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The electric drive control system of corner reflectors of the spacecraft interferometer

Sergey Langraf[1,*], *Dmitriy* Bunkov[1], *Ivan* Odnokopylov[1], and *Olga* Galtseva[1]

[1]Tomsk Polytechnic University, 634050 Tomsk, Russia

Abstract. This paper presents the electric drive control system of corner reflectors of the infrared Fourier transform spectrometer for meteorological satellite. Limited-swing brushless DC motor with a torsional bearing is used as a drive motor. Stringent requirements are imposed to the drive control system for stabilization of moving speed of the reflectors while obtaining the interferogram and for limitation of the reverse time. Research of influence of torsion on steady-state error of speed and ways of its compensation is conducted. The obtained results are consistent with the simulation results of the drive. It is shown that the developed drive is operable in a spacecraft system.

1 Introduction

Electrical engineering is widely used in the space industry. There are several features associated with toughening of requirements for such electromechanical devices: creation of compensating device, special conditions to the heat sink, the high requirements for reliability and fault tolerance, radiation resistance.

The creation of meteorological satellites is one of the promising directions of development of space industry for civil purposes. They allow observing the Earth's atmosphere from space. Due to the rapid development of space meteorology in 2014 the infrared Fourier transform spectrometer (IFTS) appeared on board of the spacecraft "Meteor-M". Thanks to the advent of IFTS it has become possible to obtain an infrared spectrogram of the atmosphere and the Earth's surface that facilitates the temperature and humidity sounding [1, 2].

The scan accuracy of infrared radiation depends on the accuracy of the reciprocating motion of drive of the pendulum of corner reflectors of the interferometer; this is the only constantly moving element of IFTS. Therefore, an important task to develop the drive control system that meets the high requirements to IFTS for obtaining the interferograms in space conditions [3].

[*]Corresponding author: langraf@tpu.ru

2 Materials and methods

The operation principle of IFTS is based on the phenomenon of interference of waves. The interferogram from the photodetector is a function of the optical difference of path of two beams [4]. The division into two equal intensity beam occurs using the beam splitter (Figure 1). The change of optical difference of path transpires due to the uniform displacement of the pendulum with corner reflectors on the value of ±2 degrees. Stringent requirements are imposed to the drive of the pendulum of reflectors. Firstly, it is necessary to ensure a high stability of defined speed of at least 1% of the operating speed at moving of corner reflectors. The quality of the resulting interferogram depends on the accuracy of sustaining of the defined speed directly. Secondly, it is essential to make a quick change of direction movement of corner reflectors at 0.05 s. This will reduce an idle of IFTS operation.

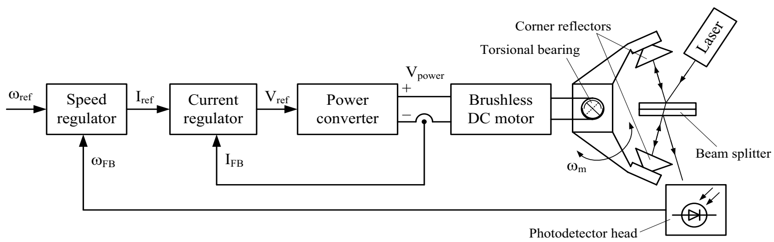

Fig. 1. Functional scheme of the electric drive of corner reflectors of the interferometer.

The electric drive system works in a cyclical pendulum mode, consisting of two zones: interference and reverse. Processing the infrared radiation from the Earth's surface occurs in the interference zone. The drive should work in mode of speed stabilization at the approach to the interference zone after each reverse.

Limited-swing brushless DC motor is proposed to use for implementation of the electric drive system [5]. Ensuring the long-term operation of the limited-swing drive in space conditions is achieved using the torsional bearings which have significant advantages compared to radial bearings.

For implementation of the requirements of the speed stabilization it is need to use a double circuit control system made in accordance with the principles of the subordinate regulation. Formation of the feedback signal for the speed loop occurs by means of high-precision laser measurement system of moving of corner reflectors. An additional laser interferometer is used for this purpose; laser radiation passes through the beam splitter and corner reflectors and gets to the receiving photodetector (Figure 1). The resulting sequence of pulses converted into signals with accurate information about the current speed of movement on the photodetector output.

The control loop by motor current is the inner loop of control system, the control loop by speed of the moving of the drive is the external circuit of system. Proportional-integral controller is used in current loop. The optimization is performed in view of achieving the limit rapidity of the system; it is characterized by a total inertia of the elements of the power channel and current measurements. Also proportional-integral controller is used in the control loop by speed of the moving for improving the accuracy characteristics. The optimization is performed according to the method of symmetrical optimum [6] to ensure a maximum rapidity with minimizing the error value.

3 Results

Analysis of conditions of drive operation with the torsional bearings shows that a gradual increase of resistance torque from the torsional bearings occurs at the deviation of the pendulum with the reflectors from the concerted position. Thus, disturbing load from the torsions is changed by the linearly-increasing dependence at the drive movement with constant speed [7].

Mathematical analysis of transfer functions of electric drive control system shows that the use of proportional-integral controller in speed loop gives the opportunity to provide the second-order astaticism on control for electric drive; only the first-order astaticism on disturbance is possible. In this regard, the steady-state error of regulation will appear during the electric drive operation with a constant speed of movement in conditions of linearly increasing resistance [8]. The calculated value of the steady-state error, as a result of exposure of linearly increasing load from the torsions, can be determined from the expression of the transfer function of loop speed on disturbance.

The calculated value of the steady-state error on speed during obtaining of the interferograms was defined on level $\Delta_{calc}= 9.54\cdot10^{-3}\%$, which is not beyond the initial requirements to the drive of movements of corner reflectors.

4 Discussion

Functional testing the proposed control system was performed using a drive simulation of corner reflectors (Figure 2).

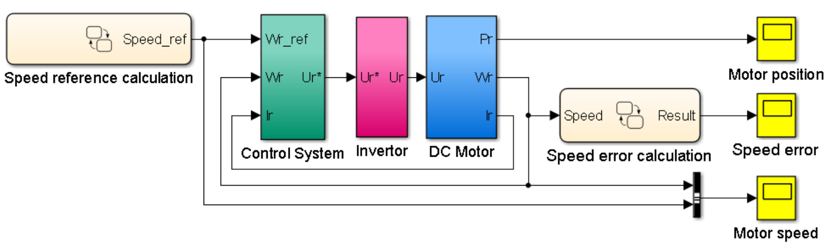

Fig. 2. Simulation model of electric drive of movement of corner reflectors of the interferometer.

The model was developed in software Matlab Simulink and takes into account the properties of the autonomous voltage inverter with limited-swing brushless DC motor with excitation from permanent magnets [9]. Power-up sensor with the S-shaped profile is used for the formation of smooth movement and optimal reverse of the motor, for limitation of the maximum speed up and for exclusion of jerks at the electric drive operation. The main feature of this model is the consideration of the torque load from the torsional bearings depending on the current angle of the pendulum of the interferometer.

The main simulation results are presented as graphs of transient processes (Figure 3).

Drive speed error has constant level at work in the interference zone. The error sign depends on the current direction of movement, but module of error value corresponds to the expected calculated value at the level $\Delta = 9.55\cdot10^{-3}\%$. In the reverse zone, the electric drive shows high dynamics; the time of readiness for the next cycle of work in the interference zone is t = 0.05 s.

It is shown that the developed system of the pendulum electric drive with corner reflectors can be successfully used for organization of the IFTS work in the composition of the spacecraft.

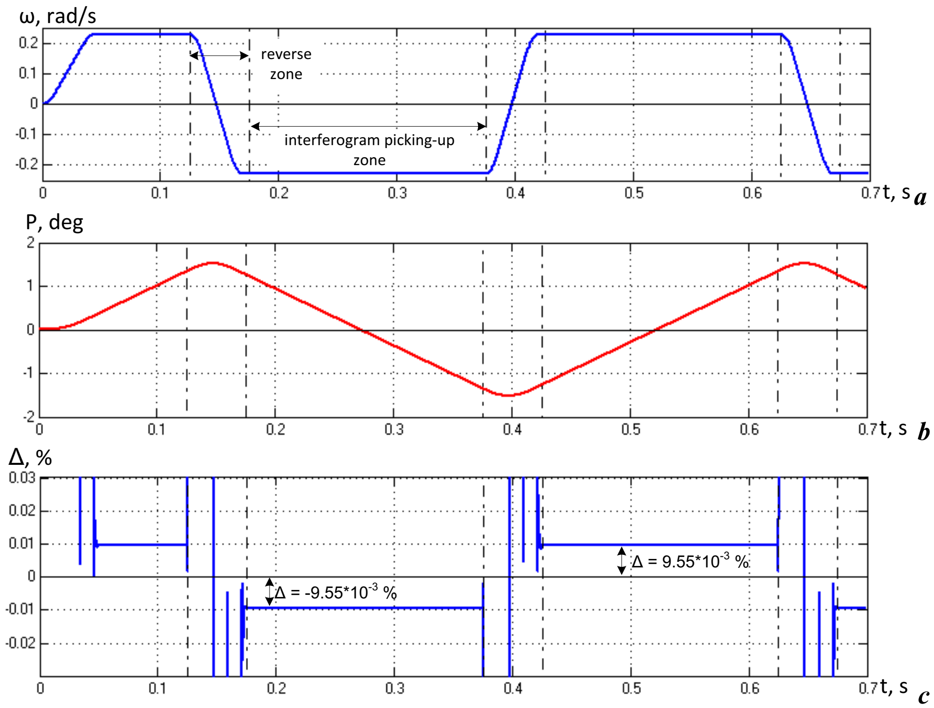

Fig. 3. Graphs of transient processes of electric drive of corner reflectors, where *a* is a speed, *b* is the position, *c* is the speed error.

5 Conclusions

The results of the study show that a module of speed error of drive has a constant level and corresponds to the expected calculated value at the level Δ= 9.55·10-3 % compared to the working speed. It corresponds to the requirements for IFTS of the electric drive in the obtaining mode of interferograms (1%). In the reverse mode the drive is ready to the next cycle for work in the interference zone at t=0.05 s; it fully meets the necessary initial conditions.

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