect to the longitudinal direction of the fibre optical waveguide, thus enabling a symmetric deformation of the stud element.

According to an advantageous development, the transverse force transducing fibre Bragg sensor is preferably embedded in the roll cover and/or in-between the roll cover and the roll core, with the stud element being located within a cavity formed in the roll cover and/or in-between the roll cover and the roll core. To enable an elongation of the Bragg grating joined to the stud element when exposed to a transverse force, the dimension of the cavity in the longitudinal direction of the fibre optical waveguide is preferably larger than that of the stud element in that direction. This allows the stud element to intrude the cavity upon being pressed. An improved sensitivity is achieved with the stud element being arranged within the cavity so as to leave a void on both sides of the stud element with respect to the longitudinal direction of the fibre optical waveguide.

An effective transformation of transverse forces in a longitudinal strain of a fibre Bragg grating is achieved by the stud element being arranged on the fibre optical waveguide such that the fibre optical waveguide penetrates the stud element. To achieve a controlled transformation of forces directed in a radial direction of the fibre optical waveguide, the stud element may further have a rotationally symmetric geometry with the axis of the fibre optical waveguide located at the axis of symmetry of the stud element.

The first component of the stud element may further have a shape resembling a sphere, a prolate or oblate spheroid, a double cone, a disk, a cylinder, a bellied cylinder or the like more rotational shapes, which enable a defined transformation of transverse forces in longitudinal forces.

If a fibre optical sensor with a stud element comprising a first element sandwiched between two second components in the longitudinal fibre direction is embedded in a further material, a relatively homogenous compression of the second component can be achieved with the second component of the stud element having a roughly conical or truncated conical, i.e. frustum shape contacting the first component with the base of the geometry.

If the optical fibre comprises a coating, like e.g. a protection coating, the coating forms preferably part of the nonpositive joint between the stud element and the circumferential surface of the fibre optical waveguide.

In a preferred embodiment, silicone rubber is used for the first material and/or polymer foam for the second material.

The industrial roll further advantageously comprises a sensor supply means with a broad-band light source for launching light into the fibre optical sensor, a coupler adapted for coupling out light from a fibre Bragg sensor which has been reflected at a Bragg grating of the fibre Bragg sensor, a spectral sensor for a wavelength sensitive conversion of light coupled out from the fibre Bragg sensor into electrical measurement signals, a signal processing means for processing the measurement signals, and a transmitting means for transmitting the processed measurement signals. The sensor supply means is hereby preferably located on a side face at the rim area of the circumferential surface of the roll. The optical components of the sensor supply means are hereby preferably arranged on a side face of the cylindrical section of the roll core such that the effects of diverging components of centrifugal forces acting on individual optical components are minimized.

To enable measurements at different locations with only one fibre, at least one fibre Bragg sensor comprises more than one Bragg grating with different grating spacings. This allows identifying the Bragg grating giving rise to a measuring signal by the wavelength of the signal. A respective measuring method is called wavelength multiplexing.

To further augment the number of discernible measuring points in a single fibre, groups of Bragg gratings separated from each other by a fibre optical waveguide section containing no Bragg gratings are provided, whereby the Bragg gratings within a group of Bragg gratings have different grating spacings, and whereby the length of a fibre optical waveguide section separating two groups of Bragg gratings is chosen sufficiently long in order to enable a time-separated registration of light reflected in different groups of Bragg gratings. Hereby the grating spacings of Bragg gratings within one group of Bragg gratings preferably correspond to the grating spacings of Bragg gratings within another group of Bragg gratings, allowing the maximum number of gratings within a group.

With at least one fibre optical sensor being embedded in the roll cover and/or in-between the roll cover and the roll core substantially in parallel to the axis of rotational symmetry of the roll, the fibre Bragg sensor is not influenced by a tangential stretching of the roll cover thereby providing measuring signals being directly related to nip forces directed in the radial direction of the industrial roll. To accommodate a fibre Bragg sensor with a multitude of Bragg grating groups separated by 'delay' sections in-between, the sections of the fibre Bragg sensor containing a group of Bragg gratings are advantageously oriented in parallel to the axis of rotational symmetry of the roll, and the sections of the fibre Bragg sensor separating two groups of Bragg gratings are preferably oriented along a substantially helical line around the axis of rotational symmetry of the roll. Thus a multitude of Bragg gratings can be arranged in a line parallel to the rotation axis of the industrial roll, without the 'delay' sections resulting in an increased distance between Bragg gratings.

With at least one fibre optical sensor being embedded in the roll cover and/or in-between the roll cover and the roll core substantially along a helical line around the axis of rotational symmetry of the roll, it is possible to determine the hoop strain of the roll cover in the nip section.

To minimize the tensile load exerted on the fibre, at least one fibre optical sensor may be embedded in the roll cover and/or in-between the roll cover and the roll core with at least one fibre Bragg grating being oriented at an angle of between 10° to 80° with respect to the circumferential direction of the roll, and preferably at an angle of 45° with respect to the circumferential direction of the roll.

Advantageously at least one of the Bragg gratings located in a section of the fibre Bragg sensor oriented along a substantially helical line around the axis of rotational symmetry of the roll is not joined to a stud element.

In a preferred embodiment the roll cover has elastic properties characterized by a Young's modulus in the range of 5 kN/mm^2 to 10 kN/mm^2.

Further features of the invention will be apparent from the description of embodiments of the invention together with the claims and the attached figures. Embodiments of the invention may implement single features or several features in combination. In the following description, the present invention is explained in more detail with respect to special embodiments and in relation to the enclosed drawings, in which

Figure 1a shows an industrial roll having a roll cover with a fibre Bragg sensor embedded in the roll cover parallel to the axis of rotation,

Figure 1b shows an industrial roll having a roll cover with a fibre Bragg sensor embedded in the roll cover along a helical line around the axis of rotation,

Figure 1c shows an industrial roll having a roll cover with a fibre Bragg sensor embedded in the roll cover, whereby two sections of the sensor are orientated parallel to the axis of rotation, and the section between these two is oriented along a helical line around the axis of rotation,

Figure 2 shows a first example of a transverse force transducing fibre Bragg sensor,

Figure 3 shows a second example of a transverse force transducing fibre Bragg sensor,

Figure 4 shows a third example of a transverse force transducing fibre Bragg sensor,

Figure 5 shows a fourth example of a transverse force transducing fibre Bragg sensor,

Figure 6 shows a detailed view of a roll cover section having an embedded transverse force transducing fibre Bragg sensor according to the first example illustrated in Figure 2 with the stud element being accommodated in a cavity larger than the stud element,

Figure 7 shows a section of a roll cover with an embedded transverse force transducing fibre Bragg sensor according to the first example illustrated in Figure 2 in a detailed view,

Figure 8 shows a detailed view of a roll cover section with an embedded transverse force transducing fibre Bragg sensor according to the second example illustrated in Figure 3,

Figure 9 shows a schematic representation of a fibre optical measurement system for pressure monitoring in roll covers, and

Figure 10 shows a modified fibre optical measurement system for measuring radial deformations of a roll cover.

A schematic representation of an industrial roll 20 with an optical roll cover sensor system is shown in Figure 1a. The industrial roll 20 comprises a roll core 21 with a substantially circular cylindrical corpus and a roll cover 6 sheathing the major part of the corpus. The roll core 21 may be made of metal or fibre-reinforced plastics or any other suitable material used for industrial roll cores 21. The corpus of the roll core 21 may be configured with a shell having an outer surface and an internal lumen so that the roll cover 6 overlays the outer surface either in total or except for the edgewise rims. For the roll cover 6, any commonly used material like rubber, polyurethane, fiber-reinforced plastics and the like can be used.

The roll cover 6 further comprises an embedded fibre Bragg sensor 10 that is adapted to measure forces directed transverse to the longitudinal direction of the fibre 10, that is in a with respect to the industrial roll 20 radial direction. The fibre Bragg sensor 10 comprises one or more stud elements 4 described in more detail below, which elongate (or alternatively compress) Bragg gratings located in the fibre 10 upon being compressed.

On at least one side face of the roll 20 a support for mounting a sensor supply means 22 is provided. In the example shown in Figures 1a to 1c, a housing 30 mounted on the side face of the roll core 21 forms the support. The sensor supply means 22 is arranged within a recess 23 of the housing 30. The term sensor supply means 22 as used in this specification denotes equipment used for operating the fibre Bragg sensor 10, that is for launching light into the sensor 10, for determining the wavelength distribution and intensity of the light reflected at the Bragg gratings of the fibre optical sensor 10 and for providing measurement signals representing the reflected light characteristics. The sensor supply means 22 preferably further comprises a transmitter or transceiver for enabling a wireless data communication with measurement equipment or control equipment remote to the industrial roll 20. The sidewalls of recess 23 are preferably flat and have a tangential orientation with respect to the rotation axis 8 of the industrial roll 20. The sensor supply means 22 is preferably mounted on these sidewalls in order to make sure that the individual components and of these in particular the optical components are not subject to diverging centrifugal forces. Although the sensor supply means 22 is represented in Figures 1a to 1c as a single module, it is noted that the sensor supply means 22 may also comprise several modules, each which may be mounted on a different face of the sidewalls. It is however understood that also one or more modules may share one of the sidewall faces. To avoid unbalanced masses, the sidewalls of recess 23 preferably form a regular polygon.

The sensorized industrial roll 20 shown in Figure 1b is distinct from the exemplary embodiment shown in Figure 1a by the way the fibre Bragg sensor 10 is arranged in the roll cover 6. While the fibre Bragg sensor 10 according to the exemplary embodiment of Figure 1a is oriented in parallel to the rotation axis 8 of the roll 20, the fibre Bragg sensor 10 of Figure 1b follows a helical line around the rotation axis 8 which extends over only a part of the rolls circumference. In different embodiments, which are not illustrated in one of the Figures, the helical line followed by the fibre sensor 10 extends about the full circumference or winds several times around the axis 8. Further, the fibre optical sensor 10 may comprise some blank measuring sections, i.e. Bragg gratings without stud elements 4 attached to it. With these blank measuring sections being oriented having a circumferential component with respect to the rotation axis 8 of the roll 20, also tangential forces due to e.g. hoop strain can be measured.

In Figure 1c a combination of the two fibre arrangements of Figure 1a and 1b is shown. This configuration is the preferred embodiment for fibre optical sensors adapted for combined wavelength and time multiplexing as is described in more detail further below. To enable both multiplexing techniques, the transverse force transducers (formed by stud elements 4) and thus the Bragg gratings served by it, are aggregated in two or more groups 12, being separated by a section 11 of the fibre sensor 10 containing no Bragg gratings. Section 11 delays reflected light signals originating from groups located on the far side of the fibre, thus providing the signals from different groups at a different time.

It is to be noted that different to the representations of Figures 1a, 1b, and 1c, more than one fibre Bragg sensor 10 may be used in a roll cover 6, and that one or all of the sensors 10 may also be located in-between the roll cover 6 and the role core 21 instead of being embedded in the roll cover 6 as shown. Guiding the optical fibre 10 through the roll core 21 to the sensor supply means 22 as shown is not mandatory. Arranging the fibre lead in a groove of the roll core 21 is one of many possible alternatives.

Figure 2 shows a first exemplary embodiment of a fibre Bragg sensor 10 adapted for the measurement of forces directed transversely to the longitudinal direction of the fibre. The fibre Bragg sensor 10 comprises an optical fibre 1 with a fibre core 2 and a Bragg grating 3 inscribed into the fibre core 2. The fibre core 2 has a higher refractive index than the fibre cladding, i.e. the part of the optical fibre surrounding the fibre core 2, for enabling a light propagation limited to the fibre core by total reflection. The fibre 1 may further have a protective coating (not shown in the Figure), which is usually formed by a tough resin buffer layer that may further be surrounded by a plastic jacket layer. Respective protective coatings may be used to improve the mechanical resistivity of the fibre but are not necessarily required for a fibre Bragg sensor according to the invention. A reliable adhesion of the coating on the cladding is required when Bragg fibres 1 having a protective coating are used.

The fibre Bragg sensor 10 of Figure 2 further comprises a stud element 4 surrounding the optical fibre 1 in the region where the Bragg grating 3 is located. In the illustrated embodiment, the stud element 4 is formed of a single component 4a. The stud element 4 is shown having a spherical shape with the optical Bragg fibre 1 penetrating it at an axis of rotational symmetry. The stud component 4a is made of an elastic material. The term elastic material as used in this specification denotes a material that can be reversibly deformed under stress. This means that an object made from an elastic material is subject to deformation under stress with the object returning to its original shape when the stress is removed. A respective material is also referred to as a flexible material. A high flexibility is given when the range within which the object can be reversibly deformed extends to some percent or even much more of the object dimensions. Some highly elastic materials allow a reversible stretching of an object of up to 700 percent.

The material used for the stud component 4a is further not compressible in a technical sense, i.e., the total volume of the stud component 4a will not vary substantially under deformation. Accordingly, when the spherically shaped stud element 4 of Figure 2, which is formed of only one component 4a, is compressed by a force acting transverse to the longitudinal direction of the fibre 1, the spherical shape will take on a more oblate form, with the dimension of the stud element 4 being enlarged in the longitudinal direction of the fibre 1. The prolongation of the stud element 4 along the longitudinal direction of the fibre 1 is transferred to the fibre section located within the stud element 4, due to the adhesive contact formed between the stud element 4 and the surface of the fibre 1. The corresponding strain results in a lengthening of the fibre Bragg grating 3 and thus in wider grating spacings. The enlarged grating spacings give further rise to a shift in the wavelength of light reflected at the Bragg grating 3.

Materials suitable for manufacturing a stud component 4a are for instance elastomers and in particular silicon elastomers, like e.g. silicone rubber. But any material having a sufficient elasticity in the above explained sense may be used, like e.g. unsaturated or saturated rubbers, thermoplastic elastomers, thermoplastic vulcanizates, thermoplastic polyurethane, thermoplastic olefins, resilin, elastin or poly-sulphide rubber.

Although the stud component 4a is shown in Figure 2 having a spherical shape, it is not limited to that form. It is even not necessary that the stud element 4 surrounds the fibre 1 as shown, since also a stud element 4 being joined to the fibre 1 on only one side enables a transfer of an elongation or contraction of the stud element 4 to the respective Bragg grating 3 section of the fibre 1. The only prerequisite for this is a nonpositive join between the stud element 4 and the outer surface of the fibre 1, i.e., a connection between a partial area of the fibre's circumferential surface and a surface of the stud component 4a allowing a force transmission. A one-sided arrangement of the stud element 4 on the fibre 1 is preferred, when the fibre 1 is supported on a hard surface of an object or at the boundary between a hard layer and a flexible layer of a compound material or object.

If the fibre Bragg sensor 10 will however be used embedded within a flexible material, a rotationally symmetric geometry of the stud component 4a will be preferred, like the sphere shown or a shape substantially resembling a prolate (cigar like) or oblate (disk like) spheroid, a double cone, a disk, a cylinder, a bellied cylinder or the like more rotational geometries. An example for an irregular shaped rotational geometry is e.g. illustrated in Figure 5 for the stud component 4a as well as for the stud component 4b.

There may be applications where the fibre Bragg sensor 10 will be used for isotropic pressure measurements. In this case, the pressure forces act on the stud component 4a equally from all sides, so that the stud component 4a will practically not be deformed when being only elastic but not compressible. To allow a respective pressure measurement, the stud component 4a is therefore made from a material with both elastic and compressive properties. When using a compressible material like for instance a foamed polymer, an increasing ambient pressure will reduce the size of the stud component 4a, which will further be transferred to the fibre Bragg grating 3 enabling a pressure measurement by monitoring the wavelength reflected at the Bragg grating 3.

Using an elastic stud element 4 whose compressibility is adapted to the respective application enables a measurement of forces acting transverse to the longitudinal direction of a fibre Bragg grating and also the measurement of uniform ambient pressures. A fibre Bragg sensor 10 with a compressible stud element 4 can therefore be used as a pressure sensor embedded in a roll cover 6 used in papermaking machines. A respective embedding of a fibre Bragg sensor 10 with a geometry according to Figure 2 is shown in Figure 7. If only pressure forces transverse to the longitudinal direction are to be detected, the spherical shape of the stud element 4 surrounding the fibre 1 is preferably replaced by a rather block like shape located on the side of the fibre 1 exposed to the forces.

The stud element 4 used in the above explained fibre Bragg sensors 10 is to be regarded as a force and/or pressure transducing element redirecting the impact into the longitudinal direction of the fibre 1. The stud element 4 may be formed as an individual element nonpositively joined to the fibre 1 by use of adhesives or other connection techniques, but also as an integral part of the optical fibre 1 itself, e.g. as a bulge of the protective coating, formed for instance within the coating's tough resin buffer layer.

The Young's modulus of materials preferred for manufacturing the stud component 4a is preferably below 10 kN/mm^2. If the Young's modulus is not applicable for characterizing the elasticity or flexibility of a material used, a material characterized by a secant modulus rendering a comparable deformation may be used.

Figure 3 shows a modified form of the Figure 2 embodiment. The stud element 4 is in this embodiment composed of two components, a first inner component 4a and a second outer component 4b, internalizing the inner component 4a. The inner component 4a is preferably made from an elastic material of an at the utmost minimal compressibility. The outer component 4b however is made from an elastic material of high compressibility. Like indicated above, an object is in the context of this specification regarded as being compressible, when its volume changes in response to a change in the pressure it is exposed to. The compressibility of a material can be characterized by its bulk modulus indicating the relative volume change of an object in response to a pressure change when uniformly compressing the object made from the material. Materials suited for fabricating the second component 4b are for instance soft foamed polymers, foamed plastics or other soft foams.

The embodiment of the fibre Bragg sensor 10 illustrated in Figure 3 is particularly suited for being embedded in elastic materials like e.g. roll covers for papermaking machines as illustrated in Figure 8. When the part of the roll cover with the measuring section of the sensor 10 embedded therein, i.e. the section comprising the stud element 4 around or at the fibre Bragg grating 3, is located within the nip section of two cooperating rolls, the outer surface of the stud element 4 is uniformly pressurized. If the volume change of the roll cover 6 under pressure is transferred to the stud element 4, the inner component 4a of the stud element 4 will be flattened by the pressure, with the parts of the component 4a closer at the fibre 1 intruding in the space held before by the compressible outer component 4b. Since the equatorial circumference of the inner component 4a increases when being flattened, the fibre Bragg grating 3 is subject to strain. Of course it is also possible to use a stud element 4 having a structure rotated by ninety degree with the major axis of the spheroid 4 being oriented perpendicular to the longitudinal direction of the optical fibre 1, thus representing a prolate spheroid. In this case the grating section 3 of the fibre is not elongated when the roll cover 6 is pressurized but contracted.

The spheroidal shape of the stud element 4 shown in Figure 3 represents only one of the many possible shapes that can be used. The incompressible elastic inner component 4a of the stud element 4 shown in Figure 4 has a cylindrical form and is sandwiched between two conically shaped compressible outer components 4b having their respective bases oriented face to face. This geometry minimizes the deformation of the inner component 4a at its periphery and maximizes the deformation at the junction to the fibre 1. In many cases the desired function is already sufficiently achieved using frustoconically shaped outer components 4b. Figure 5 gives an example for a stud element geometry providing a non-linear transformation of a pressure variation into a variation of the strain induced into the fibre Bragg grating 3. When a fibre Bragg sensor 10 with a stud element 4 according to Figure 5 is embedded in a roll cover 6, two deformation characteristics have to be considered when calculating the strain imposed on the measurement section 3 of the fibre 1: the change of the pitch between the two toroidal side structures, and the elongation or compression of the central part around the fibre 1. For low pressures, the toroidal sections are mainly pressed to the sides, and for higher pressures, the inner stud element 4a is elongated in the region near the fibre 1.

When embedding a fibre Bragg sensor 10 according to an embodiment illustrated in Figure 2 in a roll cover 6, whereby the stud element 4 is made from an elastic, incompressible material, the embedding is preferably carried out as illustrated in Figure 6. The stud element 4 is located within a cavity 5 formed in the embedding material 6, especially in the roll cover 6, whereby the stud element 4 is in contact with two opposite sides of the cavity 5. Upon the embedding 6 being pressurized, the pressure forces are transferred via the contact faces onto the stud element 4 deforming it in a way that the circumference of the stud element 4 near the fibre 1 increases causing a strain in the fibre Bragg grating 3.

When not the absolute values of the pressure forces present within a roll cover 6 are of interest but their respective dynamics, the configuration of Figure 7 may be used with the stud element 4 being formed of an incompressible elastic material. Since static pressure forces have an isotropic distribution within the roll cover's nip section, only pressure wave fronts result in a measurable deformation of the stud element 4. Combining an embedded measuring section like the one just described with others as described above, enables a monitoring of the pressure profile present in a nip section of a roll cover 6 both with respect to the pressure dynamics and the nip pressure distribution within the nip.

When fibre optical sensors 10 with more than one Bragg grating 3 are used, the Bragg gratings 3 favourably differ from each other by their respective grating spacings. Thus the wavelength range in which a measurement signal is found allows the identification of the grating 3 from which the signal originates. Since the wavelength of light reflected on a Bragg grating 3 shifts according to the strain present there, the variation of the grating spacings from Bragg grating 3 to Bragg grating 3 has to yield a higher wavelength shift caused by the maximum allowable strain at a grating 3.

It is further to be noted that stud elements 4 are not necessarily located directly at the Bragg grating sections of a fibre sensor 10, but sideways to it, so that each Bragg grating is flanked by a pair of pressure transducing stud elements 4. An elongation of the stud elements 4 in the fibre region results then in a compression of the Bragg grating 3 located between each pair of stud elements 4 with the same physical effects as described above.

The illustration of Figure 9 shows a schematic representation of a fibre optical measurement system 100 using two fibre Bragg sensors 10 according to one of the above or below explained embodiments. Although each fibre 1 is shown with only four measuring sections represented by oblate spheroids 4, it is appreciated by a person skilled in the art that the number of measurement sections within a fibre 1 as well as the number of fibres 1 used in total is determined according to the given measurement task and is not limited to the illustrated embodiment.

The upper part of Figure 9 shows the principle configuration of the fibre optical measurement system 100, and the lower part of the Figure contains a schematic representation of the spectral sensor 105 used in the system 100.

A broadband light source 104 like for instance a Superluminescent Light Emitting Diode (SLED) emits light within a certain wavelength range, e.g. a range from about 800 nm to about 850 nm. The light is propagated via a fibre optical output 101 and a following fibre optical coupler 103 in a fibre optical sensor array formed by one or more fibre optical sensors 10 embedded within a roll cover material 6. The optical sensors 10 are preferably formed by single-mode fibre optical waveguides 1 having Bragg gratings 3 inscribed therein with stud elements 4 joined to each fibre section accommodating a Bragg grating 3. The average grating spacings of the measurement sections differ from each other for enabling a wavelength multiplex measurement.

For increasing the number of measurement sections within one fibre 1, the Bragg gratings 3 are aggregated in groups 12 as e.g. indicated in Figure 1c. Within a group 12 a different grating spacing is used for each Bragg grating 3. In different groups 12 equal or similar grating spacings are used. An optical fibre section 11 containing no Bragg grating 3 separates the groups from each other. Section 11 has a considerable length in order to enable a clear distinction of the optical measurement signals by the different propagation times involved with the different distances of the groups of Bragg gratings 3 to the light source and the spectral sensor 105. A fibre optical measurement system 100 using respective fibre optical sensors 10 is referred to as a combined wavelength multiplex and time multiplex system. Since the length of the optical fibre 1 between two groups 12 of gratings 3 has to be long in relation to the dimension of the groups, these intermediate sections 11 are preferably arranged within a roll cover 6 in a low pitch helical arrangement, while the fibre grating group sections 12 are favourably arranged along the length of the roll cover 6 more or less parallel to the roll axis 8.

The lengths of the Bragg gratings 3 in a fibre optical sensor 10 vary from about 2 to about 10 mm, whereby an average length of the Bragg gratings 3 of around 6 mm is preferred. Due to the extended length of the gratings 3, ellipsoidal stud elements 4 with the main axis coaxial to the fibre axis are favourably used. The stud elements 4 together with the Bragg gratings 3 surrounded by them form the individual measurement sections of the fibre optical sensors 10. Light reflected at the various Bragg gratings 3 exits the optical fibre sensor 10 at the coupling means 103 and passes into the fibre optical waveguide 102 leading to the polychromator 105 serving as a spectral sensor for the wavelength sensitive conversion of the optical measurement signals into electrical signals. The spectral information carrying electric measurement signals are then transferred to a signal processing means 106 which may be implemented in part at the location of the polychromator 105 and in part remote thereto. Since the remote part is usually not on the roll 20 supporting the fibre optical sensors 10, data are preferably exchanged between the two or perhaps more parts of the signal processing means 106 by means of a radio link.

The lower part of Figure 9 shows the basic configuration of a polychromator 105 that may be used as spectral sensor. Light enters the configuration via the entry cleavage 108 at the exit of a coupling element 107 terminating the fibre optical waveguide 102. The emitted light beam 111 widens and illuminates a reflective grating 109 having a curved surface. The curvature of the grating is adapted to focus each spectral component 112, 113 of the light beam 111 onto a different location of a photosensitive means 110, like, e.g., a Charge Coupled Device (CCD), outputting the electrical signals according to the location of their respective generation.

To reduce the amount of measurement data to be transferred from the part of the processing means 106 located near the spectral sensing means 105 to the remote part, under-sampling is employed. Under-sampling means that only one or a few samples are taken from each measurement signal at a time. Sampling is repeated at each further occurrence of the signal, but with slightly shifted sampling positions. Assuming that signal changes are very slow compared to the sampling rate (i.e. the frequency with which the sampling is repeated), the measurement signal can be restored with sufficient accuracy from the under-sampled data.

In the present case, the measurement signal is related to the pressure in the roll cover 6 passing the nip section. Except for special failures, like e.g. a roll fracture or the like, the pressure profile in the nip does only change very slowly, if at all. Accordingly, the measurement signals obtained with fibre Bragg sensors 10 located in the roll cover 6 will be identical or almost identical for subsequent revolutions of the roll 20. This gives the possibility to sample the pressure forces only once or a few times per roll revolution, but at a slightly shifted revolution angle from one measurement to the next. The pointwise measurement provides a significant reduction of the measurement rate without impairing the precision of the pressure profile representation.

Light source 104, waveguides 101 and 102, coupler 103, spectral sensor 105, and the local module of the signal processing means 106 are as mentioned above preferably mounted in the recess 23 within the housing 30 located on the side of the roll 20 supporting the roll cover sensory 100 as shown in Figures 1a to 1c. The housing 30 is preferably removably attached to the roll core 21. Due to the centrifugal forces involved, the light source is oriented for emitting the light in a direction radial to the rolls rotation axis 8. Therefore, only the distance between the light emitting area of the light source 104 and the fibre 101 may change with the rotation speed of the roll 20, but not the lateral adjustment of the optical fibre 101 relative to the light source 104, thus guaranteeing a reliable coupling of the light into the fibre optical waveguide.

The polychromator 105 is favourably mounted on a plane oriented tangentially with respect to the rotation of the roll 20, resulting in all components of the optical system being exposed to substantially the same forces. With the optical components thus not being subject to diverging forces, the optical paths of the polychromator 105 are not affected by the roll rotation. Possibly existing diverging force vectors close to the edges of the polychromator's base plate (located at a slightly larger distance from the centre of rotation) are compensated by application of a buffer material placed below the base plate and the rotating housing, which is made slightly thinner or softer in the central region of the base plate.

In a different embodiment of the fibre optical measurement system 100, fibre Bragg grating sensors 1 are used without a stud element 4 for transforming transverse forces. A respectively modified fibre optical measurement system 100 is shown in Figure 10. The fibre 1 containing the Bragg gratings 3 is embedded in the roll cover 6 in a serpentine arrangement, whereby the lateral deflections are oriented in the radial direction of the roll, i.e. perpendicular to the rotation axis 8. The gratings 3 are located between two local extrema of the arrangement. Accordingly, the longitudinal axis of each Bragg grating 3 has a component directed into the radial direction of the roll cover 6, and is thus suited to measure the radial component of the roll cover deformation in the nip section of two cooperating rolls 20. The serpentine like embedding can easily be accomplished when the roll cover 6 is manufactured in several layers. First an inner layer is produced, which will be directly supported on the shell 7 of a roll core 21. The second layer comprises a series of holes arranged along a line like in a dotted line. The Bragg fibre 1 is then threaded through the holes along the line resulting in the desired serpentine configuration. This central layer carrying the fibre 1 is then pulled over the inner roll cover layer and covered with a further or final layer. Different to the embodiment shown in Figure 10, some of the serpentine deflection may be oriented tangentially to the roll 20 for measuring tangential forces.

Unfortunately the grating spacings of the Bragg gratings 3 are not only subject to strain but also to temperature changes. To compensate for the temperature changes within a roll cover 6, one of the two fibre optical sensors 10 shown in Figure 9 is preferably formed by a Bragg grating fibre 1 without any stud elements 4 attached to it, whereby the fibre 1 is arranged along the length of the roll cover 6 in parallel to the roll axis. Since the grating spacings of this fibre 1 are then not affected by roll cover deformation, they are only sensible to temperature changes. Comparing the measurement signals obtained from one of the fibre optical sensors 10 explained above with the reference measurement signals obtained from this sensor fibre 1 does thus allow for a temperature compensation of the measurement signals.

In a different approach temperature compensation can be achieved under the assumption that the temperature conditions within a roll cover 6 will not change within one revolution of the roll 20. Particularly when the peak height of the pressure extremum in the nip is the only object of the measurement, temperature monitoring can be achieved using the measurement signals from Bragg gratings 3 located outside the momentary nip section as temperature reference signals.

Claims

1. An industrial roll, comprising:

- a roll core (21) having a section with a substantially cylindrical geometry;
- a roll cover (6) sheathing the cylindrical section of the roll core (21) at least in part; and
- one or more fibre optical sensors (10) embedded in the roll cover (6) and/or located in-between the roll cover (6) and the roll core (21);

wherein one or more of the fibre optical sensors (10) comprise at least one measuring section that is formed by a transverse force transducing fibre Bragg sensor (10) comprising a fibre optical waveguide (1) and a stud element (4), with the fibre optical waveguide (1) comprising a fibre core (2) and a fibre cladding, and with the stud element (4) being nonpositively joined to a partial area of the circumferential surface of the fibre optical waveguide (1), and wherein

- the fibre optical waveguide (1) comprises a Bragg grating (3) located in the fibre core (2);
- the dimension of the partial area in the longitudinal direction of the fibre (1) is longer than a grating spacing of the Bragg grating (3);
- the partial area is located at a section of the fibre optical waveguide (1) which houses the Bragg grating (3); and
- at least a first component (4a) of the stud element (4) is formed from a first material having a Young's modulus of less than 10 kN/mm^2.

2. An industrial roll according to claim 1, wherein the compressibility of the first material is characterized by a bulk modulus of preferably more than 10^{10} Pa.

3. An industrial roll according to claim 1 or 2, wherein the first material has a Young's modulus of less than 1 kN/mm^2, and more preferably a Young's modulus in the range of 0.001 to 0.01 kN/mm^2.

4. An industrial roll according to claim 1, 2 or 3, wherein the transverse force transducing fibre Bragg sensor (10) comprises at least one second component (4b) formed of a second material that is arranged adjoining the first component (4a) with respect to the longitudinal direction of the fibre optical waveguide (1) and on the circumferential surface of the fibre optical waveguide (1), whereby the second material has a Young's modulus of less than 10 kN/mm^2 and a high compressibility characterized by a bulk modulus of preferably less than 106 N/m^2.

5. An industrial roll according to claim 4, wherein the stud element (4) comprises two second components (4b) adjoining the first component (4a) on opposite sides with respect to the longitudinal direction of the fibre optical waveguide (1).

6. An industrial roll according to one of the claims 1 to 5, wherein the transverse force transducing fibre Bragg sensor (10) is embedded in the roll cover (6) and/or in-between the roll cover (6) and the roll core (21), with the stud element (4) being located within a cavity (5) formed in the roll cover (6).

7. An industrial roll according to claim 6, wherein the dimension of the cavity (5) in the longitudinal direction of the fibre optical waveguide (1) is larger than that of the stud element (4) in that direction.

8. An industrial roll according to claim 7, wherein the stud element (4) is arranged within the cavity (5) so as to leave a void on both sides of the stud element (4) with respect to the longitudinal direction of the fibre optical waveguide (1).

9. An industrial roll according to one of the preceding claims, wherein the stud element (4) is arranged on the fibre optical waveguide (1) with the fibre optical waveguide (1) penetrating the stud element (4).

10. An industrial roll according to claim 9, wherein the stud element (4) has a rotationally symmetric geometry with the axis of the fibre optical waveguide (1) located at the axis of symmetry of the stud element (4).

11. An industrial roll according to one of the preceding claims, wherein the first component (4a) of the stud element (4) has a shape resembling a sphere, a prolate or oblate spheroid, a double cone, a disk, a cylinder or a bellied cylinder.

12. An industrial roll according to one of the claims 4 to 11, wherein the second component (4b) of the stud element (4) resembles a cone or a frustum contacting the first component with its base.

13. An industrial roll according to one of the preceding claims, wherein a fibre coating forms part of the nonpositive joint between the stud element (4) and the circumferential surface of the fibre optical waveguide (1).

14. An industrial roll according to one of the preceding claims, wherein silicone rubber is used as the first material.

15. An industrial roll according to one of the claims 4 to 14, wherein a polymer foam is used as second material.

16. An industrial roll according to one of the preceding claims, further comprising a sensor supply means (22) with

- a broad band light source (104) for launching light into the fibre optical sensor (10);
- a coupler (103) adapted for coupling out light from a fibre Bragg sensor (10) which has been reflected at a Bragg grating (3) of the fibre Bragg sensor (10);
- a spectral sensor (110) for a wavelength sensitive conversion of light coupled out from the fibre Bragg sensor (10) into electrical measurement signals;
- a signal processing means (106) for processing the measurement signals; and
- a transmitting means for transmitting the processed measurement signals;

whereby the sensor supply means (22) is located on a side face at the rim area of the circumferential surface of the roll (20).

17. An industrial roll according to claim 16, wherein the optical components (101, 102, 103, 104, 105, 106) of the sensor supply means are arranged on a side face of the cylindrical section of the roll core (21) such, that the effects of diverging components of centrifugal forces acting on individual optical components are minimized.

18. An industrial roll according to one of the preceding claims, wherein the at least one fibre Bragg sensor (10) comprises more than one Bragg grating (3) with different grating spacings.

19. An industrial roll according to claim 18, comprising groups of Bragg gratings (12) separated from each other by a fibre optical waveguide section (11) containing no Bragg gratings (3), with the Bragg gratings (3) within a group of Bragg gratings (12) having different grating spacings (3), and with the length of a fibre optical waveguide section (11) separating two groups of Bragg gratings (12) being sufficiently long for enabling a time-separated registration of light reflected in different groups of Bragg gratings (3).

20. An industrial roll according to claim 19, wherein the grating spacings of Bragg gratings (3) within one group (12) of Bragg gratings (3) correspond to the grating spacings (3) of Bragg gratings (3) within another group (12) of Bragg gratings (3).

21. An industrial roll according to one of the preceding claims, wherein at least one fibre optical sensor (10) is embedded in the roll cover (6) and/or in-between the roll cover (6) and the roll core (21) substantially in parallel to the axis (8) of rotational symmetry of the roll (20).

22. An industrial roll according to one of claims 1 to 20, wherein at least one fibre optical sensor (10) is embedded in the roll cover (6) and/or in-between the roll cover (6) and the roll core (21) substantially along a helical line around the axis (8) of rotational symmetry of the roll (20).

23. An industrial roll according to one of claims 1 to 20, wherein at least one fibre optical sensor (10) is embedded in the roll cover (6) and/or in-between the roll cover (6) and the roll core (21) with at least one fibre Bragg grating (3) being oriented at an angle between 10° to 80° with respect to the circumferential direction of the roll (20), and preferably at an angle of 45° with respect to the circumferential direction of the roll (20).

24. An industrial roll according to claim 19 or 20, wherein a section (12) of the fibre Bragg sensor (10) containing a group of Bragg gratings is oriented in parallel to the axis of rotational symmetry of the roll, and wherein a section (11) of the fibre Bragg sensor (10) separating two sections (12) of the fibre Bragg sensor that each contain a group of Bragg gratings is oriented along a substantially helical line around the axis (8) of rotational symmetry of the roll (20).

25. An industrial roll according to one of claims 22 to 24, wherein at least one of the Bragg gratings (3) located in a section of the fibre Bragg sensor (10) oriented along a substantially helical line around the axis (8) of rotational symmetry of the roll (20) is not joined to a stud element (4).

26. A roll cover comprising one or more fibre optical sensors (10) embedded in the roll cover (6) and/or located in-between the roll cover (6) and the roll core (21); wherein one or more of the fibre optical sensors (10) are formed by a transverse force transducing fibre Bragg sensor (10) comprising a fibre optical waveguide (1) and a stud element (4), with the fibre optical waveguide (1) comprising a fibre core (2) and a fibre cladding, and with the stud element (4) being nonpositively joined to a partial area of the circumferential surface of the fibre optical waveguide (1), and wherein

- the fibre optical waveguide (1) comprises a Bragg grating (3) located in the fibre core;
- the dimension of the partial area in the longitudinal direction of the fibre (1) is longer than a grating spacing of the Bragg grating (3);
- the partial area is located at a section of the fibre optical waveguide (1) which houses the Bragg grating (3); and
- at least a first component (4a) of the stud element (4) is formed from a first material having a Young's modulus of less than 10 kN/mm^2.

27. A roll cover according to claim 26, having a Young's modulus in the range of 5 kN/mm^2 to 10 kN/mm^2.

28. A fibre optical sensor corresponding to a transverse force transducing fibre Bragg sensor (10) according to one of the claims 1 to 25.

Figure 1a

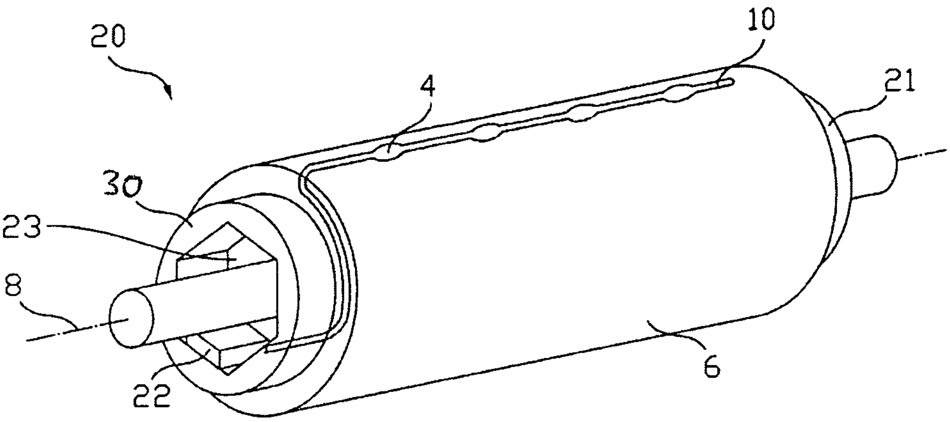


Figure 1b

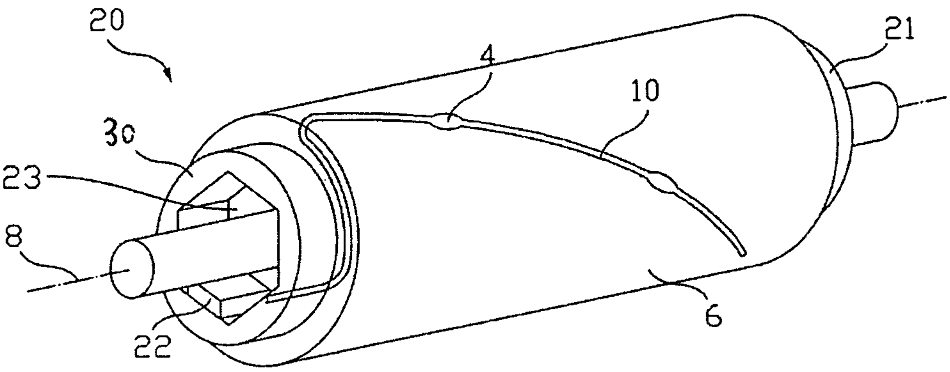


Figure 1c

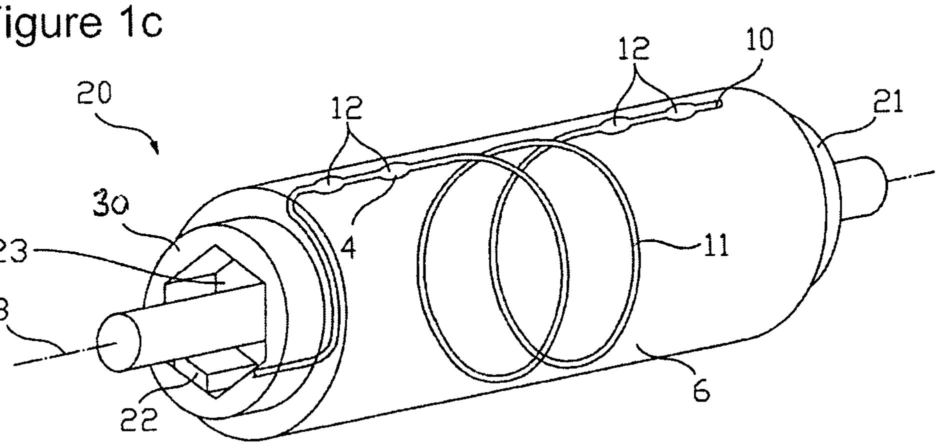


Figure 2

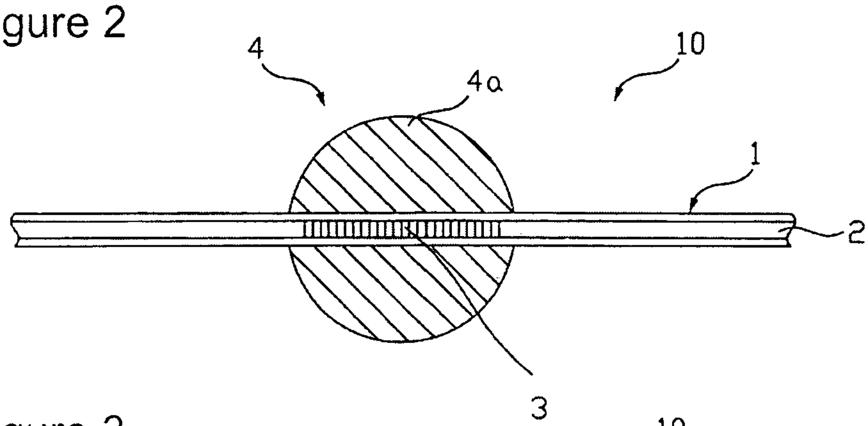


Figure 3

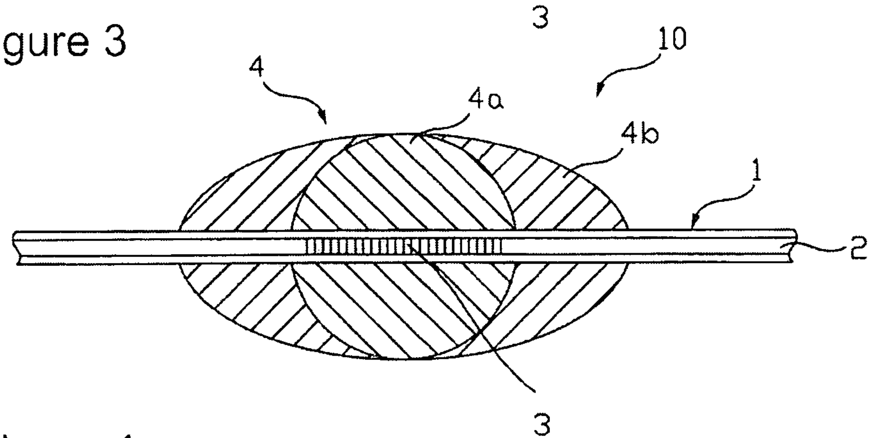


Figure 4

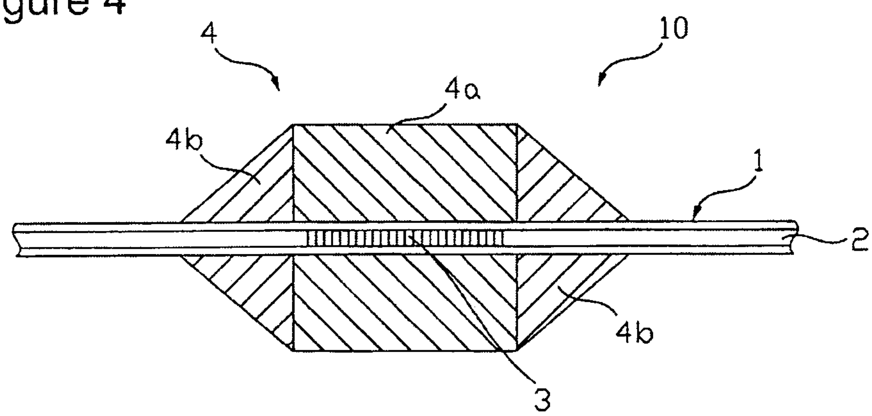


Figure 5

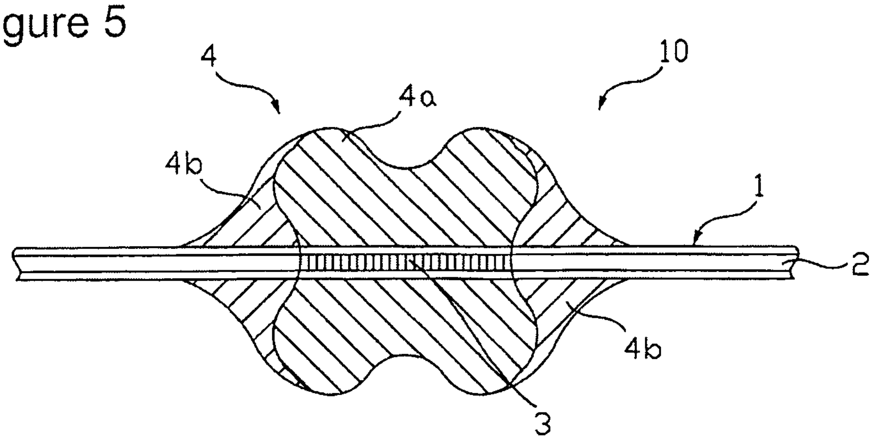


Figure 6

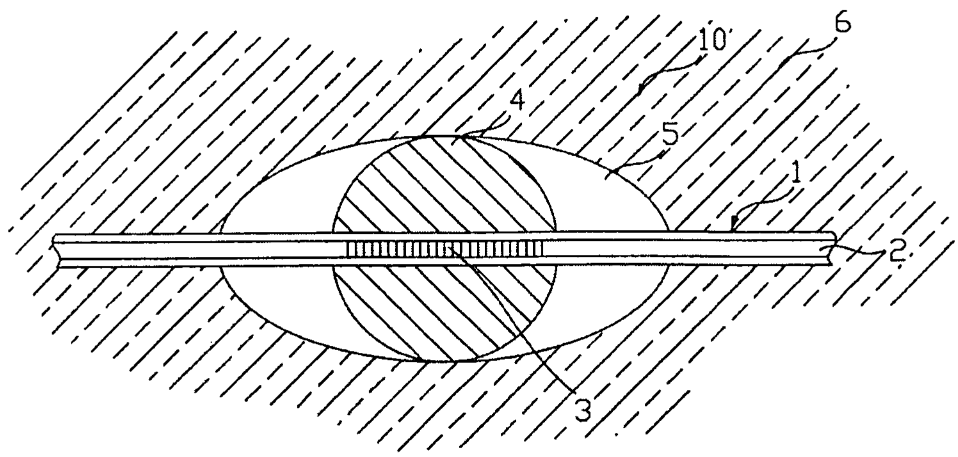


Figure 7

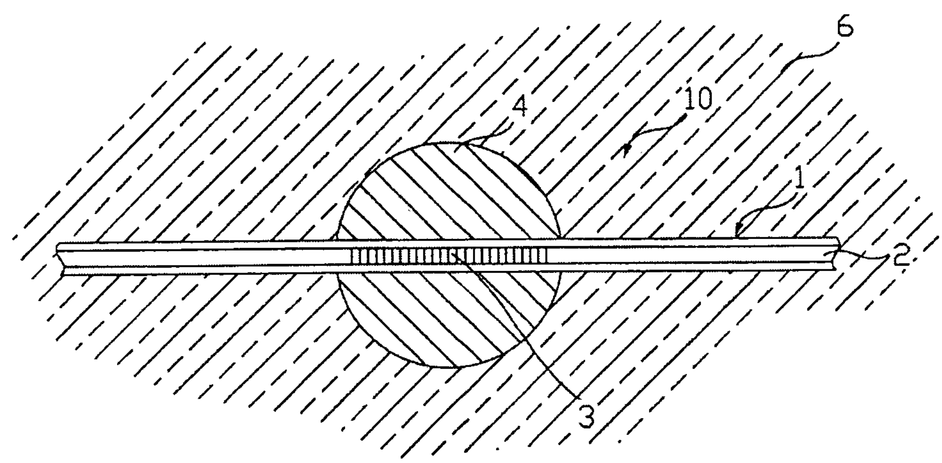


Figure 8

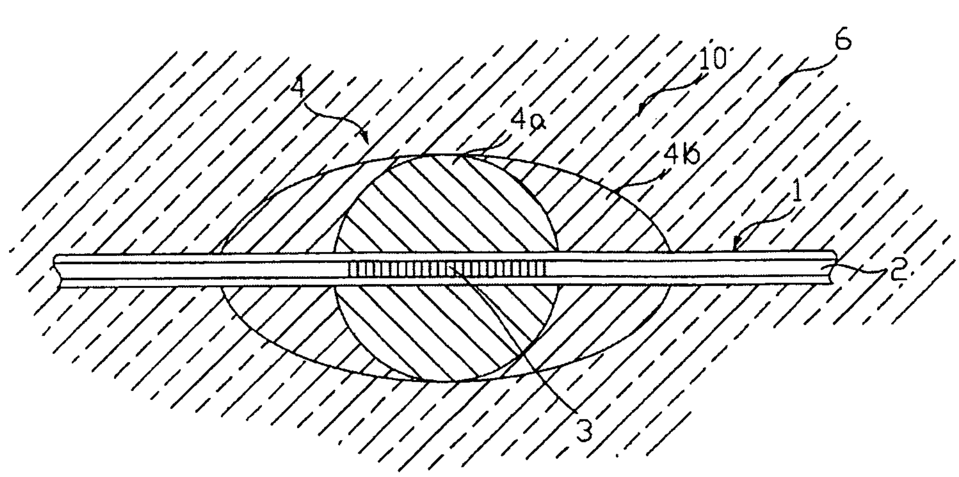


Figure 9

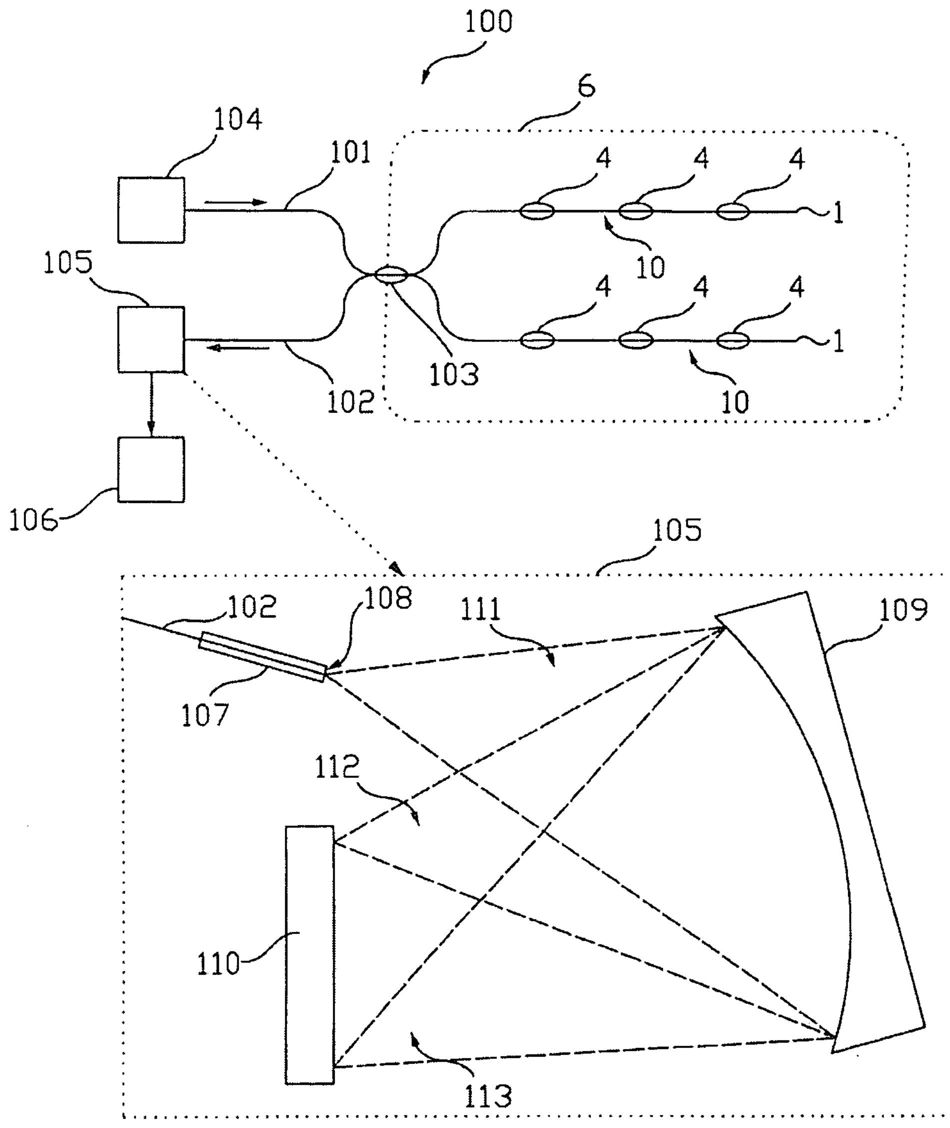
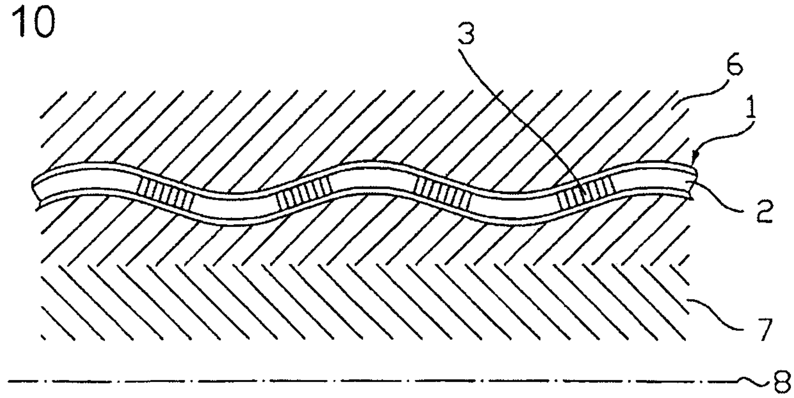


Figure 10



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2008/008050

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01L5/00

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)
G01L

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 1 392 917 A (STOWE WOODWARD LLC [US]) 3 March 2004 (2004-03-03) cited in the application paragraphs [0019] - [0021]; figures 3-7	1-28
A	US 5 557 100 A (JEUNIAUX FRAN OIS [FR] ET AL) 17 September 1996 (1996-09-17) column 3, line 30 - line 36; figures 2,3 column 4, line 17 - line 19	1
A	WO 03/076887 A (LIGHT STRUCTURES AS [NO]; SAGVOLDEN GEIR [NO]; WANG GUNNAR [NO]; PRAN) 18 September 2003 (2003-09-18) page 7, line 16 - line 26; claim 13; figure 2b	2-28

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

[X] See patent family annex.

* Special categories of cited documents :

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 June 2009	03/07/2009

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, Fax: (+31-70) 340-3016	Mucs, André

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2008/008050

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2005/285059 A1 (GERBER TERRY L [US] ET AL) 29 December 2005 (2005-12-29) paragraphs [0016], [0038]; claim 1; figures 5a,6	1-28

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2008/008050

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
EP 1392917	A	03-03-2004	AT	325923 T	15-06-2006
			BR	0209545 A	20-04-2004
			CA	2442055 A1	12-12-2002
			DE	60211331 T2	19-04-2007
			MX	PA03010857 A	17-02-2004
			WO	02099188 A1	12-12-2002
			US	2002179270 A1	05-12-2002
US 5557100	A	17-09-1996	NONE		
WO 03076887	A	18-09-2003	AU	2003212719 A1	22-09-2003
			GB	2405202 A	23-02-2005
			NO	20021257 A	15-09-2003
US 2005285059	A1	29-12-2005	NONE		