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DESIGN SOURCE ERRORS ANALYSIS IN THE ANGLE MEASURE DEVICES TO THE PRECISION ANTENNAS

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Summary. The results of calculating the total error testing support rotation angle satellite antenna system. The analysis suggested calculating the optimum design rotation device, in which the total working angle of rotation error will not exceed 4'.

Key words: satellite antenna, azimuthal axis, angle sensor, resilient backlash, rotation angle error.

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Statement of the problem, its importance. Designing high precision systems for large-sized objects control designed for specified coordinates direction, tracking by given trajectories or detection of movable objects is an important problem for many branches of mechanical engineering, defense field. Particularly, this is relevant for the synthesis of the systems for superdirectional satellite antennas and satellite antenna systems control.

The important elements of such systems are devices for determination of the angular positions of antenna axes designed for precision measurement of the angles of the reflector beam directing and tracking the space objects by the antenna system. The efficiency of the entire antenna complex operation depends on the accuracy of measuring the absolute angular positions of the antenna axes position, since the angle measurement errors result in improper guidance and loss of communication with the satellite. Therefore, the task to detect and analyze the error sources in the designs of angle gage devices, as well as the units of their interfacing with the axes of antenna systems in order to minimize these errors is of great importance.

Analysis of the results and investigations of the problem. Numerous errors occurring in antenna systems and determining the total error of guidance of the electric axis of the antenna direction diagram (ADD) on the satellite are analyzed in many sources [1 – 2]. Mainly analysis of the errors of support-rotating device structures of SA (inaccuracy of the axes installation, deviation from the axes perpendicularity, deformation of SA structures under the influence of weight, etc.) is carried out.

With the development of space communication systems, radio monitoring, remote sensing of the Earth (RSE) in order to provide greater flow of information exchange, the SA designers move to higher frequency ranges from 8 GHz to 20 GHz (and more), and use parabolic antennas with large diameters of reflectors from 5 to 12 m, providing the narrowing of SA direction diagram and necessity to determine the angles of the antenna beam directing to satellites with errors that do not exceed 1 – 2 angular minutes. This demands the increased requirements for the accuracy of angle sensors, the use of advanced intelligent angular sensors [3 – 5], as well as the improvement in the interface units of angle measurement devices with antenna axes.

The objective of the paper. Analytical estimation of sources and total error of interface units of angular sensors in the structure of the support-turning platform of antenna devices in order to optimize the design and software – hardware minimization of errors of the SA pointing angle determination.

Analysis of the errors sources and calculation of the total error for angular position measurement devices. For precision measurements of the rotation angles of antenna system with 5 m reflector diameter, we designed the angle measuring device including an angle sensor and interface mechanism with the antenna axis.

The device is mounted on the support-rotating antenna platform and controls the angles of each axis rotation directly to the shaft without the use of any additional mechanical gears. According to the technical requirements, the error of angles follow-up should not exceed 4 (angular minutes). The optoelectronic angular sensor, designed by PV of TNTU with the resolution of 20 angle sec., and the total error up to 2 is used in the designed device. Therefore, the total kinematic error of the mechanism of the angle sensor shaft connection with the fixed antenna case (actuator of the angle sensor) should not exceed 2.

The version of the design of the corner-shaped device with the rigid bearing shaft and two couplings for interfacing with the axis of «Crystal-5m» SA, for which the control system has been developed by us, is shown in Fig.1.

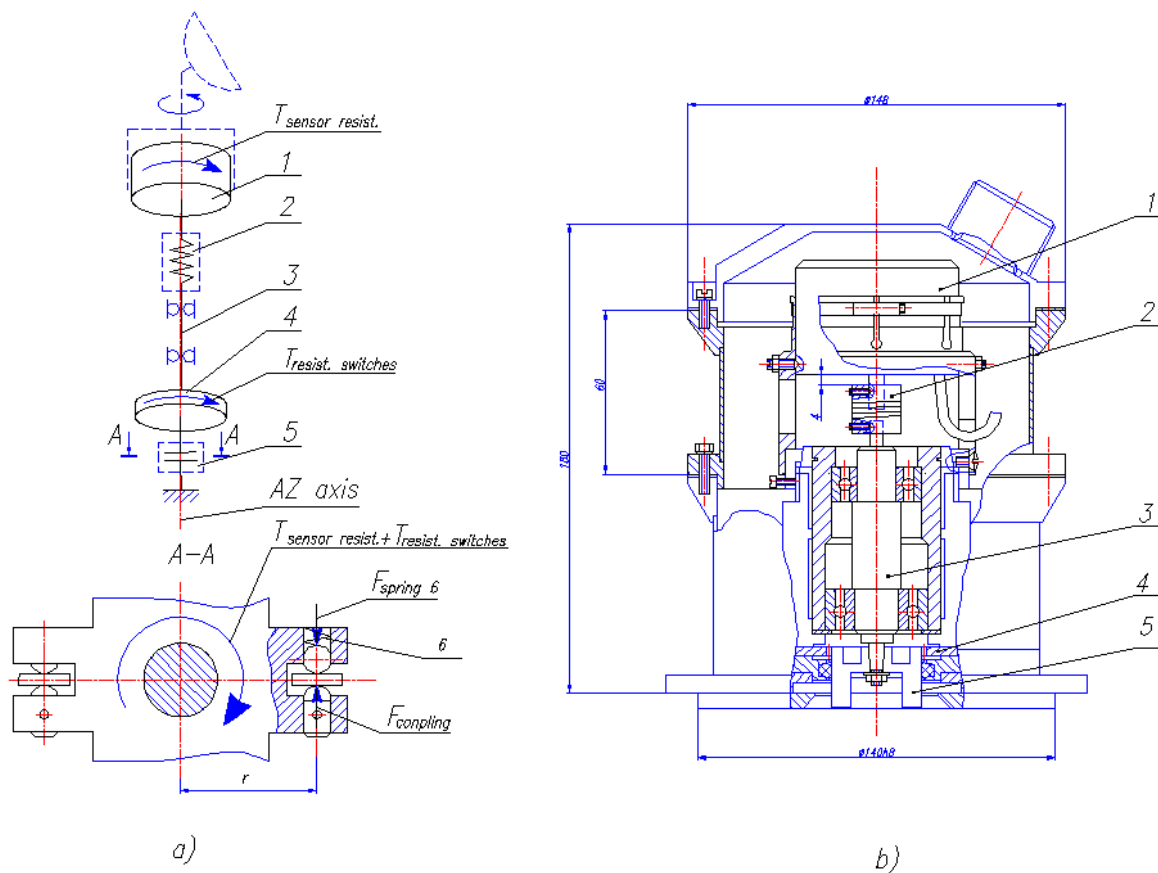


Figure 1. Scheme a) and construction b) angular measuring device with a rigid shaft and a flexible coupling

The designed device consists of the optoelectronic angle sensor with built-in microcontroller for the information processing 1 (intelligent sensor) [4] elastic coupling 2 compensating possible radial and angular inequality of the sensor output shaft and the rigid bearing shaft 3, and the hinge-cross coupling 5. The sensor driver construction is free from slack. Kinematic errors while measuring the antenna rotation angle occur only due to elastic deformations of the coupling 2 from the action of the friction moment $T_{\text{sensor resist.}}$ in the angle sensor supports 1 and the springs deformation 6 in the hinge-cross coupling 5 from the total moment $T_{\text{sensor resist.}}$ and resistance moment $T_{\text{resist. switches}}$ occurring in the final switches mechanism 4. When the antenna is reversible, these elastic deformations are doubling.

Results of the evaluation of errors sources of such construction version are given in Table.1. Calculations are made for two versions of the coupling 2: with elastic element in the form of spiral cylindrical threading and with ring cuts up to the half of the coupling diameter (has larger twist rigidity). It is also considered that optoelectronic angular sensors can be used in both versions: with sliding bearings and a cuff for sealing the output shaft (sealed, can be used under atmospheric conditions, it is experimentally investigated that their own resistance moment is 0.075 Nm) and with roller bearings (have their own moment of resistance forces 0.015 Nm).

Table 1

Calculation total error kinematic drive mechanism angular sensor with a rigid shaft and flexible coupling

1. Moment of sensor resistance forces 1 (shift effort)	$T_{sensor\ resist.}$	With sliding sleeves and seals		With rolling bearings	
		0,075 Nm		0,015 Nm	
2. Hardness when twisting elastic coupling	$C_{elastic\ coup.}$	Spiral threading	Ring cuts	Spiral threading	Ring cuts
		40 Nm/rad	250 Nm/rad	40 Nm/rad	250 Nm/rad
3. Strength of spring 6 of cross coupling 5	$F_{spring\ 6}$	10 N			
4. Arm r of the cross coupling 5	r	14 mm			
5. Moment of resistance forces of the final switches mechanism 4	$T_{resist.\ switches}$	0,075 Nm			
6. The minimum required force of the spring 6 when transmitted by the cross coupling 5 of the torque $T_{sensor\ resist.} + T_{resist.\ switches}$	$F_{coupling} = \frac{T_{sensor\ resist.}}{2r} + \frac{T_{resist.\ switches}}{2r}$	5,36 H ($F_{coupling} < F_{spring\ 6}$, then the spring deformation 6 and the elastic dead stroke of the coupling 5 are equal to zero)			
7. Twisting angle of the elastic coupling 2	$\varphi_{elastic\ coup.} = \frac{T_{sensor\ resist.}}{C_{elastic\ coup.}}$	6,4'	1,03'	1,2'	0,2'
8. Elastic dead stroke during reverse movement	$\Delta_{d.stroke} = 2\varphi_{elastic\ coup.}$	12,9'	2'	2,4'	0,4'

The version of the angle gage device design with long thin shaft and rigid coupling is shown in Fig. 2.

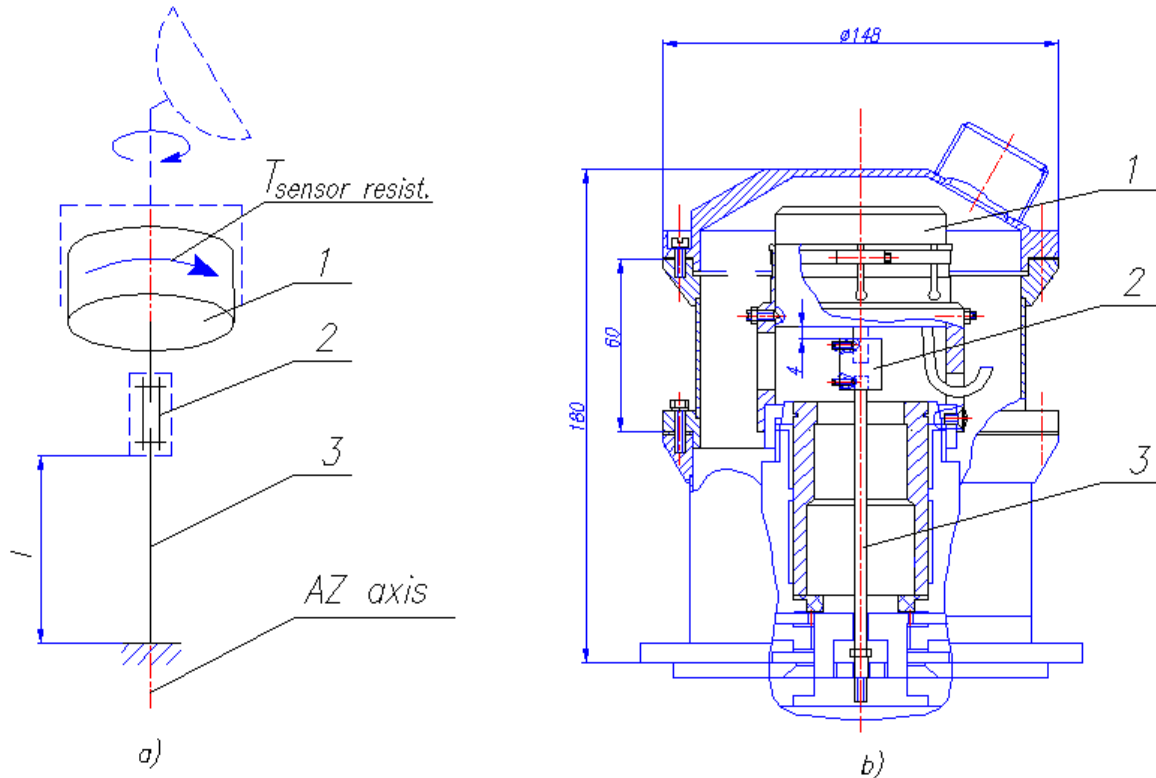


Figure 2. Scheme a) and construction b) angular measuring device with a thin Hučko shaft and deaf coupling

The peculiarity of this construction is that the shaft of the sensor 1 through the rigid coupling 2 and the thin steel shaft 3 with diameter $d = 6$ mm and operating length $l = 107$ mm direction is directly connected to the antenna body. There are no gaps in the connection. The permanent cross coupling (not shown in Fig. 2) connects to the fixed antenna case only final switches mechanism and is not affected by its error on the dead stroke of the sensor drive. The deformation of the fixed coupling 2 and the output shaft of the sensor are neglected. The possible inequality of the sensor shaft 1 and shaft 3 is compensated due to the elastic deformations of the thin, and, therefore, relatively flexible shaft 3. Unfortunately, the twisting angle of such flexible shaft from the resistance moment $T_{оп.дав.}$ in sensor supports is harmful. It will create the kinematic error in this design version of the angle gage device when measuring the antenna rotation angle.

Table 2

Calculation of total kinematic error Azimuth device with a thin flexible shaft coupling and deaf

1. Resistance forces moment of the angle sensor 1	$T_{sensor\ resist.}$	With slide bushings slip and seals	With roller bearings
		0,075 Nm	0,015 Nm
2. Length l and diameter d of the steel shaft 3	l d	$l=107\text{ mm};$ $d=6\text{ mm}$	
3. Modulus of elasticity at torsion	G	$8 \times 10^4\text{ MPa}$	
4. Polar moment of inertia of the shaft 3 cross-section	$I_p = \frac{\pi \cdot d^4}{32}$	$127,17\text{ mm}^4$	
5. Torsion angle of shaft 3	$\varphi =$ $= \frac{T_{sensor\ resist.} \cdot l}{G \cdot I_p}$	$2,75'$ $(0,0008\text{ rad})$	$0,54'$ $(0,00016\text{ rad})$
6. Elastic dead stroke at reverse motion	$\Delta_{d.stroke} = 2\varphi$	$5,5'$	$1,08'$

Conclusion. The total error of the rotation angle follow-up in the angular gage device do not exceed $4'$ only in the following cases: for the construction version shown in Fig.1 – in case the elastic coupling 2 with ring cuts is used, and the springs 6 loading should be not less than $5,36\text{ N}$; for the construction version shown in Fig.2 – in case the angle sensor with roller bearings is used.

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АНАЛІЗ ДЖЕРЕЛ ПОХИБОК КОНСТРУКЦІЙ КУТОВИХ ВИМІРЮВАЛЬНИХ ПРИСТРОЇВ У ВИСОКОТОЧНИХ АНТЕНАХ

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Резюме. Наведено результати аналітичного оцінювання джерел похибок та розрахунків сумарної похибки відпрацювання кута повороту різними конструкціями куткових вимірювальних пристроїв супутникових антен. Проаналізовано конструкції з жорстким валом на підшипниках кочення і двома компенсуючими муфтами та конструкції з тонким гнучким валом і однією глухою беззазорною муфтою. Представлені результати розрахунків свідчать, що мінімальної похибки (до двох куткових мінут) вузлів спряження куткових сенсорів з осями антени можна досягти в першому випадку (конструкція з жорстким валом на кулькових підшипниках) тільки при застосуванні куткових сенсорів з підшипниками кочення та пружної муфти з кільцевими надрізами, яка має більшу крутильну жорсткість. А в другому випадку (конструкція з тонким гнучким валом і глухою беззазорною муфтою) – при застосуванні куткових сенсорів з підшипниками кочення. Враховуючи, що варіант кутомірного пристрою з гнучким валом має простішу конструкцію і меншу кількість вузлів, що можуть бути потенційним джерелом похибок відпрацювання кута повороту (наприклад, відсутня шарнірно-хрестова муфта, а замість пружної муфти на вихідному валу сенсора застосована беззазорна глуха), цьому варіанту слід надавати перевагу. В дослідженні оцінювались тільки похибки вузлів спряження вихідних валів куткових сенсорів з осями антени. Похибки самих куткових сенсорів при розрахунку сумарної похибки кутомірних пристроїв приймалися однаковими, тому що у всіх розглянутих конструкціях застосовувалися розроблені на кафедрі ПВ ТНТУ оптоелектронні кутові сенсори із загальною похибкою, що не перевищує двох куткових мінут. На основі аналізу розрахунку запропоновано оптимальну конструкцію кутомірного пристрою, в якій сумарна похибка відпрацювання кута повороту не буде перевищувати 4' (кутових мінут).

Ключові слова: супутникова антена, азимутальна вісь, давач кута, пружний мертвий хід, похибка кута повороту.

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