PRECISION FIBER OPTICAL GYROSCOPE WITH LINEAR DIGITAL OUTPUT

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Abstract

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serrodine transformer, automatic control.

The design and industrial production problems of closed loop fiber-optic gyroscopes worked as a sensor of rotation rate are considered. This gyro is characterized by high accuracy and can be applied in the inertial systems of space navigation. General concept of configuration of optic path of gyroscopes with integrated-optic elements is presented. The features of the block diagrams and signal processing techniques are described.

Introduction

Per se the opportunity of commercial production of precision fiber–optic gyroscope (FOG) is directly determined by the level of technological base its main components and mainly polarization maintaining optical fibers and integrated optic circuits. So, working over the project on creation of high precision FOG gyroscope, the all our experience was used. All knowledge of principals and design features was applied. We used results, which were checked and experimentally confirmed. We had to create our own infrastructure to produce such components as multifunctional integrated optic element (MIOE), polarization maintaining fiber (PANDA), fiber splitter, fiber depolarizer (DP) and fiber coil (FC).

Some of the engineering solutions offered (related to fiber and integrated optical technologies and signal processing electronic devices) are protected by the patents and their efficiency is experimentally confirmed.

Developing the device of a high accuracy we don't exclude the creation of devices of middle and low grades of accuracy. Because of geometrical flexibility of FOG we get the lowest version without problem from high accuracy devices.

Compensation (zeroing) of Sagnac phase shift is carried out in the feedback closed loop FOG with the help of phase modulator (PM), which is placed on the ends of fiber loop, together with dynamic shift phase difference interfered light wave on the $\pi/2$ radian. In this case the control signal of the PM can be used to measure the rotation rate. It is well known that at such approach output characteristic of FOG is linear and scale factor (SF) is independent from parameters of most structural components of the device [1]. This is very important because if we process the information by means of a variable signal or a digital method, then along with the stability improvement of SF the number of the electronic factors which have an influence on the output signal error is essentially reduced.

Residual error measurement of rotation rate can be reduced with the help of algorithmic compensation of zero signal deviation or modification of SF (this is possible even for an open-loop FOG [2]). However it is clear, that in this case we must talk about compensation of only those error components, which depend on specified parameters (temperature, time etc.), i.e. predetermined. Random components can only be reduced (but not compensated!) with the help of effective design and engineer solutions and perfection of FOG component technology.

In this project we are trying to achieve the following error value (including random error) of main FOG features under environment conditions similar to exploitation on the space vehicles:

- bias repeatability, 3σ, °/h	$\leq$ 0.1;
- random walk, $°/\sqrt{h}$	~ 0.005;
- scale factor repeatability, %	$\leq$ 0.01.

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Main directions of technical release of the project are:

- use of single-mode fiber PANDA with strong birefringence and small loss for fiber coil symmetrical wound with length more then 1000 meters and diameter 140 millimeter;
- development and application of MIOE, produced by the proton exchange method, which performs the functions of Y – splitter, polarizer and PM;
- use of thermal stabilized semiconductor superluminescent diode (SLD) as a light source. The light power at the output of pigtailed single-mode waveguide is not less 2 mW;
- development of special data processing serrodine circuit with closed loop of feedback, which provides minimal errors in transformation and linear digital output both rotation rate and rotation angle cumulative value;
- development of a non-welding technology of assembling of the optical block.

1. Basic architecture and technologies

The general block diagram of the device, which will be the initial one, is shown on the Fig.1. This architecture type («minimum configuration»), as known [3], has a very important for the FOG practical application property of spatial and polarized reciprocity. This property provides high sensitivity to the rotation, and presence of a broadband phase modulator in the MIOE allows us to control phase shift of light wave on any to the beforehand given algorithm almost without distortion. Due to this fact there appears a new basic opportunity to achieve the accuracy limit of FOG, which is determined by optical components, (approaching the fundamental accuracy in the process of quality improvement).

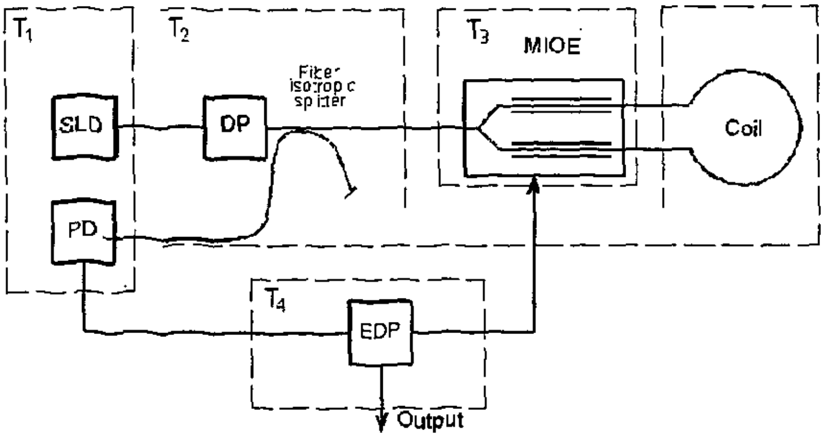

Fig.1. Fiber optic gyroscope minimum configuration. PD – photodiode

Four structure parts of FOG are marked by the dotted line on the scheme (Fig.1). These units have different functions, but the same production technology.

Such (base) technologies are as follows:

T_1 – semiconductor light emitter and receiver, T_2 – fiber components, T_3 – integrated optical element, T_4 – electronic (microelectronic) control.

Ownership of these technologies by a single enterprise allows us to develop and manufacture FOG in a full cycle (the raw and element base for them is accessible and relatively cheap).

2. FOG's block diagram

In the serrodine closed loop compensation of Sagnac phase difference $\Delta\varphi_c$ is realized by phase shift $\Delta\varphi_m$, brouht in the light wave sawtooth phase modulation on the line section (Fig. 2):

$$\Delta\varphi_m = \frac{\varphi_{rs} f \Delta\tau_g}{1 - \Delta t f},$$

where $\Delta\tau_g = \frac{Ln}{c}$ – time difference of light waves group delay, $f = \frac{1}{T}$ – frequency of sawtooth signal, φ_{rs} – sawtooth double amplitude, L – fiber coil length, n – fiber core refraction index, c – velocity of light in the vacuum, Δt – sawtooth reset time.

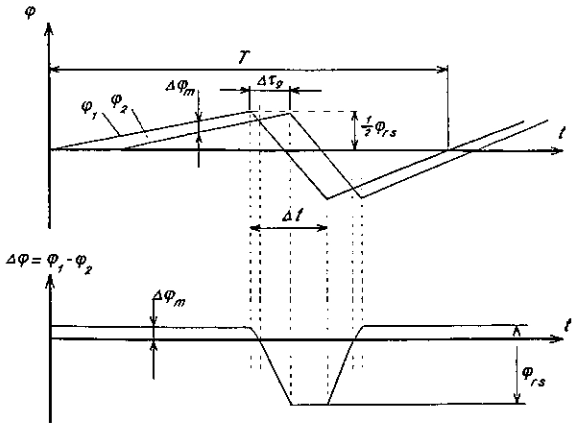

Fig. 2

Servomechanism provides equality of these values with opposite signs, and expression of measured rotation rate Ω_{msr} (up to sign) is:

$$\Omega_{msr} = \frac{\lambda n}{2\pi D(1-\Delta t f)}(\varphi_{rs} \times f), \tag{1}$$

where λ – central wavelenght, D – fiber loop diameter (mean value).

Nonlinear dependence of Ω_{msr} on the frequency because of the presence in (1) of a random variable Δt gives a main error of rotation rate measurement, which results in nonstability and nonlinearity. The use of a high-speed electronic components allows to reduce Δt to the law, but nevertheless finite, value, thus providing an acceptable for most applications SF error – with $\Delta t \to 0$ function (1) is linear rather f :

$$\Omega_{msr} = \frac{\lambda n}{2\pi D}(\varphi_{rs} \times f) \tag{2}$$

However, we can solve this problem, if the value Δt is not reduced, but is specially maintained equal to the half of a sawtooth signal period $\Delta t = T/2$ for any value of frequency f . In this case serrodine signal is transformed into the triangular waveform, and the Sagnac phase continuous compensation problem is solved by periodic inversion of this signal on the input of PM with the same frequency and expression (1) will be as follows:

$$\Omega_{msr} = \frac{\lambda n}{\pi D}(\varphi_{rs} \times f) \tag{3}$$

In the expression (3) as distinct from (2) frequency f – is frequency of the triangular waveform. Arising change for the worse (two times) of discreteness of transforming is compensated by relative simplicity of receiving a symmetric variable voltage of a triangular waveform with the given amplitude and with the frequency, which is determined by error signal of main servomechanism. And if we count both positive, and negative peaks of this voltage, expression (3) becomes equivalent to the (2).

Thus, having constants λ, n, D the measure of rotation rate is a multiplying $\varphi_{rs} \times f$. Obviously, it is impossible to measure phase amplitude φ_{rs} of sawtooth light wave modulation, as distinct from frequency f . We can estimate the phase amplitude value with the help of voltage value, supplied on the PM, but in this case we need exact data of its transfer characteristics, which is nonstabile itself. Generally, this method is very interesting and important, but unfortunately it is not investigated good enough by us. That is why we concentrate on the standard method of stabilization phase amplitude of sawtooth modulation with $\varphi_{rs} = 2\pi$ rad and additional servomechanism in the signal processing scheme. In this case according to expression (2) we have:

$$f = \frac{D}{\lambda n}\Omega, \tag{4}$$

where Ω – input rotation rate.

The fluctuation of values D and n have a thermodynamic character. For stabilization of these values a coil is made by wounding fiber on the heat-insulated frame with symmetric by raw packing with stable tension.

The main disadvantage of semiconductor superluminescent diode is a strong dependence of its spectrum on the temperature – about 0,04 % per degree. It results in a temperature instability of SF in (4), equal, for example, to 1,6 % in a range of temperatures 0÷40 ^{O}C instead of required 0,01 %.To reduce this instability in the FOG there is a temperature controlling device, which maintains the temperature of a crystal oscillator on the given level with accuracy of 0,25 ^{O}C.

It is well known that the highest efficiency of classic dynamic phase difference shift of interference light wave in the fiber loop with simultaneous reduction of parasitic amplitude and polarization modulation is reached at the rectangular form of a so-called auxiliary (square-wave biasing) modulation with amplitude $\pi/2$ rad. and frequency $F = \dfrac{1}{2\Delta\tau_g}$, which corresponds to the eigen frequency of fiber loop.

Reliable realization of criterion $2F\Delta\tau_g = 1$ is provided when the voltage for auxiliary modulation is formed out of a reference variable signal, which frequency is stabilized by the quartz resonator. The frequency value of a given length of fiber loop, which guarantees the required accuracy of rotation rate measurement, is determined according to a condition (for silicon fibers) $F \cdot L \approx 10^8 (Hz \cdot m)$. For example, if $F = 96kHz$ then $L = 1070$ m.

It is not so easy to maintain the amplitude of auxiliary phase modulation at a level $\pi/2$ radian. The main problem is not in making a stable voltage of modulation. The problem is that even with a stable voltage, the phase amplitude is nonstable either as a light wavelength or as a transfer function of phase modulator etc. depending on chosen signal processing scheme and external factors. The cardinal solution of this problem is construction of servomechanism, which is automatically maintaining the value of interfered lightwave phase difference on the determined value. Gyro's response to the periodic excitation (a voltage pulse which is applied to the phase modulator) can serve as an error signal for such servomechanism.

In order to construct an automatic system of auxiliary phase modulation amplitude control the following algorithm of construction is offered:

- stable reference voltage forms amplitude voltage of auxiliary modulation U_{am}, which corresponds to the phase amplitude $\pi/2$ radian – the voltage is installed according to the maximum output signal of FOG at the given rotation rate with open-ended feedback of the main loop;
- precision resistance divider forms a similar voltage of modulation with amplitude equal $3U_{am}$;
- periodically at the given moments of time voltage 3 U_{am} is delivered on the modulator instead of a voltage U_{am} . the $3U_{am}$ frequency is considerably less then F, and the duration of the $3U_{am}$ delivery is sufficient for measurement of the response on disturbance by means of the device of sample and hold. It is clear, that at constant parameters of system there will be no reaction to such an excitation – error signal is equal to zero. But if, for example, the efficiency of phase modulator increases, phase amplitudes from both influences will also increase proportionally, but the photocurrent from main modulation U_{am} will decrease, and from revolting – will increase! This photocurrent difference will represent an error signal, by means of which the servomechanism reduces U_{am} until this difference turns to zero. With reduction of the phase modulator, the efficiency the process of regulation will proceed in opposite direction.

Fig. 3 shows a diagram, which explains the work of stabilization system

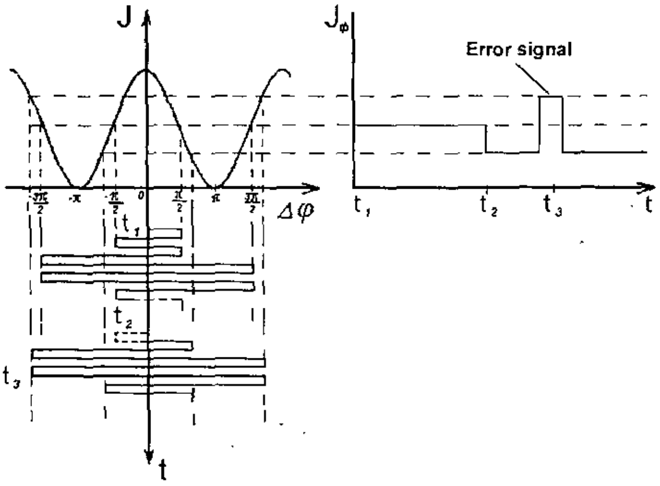

Fig.3 Auxiliary modulation.
On the diagram transition states aren't shown.

The value of phase amplitude of compensating modulation, equal to 2π rad, is easy to form from the reference voltage, which is used for forming calibration signal of auxiliary modulation – it is enough to transform it into the reference signal for sawtooth voltage with coefficient $4/3$. Thus stabilization system of phase amplitude of auxiliary modulation will automatically be the stabilizer of sawtooth phase amplitude. At the same time it is very important, that the disturbance caused by the sawtooth reset does not lead to the breakdown of the stabilization loop amplitude and vice versa, disturbance which is caused by calibration pulses does not lead to the breakdown in the Sagnac phase compensation loop.

The following fact makes the solution of this problem more complicated. The frequency of sawtooth voltage resets depends on the rotation rate, and consequently is a variable value. There are two operating modes: the mode of low and the mode of high rotation rates. In the first case the frequency of calibration pulses must not depend on the sawtooth frequency, because of frequency can be nearly zero, and may lead to an information loss. In the second case sampling time of phase amplitude has to depend on the sawtooth frequency, but we must avoid interaction of two stabilization loops. One of the variants of the algorithm of FOG work has been realized in this project.

To the mentioned above it is important to add the requirements of light source reliability (under the influence of environment factors), which is provided by SLD powering through the power light stabilizer (PLST), and the requirement of maximum possible attenuation of in-phase synchronous inducing on the input circuit of photodetector (PhD), that is provided by the galvanic isolation of this circuit from the rest of electronic components and by a differential amplification. As a result of this requirement, block diagram of FOG is (Fig4):

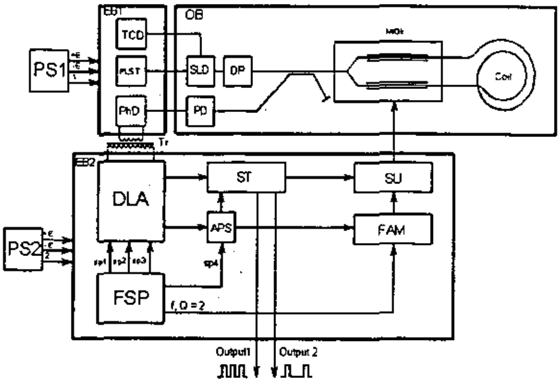

Fig. 4. Block Diagram of fiber optical gyroscope
PS1, PS2 – secondary power sources, EB1, EB2 – electronic blocks, OB – optical block; DLA -differential lock-in amplifier; FSP – former of synchronizing pulses; CT – serrodine transformer; APS – amplitude producing scheme; FAM – former of auxiliary modulation; SU – summation unit; SP1÷ SP4 – synchronizing pulses specifying algorithm of information processing; Tr – transformer

The functional content of the block diagram becomes clear by marking separate units and connections between them. We developed two versions of this scheme:

- with analog form of sawtooth modulation on the line section without fixation of the moment of "sawtooth " reset to the frequency of dynamic shift;
- with "staircase" form of sawtooth modulation on the line section with fixation the moment of "sawtooth " reset to the frequency of dynamic shift and full digital signal processing.

Advantages and disadvantages of both are well known.

3. Fiber coil and fiber components

FOG sensitivity to the rotation is mainly determined by the fiber coil design, its size, fiber type, and the wounding method. In this project it is efficient to use a single-mode polarization maintaining optical fiber PANDA with strong birefringence. Present technology level of fiber manufacturing on the "Optolink" LLC allows to produce fiber with following parameters:

– loss of optical light power, α	3÷4 dB/km;
– polarization beat length, L_p	$\leq 2{,}5$ mm;
– coefficient of intermode polarization coupling, h	$\leq 5 \cdot 10^{-5}$ 1/m;
– outer diameter, d	≤ 80 μm.

The expression for upper bound phase error of FOG, which appears as a result of the main destabilizing factor – polarized nonreciprocity [4] – leads to the dependence of minimal measured rotation rate on the fiber coil parameters:

$$\Omega_{\min} \sim \frac{\sqrt{hL_p}}{DL}.$$

This dependence is as follows: the transition from fiber coil on an elliptic fiber with parameters $L_p \approx 8$ mm, $h \approx 10^{-3}$ 1/m, $D \approx 80$ mm, $L \approx 200$ m (for example, ВГ910 device) to the fiber coil on the fiber PANDA with parameters $L_{p\approx} \approx 2{,}5$ mm, $h \approx 10^{-5}$1/m, $D \approx 140$ mm, $L \approx 1000$ m with other equal conditions value $\Omega_{\min}$ decreases more than 150 times.

Directed splitters, produced by the method of curling – fusion extraction from isotropic single-mode fiber, have the following typical parameters ($\lambda =$ const) under the values of temperature, spectral, and polarization sensitivity division coefficient within the set limits:

– power division coefficient, %	50±1;
– extra power loss, dB	0,1.

Lyot fiber depolarizer was taken as a basis of depolarizer design construction well known like. The technology of manufacturing of this element provides achievement of the following parameters:

– optical power loss, dB	< 0,5;
– residual light polarization at the width of a spectral line 15 nm, %	< 0,1.

4. Multifunctional integrated optical element

One of the main fiber optical gyroscope's components is MIOE, which consists of integrated electro-optical phase modulator on the basis of Y – splitter formed at X-cut lithium niobate crystal. Integrated optical Y-splitter is manufactured by planar technology of high temperature proton exchange. The processes are held in the specially developed containers. The specially developed metals and dielectric films used as masks to provide locality proton exchange diffusion. Then by vacuum deposition of electrodes, the integrated electro-optical phase modulators are formed. This method was developed by "Optolink" LLC [5].

A very important advantage of proton exchange waveguides is following. In such waveguides the extraordinary refraction index is increasing, while refraction index of ordinary ray is decreasing. As a result, proton exchanged waveguides support propagation only extraordinary polarization modes (TE in our case). Therefore, it is no necessity to use in the fiber optical gyroscope a polarizer, which brings additional loss.

It is well known, that standard technology of proton exchange waveguide (APE-technology) applies a two-level process, which consists of a proton exchange, (melting benzoic acid as a rule) and subsequent annealing. It was recently obtained, that different defects are formed in the surface area of waveguide due to different phase transitions. These defects are sources of additional scattering of light. High-temperature proton exchange, in contrast to APE, does not allow any phase transitions, and, therefore, allows one to achieve the smaller optical losses and higher electro-optical coefficients.

The modeling Y – splitter with the help of the software "BPM-cad" produced by Optimave Corp. allowed us to choose an optimum function of Y-splitting.

After fabrication of Y – splitter and electrode deposition, first plates are cut (the angle is 10 degree to the Y axis). Then the end surfaces are polished, and finally they are coupled with input isotropic and two output anisotropic PANDA fibers. Then the packaging (installation into the case) follows and phase modulator electrodes are joined with outputs by means of welding.

Multifunctional integral optical element is a monoblock hermetic product, which can be connected to the optical block of fiber optical gyroscope by means of fiber waveguide welding and soldering phase modulator electrical outputs to the electronic blocks.

Main parameters of multifunctional integral optical component with operating wavelength 0,83±0,03 μm are following:

– optical power loss (at depolarized light), dB	< 8;
– polarizer extinction ratio, dB	> 40;
– division coefficient	0,5± 0,05;
– phase sensitivity of each of modulator, rad/V	> 1.

5. Source and receiver of the light

As a light source is used emitter ILPN-330-4, which is produced by the enterprise "Ingect", Saratov. The emitter contains the following components:

1. Stripline SLD on the basis of double heterostructure system GaAs/GaAlAs with isolation by opposed *p-n* junction, which have an absorbe layer in the active area. Such design of SLD provides practically smooth

spectrum with halfwidth 15÷18 nm and with light power up to 1.5÷2 mW on an output built – in single-mode fiber waveguide.

2. Microcooler on the base of Peletie elements for maintaining SLD crystal temperature in the given range at joint operation with the thermal control device.

3. Thermoresistor for error signal formation in the thermal control device.

4. The photodiode on the basis of silicon p-i-n structure for formation of a steering command in the PLST.

All components in the ILPN -330-4 are placed in the standard hermetic case, with electric and optic pressure seals.

As a light detector the photodiode is used (on the basis of silicon p-i-n of structure such as FP1-850 K, produced by the same enterprise). The photodiode has electric current sensitivity to the wavelength $\lambda = 0{,}835$ μm not less than 0,3 A/W with delay time of a pulse signal front no more than 2 ns.

The photodiode is placed in the hermetic case with built-in multimode fiber waveguide

6. Electronic support of FOG

FOG electronic components are carrying out the following functions:

- the emitter to the power source connection with simultaneous stabilization of light power and SLD crystal temperature;
- signal transformation, amplification and synchronous demodulation from the optical block output;
- voltage forming for auxiliary phase modulation of light waves;
- voltage forming for compensative phase modulation of light wave;
- output signal forming.

Chief feature of all these schemes is that they are closed systems of automatic regulation with the first order of astatism. This allows improving dynamic properties of the device and decrease static errors all types.

On the Fig 5 the block diagram of the main regulation system, which supports the Sagnac phase difference close to zero, is shown.

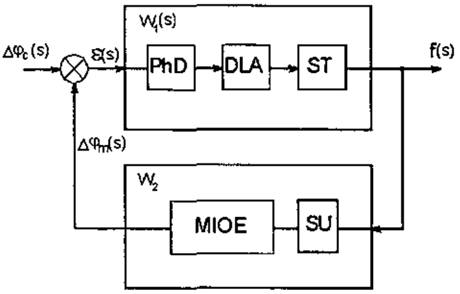

Fig. 5. The main regulation system block diagram; s – Laplace transformation symbol, $\mathcal{E}$ (s) – regulation error

Input (control) effect on this system is a Sagnac phase difference $\Delta\varphi_c(s)$, output signal is a pulses consequence, with frequency $f(s)$ which is proportional to the rotation rate (4), and the pulses number determines the rotation angle of the device with discreteness $\frac{\lambda n}{D}$. Transformation and regulation error is determined by the transfer function of the closed system by control effect and by error correspondingly. Electronic circuits, which include structural units of FOG, determine the transferring functions of the parts of the direct (straight) circuitry $W_1(S)$ and feedback W_2:

$$W_1(s) = \frac{\pi K}{2\varphi_{rs} V_\pi T_1 T_2 s}, \tag{5}$$

$$W_2 = 2\varphi_{rs}\Delta\tau_g, \tag{6}$$

where K – amplification coefficient of an open loop system; V_π – half-wave voltage of phase modulator; T_1, T_2 – time constant correspondingly integrator of the DLA and ST – block.

Dimensionality of Q-factor in our system K corresponds with the voltage (phase shift to the voltage transforming); and its value is determined by many optical and electrical factors: K value is proportional to the intensity of light, which is applied to the photodiode (this is a power of superluminescent diode and losses of optical path); visibility of fringes (this level of light coherence and division factor of multifunctional integral optical component), photodiode efficiency, amplification factors of photodetector and differential synchronous amplifier, it has a maximum at optimum frequency and depth of auxiliary modulation.

Taking into account the relations (5), (6), we have transfer function on control

$$F(s)=\frac{1}{2\varphi_{rs}\Delta\tau_g(1+Ts)} \tag{7}$$

and transfer function on error

$$E(s)=\frac{Ts}{1+Ts}, \tag{8}$$

where $T=\dfrac{V_\pi T_1 T_2}{\pi K\Delta\tau_g}$ – time constant, which determines dynamic features of FOG, its transmission band and dynamic regulation error.

Thus, according to (7) and (8), feedback closed loop of main system of control effect is the inertia link of the first order, and the one of error – an inertia differentiator. By means of the well known methods of mathematical analysis (provided initial requirements to the precision and dynamic characteristics of FOG are taken into account) we may estimate the potential range of the elements' parameters, which determine the T-value and their optimal values, which guarantee the stability and precision of the control system. But already these interrelationships may lead to the conclusion that in order to obtain good parameters of the FOG we should improve the Q-factor, (mainly its optical component), the efficiency of the phase-modulator (reduction of V_π) and to increase the length of fiber loop (an increase $\Delta\tau_g$), of course within the allowed limits. The qualitative advantage of this kind of FOG structure is as follows: the control error at the constant angular velocity is equal to zero and its constant nonaccumalative value at the constant change of the latter.

To implement the circuit (loop) of the amplitude regulation of the compensative modulation the same structural units as for the main block are used. The only difference is that here the control effect is carried out by means of the error signal (as a response to the mentioned calibration check). The algorithm of simultenious work of the feedback loops is arranged in such a way, so that they do not interact (as it may distort the operation), and to provide an independent reduction of the controlled variables to the values $\Delta\varphi_c=0$ and $\varphi_{rs}=2\pi$. Under this condition in the set state (S=0) from (7) we automatically get the expression (4) for SF.

One more feedback loop (in the stabilizer of power light) is intended to maintain the light power of SLD under the influence of the environment factors and in transition modes on the level corresponding to the nominal pumping current at the given (normal) temperature. Here two important tasks are solved:

- the bandwidth of the FOG is stabilized, hence the noise level at its output;
- unauthorized (even minimum) exess of the allowed radiation power level that may cause SLD degradation is excluded.

Light power stabilizer block diagram is shown on Fig. 6.

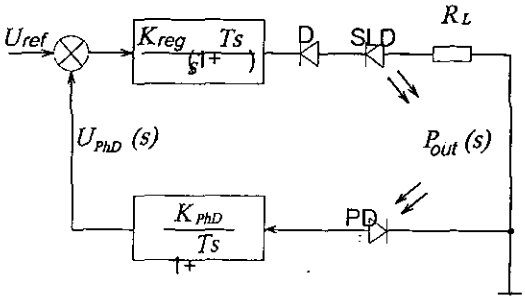

Fig. 6. U_{ref} – reference voltage, K_{reg} – regulator coefficient of amplification, D – protective diode, T – time constant of regulator circuits and photodetector, K_{PhD}– coefficient of amplification photodetector, R_L – load resistor, P_{out} – superluminescent diode light power, S – Laplace transform symbol, U_{PhD}– photodetector output voltage, PD – photodiode

Transfer characteristic of the light power stabilizer, its dependence P_{out} (S) on the scheme parameters and on time, is written with the help of Laplace transform symbols:

$$P_{out}(S)=\frac{K_{SLD}\left[K_{reg}(1+TS)U_{ref}-S(V_D+V_{SLD})\right]}{R_L S+K_{SLD}K_{reg}K_{PhD}},$$

where: K_{SLD} – SLD efficiency, V_D and V_{SLD} – potential drop on the diode D and SLD respectively.

In the stable state mode $(S=0)$ the light power, which is radiated by the SLD is:

$$P_{out}=\frac{U_{ref}}{K_{PhD}},$$

light power determined by the value of the reference voltage and photodetector coefficient. Thus the accuracy of P_{out} depends on the precision of the proportion $\frac{U_{ref}}{K_{PhD}}$. The values U_{ref} and K_{PhD} are independent; that is why we must require the stability of U_{ref} and K_{PhD} for supporting P_{out} – stability of the whole system. Stability of U_{ref} is reached by application of precision stabilitron and resistors of forming circuit. The K_{PhD} stability is provided by the photodiode and amplifiers stability. Amplifier accuracy is reached by application of operational amplifiers with large coefficient in the circuit without feedback and precision resistors for feedback forming. Accuracy of power light stabilization system of SLD in the stationary state is determined by the accuracy of photodiode transfer characteristic.

The structure of feedback loop in the temperature control device is similar to the structure of loop in the light power stabilizer.

One of the factors that set a limit on the number of potential circuit engineering solutions for transformation of high-frequency opto-phase data on the angular velocity into the low-frequency electronic data is an extremely low sign level at the optic path output. For instance, at the rate of 0.1 °/h, power of the radiation source 2mW, total losses of optic path at the level of 20 dB, diameter and length of the fiber coil D=140 mm and L=1070 m, respectively, and the photodiode effectiveness at the level 0.3 A/W, the effective component of the photocurrent equals to the level 0.01nA. Under these conditions common-mode interference and inducing play an important part both at the electronic block input and at the power supply chain, as well as own noise and electronic stage shifts.

For supporting the relation sign/noise at the level, formed by the optic part of the FOG the following main solutions have been used during the design work:

– photodetector is produced on the basis of low noise wide-band amplifiers according to the scheme with a differential input and output (with a high level of geometric simmetrization of electric circuits, that connect the photodiode with the amplifiers);

– power supply chains of optical block, (as well photodetector) are decoupled galvanically from the power supply chains of the rest of the FOG;

– when the FOG is under regulation, a balance of the trimming arm in differential synchronous amplifier is provided to achieve maximal suppression of the phase coincidence inducing component, which is synchronous with the demodulation process.

Another special feature of electronic block is the following: to minimize the zero drifts of the FOG, which are caused by the bias in electric circuits, the data processing is carried out on the basis of the variable signal (or in a digital way) on all stages except one – the integrator of the main control system. This stage (cascade) is made on the precision IC, where the zero drifts within the whole temperature range may lead to the output drifts not more than 0,002 °/h.

The fiber optical gyroscope is powered from an external source with direct voltage 18÷36 V through three galvanic independent DC/DC transformers with output voltage ±15 V, ±12 V and ±5 V.

Power consumption does not exceed 6 watt in the set mode, and no more than 30 watt in a transitive mode during 0.1 second after switching-on.

At present time most units of the electronic block are produced on the basis of the solid-state technology. Improvement of this technology leads to better energy features. And, we hope, that at the same time precision factor will improve too.

7. Optical block assembly technology

A zero signal stability of a fiber optical gyro is provided not only by the quality of fiber components and multifunctional integral optical component, but also by the assembly technology of optical block. It is well known, that the welded connections of fibers are the reason of redundant losses of optical power and centers of cross connection between polarizing modes. As a result of this integration multifunctional integral optical component to the optical block is made by direct joining its waveguide with the ends of fiber loop and with one of the ends of input isotropic splitter (with length, sufficient for a spatial filtration of light). Depolarizer and photodetector are connected to the isotropic fiber by means of welding.

Conclusion

Calculation and experimental data, obtained at the "Antares", Saratov, and ''Optolink" LLC Zelenograd, shows us that this fiber optical gyroscope configuration can be applied in the inertial navigation systems of space vehicles.

With transition to operation wavelength of 1,55 μm in the process of realization of algorithmic compensation, it is possible to improve parameters, given in the report, considerably.

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