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Computer Thermal Modeling of Zeeman Laser Gyros in the Design Taking into Account the Creation of Digital Thermal Twins

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***Abstract* –With the development of technology, the temperature range of environmental exposure is constantly expanding. Simultaneous miniaturization of optoelectronic devices leads to an increase in the density of internal heat emissions. Therefore, during thermal testing of manufactured devices, failures of product components are often detected due to their overheating. This also applies to Zeeman laser gyros.**

In this paper, the following scientific problem is set and solved. It is the development of such an algorithm for creating a laser gyro, which would ensure the detection of the product overheating at the early stages of design before the models or prototypes production. The algorithm is based on a digital simulation of the thermal process taking into account the design features of the device. It also improves the technical and economic performance of creating a laser gyro due to the fact that early detection of possible overheating of the gyro elements allows you to make the necessary changes to the device design drawings before making a mock-up or prototype. Making changes to the drawings and, accordingly, to the thermal model of the laser gyro is much cheaper than making them in the manufactured products. The design time of the device is reduced. Peculiarity of this work is also the proposal to create programmed digital twins of the thermal modes of the laser gyro. The main purpose of digital twins is to store information for setting up the devise during their manufacture and diagnostics during operation in various conditions of external influences.

***Index Terms* – optoelectronic devices, design, development, thermal modeling, algorithm, technical and economic efficiency, thermal twin**

I. Introduction

The imperfection of the most of the designing methods of laser gyros used at enterprises results from the use of simplified methods for calculating thermal loads on electrical and radio devices, although the performance of optoelectronic devices and the errors of the output parameters often depend on the values of their temperatures. Often, the development and creation of laser gyro designs is carried out intuitively on the basis of engineering experience using the simplest formulas and subsequent experimental studies of the models. Such an analytical and experimental approach without a scientifically based methodology for modeling the ongoing thermal processes, gives satisfactory results of creating only simple designs of optoelectronic devices.

The existing approach to the creation of laser gyros, as complex optoelectronic devices, does not allow us to determine with good accuracy at the early stages of design the proximity of the true temperature values, and according to them the thermal loads of the product in relation to the permissible standards [1]. Only during the tests of an already manufactured model or even a prototype of the device, overheating or burnout of the elements, or temperature drifts of the gyro parameters are being detected [2, 3]. This leads to the need for a partial or complete redesign of the device, and, consequently, to a decrease in the technical and economic indicators of the design process (due to the lengthening of the terms of creation of the device, additional costs for making changes to its finished design, which affects the rise in price of the product).

In this regard, the development of a scientifically based algorithm for designing a laser gyro, the creation and implementation of a new technique based on digital modeling of thermal processes in a gyro using the software of the automated ASONIKA system are relevant.

II. Description of the Developed Algorithm

Figure 1 shows the developed algorithm for digital modeling of the laser gyro. Block 2 of the algorithm provides for the creation of drawings of the laser gyro using the AutoCAD program or another program that allows you to get the design of the device on the computer. Figure 2 shows an example of one of such devices. This is a laser gyro, widely used in aerospace electronics.

To build a thermal model of a laser gyro (block 3 of the algorithm), it is necessary to conditionally divide its design into separate parts, between which the conductive, convective and radiant heat transfer will be taken into account when building a thermal model. In order to obtain the temperature on each element, the device is modeled in two stages. At the first stage, thermal modeling of the laser gyro as a whole is carried out in order to determine the average temperatures of individual parts of the gyro structure. In this case, each printed circuit unit (PCU) is usually represented as a separate part of the device. Then, at the first stage of modeling, for each printing unit, its average temperature is obtained as an isothermal body. The thermal process in each PCU is modeled at the second stage in order to obtain the temperature of each part standing on it. For this purpose, the program of the ASONIKA-TM subsystem is used [4].

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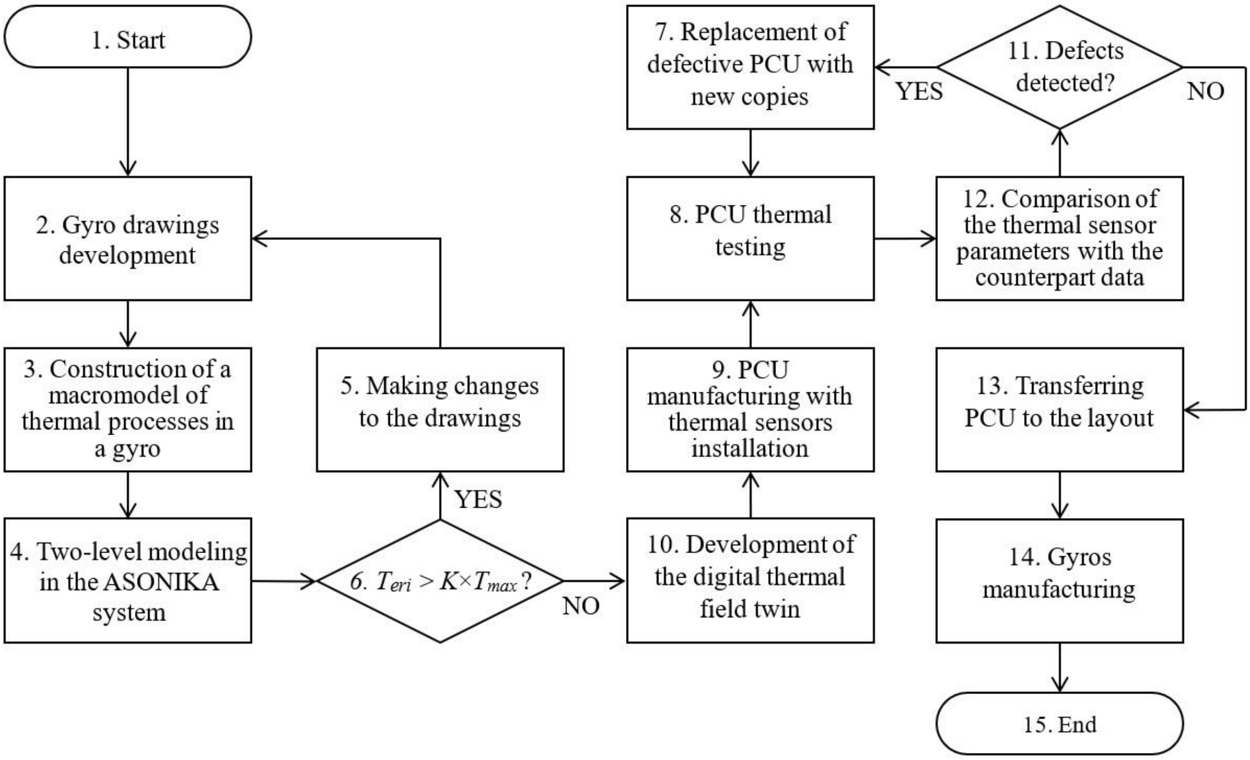

Fig. 1. Algorithm of a gyro digital modeling methodology.

Fig. 2. Three-axis laser gyro with the body cover removed.

Figure 3 shows an example of dividing the laser gyro construction into separate large parts. To improve the accuracy of the simulation, the selected parts may need to be divided into smaller parts. When setting up a digital simulation of the device of a particular type, it may be needed to repeat the simulation with different types of splitting the design into parts, i.e., more or fewer parts, because if you increase the number of parts of the building thermal model, then the modeling process is delayed, but the accuracy of the temperatures of selected parts increases.

Thermal modeling is carried out on a computer screen using the ASONIKA-T subsystem [4]. The principles of constructing a thermal model of a laser gyro are developed in this paper. The model has the form of an undirected graph, nodes (vertices) which correspond to the parts of the laser gyroscope highlighted in Figure 3, and the branches (edges) of the model connect the nodes corresponding to the parts of the device located near each other, between which there is a heat exchange. Finally,

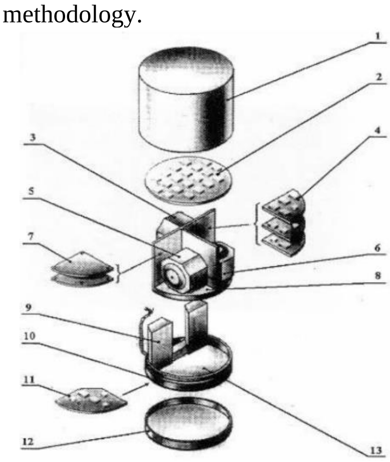

Fig. 3. Separate parts of a laser gyro: 1 – top cover 2 – management system perimeter of the annular laser beam PCU, 3 – laser sensor along the Y-axis, 4 – ignition system of laser beams PCU, 5 - laser sensors on the X-axis, 6 – laser sensor in the Z-axis, 7 – current regulator PCU, 8 – bearing structure (cross) for fastening the three laser sensors 9 – secondary power supply PCU, 10 – base, 11 – magnetic stand PCU, 12 – external screen 13 – internal display

the thermal graph is similar in appearance to that of an electrical circuit. In other words, it is possible to use electrothermal mathematical analogy in thermal modeling.

Each part of the laser gyro is considered as an isothermal body, and each branch corresponds to one of the types of heat exchange: conduction, convection, or radiation. Therefore, the thermal resistances in the branches are calculated in the ASONIKA-T program using the corresponding formulas at the beginning of the simulation. In addition to the effects of temperature, humidity, and ambient pressure, the simulation takes into account heat generation in other parts of the device (for example, in a laser gyroscope - this is a laser sensor) [6]. Therefore, the thermal effects on the device are set by branches with sources of ambient temperature in °C and with sources of heat release in W for each printed circuit unit in the laser gyro.

The temperatures of all elements obtained after two stages of modeling the thermal process in a laser gyro are separately analyzed and checked in block 6 for non-exceeding the maximum permissible values of the thermal load coefficients, taking into account the reserves for the available variations of parameters (thermal conductivity coefficients of materials, blackness coefficients of the selected parts' surfaces, etc.).

The thermal load coefficient of each element is calculated by the formula:

$$K = Teri + Tmax \qquad (1)$$

where *Teri* is the actual temperature of the element obtained as a result of thermal modeling; *Tmax* is the maximum permissible temperature on the body of the electronic element according to the specifications for this element.

If it turns out that the inequality in block 6 of the algorithm does not hold on at least one element, then the necessary changes are made to the original drawing obtained in AutoCAD (see blocks 5 and 2 in Figure 1), in order to remove some of the heat from this element. Changes can be such as connection of the element to the radiator, mounting of the thermal bus (especially if you want to remove heat from several elements) or any other methods of heat dissipation. This also entails making corrections to the thermal model of the printed circuit unit and the gyro as a whole (block 3).

The obtained new results of thermal modeling are again checked in block 6 of the algorithm for thermal overloads, and, if they were not detected, the development of a control system for the diagnosis of a laser gyro during its manufacture begins, taking into account the need for the influence of the thermal process on the performance of the device. In block 10 of the algorithm, this work is designated as "Development of the digital thermal field twin". It is proposed in this paper to compensate for the influence of other external and internal operational factors (vibrations, shocks, pressure and humidity of the environment, aging of materials, replacement of materials, technological variations of parameters, etc.).

The data of the digital thermal twins in block 12 in Figure 1 are used in the control of manufactured PCU according to blocks 9 and 8 of the algorithm. If the diagnostics of the finished gyro PCU shows the presence of a defect (block 11), then the defective PCU is replaced with new copies (block 7).

PCU that have successfully passed the diagnosis is transferred to the gyro layout (block 13). The process is completed by the complete production of the laser gyro (block 14).

III. The Essene of the Digital Twin

A digital twin in this paper can be defined as a computer prototype of the thermal state of the laser gyro, which, as a result of mathematical modeling, was achieved in accordance with the requirements of the design specification. The more accurately a digital double is described in a computer environment, the more it corresponds to its real prototype.

The concept of a digital twin was proposed by Professor Michael Grieves of the University of Michigan back in 2002 [7, 8]. He defined a digital twin as follows: "A digital twin is a set of virtual information constructs that fully describes a potential or actual industrial product: from its atomic functions to its geometry. Under ideal conditions, all the information that can be obtained from the product can be obtained from its digital twin."

Currently, in this paper, a less abstract definition of the digital twin is offered. According to the topic of the work, a digital twin of the optoelectronic device, such as a laser gyro, can be created and considered in the following situations:

- a model as a physical product, i.e. a prototype of a real sample of the optoelectronic device,
- a computer program that simulates the design of the optoelectronic device and the physical processes in it,
- ready-made data results of modeling the physical processes that occur in the optoelectronic device.

Since the model indicated in the first paragraph is intended for experimental studies of thermal processes with the use of thermal (climate) chambers, it should be emphasized that it does not allow you to fully reproduce the conditions of real use of the laser gyro in a particular operating environment. As a rule, developers of laser gyros do not know exactly, for example, which parts of the object of the installation of the device will be heat-exchanged by radiation. Obviously, in the heat chamber radiation emission on the walls of the chamber is carried out in a different way. The presence of temperature sensors themselves also contributes to the test errors.

A computer program of thermal simulation can be configured for different production and operation conditions. At any time, setting of the digital twin in the form of a computer program can be easily changed. Such a digital twin of thermal processes in the device can be configured for both thermal test conditions and operating conditions. Under uncertain operating conditions, it allows you to view several options and find the best options for the scheme and design of the device, taking into account the possibilities of its production and operation.

In this paper, such a digital twin of the thermal regime of the lase gyro is considered as a computer prototype of real physical processes, which also dynamically change over time depending on changes in the parameters of the construction materials (wear, aging, the influence of humidity, radiation, etc.). The more accurately the digital double is described in a computer environment, the more it corresponds to its real prototype [9, 10].

A simplified version of the digital double in the form of ready-made data of the final results of modeling thermal processes can be recorded in programmable logic integrated circuits and placed in the most heated parts of the laser gyro for current temperature control, signaling a dangerous temperature increase and, perhaps, reconfiguring the device or the object of their installation. [11, 12]

Because of the human peculiarities of perception, such implementation of the digital twin is better to understand, because firstly you can get a visual representation of the thermal field and only secondly move on to research its properties, such as coefficients of thermal loading, the response to external influence, on the operating conditions, the natural aging process, etc. To combine in a twin all these properties it is usual to use the following:

- developed graphics 3D digital model of the device structure using CAD systems of engineering design;
- technologies for visualizing the thermal fields of printed circuit units, providing real data on the thermal load coefficients of each product;
- mathematical models of thermal processes integrated with models of electrical processes in the devise circuits,

mechanical models of vibrations, shocks, linear accelerations and acoustic noise.

IV. Conclusion

The algorithm developed in this paper for designing a Zeeman laser gyro using computer simulation of thermal processes has been successfully tested in the creation of laser gyros. The first results of testing have already shown that increasing the accuracy of determining the thermal loads coefficients of elements by computer simulation of the most important thermal processes occurring in the device can significantly improve the technical and economic performance of the development process. This is due to the fact that design errors are eliminated by changing the parameters of mathematical models at the first stages of creating a gyro, and not by changing the designs of manufactured models or prototypes.

The essence of the proposed digital thermal twin is to store in the device's memory the last final temperature values of some elements obtained during thermal modeling during design [7, 8]. The number of selected elements depends on the design possibilities of installing temperature sensors on these resistors. The sensors allow you to record the actual operating temperature values on these elements to transfer them to the memory of the digital thermal twins in order to compare the operating values with the model temperature values. If there is a discrepancy between the values above the set tolerance, the monitoring and control system, firstly, sends an alarm signal to the control center, and, secondly, automatically transmits signals to the actuators to reduce the loads on the element, if such actuators are provided in the design of the device.

References

[1] E. Kuznetsov, Y. Kolbas, Y. Kofanov, N. Kuznetsov, T. Soloveva, “Method of Computer Simulation of Thermal Processes to Ensure the Laser Gyros Stable Operation, in: Computational and Experimental Simulations in Engineering,” Proceedings of ICCES2019 Vol. 75. Cham: Springer, 2020, pp. 295-299.

[2] V. Gribov, Y. Kofanov, V. Strelnikov, “Reliability of onboard aerospace control systems,” edited by prof. Y. Kofanov, M., Energoatomizdat, 2015, 699 p.

[3] Y. Golyaev, Y. Kolbas, A. Rasskazov, “Approximation of reproducible time and temperature dependences of the zero offset of a ring laser,” Electronic equipment-ser. 11-v. 2 (58), 1991, pp. 68-73.

[4] A. Shalumov, N. Malyutin, Y. Kofanov, D. Posob, V. Zhadnov, V. Noskov, A. Vachenko, “Automated system ASONIKA for designing highly reliable radioelectronic devices based on the principles of CALS technologies,” ed.: Y. Kofanov, N. Malyutin, A. Shalumov, vol. 1., Moscow: Energoatomizdat, 2007, 365 p.

[5] Y. Kofanov, E. Kozlova, E. Poluyko, L. Mirzoyan, V. Malievskaya, V. Avdeyenkov, “The Method of Modeling Thermal Process for High Reliability On-Board Radio-Electronic Systems,” in: 2020 Moscow Workshop on Electronic and Networking Technologies (MWENT), IEEE, 2020, pp. 6-11.

[6] Y. Kofanov, Y. Vinokurov, S. Sotnikova, “Optoelectronic Devices' Thermal Working Modes Providing Method,” in: 2019 International Seminar on Electron Devices Design and Production (SED), IEEE, 2019, pp.1-4.

[7] M. Grieves, “Origins of the Digital Twin Concept,” Florida Institute of Technology, Michael W. Grieves, LLC, 2016, 6 p.

[8] M. Grieves, “Digital Twin: Manufacturing Excellence through Virtual Factory Replication,” Florida Institute of Technology, Michael W. Grieves, LLC, 2014, 7p.

[9] Infrastructure center "Technet" NTI, “Digital twins in the high-tech industry,” Moscow, 2019, 58 p.

[10] Bauerenhansl, S. Hartlife, T. Felix, “The Digital Shadow of production — A concept for the effective and efficient information supply in dynamic industrial environments,” Procedia CIRP, Stuttgart, Germany, 2018, pp. 69-74.

[11] Y. Kofanov, S. Sotnikova, “Method of Digital Counterpart Creation of Physical Processes at Productive Foresight Modeling of Cyber-Physical Systems,” in: 2020 Moscow Workshop on Electronic and Networking Technologies (MWENT), IEEE, 2020, pp.1-5.

[12] K. Petrosyants, N. Ryabov, “Quasi-3D Thermal Model of Stacked IC-TSV-BGA Package,” in: 25th INTERNATIONAL WORKSHOP on Thermal Investigations of ICs and Systems (THERMINIC 2019), Milan: IEEE, 2019, ch. P2-2.123. pp.1-4.