

## FIBER OPTIC GYRO RELIABILITY ESTIMATION

The method for calculation of reliability parameters of fiber optic gyros is presented. The method is used to estimate lifetime and mean time to failure (**MTTF**) for Fizoptika sensors.

### 1. MAIN RELIABILITY PARAMETERS

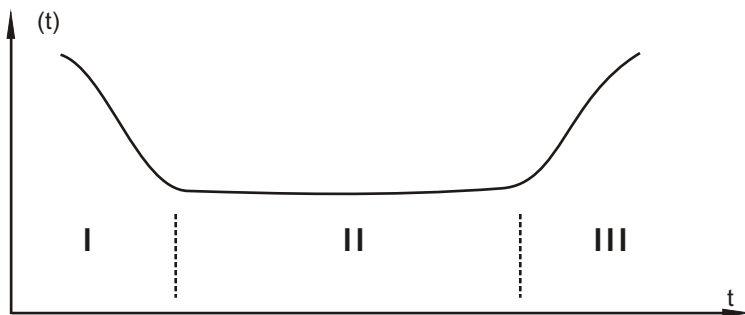
Reliability is a composite index which includes operability, life time etc. Main reliability (operability) parameters for non-repairable units (which can not be recovered after failure - e.g. microcircuits, connectors etc.) are listed below:

- probability of no-failure operation during  $t$  period:  $P(t)$ ;
- probability of failure during  $t$  period:  $Q(t) = 1 - P(t)$ ;
- failure rate  $\lambda(t)$  – the frequency with which a sensor fails, expressed in failures per hour;
- mean operating time to failure  $T$ .

Main assumptions:

- $P(0) = 1$  (only operating units are considered );
- $\lim_{t \rightarrow \infty} P(t) = 0$  ( operability can not be kept for infinitely long period );
- $dP(t)/dt \leq 0$  ( a unit can not be repaired after failure ).

Typical dependence  $\lambda(t)$  during operation life is presented below:



- I – initial run-in stage  $d \lambda(t)/dt < 0$
- II – normal use stage  $\lambda(t) = \text{const}$
- III – ageing stage  $d \lambda(t)/dt > 0$

Reliability parameters interrelation:

$$P(t) = \exp\left(-\int_0^t \lambda(t) dt\right) \text{ for stage II } P(t) = \exp(-t/T)$$

$$T = \int_0^{\infty} P(t) dt \text{ for stage II } P(t) = \exp(-t/T), \text{ где } T=1/\lambda$$

Reliability of non-repairable units is characterized by mean operating time to failure  $T$

## 2. RELIABILITY CALCULATION METHOD

Calculation background:

- calculation is performed for normal use stage -  $(t) = \text{const}$ ;
- unit reliability diagram is known;
- failure of unit is caused by a failure of any component (group of components) which is included in reliability diagram;
- each component (included in reliability diagram) is characterized by failure rate  $\lambda_i$  and probability of no-failure operation  $P_i(t)$ ;
- the failures of components are mutually independent (at least to the first approximation).

The probability of the unit no-failure operation  $P_{unit}(t)$  is therefore:

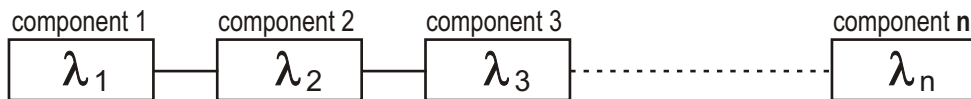
$$P_{unit}(t) = P_1(t) * P_2(t) * \dots * P_n(t) = \prod_{i=1}^n P_i(t);$$

And for failure rate of the unit  $\lambda_{unit}$  :

$$\lambda_{unit} = \lambda_1 + \lambda_2 + \dots + \lambda_n = \sum_{i=1}^n \lambda_i \quad (\text{exponent indexes are summarized in expression } P = \exp(-\lambda t))$$

Finally, mean operating time to failure  $T_{unit} = 1/\lambda_{unit}$ .

As a first step of calculation the set of most critical components should be determined and reliability diagram of the unit under consideration should be composed.



Failure of any critical component results in the unit's failure. Summarized failure rate of unit is calculated in accordance with reliability diagram.

## 3. CALCULATION RESULTS

### 3.1. CALCULATION BACKGROUND

Fizoptika fiber optic gyro comprises two main modules which are built in common housing: optical module and electronics module.

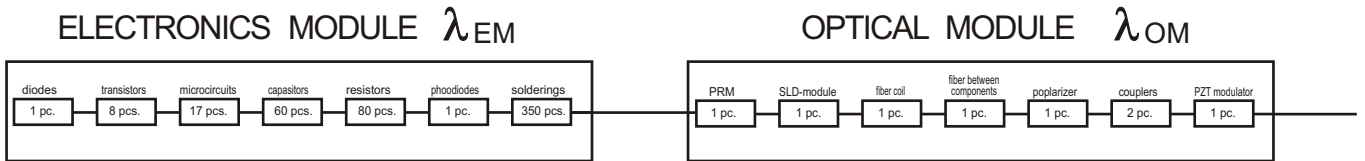
Reliability estimation was based on MIL-HDBK-217F and on the data from united handbooks "Reliability of products of electronic engineering and quantum electronics" (issued by SRI "Electrostandard").

Failure rate values for main components of optical module are based on relevant information from manufacturers, on statistical data accumulated during many years' production of fiber optic gyros.

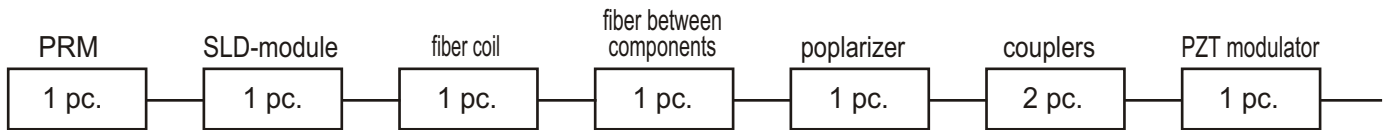
Summarized failure rate is estimated for Ground Fixed Operation (GF) environment and for ambient temperature +25 °C.

### 3.2. RELIABILITY DIAGRAMS

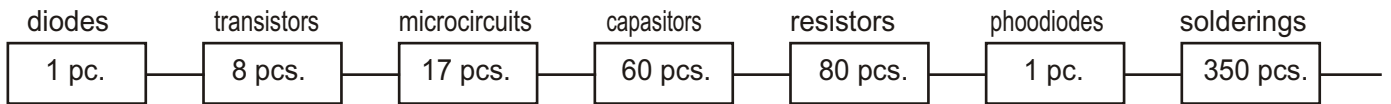
Reliability diagram of fiber optic rotation sensor and its modules are presented below:



Reliability diagram of optical module:



Reliability diagram of electronics module:



Electronics module OE141FOS-3: failure rate of components

| Component type           | Number of components per unit | Number of failures for 1 million hours [ $10^{-6}/h$ ] |
|--------------------------|-------------------------------|--|
| Diode                    | 1                             | 0.008  |
| Transistor               | 8                             | 0.12   |
| Microcircuit chip        | 17                            | 0.024  |
| Capacitor                | 60                            | 0.016  |
| Resistor                 | 80                            | 0.005  |
| Semiconductor photodiode | 1                             | 0.03   |
| Soldering joints         | 350                           | 0.0004   |

Optical module: failure rate of components

| Component type           | Number of components per unit | Number of failures for 1 million hours [ $10^{-6}/h$ ] |
|--------------------------|-------------------------------|--|
| Photo-receiving module   | 1                             | 1.5  |
| SLD                      | 1                             | 20   |
| Fiber coil               | 1                             | 0.5  |
| Fiber between components | 1                             | 1.5  |
| Polarizer                | 1                             | 20   |
| Coupler                  | 2                             | 1  |
| PZT modulator            | 1                             | 2.5  |

### 3.3. MTTF ESTIMATION

From the above failure rate data

- for optical module:  $OM = 1 \cdot 1.5 + 1 \cdot 20 + 1 \cdot 0.5 + 1 \cdot 1.5 + 1 \cdot 20 + 2 \cdot 0.5 + 1 \cdot 2.5 = 47 [10^{-6}/h]$

- for electronics module:  $EM = 1 \cdot 0.008 + 8 \cdot 0.12 + 17 \cdot 0.024 + 60 \cdot 0.016 + 80 \cdot 0.005 + 1 \cdot 0.03 + 350 \cdot 0.0004 = 2.91 [10^{-6}/h]$

It may be noticed that summarized failure rate of electronics module is 10 times less than summarized failure rate of optical module. It is well correlated with statistical data.

Taking into account the values of failure rates ( $OM$ ,  $EM$ ) calculated above, mean operating time to failure  $T$  for fiber optic rotation sensors can be estimated as follows:

$$T = 10^6 / (OM + EM) = 20000 \text{ hours.}$$

### 4. LIFETIME PREDICTION

From the point of gyro lifetime the optical fiber is the most critical component as long its length (~100m) is placed into sensor' housing in a stressed state. That can result in micro-cracks grow that eventually lead to break of fiber (so called - "glass static fatigue"). Estimation of fiber lifetime is based on the following expression:

$$T = t_0(\epsilon_r/\epsilon)^n$$

where  $n \approx 20$  – fiber static fatigue parameter,  $\epsilon_r$  – fiber specific elongation at its rewinding under tension,  $\epsilon$  - fiber specific elongation in use,  $t_0$  – time parameter.

By the above expression the lifetime equals  $t_0$  if the fiber is elongated to  $\epsilon = \epsilon_r$ . Typical values of  $t_0$  parameter for fiber section of **100m** length can be characterized by 1s ( $t_0 \approx 1s$ ).

If specific elongation of fiber in use  $\epsilon$  equals to **0.3** $\epsilon_r$ , the lifetime is estimated as tens of years due to big value of fiber static fatigue parameter ( $n$ ). If specific elongation of fiber in use  $\epsilon$  is close to **0** the fiber life time tends to infinity. If  $\epsilon \leq 0.3\epsilon_r$  the calculation of lifetime gives tens of years.

Fiber deformations are generated in manufacturing process (winding of sensing coil, fiber placing etc.). Fiber deformations remain constant during all stages of life cycle (storage, use, testing). Fiber stress arises due to fiber bend at coil winding which results in different length of internal and external sides of wound fiber.

Fiber specific elongation  $\epsilon$  can be calculated from the following expression:

$$\epsilon = d/D,$$

where  $d$  – diameter of quartz part of the fiber,  $D$  - diameter of winding.

Optical fiber for Fizoptika gyros is rewound on test bobbin under tension of **40 g**, that corresponds to fiber specific elongation  $\epsilon_r = 0.5\%$ . In order to reach lifetime 15 years the specific elongation should be less than **0.15%**. For diameter of fiber quartz part 0.04 mm the minimal value of diameter of winding  $D = 2.5 \text{ cm}$ . This value is typical for miniature fiber optic gyro, therefore the gyro' lifetime exceeds **15 years**.