Nano Star Tracker AZDK-1

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Abstract

Nano Star Tracker AZDK-1 is under development by Azmerit LLC. This star tracker is designed first of all for nano and micro satellites, but can also be used on larger spacecrafts. Its dimensions, which are 56×60×93 mm, its weight is 193 g, and its average power consumption of 0.3W (1,25 W peak) enable to use it in a CubeSat satellites. AZDK-1 has a high attitude accuracy, which is achieved through a more complicated image processing, allowing of taking into account the systematic errors. It is expected that the use of CMOS photo sensor with effective size of 512×512 pixels and with an update rate of 5 Hz gives the attitude error $\sigma_{XY} \approx 5''$. Attitude accuracy improvement technique was taken from the processing of astronomical images. In the article present the results of functional, vibrodynamic, thermal vacuum tests.

Introduction

The task of company Azmerit was to develop a budget star tracker of moderate accuracy for primarily nano and microsatellites. In the near future, a massive launch of nanosatellites is planned for their use for remote sensing and communications tasks. The company has developed a special solution – the Nano star tracker AZDK-1. The Nano star tracker AZDK-1 has passed ground tests. In 2019 flight tests are planned.

Appearance and parameters of the Nano star tracker

The developers were faced with the task of finding the optimal solution for mass-dimensional characteristics and power consumption, and to ensure the accuracy of 5-10 arc-seconds [1, 2]. We used the well-pack of the star tracker. At the heart of the well-pack layout is a flex-rigid printed board [3], shown in Figure 1.

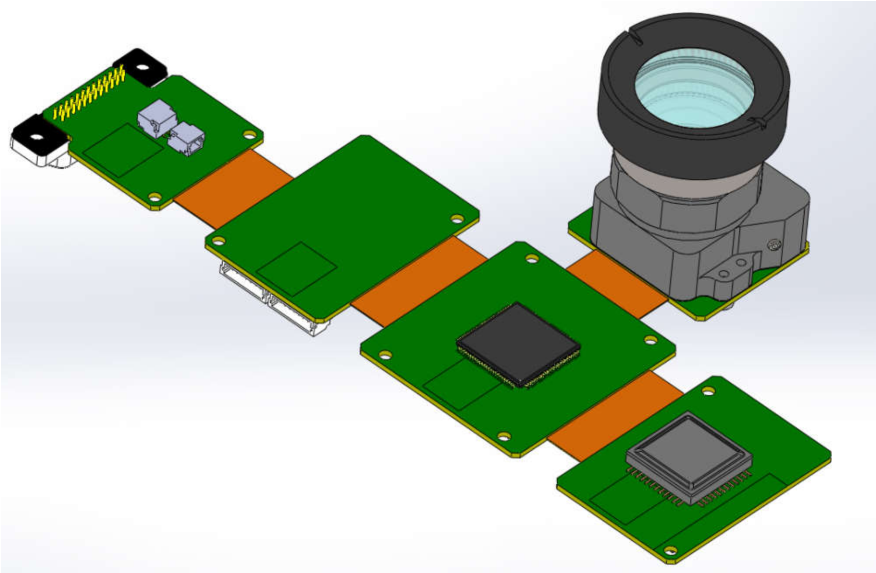
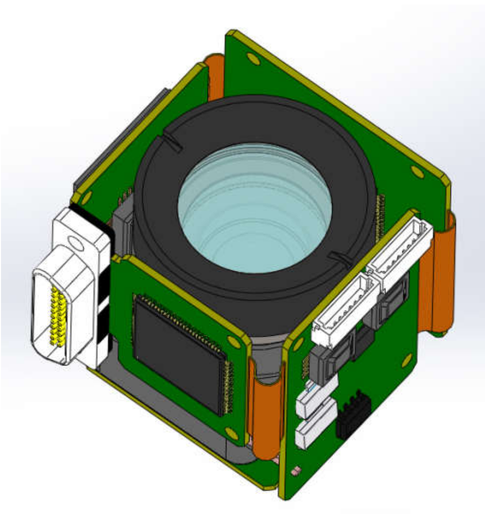


Fig.1 – Flex-rigid printed board with an installed lens and lens-holder

Flex-rigid printed board folds into a "cube". After that it is installed in the body of the star tracker. The flex-rigid printed board folded into a “cube” is shown in Fig. 2



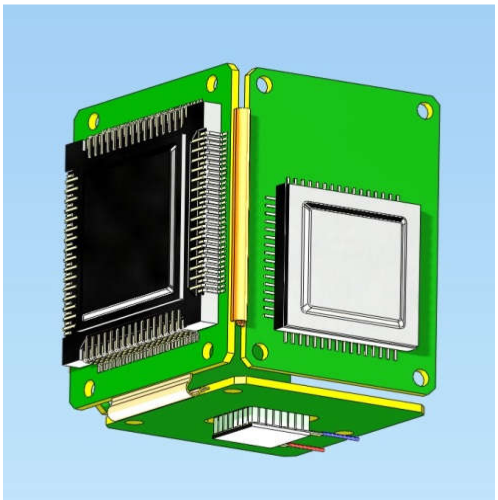


Fig. 2 - Flex-rigid printed board with installed chips, folds into a "cube" for installation in a body of a star tracker

Electronic component base (chips)

A CMOS array of 1024 × 1280 pixels is used as a photodetector. The developers adhered to the concept of import substitution, so all the chips with the exception of the photodetector of russian production.

After folding the flex-rigid printed board into a "cube" (see Fig. 2), the flex-rigid printed board is installed in the body of a star tracker , shown in Fig. 3

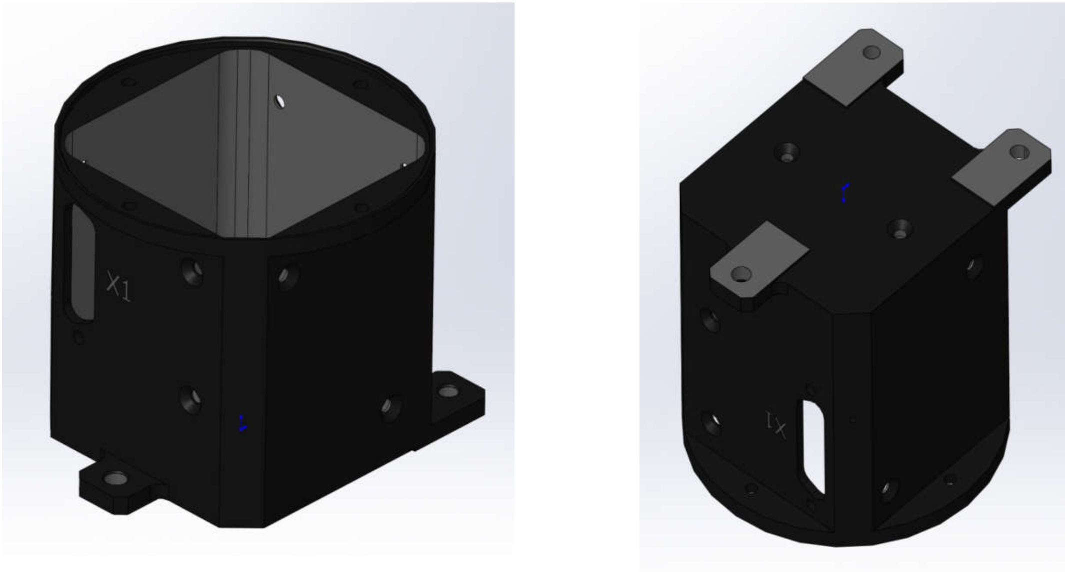


Fig.3 – Body of a Nano star tracker AZDK-1

After installing the flex-rigid printed board in the body, it is closed with a hood and tightened with screws from the bottom of the body base.

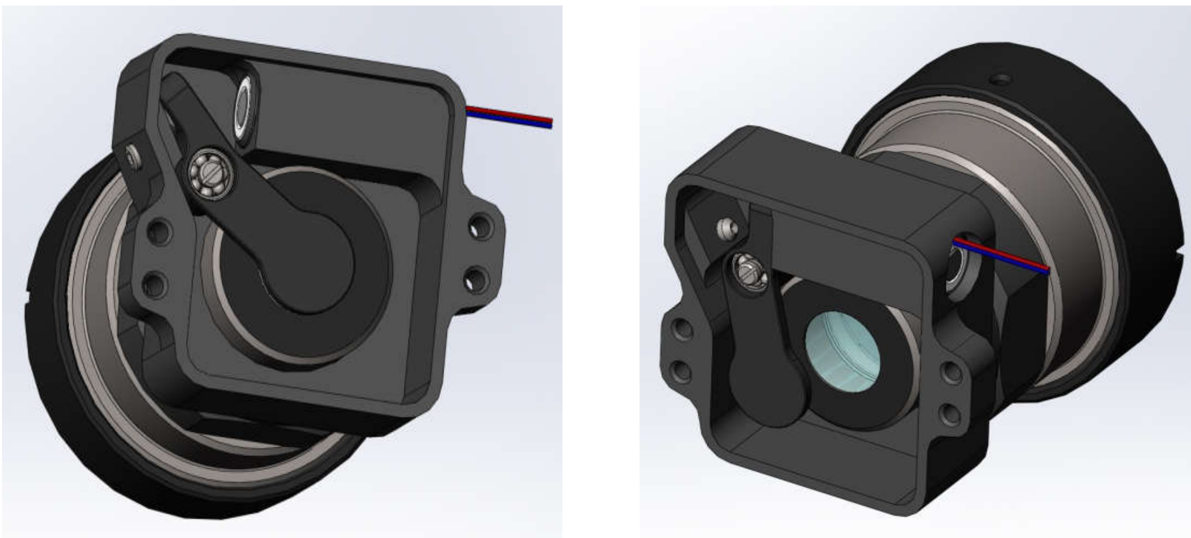


Fig. 4 - The upper part of the star tracker body consisting of a lens-holder with a calibration shutter, a lens and a lens hood.

In the Nano star tracker to more accurately account for the dark currents of the photodetector, it is possible to measure them directly in flight. Calibration of dark currents is performed using a calibration shutter for a short (1-10 sec) overlapping light flux. This allows you to calculate the dark current individually in each pixel and create a dark current map for its subsequent consideration in image processing [3]. In addition, the Peltier element is located on the back side of the photodetector, allowing the photodetector to be cooled, thereby reducing the dark current caused by thermal electrons, as well as the radiation degradation of CMOS. Nano star tracker AZDK-1 assembly and its parameters are presented below.

Table 1 - Parameters of the Nano star tracker AZDK-1

Dimensions	56×60×93 mm
Total mass	193 g
Power \ Peak Power	0.3 W \ 1.25 W
Accuracy	5 arc sec
Maximum slew rate	3°/ sec
Output Solution	5 Hz
FOV	20°
Detector	1024×1280 (CMOS)
Limiting magnitude (0.1 sec)	5.8^{m}
Catalog	2400 stars

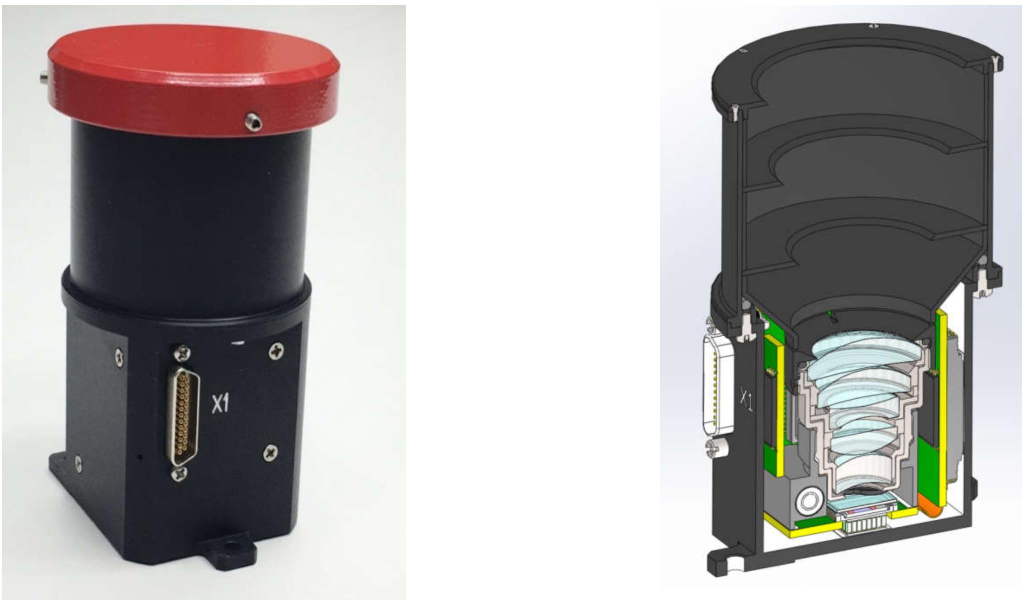


Fig. 5 - Nano star tracker AZDK-1: appearance and cut

The Nano star tracker AZDK-1 has passed a full cycle of ground tests, including functional, vibrodynamic and thermal vacuum tests. Patents for design solutions applied in the MPD AZDK-1: RU 2585179, RU 2577558, RU 154706, NUMBER EUR-AZ. PATENT 026970.

Test star tracker in the night sky

To measure the permeable magnitude of the star tracker at the time of its work (exposure 0.1 sec), observations of the night sky were performed. The observations were carried out in Moscow on the roof of the Sternberg astronomical Institute. In fig. 6 shows observations of the Pleiades star cluster. The permeable magnitude at exposure 0.1 seconds was 5.8 magnitudes. The value of penetrating ability allows you to confidently value confidently working across the entire night sky. The catalog of the Nano star tracker AZDK-1 includes about 2400 stars.

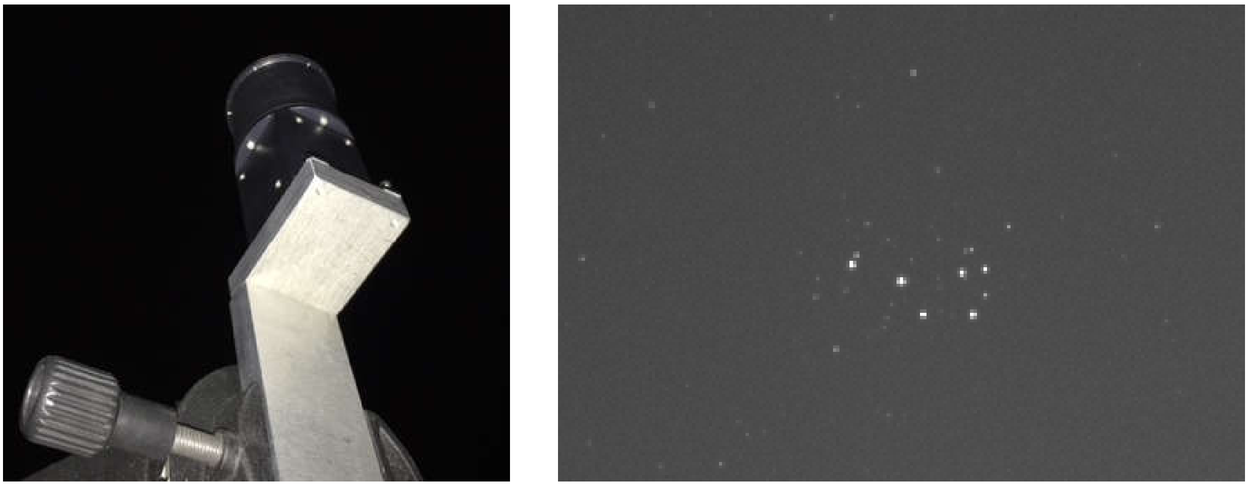


Fig. 6 - Nano star tracker AZDK-1 on a tripod during the field tests and the resulting image of the Pleiades cluster with an exposure time of 0.1 seconds

Vibrodynamic tests

The Nano star tracker AZDK-1 has passed vibrodynamic tests. During the tests, the star tracker was subjected to sinusoidal, random (white noise) and shock effects. Below are the star gage test modes.

Sinusoidal impact along the X, Y and Z axis:

Along the X, Y, and Z axes		Unit measuring
Frequency Hz	Impact level	

from 5 till 14	± 10,1	mm
от 14 до 100	8	g
Frequency range	from 5 till 100 Hz	
Frequency change rate	4 octaves/min	

Broadband random vibration along the X, Y and Z axis:

Impact duration, s	Frequency ranges, Hz					vibration accelerations, g
	20-100	100-200	200-500	500-1000	1000-2000	
	Vibration acceleration levels, g^2/Hz					
240	0,0225	0,0225-0,05625	0,05625	0,05625-0,028125	0,028125-0,014625	7,9

Notes:

1. g = 9.81 m/s^2.
2. Permissible deviations of vibration acceleration levels: ±3 decibel.

After each exposure along the X axis of Y and Z, a check was performed on the functioning of the Nano star tracker AZDK-1. A MEMS-gyro check was performed. A internal temperature star tracker was also checked.

The parameters of the peak shock acceleration along the X, Y and Z axes are given below:

Peak shock acceleration, g	9	25
Shock Acceleration Duration, (milliseconds)	5-10	1-3
The number of beats on each axis (no more than 120 beats per minute)	2000	7

Influence of vibrodynamic tests on the focal length of the lens of the Nano star tracker AZDK-1

To measure the change in the focal length of the lens of the MPD AZDK-1 before vibrodynamic tests, a frame of a uniform grid was made over the entire field of view of the Nano star tracker AZDK-1.

After vibrodynamic tests, the frame of a uniform grid is made again. In Fig. 7 shows the imposition of frames of a uniform grid before and after vibrodynamic tests. The focus shift was within the range of measurement errors of the focal length. The relative change in focal length, calculated using the least square method, was minus $2.9 \cdot 10^{-6}$.

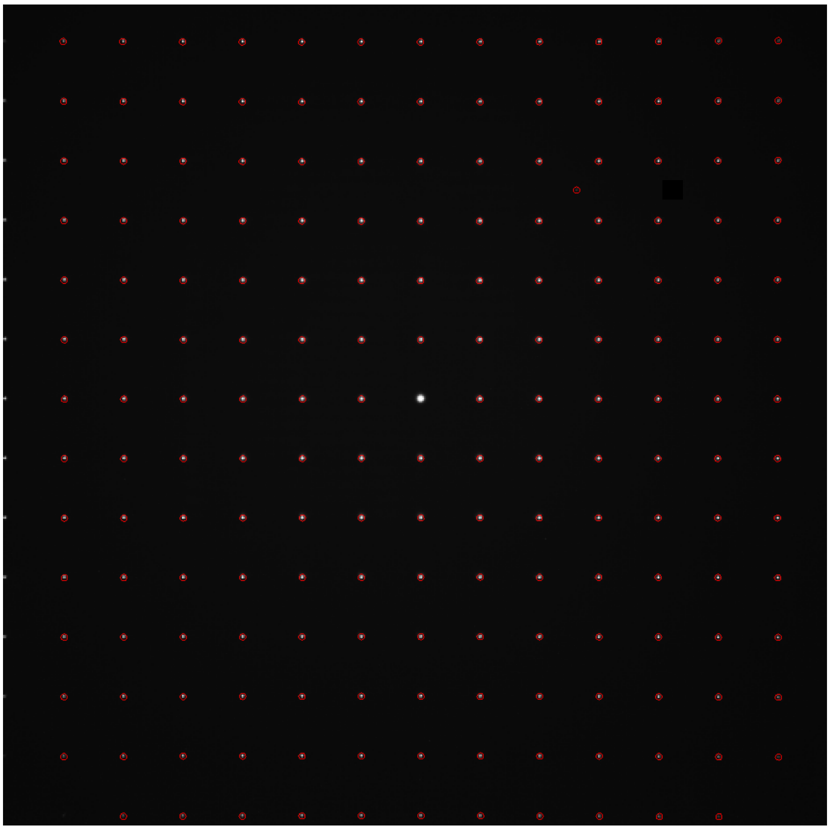


Fig.7 - Overlay frames uniform grid to (light dots)and after vibrodynamic tests (red circles).

Thermal Vacuum Testing

During all thermal vacuum tests, the pressure inside the chamber did not exceed $2 \cdot 10^{-6}$ bar, which corresponds to a high vacuum. The extreme temperatures of the thermal cycle were –27°C and +57°C. The total time of the technological vacuum was 71 hours and 40 minutes. The star tracker went through three thermal cycles. The initial temperature of the thermocycle was +20°C. Then the temperature rose to +57°C and was held for two hours. Then the temperature dropped to minus 27°C and this value was held for two hours. And then the temperature increased again to 20 degrees. The duration of the thermal cycle was a working day. Until the next day, the temperature remained +20. The next morning, the thermocycle was repeated. Thermovacuum tests lasted three days.

During thermal vacuum tests, the Nano star tracker AZDK-1 function was continuously checked. Continuous measurements were taken of the change in focal length, dark currents. The operation of the calibration shutter and Peltier element was continuously checked. Tests have shown that the Peltier element is cooling the components of AZDK at 21°C.

The results of thermal vacuum tests showed that the Nano star tracker AZDK-1 confirms its characteristics (see Table 1). The star tracker retains its performance, structural integrity and appearance after exposure to thermal cycles in the claimed temperature range from minus 27 °C to 57 °C in vacuum.

From the above graph, it follows that, as expected, with a rise in temperature inside AZDK-1, the average value of the dark current increases exponentially with increasing temperature.

When the internal temperature reaches 52 °C, the average value of the dark current is $5 \cdot 10^3$ electrons per second, and the maximum values of the dark signal at accumulation duration of 1 second lead to saturation of the photo-receiving elements.

During operation, the number of elements with large dark current values will only increase, reducing the signal-to-noise ratio values. The permeability of Nano star tracker AZDK-1 will decrease and the accuracy of determining orientation will decrease, accordingly.

Thus, the temperature range above 52°C (according to the internal temperature sensor) can be assessed as non-working and not recommended for use.

According to the test results, it is recommended to turn on the Peltier element at a seating temperature of more than 20°C.

Conclusion

The Nano star tracker AZDK-1 successfully completed functional, vibrodynamic and thermal vacuum tests. Flight tests of the MPD AZDK-1 are scheduled for the end of 2019.

Fig. 8 – Nano star tracker AZDK-1in the transport suitcase

Nano star tracker AZDK-1 in accuracy and mass-dimensional characteristics (see Table. 1) is not inferior to best foreign analogues at a cost 2-3 times lower. Nano star tracker AZDK-1 can be bought. More information on the company website www.azmerit.ru

References

1. Zakharov A.I., Prokhorov M.E., Tuchin M.S., Zhukov A.O. *Minimum Star Tracker Specifications Required to Achieve a Given Attitude Accuracy* // Astrophysical Bulletin. 2013. V. 68. P. 371-383.
2. Tuchin M., Zakharov A., Prokhorov M., Biryukov A., Nickiforov M. *On Random and Systematic Errors of a Star Tracker* // Proceedings of 27th Annual AIAA/USU Conference on Small Satellites. Logan: Utah State University. 2013. Id. 1-7.
3. Prokhorov M., Abubekerov M., Biryukov A., Stekol'shchikov O., Tuchin M., Zakharov A. *Star Tracker on Chip* // Proceedings of 27th Annual AIAA/USU Conference on Small Satellites. Logan: Utah State University. 2013. Id. 1-5.