Control Moment Gyro for the Agile Small Spacecraft

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Abstract: This paper considers the problems of construction of control moment gyro for spacecraft attitude control. The architecture and reasoned device embodiment are presented. The description of the main elements construction and the performance attributes are cited.

Keywords: attitude control system, spacecraft

1. INTRODUCTION

The structure analysis of the spacecraft control systems (ACSs) shows that control moment gyroscopes (CMGs) remain the main executive parts of the ACS for modern and prospective agile spacecraft with a long term of active operation. All projects of this spacecraft ACS type apply in practice one-axis CMGs – gyrodynes. The number of gyrodynes installed equals to 4 or 6.

In the Federal State Unitary Enterprise "Command Devices Research Institute" wide experience was accumulated on the development and operation of gyroscopic systems with gyroscope's angular momentum from 100 to 2500 Nms. Currently, the field for application of these devices is increasing due to the emergence of small spacecraft with mass up to 1000 kg.

This paper presents results of the powered gyroscopic device for small spacecraft development, based on the control moment gyroscope with rotor's angular momentum 25 Nms.

2. FUNCTIONAL SCHEME OF DEVICE

A functional scheme, which is typical for this class of devices, is presented in the Fig. 1. The following designations are introduced at the scheme:

APMU – angular position measuring unit,
BM – brushless motor,
CD – contact device,
DCU – drive control unit,
GM – gyro motor,
IU – interface unit,
MCU – motor control unit.

The MCU, DCU, APMU blocks each have two independent channels («cold» back up), the IU block uses mixed back up, so that one possible fault in any unit does not result in failure of the whole device.

The device is ready to work after the voltage of 27 VDC is supplied. After giving the command to turn on the first or second terminal device in the IU, the device is ready for the information exchange via the multiplex channel through the main (LIT-A) or backup (LIT-B) lines of information transfer on the basis of the main serial interface according to the Russian State Standard R 52070-2003.

Further control of the device engage and setting of the required speed of gimbal rotation is carried out through the code signals.

The reply message contains the information about turned on units, the gimbal's angular position and the values of parameters in question.

3. THE PARTS OF DEVICE

The gyrodyne consists of the following functional devices:

- Control moment gyroscope (CMG),
- Operating electric drive (OED),
- Output device (OD).

3.1 Control Moment Gyroscope

The control moment gyroscope consists of the gyromotor and the motor control unit. Gyromotor have a hermetic package, inside which the rotor at two combined journal-and-thrust bearing, oil charge blocks, and the brushless DC motor are placed.

Usage of a motor without a rotor position sensor determines the presence of special modes of operation.

In the slew mode the process of rotor's special orientation relative to the stator takes place. It occurs through magnetic fields interaction of a rotor and a stator, the winding of which has a constant current of the desired direction.

In the spin-up mode the rotor is spinning up according to the rotor frequency program. At that time the rotor monitors the increase in frequency of supply voltage from zero to the frequency of the automatic shift to the self-switching mode. The switching of phases is carried out by the signals of rotation's electromotive force, read from the gyromotor's phases. In the self-switching mode further spin-up takes place till the nominal rotor's rotation frequency is reached. Than the rotation frequency is stabilized.

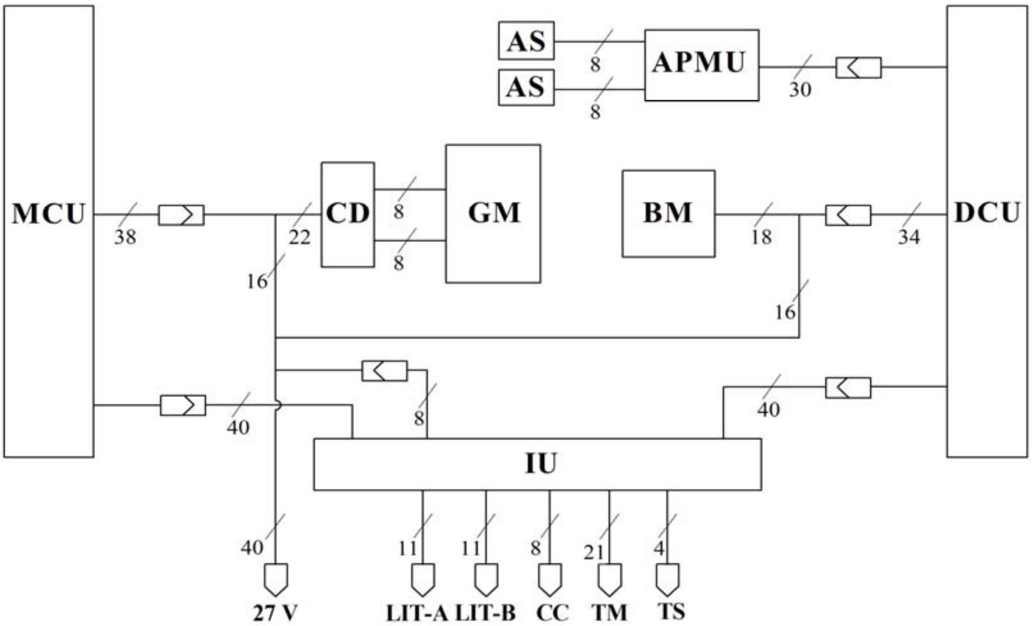

Fig. 1. Functional scheme of the device

3.2 Operating Electric Drive

The operating electric drive consists of:

- brushless DC motor with matched windings,
- single-reduction gear unit,
- drive control unit.

In the drive the scheme of direct digital control over the motor's rotor rotation speed is applied.

The principle of this scheme operation is based on a comparison of the code of the current angle value with the code of the integral of a given speed value over a step of measurement, and on the outputting latitude-modulated control voltage corresponding to the adjusted difference in these codes to the power amplifier.

The quality of transition processes during the change of control and perturbing effects, the accuracy in the specified speed keeping, preventing the mobile part from the crank are achieved through negative feedback on the corner with a proportional-integral-differential controller (PID controller).

The choice of the PID control parameters was done by the Ziegler-Nichols method on the mathematical model of the device. The motor's rotor is connected with the axis of the gyromotor's gimbal through the reduction gear with the end play choosing device.

3.3 Output Device

The output device is intended for the forming the gyromotor's gimbal angle code and includes two multipolar induction sensors of the angle, and also angular position measuring unit. Through the matching and transformation devices, the signals from the rough and precise indications of the angle's sensor go to the microcontroller.

The microcontroller carries out the angles of rough and precise indications identification, their matching, formation of 19-bit angle's code, and transfer to the drive control unit and further to the synchronizer unit via RS-485 interface transceiver.

To reduce the random component of the error in determining the angles values, the algorithms of digital filtering code, arriving to the microcontroller, are used.

When matching rough and precise indications, calibration tables are used to exclude a systematic error of the angle's sensor.

Discretization of the angle's code formation is 2.5 arc sec.

The device also includes a contact device. It is designed to transfer power for the two duplicate three-winding of a gyromotor with the zero point output for the unlimited gimbal's axis angle. The device is built from the rings and brushes of a special alloy, which is a complete structural unit.

4. CONSTRUCTIVE SCHEME OF THE DEVICE

As for the constructive scheme of the device, the option of monoblock unit was accepted. That solution provides the best performance characteristics of the device as a whole.

The embodiment and the surface appearance are presented in the Fig. 2. The body of the device is a frame in the shape of parallelepiped, on the lower bound of which the flange mounting is located. The body represents a composite construction of the four walls, connected with each other in a special way, with subsequent mechanical finish.

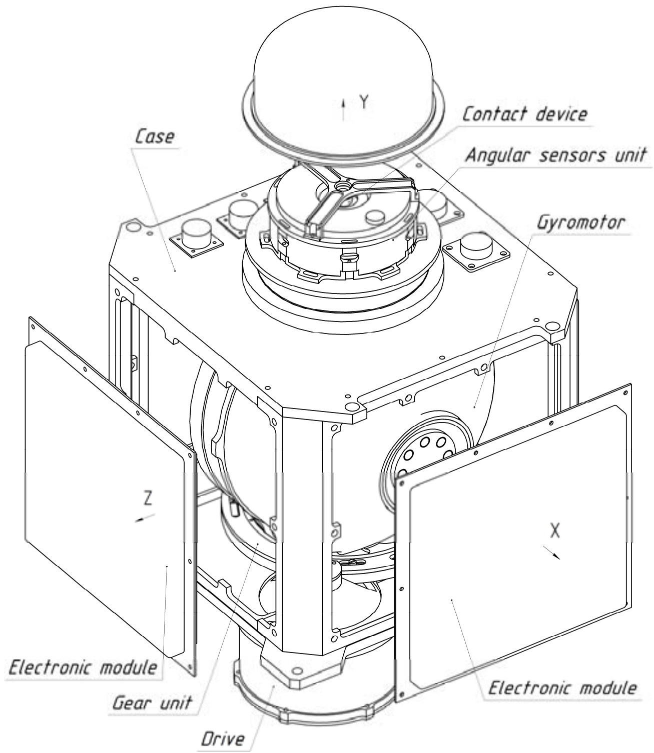

Fig. 2. The constructive scheme of the device

The electronic units are installed on the lateral sides, the drive is located on the lower verge, the angle's sensors and connectors are on the top.

The device case is not hermetic.

According to the results of the thermal calculation the device's elements overheating relative to the temperature of the heat sink does not exceed 15°C.

The main technical characteristics of the device are presented in Table 1.

There is also a possible option to change nominal angular momentum from 15 to 35 Nms, as well as to implement the interface type according to the consumer's requirements.

5. CONCLUSIONS

Calculated and experimental works, as well as testing prototypes of the elements and functional devices, have shown that adopted structural solutions provide the implementation of all requirements to the dynamic and operational parameters. In-flight certification of the device is planned for 2011.

Table 1. The main technical characteristics of the device

Parameter	**Parameter's value**
1. Angular momentum (AM), Nms	25 ± 2.5
2. Time of rotor's spin-up, min	60
3. The variation range of rotation speed of gyromotor's gimbal, deg/s	± 60
4. Minimum speed of AM vector rotation, deg/s	0.0146
5. Accuracy of fulfillment of average speed of gimbal's axis rotation, %, not more than	1
6. The frequency of the code speed change, Hz	10
7. Angle of the AM vector rotation	Unlimited
8. Accuracy of an angle measurement, arc min	3
9. Supply voltage, V	27^{+5}_{-4}
10. Power consumption from the power supply at a voltage of 27 V, W: - in the stabilization mode - in the rotor's spin-up mode	 30 55
11. Data Interface	Multiplex exchange channel according to Russian State Standard P 52070-2003
12. Total Weight, kg	15.5 ± 0.5
13. Overall dimensions, mm	375×280×280
14. Life requirements, hours, not less than	75 000