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Optical wheel-rotation sensor

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Abstract

We describe a fiber-optic rotation sensor being developed for anti-lock braking systems (ABS). The basis of the sensor is the magneto-optic detection of the magnetic fields generated by a wheel of alternating magnetized magnets fixed to a wheel of the automobile. Highly sensitive iron garnet crystals serve as the magneto-optic sensing elements. For films with perpendicularly- magnetized domains, the domain structure produces diffraction which is magnetic-field dependent. Exploitation of this effect permits the construction of magneto-optic magnetic field sensors requiring no polarization elements or lenses.

A fiber-optic wheel-rotation sensor has several advantages over present day sensors. It would be directly compatible with other optic sensors, processing computers, and equipment. It would also help solve a corrosion problem, especially common on trucks, that has prematurely ended the life of many ABS systems by destroying the wires running from the wheel sensors to the controller. Fiber optics are easily shielded and are not subject to salt damage. Operational advantages are present as well because the magneto-optic sensor detects the magnetic field strength directly, not its change in time. Thus there is no signal loss when the speed diminishes, as is the case with an inductive sensor. Since the magneto-optic sensor works all the way down to zero speed, the same sensor can be used for the speedometer, and by sensing small differences in wheel speeds it can also operate a traction control device, providing a change in coupling efficiency from the transmission to the wheels to prevent spinning.

A typical ABS sensor consists of a series of magnets mounted as an integral part of the wheel bearing and a sensor in close proximity to detect the presence of those magnets as they rotate with the wheel. A Faraday effect sensor detects the change in direction of the polarization of laser light in the presence of a magnetic field within some sensitive medium, glass or a crystal. Our first ABS sensor, shown schematically in figure 1, used a crystal with a very high magneto-optic sensitivity, bismuth iron garnet(BIG). The fiber is multimoded with a core diameter of 100 μm and the laser source is at 1.3 μm. The sensor element has four components, a lens to collimate the light, a polarizing medium, the sensing element (the BIG crystal), and a reflective surface or mirror. An alternative to this arrangement is to employ a GRIN lens for the focusing but to intentionally have the fiber off axis with respect to the GRIN lens so that the reflected light does not reenter the original fiber but is captured by a second fiber adjacent to the input fiber. In this manner the fiber optic splitter(coupler) can be eliminated. With both schemes there is considerable adjustment of the optical elements required for proper operation. Our work in this field has been preceded by that of others.[1]

In addition to the Faraday effect which produces a polarization rotation of the light, there are also diffraction effects arising from the iron garnet's two-dimensional magnetic domain structure. The domains in the films used in this study are naturally magnetized perpendicularly to the film surface. In the demagnetized state, domains with their magnetization vectors pointed up cover an area equal to that of domains with their magnetization vectors pointed down. Optically, this arrangement acts as a two-dimensional phase grating and produces diffraction[2]. A magnetic field applied to such a film changes the areal balance of the up and down domains (through domain wall motion) which modulates the distribution of optical intensity between the various diffracted beams. In particular, the intensity of the zeroth-order (undiffracted) beam, which will readily couple back into the optical fiber, will be a minimum for zero applied field, and a maximum for a saturated field (of either polarity). The behavior of the higher-order (deviated) diffracted beams is less important since they will be highly attenuated when the light couples back into the optical fiber. The time scale associated with this process is typically much faster than the time scale of the moving magnets[3]. This effect can be so pronounced under certain conditions that the amount of light transmitted *increases* in a conventional Faraday sensor, (Fig 1), with the application of a strong magnetic field when simple Faraday effect would predict a *decrease* in light.

Using diffraction as the sensing process allows a simplification of the sensor element shown schematically in figure 2. The use of unpolarized light allows the elimination of the polarizing element. A thin iron garnet film $\sim 0.25mm$ thick, is attached to the end of a fiber, and the back of the crystal is coated with a reflector. Even without a lens, enough light is reflected back into a single mode fiber to provide a useable signal. In the absence of a magnetic field, much of the reflected light is diffracted away from the optical axis and therefore does not couple back into the optical fiber. When a magnet approaches the crystal, the diffraction diminishes and the return signal increases. This signal modulation provides an easy way to count the number of times a magnet passes the sensor element, giving wheel rotation.

The characteristics of the fiber which are needed to optimize this response to diffraction by the sensor element are, 1) the core of the fiber should be large so that the light illuminates at least several domains, and 2) it should have a small numerical aperture so that if the light is diffracted by a small angle it will not be captured in the core upon reflection. The first requirement makes the use of single mode fibers difficult as the domain sizes are typically 10 μm or more. The combination of required fiber characteristics is provided in the TEC (Thermally expanded core) approach to producing sensors.[4] One of the main arguments advanced by the TEC developers is that such a procedure is specifically aimed at mass producing optical sensors in an inexpensive and simple manner. Because of this we are presently investigating the process of developing this diffraction sensor in conjunction with TEC fibers.

Bibliography

1. "Fiber optic tachometer based on the Faraday effect", Brian J. Zook and Clifford R. Pollack, Appl. Opt. **29**, 1991, 1989.

2. "Domain effects in Faraday effect sensors", M. N. Deeter, Proceedings of the 8th Optical Fiber Sensor Conference, Monterey, CA, Jan 29-31, 1992, post deadline paper PD2.

3. "High frequency magnetic field sensors based on the Faraday effect in garnet thick films", R. Wolfe et. al., Appl. Phys. Lett. **60**, *2048*, 1992

4. "In-line Fiber Components: A New way to Integrate Functional Devices", Shojiro Kawakami, 9th Optical Fiber Sensors Conference, Firenze Italy, Th2.12, May 1993

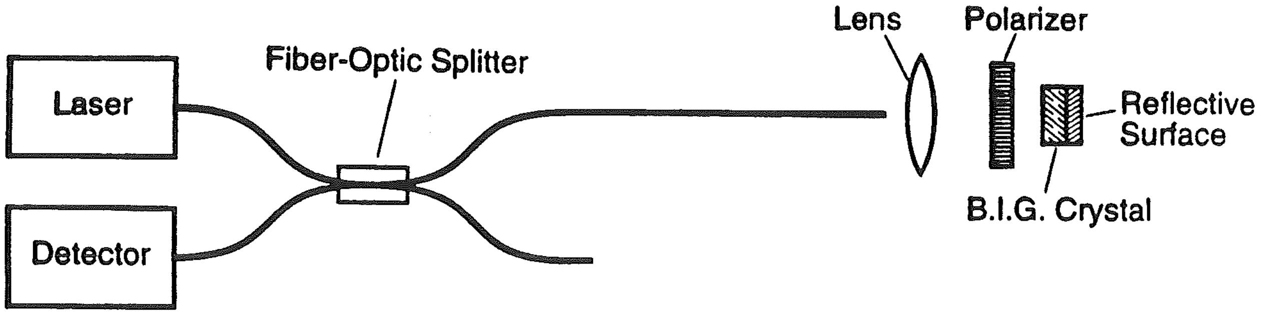

Figure 1. Schematic of a Faraday-effect ABS sensor. Laser light is collimated in a lens, passes through a polarizer and the crystal, reflects in the mirror, returns through the crystal to double the amount of polarization rotation, and is collected in the fiber. In the presence of a magnet, the polarization rotates, reducing the transmission back through the polarizer. The splitter between the fiber and the laser allows the placement of a detector where it measures the return light and provides electrical signals for the controller.

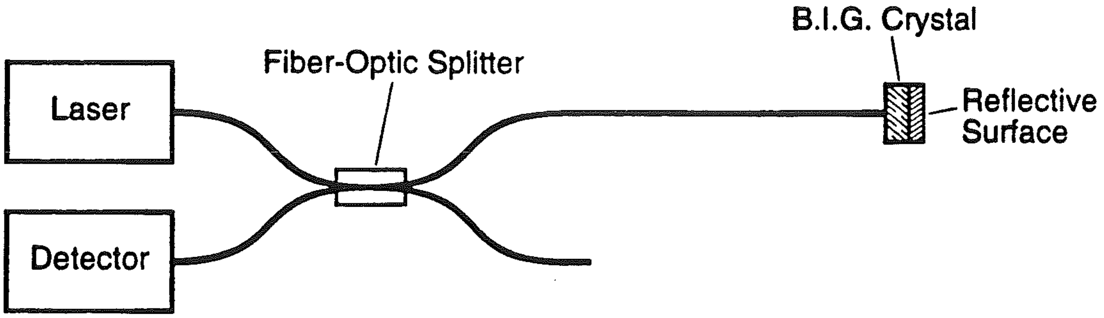

Figure 2. Magnetic domain diffraction ABS sensor. It consists of a thin crystal with magnetic domains, such as bismuth iron garnet. The crystal is coated with a reflecting back surface and attached to a fiber optic splitter to allow simultaneous connection to the laser and detector.