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Research on Geometric Errors of Intermediate Unit Shell of a Geokhod

A V Walter[1], I F Borovikov[2], R V Chernukhin[1], S S Nozirzoda[1]

[1] Yurga Institute of Technology, TPU, 26, Leningradskaya Str., 652050, Yurga, Russia
[2] Bauman Moscow State Technical University, 5/1, ul. Baumanskaya 2-ya, 105005, Moscow

E-mail: avwalter@rambler.ru

Abstract. This article includes the research results on production errors of intermediate unit shell of a geokhod prototype model. There has been a problem stated concerning the accuracy of geokhod shells; constructive and technological particularities of a intermediate unit have been specified. A short summary has been conducted of the types of approach to the determination of shell errors of large equipment. The research was performed on the basis of data received by means of coordinate control of a gekhod prototype model in a production environment. The captured data have been researched by means of statistical methods and analyzed with the purpose of unveiling the factors affecting the errors. It was showed in the article that the errors can be partially explained by the production errors of body sectors and the errors of their relative assembling position. It was demonstrated that at least a part of errors is conditioned by reasons which are not taken into account in the process of a pure geometric description of the intermediate unit manufacturing process.

Introduction

The intermediate unit is one of the most responsible assembly units of a gekhod. It takes up high loads from the transmission as well as from the geological environment [1]. From the technological point of view, the intermediate unit is the most precise large-sized assembly unit of a gekhod characterized by a high unit man-hours and significant labor costs for mechanical handling and assembly [2]. As for construction, the intermediate unit consists of two coupled solids of revolution — a body and an outer body (Figure 1). Each of the bodies consists of four sectors which are tridimensional welded assemblies divisible into shell rings, flanges, stiffening elements and transmission interworking elements.

In the work process, the outer body of the intermediate unit is driven around the body by the transmission; and its shell interacts with the geological environment [3]. In the process of gekhod exploitation, the intermediate unit shell goes a long distance against the surrounding massive material; this leads to its significant wear which can result in structural and rigidity failure of the whole construction as well as in an abnormal performance of responsible elements of the power system assembled inside the geokhod body [4]. This is a serious problem because the increase of wear-resistance of the shell by means of known technological methods analogous to the ones described in [5], [6] is hindered due to a big extension of shell surface.

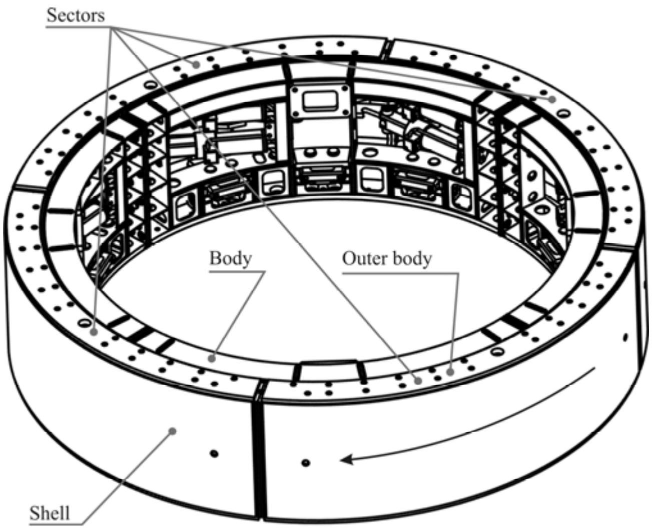

Figure 1. General view of the intermediate unit.

Wear rate depends on many factors; among these is the distribution pattern of bearing pressures on the shell surface. The rate, the character and the permanence of bearing pressures immediately depends on the shell form. The distribution of bearing pressures affects the forces that influence the transmission [7] as well as conditions energy loss connected with the resistance to traction [8].

When researching these issues, it is necessary to consider not the designed shell form but its actual form conditioned by the errors that appear in the process of its manufacture. As follows from model [9], geometric errors of geokhod shells can reach large values and depend on the particularities of the body assembly realization. Similar models based on the consideration of allowances of the form of coupled surfaces are represented in work [10], [11]. In work [12], it was mentioned that the accuracy is also affected by the intermediate sequence of elements in ring-type products. The listed models do not take into account the factors that are able to influence shell accuracy because they are based solely on the geometric approach. At the same time, the manufacturing practice of such products shows the necessity to count some hardly simulated factors, such as welding deformations [13], as well as to count a complex character of mutual influence of various factors on the combined error. Currently implemented project of launching into manufacture of a geokhod model FYURA.612322.401 allows to estimate the rate and the character of actual geometric errors of the intermediate unit shell taking into account a real production environment.

Thus, we should set the following task: to determine the values of geometric errors of the intermediate unit shell of a geokhod prototype model as well as to unveil their character.

2. Research methods

In order to solve this task, we researched on the outer body of the intermediate unit of a geokhod prototype model FYURA.612322.401. The research was conducted by means of coordinate measurement using a mobile coordinate-measuring machine (CMM) FARO Arm Edge 9. The body of the intermediate unit was mounted onto the control plate against the frontal flange. The CMM was mounted onto the plate next to the body. Due to large dimensions of the researched object, the measurement was conducted in four different CMM positions. In order to bring all coordinates received in various positions into a single coordinates system, each CMM position was bound by means of calibration cones. As a result of measurement, a data set has been formed including the coordinates of the points uniformly spread over the shell surfaces (Figure 2).

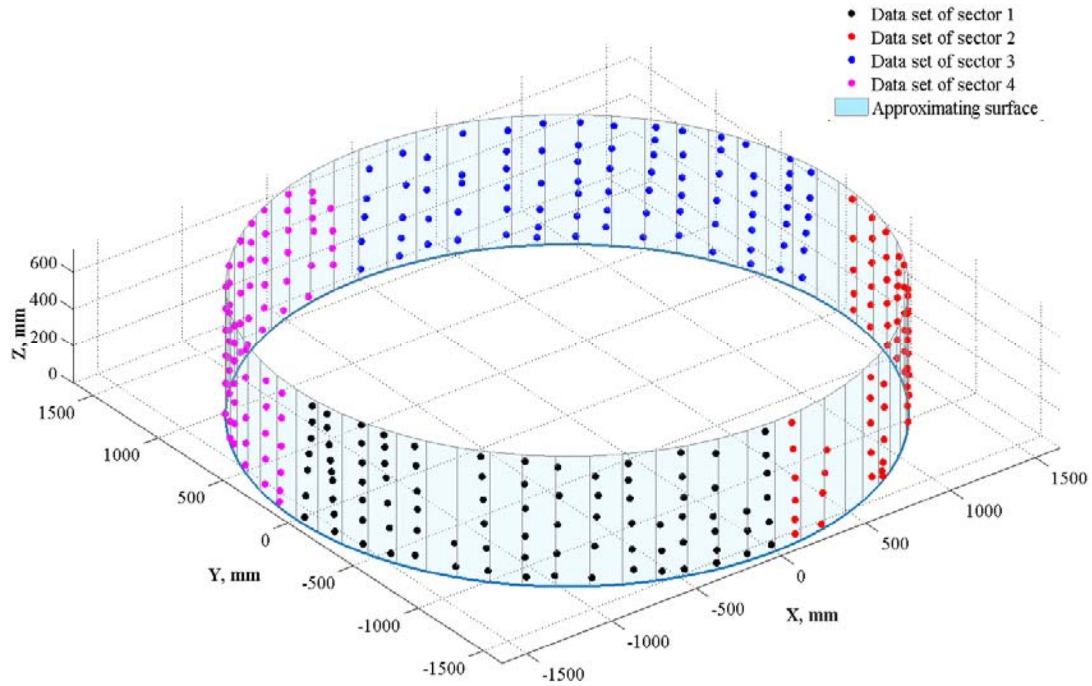

Figure 2. Measurement data sets of the intermediate unit shell as well as approximation cylinder.

For the analysis and the definition of error values of the position of sectors, a specially developed software was used. The coordinates data of the points were imported into the program and automatically split into four data sets according to each of the sectors. Further, based on the data sets, there were regression cylindrical models created and researched. The surface models were defined on the basis of the following regression equation:

$$\sqrt{A^2+B^2+C^2}-r+\varepsilon_i=0;\ a_x^2+a_y^2+a_z^2=1;$$
$$A=-a_y z_i-a_z(y_0-y_i);\ B=a_z(x_0-x_i)+a_x z_i;\ C=a_x(y_0-y_i)-a_y(x_0-x_i); \quad (1)$$

x_i, y_i, z_i are the coordinates of approximated points; a_x, a_y, a_z are the coordinates of the axis vector of the approximation cylinder; x_0, y_0 are the coordinates of the point through which goes the axis of the approximation cylinder; r is the approximation cylinder radius; ε_i are the residuals of the regression model.

The regression coefficients in equation (1) have been defined according to the method of Gauss [14]. There were five models of cylindrical surface created: one was based on the whole measurement data set, and four were based on data sets for each of the sectors. The research of the model based on the whole data set allows to define the values and the character of shell deviations in general. The research of models based on each of the sectors allows to estimate the value of deviations connected with the manufacturing errors of shell rings and the error of their relative position, as well as to define the rate and the character of errors not connected with above mentioned factors. The models were researched by means of calculation of general geometric characteristics, definition of typical statistic characteristics in the residual model rows as well as by means of correlation and regression analysis of residual rows in the sequence described in work [15].

After the coefficients of equation (1) were calculated, the coordinates of the points in the data set were transferred from the coordinates system XYZ created in the process of measurement into the coordinates system UVW connected with the axis of the corresponding cylindrical surface model (axis W of the new coordinates system must match the rotational axis of the cylinder. The transformations were performed using homogeneous coordinates and a generalized mapping grid:

$$\begin{bmatrix} u_1 & \dots & u_n \\ v_1 & \dots & v_n \\ w_1 & \dots & w_n \\ h_1 & \dots & h_n \end{bmatrix} = \begin{bmatrix} u_x & v_x & a_x & x_0 \\ u_y & v_y & a_y & y_0 \\ u_z & v_z & a_z & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 & \dots & x_n \\ y_1 & \dots & y_n \\ z_1 & \dots & z_n \\ 1 & \dots & 1 \end{bmatrix} \tag{2}$$

u_i, v_i, w_i, h_i are homogeneous coordinates of the points in the coordinates system connected with the axis of the approximation cylindrical surface; x_i, y_i, z_i are the coordinates of the points in the coordinates system created in the measurement process; u_x, u_y, u_z and v_x, v_y, v_z are the coordinates of directional vectors of the axles U and V respectively.

The vectors of axles U and V were set following the condition that the data set for each of the sectors would get into one octant of the coordinates system UVW. Moreover, vectors and theirs components are interconnected in the following way:

$$u_z = 0;\ u_x^2 + u_y^2 = 1;\ \mathbf{v} = \mathbf{u} \times \mathbf{w};\ \mathbf{w} = \mathbf{a} = \begin{bmatrix} a_x & a_y & a_z \end{bmatrix}^T \tag{3}$$

Following equations were used in order to define the deviances of the position of the sector against the mutual axis of the cylinder:

$$\cos\alpha = \mathbf{w}_\Sigma \cdot \mathbf{w}_S;\ \cos\beta = \mathbf{n}_{inc} \cdot \mathbf{v}_\Sigma;\ \mathbf{n}_{inc} = \frac{1}{\left|\mathbf{w}_\Sigma \times \mathbf{w}_S\right|} \mathbf{w}_\Sigma \times \mathbf{w}_S;\ \mathrm{tg}\gamma = \frac{x_0}{y_0};\ d = \sqrt{x_0^2 + y_0^2} \tag{4}$$

α – sector canting angle, β – sector canting surface angle; γ – direction angle of the dislocation of the sector axis in the reference plane; d – dislocation of the sector axis in the reference plane; $\mathbf{v}_\Sigma$, $\mathbf{w}_\Sigma$ – directing vectors of axles V and W of the coordinates system connected with the axis of the mutual cylinder; $\mathbf{w}_S$ – directing vector of axis W of the coordinates system connected with the axis of a separate sector; $\mathbf{n}_{inc}$ – normal vector of the plane of the largest bend of a sector (see Figure 3).

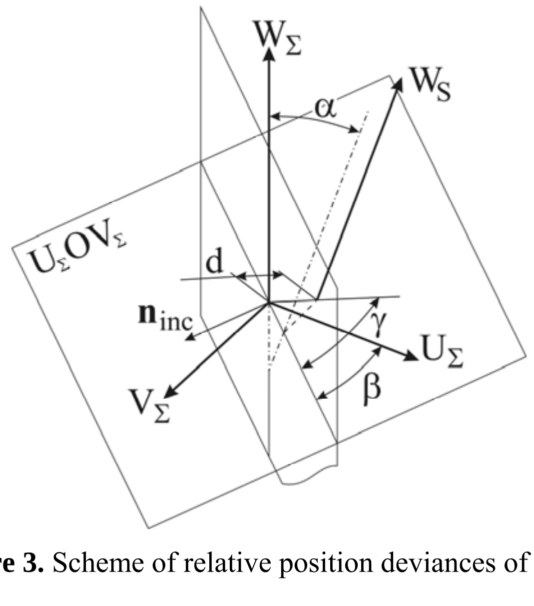

Figure 3. Scheme of relative position deviances of axles.

3. Results and discussions

The approximation results of point sets of the shell surface in general and for separate sector are represented in Table 1. The analysis of error values shows that the sectors of the body significantly differ by their actual dimensions, however, the errors are situated within defined allowances. The error value is close to the limit (10 mm per radius). The sectors are bent with different angles, in different directions as well as dislocated to different distances against the mutual axis.

Table 1. Parameters of model surfaces.

Parameter	The whole shell	Sector 1	Sector 2	Sector 3	Sector 4
Radius of the approximation cylinder, mm	**1,598.23**	**1,601.93**	**1,601.44**	**1,597.13**	**1,602.06**
Number of measured points	**311**	**90**	**64**	**83**	**74**
Standard deviation, mm	**1.72**	**0.92**	**0.94**	**0.70**	**0.68**
Maximal deviation, mm	5.26	2.42	2.11	2.23	1.92
Minimal deviation, mm	-4.22	-1.82	-2.29	-1.55	-1.63
Sector canting angle – α, deg	0	0.326	0.551	0.422	0.431
Sector canting plane angle – β, deg	0	157.272	-155.484	-51.954	55.645
Angle of dislocation direction of the sector axis in the reference plane – γ, deg	0	-131.666	24.363	-135.94	118.77
Dislocation of the sector axis in the reference plane – d, mm	0	2.17	3.82	3.96	1.28

The dislocations reach significant values comparable with allowances for shell manufacturing. Moreover, the fact is interesting that facing sectors are dislocated unidirectionally which is mostly obvious in the case of sectors 1 and 3. This effect is apparently connected with the particularities of sector position alignment in the process of assembly: the sectors are positioned not by the general base, but by their relative position. In order to define the possibility of explanation of the errors of intermediates unit shell with the manufacturing errors and relative position of sectors, the dependence curves were built of the radius of measured points against the axis of the mutual cylinders along the angular coordinate θ (Figure 4) and the height coordinate W (Figure 5).

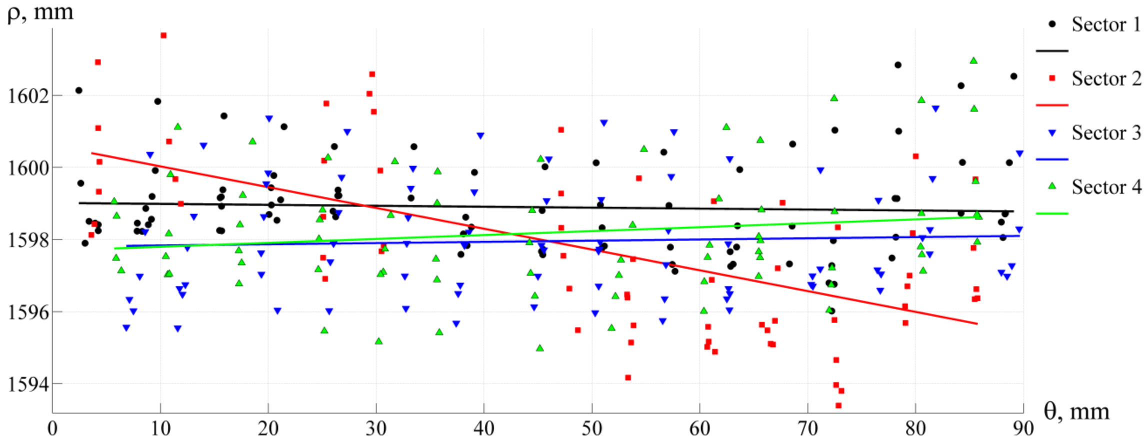

Figure 4. Dependence of the radius of measured points against the axis of the mutual cylinder along the angular coordinate *θ*.

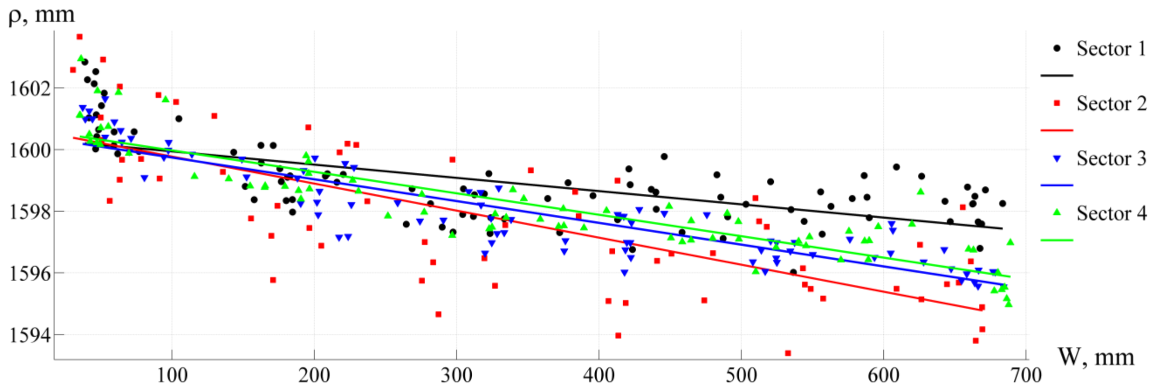

Figure 5. Dependence of the radius of measured points against the axis of the mutual cylinder along the height coordinate *W*.

As follows from the curves in Figure 4, for all sectors except sector 2, the dependence of the radius on the angular coordinate is hardly recognizable. At the same time, as follows from Figure 5, there is a marked dependence of the radius on height W.

The analysis of residual rows of sector models (Figure 6, Figure 7) shows the lack of an expressed trend. This gives evidence that at least a part of shell errors can be explained by the manufacturing errors of sectors and the inaccuracy of their relative position in the process of assembly.

At the same time, the results of the statistical model analysis represented in Table 2 show that, apart from the above stated reasons, the shell errors can be affected by other factors not counted in the model and provoking systematic errors. This can be verified by the presence of auto-correlation in the most residual rows as well as by the presence of a significant correlation in some rows.

The residuals follow the normal distribution law and are random according to the criteria of turning points test; thus, sector models adequately enough describe the character of geometric errors of the shell and explain about 50 per cent of the cumulative error value.

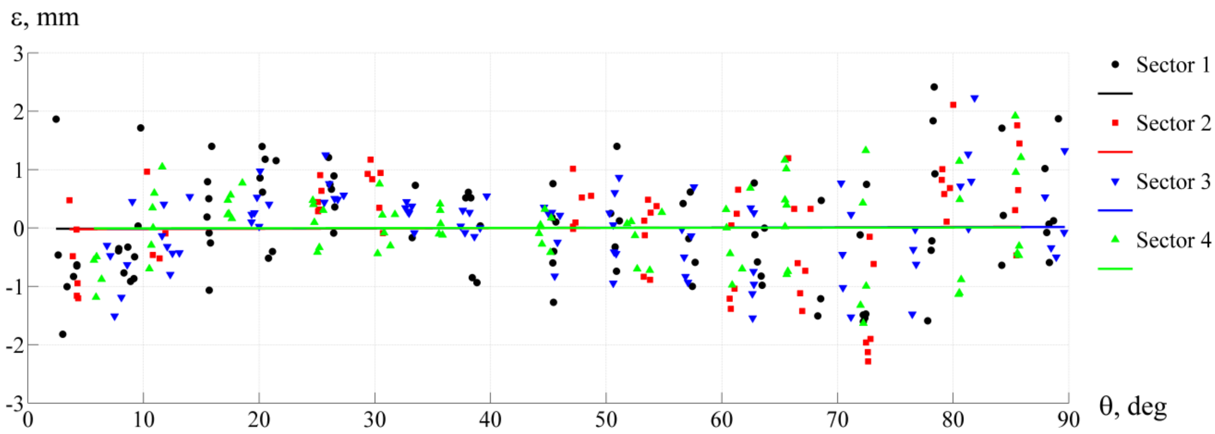

Figure 6. Residual rows of sector models along the angular coordinate *θ*.

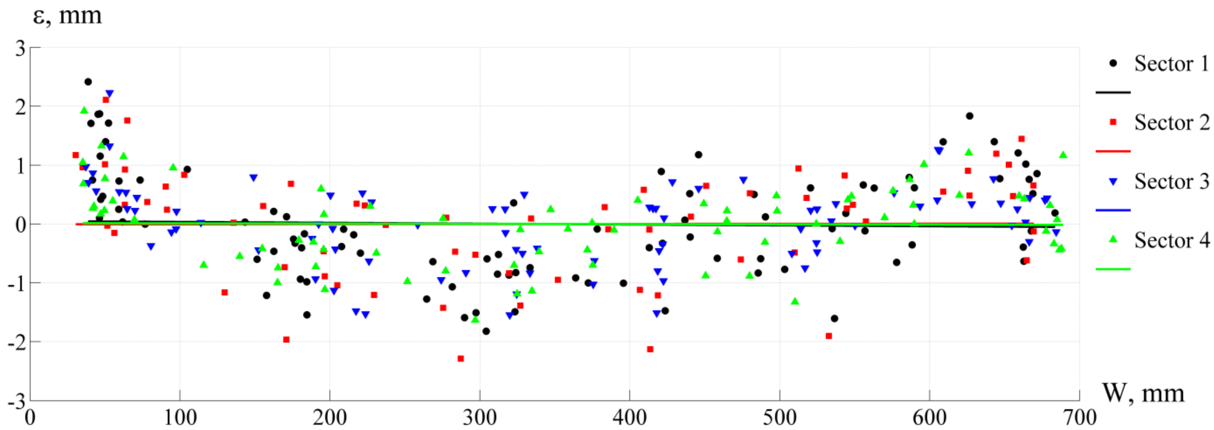

Figure 7. Residual rows of sector models along the height coordinate *W*.

Table 2. Results of statistical analysis of sector models.

Qualitative characteristic	Sector 1	Sector 2	Sector 3	Sector 4
Lack of significant correlation of residuals along *θ*	Yes	No	Yes	Yes
Lack of significant correlation of residuals along *W*	No	No	No	No
Normality of residual rows according to Jarque-Bera test	Yes	Yes	Yes	Yes
Randomness of residuals according to turning points test along *θ*	Yes	Yes	Yes	Yes
Randomness of residuals according to turning points test along *W*	Yes	Yes	Yes	Yes
Lack of auto-correlation according to Durbin-Watson test along *θ*	No	No	No	Yes
Lack of auto-correlation according to Durbin-Watson test along *W*	No	Yes	No	No

4. Conclusion

- The coordinates control of the outer body shell of the intermediate unit of a geokhod prototype model showed that the error values are close to the limit which can negatively affect the quality of products in serial production.
- A significant part of cumulative error of the shell can be explained by the production errors of body sectors and the error of their relative position in the process of assembly.
- The statistical analysis of sector models suggests that the manufacturing errors of body sectors and the errors of their relative position in the process of assembly are not the only significant factors in the formation of shell errors of the intermediate unit.

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