PATENT SPECIFICATION (11) 1 567 950

1 567 950

(21) Application No. 35428/76 (22) Filed 15 Sep. 1976 (19)
(31) Convention Application No. 2541072 (32) Filed 15 Sep. 1975 in
(33) Fed. Rep of Germany (DE)
(44) Complete Specification Published 21 May 1980
(51) INT. CL.^{3} G01R 15/07
(52) Index at Acceptance
G1U BV2
G1A A7 CF G7 P10 P11 P12 P3 P6 R7
S4 T15 T24 T2 T3 T9
G2F 23M 25P2 28W CW

(54) IMPROVEMENTS IN OR RELATING TO MAGNETO-OPTICAL CURRENT MEASURING TRANSDUCERS

(71) We, SIEMENS AKTIENGESELLSCHAFT, a German Company of Berlin and Munich, German Federal Republic, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

The invention relates to magneto-optical high-voltage current measuring transducers of the type in which a sensing element in the form of a coil of optical fibres is used to measure a magnetic field that is produced by a current in a conductor, which field acts to produce a change in polarisation of linearly polarised light transmitted through the windings of said coil, which change may be measured to ascertain the value of current flowing in a conductor.

In a known measuring transducer, polarised light flows through a first Faraday rotator, which is arranged as measuring sensing element in a magnetic field dependent upon a current in a high-voltage conductor, which current is to be measured. On passage through this Faraday rotator, the polarisation direction of a polarised light beam will be rotated in dependence upon this magnetic field. That polarised light which emerges from the Faraday rotator with an altered polarisation direction is then passed through another Faraday rotator, a so-called compensator, which operates at earth potential. The compensator is positioned in a regulatable magnetic field, so that the light whose polarisation has been altered in direction, is returned to its original polarisation direction. The required strength of the regulatable magnetic field consequently serves as a gauge of the current to be measured.

It is already known to design a Faraday rotator in the form of a coil of optical fibres. A light conductor coil of this type consists of a glass fibre which serves to convey the polarised light beam, whereby the polarisation direction of this light beam is rotated on its path through the glass fibre in dependence upon the prevailing magnetic field.

Such Faraday rotators in the form of light conductor coils are subject to limits in respect of the measuring accuracy, however, since as a result of the curvature of the light conductor fibres in the coil, mechanical tensions arise therein, which lead to birefringence.

One object of the present invention is to provide a construction which avoids this birefringence.

The invention consists in a magneto-optical measuring transducer for measuring current flowing in a conductor, in which a measuring sensing element is connected in series with a compensator element, each designed as a light conductor coil which will rotate the polarisation plane of injected linearly polarised light in dependence upon the strength of a respective magnetic field produced by the current to be measured in the case of the sensing element, and by an adjustable locally produced magnetic field in the case of the compensator element, this rotation being used as a gauge for the current which is to be measured, and wherein said elements of the measuring transducer are formed by light conductor coils whose coil configurations are substantially similar, the sensing element surrounding said conductor and the compensator element surrounding a conductor producing the local magnetic field, and the disposition of said coils being such that any birefringent effect in one coil is compensated by arranging the other coil to produce an opposite effect.

The invention is based on the novel recognition that in terms of their influence on polarised light, coils composed of light conducting fibres can be considered as equivalent to a birefringent crystal. For reasons of symmetry, a main axial direction, as hereinafter defined, is identical with the coil axis. In a birefringent crystal, main axial directions are to be understood as those directions in which a linearly polarised light beam can pass through the crystal without the polarisation of the light beam becoming altered.

Any birefringent crystal possesses two main axial directions which are at right angles to one another. If it is traversed by a linearly polarised light beam exhibiting a polarisation direction which differs from both main axial directions, elliptically, polarised light is formed. If two similar crystals are optically connected in series to one another in such manner that the direction of the main axis with a relatively more rapid light propagation in the one crystal is identical to the direction of the main axis with the relatively slower light propagation in the other crystal, i.e. if the similar main axial directions are crossed, the differences in transit time for different polarisation directions are compensated, so that a linearly polarised light beam which enters such a crystal combination or its equivalent emerges linearly polarised again, and in fact independently of its initial polarisation direction.

On the basis of this recognition, a construction in accordance with the present invention uses two identical light conductor coils connected optically in series with the coil axes aligned at right angles to one another. The one light conductor coil an be arranged as a measuring sensing element surrounding a conductor at a high-voltage potential, and the other can be arranged as a compensator, surrounding a conductor at earth potential in order that the curvature-dependent birefringence can be compensated.

However, the degree of curvature-dependent birefringence is also temperature-dependent, and since the measuring sensing element and the compensator are generally relatively widely spaced from one another in order to ensure insulation from the high-voltage conductor carrying the current which is to be measured it is difficult to ensure equal temperature for the measuring sensing element and the compensator.

In a preferred embodiment of the invention, this temperature influence is eliminated by utilising a measuring transducer whose measuring sensing element and compensator each possess two similar light conductor coils with coil axes approximately at right angles to one another. As the light conductor coils of the measuring sensing element are arranged closely adjacent to one another, these coils are subject to the same temperature influences.

An advantageous embodiment of the measuring transducer possesses light conductor fibres with a liquid core.

Compared to glass fibres light conductor fibres with liquid cores possess the advantage that remanent production-related, mechanical tensions do not occur. This is because in the production of glass fibres, irregular mechanical tensions arise within the glass fibre, and it is not possible to predetermine the strength of these tensions. Thus fibres of this type possess a production-governed birefringence which is also temperature-dependent.

On the other hand, light conductor fibres with a liquid core exhibit a birefringence which, apart from the negligible influences of mechanical surface tensions and the asymmetry of the light conductor casing, is clearly coupled to the curvature of the light conductor fibre.

The aforementioned side effects of the light conductor casing can also be compensated, if adjustment means are provided by which the coil axes can be slightly displaced out of the direction in which they are precisely at right angles to one another. The actual setting must be determined by experiment.

The invention will now be described with reference to the drawing, which schematically illustrates one exemplary embodiment.

A light source 1 at earth potential, which may be a laser produces a linearly polarised light beam which is conveyed through a light conductor fibre 2. This light conductor fibre leads to a measuring sensing element 3, which possesses two light conductor coils, 31 and 32, which are of as similar as possible a construction, and exhibit coil axes which are substantially at right angles to one another. The measuring sensing element is arranged in the magnetic field which is produced by the current in a high-voltage conductor 4, which current is to be measured, and the sensing element surrounds this high voltage conductor 4, through which flows a known part of the high-voltage current to be measured. The light conductor coil 32 is optically connected via a light conductor fibre 21 to a compensator 5, which in turn possesses two light conductor coils 51 and 52 whose coil axes are substantially at right angles to one another. This compensator is arranged to surround a winding of a conductive coil 6 producing a compensating magnetic field which is produced by means of a secondary current source 7 which is connected to the coil 6. The current strength of the secondary current source is regulated in such manner that the output of light to a detector 8 exhibits the same direction of polarisation as that from the light source 1. It is thus possible to tap from a load resistor 9 an alternating voltage which is a gauge for the high-voltage current strength which is to be measured in the high voltage conductor 4.

For example, the detector 8 can be constructed in the following known manner: By means of a Wollaston prism the incoming light beam is decomposed into sub-beams which are polarised at right angles to one another, and whose polarisation directions each form an angle of 45° with the polarisation direction of the light beam produced by the light source 1. The two sub-beams, which are polarised at right angles to one another are each conveyed to a respective light measuring device, so that the intensities of the sub-beams are measured. The ratio of the two intensities is then a gauge for the polarisation direction of the incoming light beam to the detector 8. If the ratio of the intensities is equal to unity, then the incoming light beam possesses the same polarisation direction as at the light source 1.

To simplify the drawing, the figure illustrates symbolically by arrows 100 and 101, that on the light conductor coils of the measuring sensing element and the compensator it is advantageous to provide adjustment facilities by which the coil axes of these light conductor coils can be deflected out of their directions at right angles to one another in order to compensate for any residual birefringence error, as described above.

However, a full compensation of the birefringence by series-connected birefringent elements, in which the similar main axes lie at right angles to one another, is only possible when the birefringent elements are not simultaneously Faraday rotators in a magnetic field. In an article published in Applied Optics, 11 (1972) page 617 - 621, written by Jaecklin and Lietz, it is pointed out that the compensation of the birefringence by two flint glass blocks in the form of Faraday rotators is incomplete.

Advantageously, in the measuring transducer even under the effects of the magnetic fields it is possible to achieve a particularly high compensation of the birefringence, if the respective light conductor fibres of the coils 31 and 32 of the measuring sensing element each alternately form one turn on each of the two coil bodies, i.e. if in each coil one turn is connected directly to a coil turn whose axis is at right angles to the axis of the preceding coil turn. Corresponding principles apply to the coils 51 and 52 of the compensator.

Light conductor fibres with a liquid core are known *per se*, and are described, for example, in an article by W. A. Gamblin, D. N. Payne and H. Matsumura, published in Electron. Lett. 10 (1974) p. 148 - 149.

Light conductor fibres of this type possess a liquid core consisting e.g. of hexachlorobuta - 1.3 - diene. The liquid core possesses an index of refraction $n_1 = 1.551$, and the glass casing e.g. an index of refraction $n_2 = 1.482$. Previously, however it was not known to arrange such fibres in measuring transducers.

WHAT WE CLAIM IS:-

1. A magneto-optical measuring transducer for measuring current flowing in a conductor, in which a measuring sensing element is connected in series with a compensator element, each designed as a light conductor coil which will rotate the polarisation plane of injected linearly polarised light in dependence upon the strength of a respective magnetic field produced by the current to be measured in the case of the sensing elements, and by an adjustable locally produced magnetic field in the case of the compensator element, this rotation being used as a gauge for the current which is to be measured, and wherein said elements of the measuring transducer are formed by light conductor coils whose coil configurations are substantially similar, the sensing element surrounding said conductor and the compensator element surrounding a conductor producing the local magnetic field, and the disposition of said coils being such that any birefringent effect in one coil is compensated by arranging the other coil to produce an opposite effect.

2. A measuring transducer as claimed in Claim 1, in which said measuring sensing element itself consists of a pair of similar light conductor coils whose coil axes are arranged substantially at right angles to one another, both coils of said pair surrounding said conductor whose current is to be measured, and in which said compensator element itself comprises a further pair of light conductor coils with coil axes substantially at right angles to one another and connected optically in series to the measuring sensing element via a light conductor fibre, both coils of said further pair surrounding the conductor that produces the locally produced magnetic field.

3. A measuring transducer as claimed in Claim 2, in which the light conductor coils of each pair of light conductor coils are provided with adjustment means by which the coil axes of the light conductor coils of a pair can be controllably displaced from directions precisely at right angles to one another, to compensate for any residual birefringence error of the light conductor coils.

4. A measuring transducer as claimed in Claim 2 or Claim 3, in which each pair of light conductor coils is formed by winding one turn of light conductor in one coil of the pair and then winding the light conductor as a turn of the other coil of the pair.

5. A magneto-optical measuring trans-

ducer substantially as described with reference to the drawing.

For the Applicants,
G. F. REDFERN & CO.,
Marlborough Lodge,
14 Farncombe Road,
Worthing,
BN11 2BT.

Printed for Her Majesty's Stationery Office,
by Croydon Printing Company Limited, Croydon, Surrey, 1980.
Published by The Patent Office, 25 Southampton Buildings,
London, WC2A 1AY, from which copies may be obtained.

1567950 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*