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SENSOR FOR LARGE SCALE APPLICATION

by

B. Logozinski and V. Solomatin

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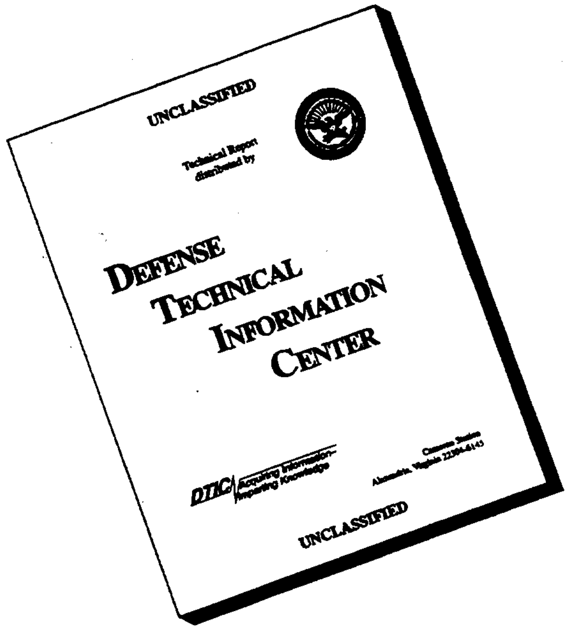

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DEVELOPMENT OF A FIBER OPTIC RATE SENSOR FOR LARGE SCALE APPLICATION

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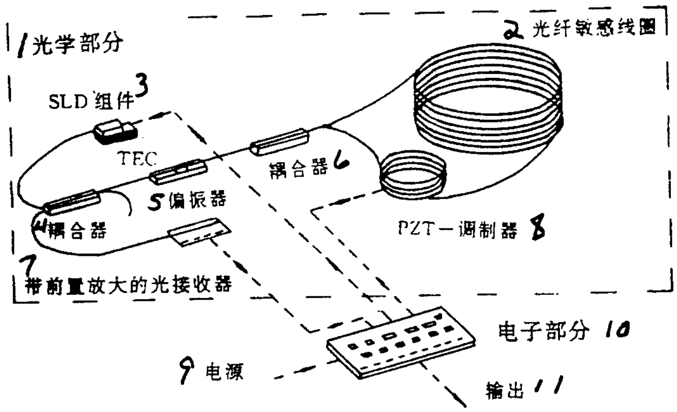
ABSTRACT

The search for and development of fiber optic rate sensors to serve as new model inertia measurement devices has been going on for 15 years. The basic causes affecting precision, and the limitations of capability potential and various phenomena on precision has already entered experimental research and been demonstrated. A number of companies have already made the transition to the development stage and have made the step toward engineering. A number of research units and companies are all actively working on combining fiber optics and physics into fiber optic gyroscopes. They have introduced a number of concepts and theories into pure optics. All this has caused the potential users of fiber optics gyroscopes use these, including those customers of long term inertia elements, unclear as to status of fiber optic gyroscopes, the possibility of their use and their effectiveness. Even more important, our experience has frequently caused us to limit use to general methods in order to estimate the capabilities of fiber optic gyroscopes, and these methods were mainly used on mechanical gyroscope characteristics in the past. Therefore, we may frequently encounter a number of unique laws governing fiber optic gyroscopes. And the existence of these (unique characteristics of FOG) and the known guidance and control systems have provided new parameters (diagnostic). This report primarily describes the most recent successes in the development and production of a single axis fiber optic gyroscope. It also summarizes the experiences of customers in using the Fizoptika rate gyroscope. Also, this article omits the technological detains in order to concentrate on a description of

the characteristics of the product. This may be even more important to the customers.

1. General description of the fiber optic rate gyroscope - technical information

Fig. 1. Structural diagram of the FOG61



1. Optical portion. 2. Fiber optic sensitive coil. 3. SLD component. 4. Coupler. 5. Polarizer. 6. Coupler. 7. PZT-modulator. 8. Optical receiver with pre-amp. 9. Light source. 10. Electronic portion. 11. output.

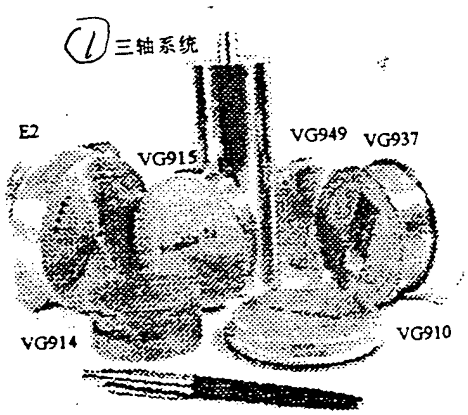
The fiber optic rate gyroscope system developed and produced by Fizoptika Company is an "open loop" system. This type of fiber optic gyroscope transmits an analogue signal (voltage) based on the number of revolutions. In principle it is divided into two parts. The electronic portion and the optical portion (see Figure 1). The optical part is basic, primarily determining the properties of the fiber optic gyroscope. The heart of the gyroscope optical circuit is the a transistor light emitting diode excited fiber optic interferometer. The optical portion also includes an optical receiver component and several optical fiber elements. The strength of the phase shift of the interference figure is directly proportional to the angular speed of the gyroscope. (The interferometer response time is several microseconds.) The cumulative phase of the fiber optic coil is similarly directly proportional to the product of the length of the optical fiber times the diameter of the fiber optic loop. Therefore, sensitivity axis and scale factors are only related to the geometric properties of the optical fiber. ((Using 100 meters of optical fiber to wind up a coil 50mm in diameter has a typical value of 1μmrad/°/h. However, the optical fiber loop as the largest optical portion in a fiber optic gyroscope determines the natural shape of the gyroscope approximates a flat-topped cylinder. The phase shift caused by other reasons is believed to be gyroscope error. Its value is related to the quality of the optical circuitry. In order to eliminate this type of phase shift a number of additional devices are used in the circuit (polarizer and coupler) as well as special manufacturing technology. In order to increase sensitivity, a piezoelectric ceramic (PZT) modulator with an operating frequency of 70Hz provides a dynamic additional phase shift. The range of phase changes of the open loop gyroscope is usually 1rad. The electronic portion will convert intensity changes in the interference figure into output voltage. It is primarily composed of a drive PZT modulator and an AC signal generator and lock-in amplifier which measures the signal on the signal amplifier frequency, and a number of additional circuits used to stabilize the scale factors (SF). An important characteristic of the fiber optic gyroscope is that the components are connected together with a soft tail fibers, and there is a certain randomness to the positioning of the elements, so it can be change the design of the gyroscope in order to meet special structural requirements. For example, optical fiber loop sensors can be placed 100 meters away from the optical and electronic portions in order to achieve remote control and monitoring capability. In addition, by changing the length of the optical fiber and the external shape of the coil it is possible to cause effective large scale changes in the scale factors. At the same time, using extremely small diameter optical fibers when manufacturing the gyroscope it makes it possible to reduce the dimensions and weight of the overall device. To demonstrate this type of gyroscope, we provide a number of potential parameters below:

- Total weight of all optical parts is less than 15 grams.
- Light emitting diode drive voltage is two volts (current is greater than 150mA.
- Total power consumption of optical portion is 0.3 Watts.

2. Typical rate gyroscope system (technological parameters, error models)

Below we will introduce in detail the VG915 gyroscope produced by Fizoptica. Its external shape is a flat-topped cylinder, just like ordinary circular interferometers. Other models in the VG9 series are somewhat smaller than the VG915. For example, the VG914 is 55m in diameter, and the VG910 is 12mm high (see picture of rate sensor).

Picture of rate sensor



1. Triaxial system.

Current status

Batch production of basic models, modified gyroscopes can be ordered and developed.

Mechanical parameters

- Volume 0.06 liter (diameter 70mm, height 15mm).
- Weight 70 grams.
- Sensitive shaft perpendicular to the column face (tolerance 3'-6'). Because the gyroscope is small and light, and because it has a large equipment mounting surface, there are many possible mounting schemes. The gyroscope can be installed using an external frame or directly installed.

Electronic parameters

The gyroscope system requires three different standard low voltage power sources, -15 volt, -15 volt and + 5 volt. In a normal state, the overall power consumption is about 1.8~2W. This power is consumed primarily in the following: $\pm$5V (80~120mA). When operating at fairly high temperatures (higher than 70°C), the +5V power source current will increase to 150~500mA. After all power sources begin normal power supply, the gyroscope begins operations (normal delay is 0.1~0.5 seconds). The gyroscope output circuit is a variable power amplified output. At times it also uses excited reverse phase output to enhance signal retrieval.

Running conditions (environmental)

Passive optical devices are made of quartz crystals so they are extremely light and can withstand heavy temperature and mechanical interference. Operational (storage) temperature extremes are primarily determined by the electrical components. When the gyroscope is using differential circuits, the operational temperature range is 100°C (-30°C~+70°C). Because the optical components have a mechanical harmonic frequency of greater than 2kHz, impact and vibration (peak value of more than 100g) will not generate a great deal of interference. Also, because there are no moving parts inside the gyroscope, the fiber optic gyroscope can very easily withstand an angular velocity of 10,000°/s. Therefore, no "damage rate" index is listed among the various parameters of the fiber optic gyroscope.

Reliability

The fiber optic gyroscope is an electrooptic instrument with very few parts. These parts operate in an environment far removed from damaging conditions and rapid aging environments. Therefore, the FOG has reliability that approaches the reliability of available standard electronic parts and optical parts. So far, special light sources (super light-emitting diodes (SLD) determine the life of the FOG. The average no-malfunction time for the FOG is estimated to be able to exceed 10,000 hours. Recently, with developments in SLD manufacturing technology, average no-malfunction time will increase to 10,000 to 100,000 hours.

Capabilities (properties)

We often use a certain error model to describe the properties of rate gyroscopes. Traditional models and conditions generally refer to mechanical equipment, and optic fiber gyroscope bring some new characteristics to rate sensing. While operating, they generally possess the following characteristics:

1. No dynamic error, its response time is within several

milliseconds.

2. Not sensitive to angular acceleration.

3. Gyroscope output not affected by magnetic viscosity and threshold.

4. No coupling between axes, only detects the rate projection on the gyroscope axis.

5. Stable acceleration has no affect on output.

6. Output characteristic completely symmetrical.

Output signals

Usually the output signal of the fiber optic gyroscope is related to the angular velocity (ω) and the temperature ($t°$).

(2.1)

Wherein, K is the scale factor, expressed in mV/°.

$B_s(t°)$ only deviated by temperature.

W(T) is the output terminal added noise (its optical spectrum is white within the output filter bandwidth)

$S(t°)$ is the scalar factor related to change in temperature.

ω_f indicates the function of the linear output limit, used to express the effective rate. Actually it can detect at an even higher rate, but output response is non-linear (>10%).

Fig. 2. FOB output (mV~°/s), ω_f~250°/s

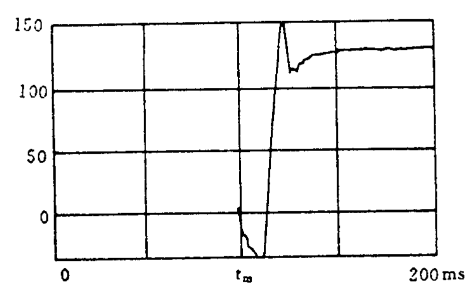


Fig. 3. FOG turning 130°/2 for 50-100ms

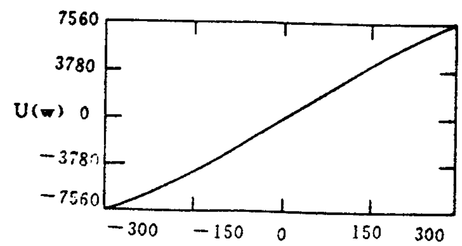


Fig. 4. FOB post start-up preheating process, total time scale 40 minutes, point average time four seconds

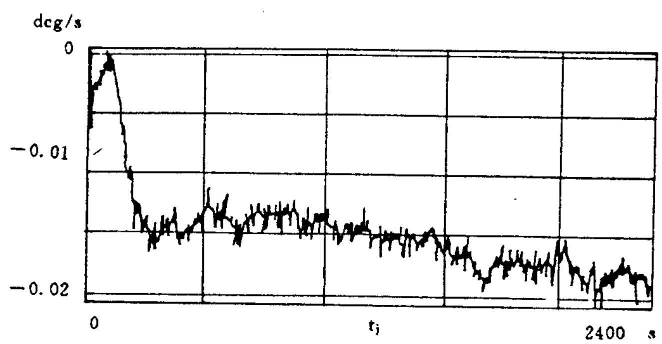


Fig. 5. Long-term (700 hours) operations at normal temperatures

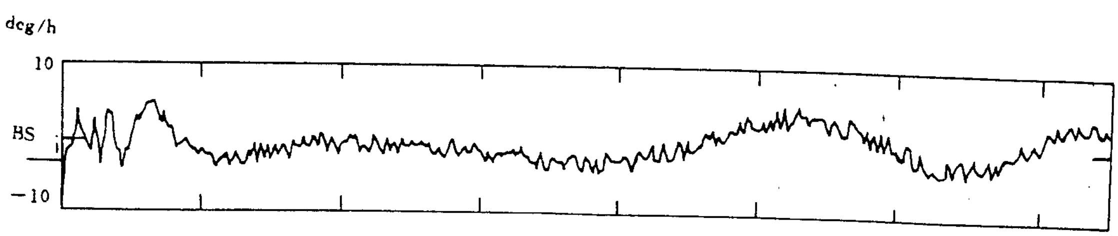


Fig. 6. FOG deviation temperature fluctuations

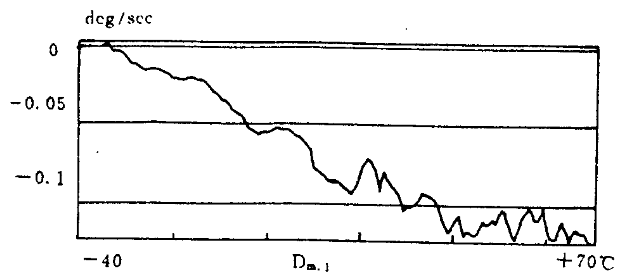
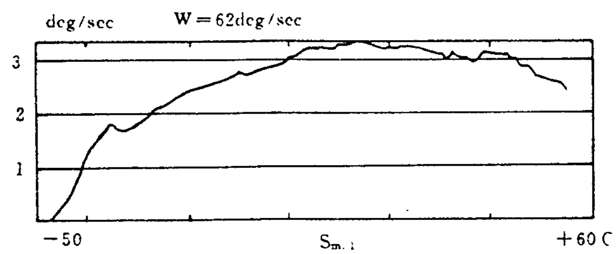


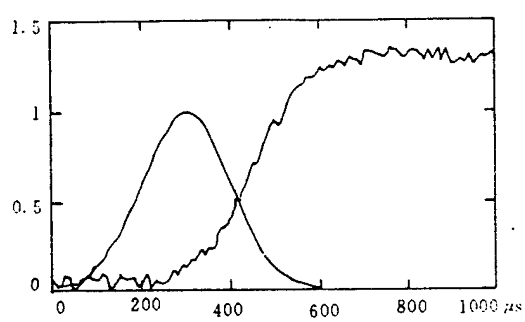
Fig. 7. Temperature dependence of turning FOG output



The scale factor (K), linearality extreme factor (ω_f) and noise level (W) correspond to the technical parameters and manufacturing parameters of the gyroscope. These factors are established once the power is turned on, and the y are constant for any FOG (see Figures 2 and 3). The deviation and scale factors related to temperature are symmetrically distributed, and they determine the precision of the gyroscope (see Figures 6 and 7). We can consider proceeding by slowly and regularly changing the ratio between B_s and s, and temperature calibration can serve as gyroscope output. That portion of the FOG output which changes quickly with temperature (more or less related to the quality of the optical components) constitute the residual error. Therefore, an overall description of the FOG properties does not require too many parameters. If there is no compensation, it is possible to describe its properties using three parameters. The typical values are: Detection range: 100~300°/s; scale factors: 30~100mV; noise spectrum density: 0.003~0.01°Hz; zero point fluctuation: 0.05-0.2°/s; Scale factor error: 3%~10°. In order to reduce temperature error, factors must be added (two to four at the most) in order to attain extreme capabilities. After calibration, the output scale factor error is generally 0.2~0.4%, and the zero point fluctuation is 0.001~0.03°/s.

It is worth noting that the heat source s has a great effect on the primary errors of the FOG. A constant operating mode can greatly improve the capabilities of the gyroscope. For example the nominal zero fluctuation for fiber optic gyroscopes is 0.01°s, and the scale factor error is 0.5%, but at constant temperatures (+1~3°C) the long term zero fluctuation is only 10°/h; the nominal factor error is only 0.03%~0.1% (see Figure 5). The graph of the effects of short time acceleration of the FOG is shown in Figure 8, and the FOG start up and preparation process is shown in Fig 4.

Fig. 8. FOG response curve (curve 2) at short time angular acceleration (curve 1)



3. Properties

A 性能	B VG915	C VG915(改进型)
1 最大输入速率	300°/s	300°/s
2 最大输出信号	12V	12V
3 标度因数误差	<3%	<0.5%
4 随机漂移(1Hz,1σ)	<0.01%	<0.01%
5 零漂(1σ)	0.03~0.1°/s	0.01°/s
6 启动时间	<0.5s	<0.5s
7 准备时间	<10min	<10min
8 信号带宽	1~3kHz	1~3kHz
9 电源功耗	<3W	<3W
10 外壳		
11 直径	70mm	70mm
12 高度	15mm	15mm
13 重量	70g	70g
14 电压	±15V. +5V	±15、+5V
15 环境条件		
16 温度		
17 工作温度	−30℃~+71℃	−30℃~+71℃
18 存放温度	−40℃~+75℃	−40℃~+75℃
19 冲击	90g	3ms
20 振动(2Hz~2kHz)	10rms	10rms
21 平均无故障时间(25℃)	10,000h	10,000h

A. Property. B. Model VG915. C. Improved model VG915. 1. Maximum output rate. 2. Maximum output signal. 3. Scale factor error. 4. Random fluctuation (1Hz, 1σ). 5. Zero fluctuation (1σ). 6. Start up time. 7. Preparation time. 8. Signal bandwidth. 9. Power source consumption. 10. external casing. 11. diameter. 12. height. 13. Weight. 14. Voltage. 15. Environmental conditions. 16. Temperature. 17. Operating temperatures. 18. Storage temperatures. 19. Impact. 20. Vibration (2Hz~2kHz). 21. Average no malfunction time (25°C)

4. Possibilities for improvements - capability extremes

A certain model of gyroscope cannot be used for all purposes, because it cannot satisfy all the different requirements for precision and design at the same time. Even so, the fiber optic gyroscope has flexibility, and it can easily use different structure, and its parameters can match up with different components and elements. This is why the primary properties of the gyroscope can be changed a lot from the basic model in order to expand its range of application. We can change the length of the optical fiber, the diameter of the coil, the brightness of the SLD or adjust (change) certain electrical components (or an entire circuit board) to change the FOG parameters (zero fluctuation, scale factors, noise level, linear scope). Furthermore, these changes will not affect the output dynamics (output dynamics are not related to the maximum and minimum values of the detection rate). Also, the weight, dimensions and external shape do not have a direct effect on the properties of the gyroscope. This makes possible meeting specific design requirements without reducing the properties of the gyroscope. The table below shows the properties which can be changed with available optical circuit quality (basic model) as well as estimates of gyroscope parameter extremes.

1 性能	2 典型值	可改进的极限值 3
4 最大输入速率	250°/s	10~10000°/s
5 零漂	0.01°/s	0.01~1°/s
6 重量	70g	25g
7 外壳		
8 直径	70mm	50mm
9 高度	15mm	10mm
10 最高工作温度	+70℃	+100℃
11 最低工作温度	−30℃	−60℃
12 响应时间	0.2ms	0.05ms
13 启动时间	300ms	10ms
14 电压	±15V, +5V	仅+5V 15

1. Property. 2. Typical value. 3. Possible extreme value. 4. Maximum output rate. 5. Zero fluctuation. 6. Weight. 7. External case. 8. Diameter. 9. Height. 10. Maximum operating temperature. 11. Minimum operating temperature. 12. Response time. 13. Start up time. 14. Voltage. 15. Only +5 Volts.

5. Multiple applications

It is generally held that fiber optic rate gyroscopes are still unable to meet all the requirements of the various different tasks. The FOG has not yet been applied to all the areas in which it is fully suited. At the present time, as a fully practical single axis gyroscope system, the FOG possesses the following characteristics:

- small and light
- live time conversion of turns to voltage signals
- improved property calculation methods most simple
- simple connections, uses standard low voltage power source
- Low power consumption, high reliability
- Parameters can be changed and design improved quickly and cheaply to meet special property requirements
- FOG easily combines and installs with the system

Therefore, we can easily predict that there may well be practical applications for the FOG in metering and control. Except for the basic element (SLD special optical fiber) being slightly expensive, the overall optical gyroscope system can already compete in cost with traditional gyroscopes. If individual electronic control portions replace the compound electronic parts, it could allow the cost of the gyroscope to be reduced to a level acceptable by the market (700 to 900 U.S. Dollars). This approaches the cost of precision electronics elements. Also considering that this instrument is compatible with standard electronic elements and its ease of installation, this says to the customer that the price is even lower. It is just because of this that in control and guidance, such as in angular lock-in, angular velocity metering (motion control, diagnostics, navigation, including combination with GPS) that FOG is believed to have a major part to play. Not only this, but it may also have applications in some non-traditional items such as:

- Large part deformation monitoring and control (aircraft, turbines, buildings, lifting equipment, etc).
- Mechanical tool metering (measuring the outside of large parts, angular vibration monitoring and measurement).
- Robot and automated production.

6. Conclusion

This article describes and discusses the present status and basic properties of the fiber optic rate gyroscope, pointing out that gyroscopes with practical value have already appeared and that they have been put to positive use. By modifying basic models, they can meet different special requirements. Fiber optic gyroscopes will become an inertia instrument with very widespread applications.