Design and technological support for the assembly of long thin-walled buildings

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Abstract. The article considers the issue of design and technological support for the assembly of extended thin-walled buildings, in particular, the problem of ensuring their entry into the reciprocal parts that ensure the functioning of the assembled products. A new method for controlling the size of the entry of buildings is proposed. The objective of the technical solution is to reduce the complexity of control of the hulls while ensuring their entry into launch tubes. The method consists in the fact that the housing is installed in two prisms according to the extreme centering thickenings. The readings of the measuring device are taken, which judge the suitability of the housing by the diameter of the adjacent cylinder, characterized in that the indicator is installed in a plane perpendicular to one of the faces of the prism, adjusted according to the standard when touching the tip of the middle centering thickening of the standard. As a result of testing in the conditions of the current production, it was found that the verification of the product is reduced several times.

1. Introduction

The conducted studies prove that to ensure the entry of the rocket engine into the starting guide, the designer must take into account the assembly conditions, which allows one to expand the tolerances on the geometric dimensions of the joined sections and the dimensions of the mating surfaces. The designer must determine the accuracy of the initial mutual position of the parts and the sequence of actions (movements of a particular part), as a result of which the required accuracy of the mutual position of the assembled parts can be achieved. If the designer does not give recommendations on the choice of the assembly method, the technologist uses the standard assembly methods applicable for this class of products and is not able to ensure guaranteed product fit, as the conditions for screwing together the parts laid down by the designer, as a rule, have a fairly wide tolerance. Therefore, in order to reduce the percentage of rejects, technologists are forced to introduce technological tolerances on the connection parameters, tightening design tolerances by a factor of 1.5-2.

Thus, the entire technological effect obtained by the designer from expanding tolerances is reduced to zero by the technologist, otherwise the latter is forced to increase labor intensity by introducing into the technological process the operations of sorting or selecting parts before assembly. The latter process, as a rule, is left to the hands of a highly skilled labor collector, who, on the basis of one’s intuition, by successive selection by the test method, achieves a suitable assembly. Therefore, the designer must lay the base surfaces in the product with the accuracy necessary to achieve the desired relative position of the parts after assembly. To ensure suitability, it is technologically necessary to
withstand the requirements laid down by the designer.

2. Materials and methods
There are a number of products with prefabricated cylindrical bodies, which differ from most engineering structures by the presence of a centering thickening in the middle of the body, the diameter of which is smaller than the diameters of the base extreme centering thickenings. For such cases, the general principle of interchangeability is not applicable based on a comparison of the diameters of adjacent cylinders (GOST 31254-2004, GOST 30893.2-2002); therefore, there is a method for directly monitoring the suitability of an assembled extended cylindrical body, for example, a jet engine body, along adjacent contours [1, 2].

3. The study of the influence of errors in the shape of the base surfaces of the precast housing in the form of ovalities
To ensure the functioning of the studied products, it is required to guarantee the case enters the launch guide. Free entry is determined by the presence of a gap between the adjacent cylinder of the housing and the adjacent cylinder of the starting guide.

As generalized boundaries, covered and covering real elements, adjacent surfaces and element profiles are accepted. From adjacent surfaces and profiles, the deviations of the shape of the surfaces are counted towards the body of the part. In this regard, the condition for the entry of simple geometric bodies having a considerable length, characterized by the ratio of length to diameter: L/D > 10. Figure 1 shows a diagram of the position of the housing in the start guide.

![Figure 1](image)

**Figure 1.** Scheme of the position of the housing in the start guide: 1 - prefabricated extended cylindrical body; 2 - starting guide.

Figure 1 shows that in order to comply with the principle of interchangeability of the housing and the starting guide, the condition:

\[
\begin{align*}
&d_1 < D_{pr.min} > d_2, \\
&0.25(d_1 + d_2) + 0.5d_3 + EF_{reh} + EF_{ovreh} = d_{reh} < D_{0dd} = A_0
\end{align*}
\]

where: \(D_{0min}\) - minimum diameter of the starting guide, \(d_1, d_2\) - diameters of extreme centering thickenings, \(d_3\) - diameter of the middle centering bulges, \(A_0\) - diameter of the cylinder of zero curvature of the starting guide; \(d_{reh}\) - step housing entry size; \(EF_{reh}\) - body axis curvature; \(EF_{ovreh}\) - the sum of the projections of the ovality of the centering thickenings of the body on the vector \(EF_{reh}\). If one critical section is laid in the structure in the housing, which ensures guaranteed entry of the housing into the launch guide, then the control method can be easily implemented using the installation used to control radial runout in the current production. In the current production, as a rule, roller prisms are used, since they facilitate the control process and do not damage the surfaces of the product being monitored, since there is no sliding of the product surfaces relative to the prisms. The
diameter of the rollers is selected so that they simulate a 90° prism, so that the subsidence of the axes of the base surfaces would be minimal. When controlling the radial runout, the housing is installed in two prisms according to the centering thickenings, and the radial runout of the average centering thickening is determined by the indicator installed in the plane of the bisector of the angle of the prisms, the average thickening [3].

The actual size of the housing entry can be expressed from the second equation of the system (1), replacing the diameters of the centering bulges \( d_1, d_2, d_3 \) twice the size of the minor axes of the ellipses of the corresponding centering thickenings \( b_{1,2,3} \):

\[
d_{0,ref} = 0.5(b_1+b_2) + b_3 + EF_{reh} + EF_{ovreh}. \tag{2}
\]

In equation (2) a priori it is assumed that the curvature vector of the axis of the housing \( EF_{reh} \) perpendicular to the measuring base, as from the experience of indirectly checking the size of the entry by measuring the radial runout of the average centering thickening, in almost all cases they coincide.

It is more difficult to establish the value and direction of the total vector of projections of the ovality of the centering thickenings of the body on the vector \( EF_{reh} \cdot EF_{ovreh} \).

According to the rules of mathematics, the projection of the sum of vectors in a given direction (in the case under consideration on the Y axis) in accordance with the gear ratios of the diameters on the size of the occurrence is determined by the dependence:

\[
EF_{ovreh} = 0.5(EF_{ovreh1} \cdot \sin \varphi_1 + EF_{ovreh2} \cdot \sin \varphi_2) + EF_{ovreh3} \cdot \sin \varphi_3. \tag{3}
\]

On the right side of equation (3) are 6 independent quantities. Tolerances for ovality of centering thickenings are given, usually such values are distributed according to the Rayleigh law. Phase angles of inclination of the major semi-axes of elliptical sections, respectively, of the centering bulges 1, 2, 3 relative to the measuring base when controlling the size of the entry \( \varphi_{1,2,3} \), obey the uniform distribution law. Equation (3) shows that the ovality of the centering thickenings have some effect on the size of the entry. It is difficult to predict such an effect due to the combination of the influence of six random variables. In such cases, it is advisable to use a statistical study of the influence of errors or mathematical modeling of this effect [4].

In indirect control of the entry size by measuring the radial run-out of the average centering bulge of the assembled case, only the ovality of the centering bulge 3 is affected by the readings, and the influence of the ovality of the centering bulge 1 and centering bulge 2 is hidden by using the special properties of prisms with an angle of 90°.

If the linear displacement sensor 3 is installed at an angle of 45° to the bisector of the angle of the prism 1, that is, perpendicular to one of the faces of the prism, then the actual case entry size will be measured directly \( d_{0,ref} \). To configure the indicator, we use standard 2, which is made close to the nominal dimensions of the case (Figure 2).

Figure 2 shows that the method for directly controlling the diameter of the adjacent body contour directly takes into account the influence of all six random components of equation (3), therefore, the shape error of all centering thickenings of the body and their phase angles do not create errors in determining the size of the entry by the studied method.

In equation (2) it is assumed that the curvature vector of the axis of the housing \( EF_{reh} \) directly affects the size of the entry, however, the displacement of the center of the centering thickening 3 relative to the common axis of the body, realized by the axis \( OO_3 \), passing through the centers of the extreme centering thickening 1 and centering thickening 2, causes the axes of the pipes making up the assembled body to skew (Figure 3).
Figure 2. The control scheme for the size of the entry of the case: 1 - prisms; 2 - standard; 3 - indicator.
Figure 3. The scheme of the influence of the skewness of the axes of the pipes of the assembled housing on the error in measuring the size of the entry

Housing pipes are connected using threaded half-locks, including threaded threads, short centering bands and ends. In the connection, both parallel displacements of the axes and their skew are possible [5, 6]. Typically, prisms are located approximately in the middle of the length of the centering bulge at a distance $L_{b1}$ and $L_{b2}$ from the edge of the pipes, so there is a shift in the line 1-1 of the size control (Figure 3) relative to the line that serves as the reference $d_{wobf}$ on the product [7, 8]. Measurement error $EFd_{wobf1,2}$ is approximately determined by:

$$EFd_{wobf1,2} = 0.5(EFd_{wobf1} + EFd_{wobf2}),$$  \hspace{1cm} (4)

where: $EFd_{wobf1} = L_{b1}\psi_1, EFd_{wobf2} = L_{b2}\psi_2$ - size measurement errors from “sagging” of the product in prisms; $L_{b1}$ and $L_{b2}$ - distance to the base section from the ends of the pipes 1 and 2.

Equality can only be exact when $EFd_{wobf1} = EFd_{wobf2}$, when lines 1-1 and 2-2 are parallel, and the corners $\psi_1 = \psi_1^*$ and $\psi_2 = \psi_2^*$ tilt axes of pipes with an axis of control (reference of the size $d_{wobf}$) are equal.

Offset control plane distance $L_{jc}$ from the junction plane, leads to measurement error:

$$EFd_{wobf1} = L_{jc}\psi_1,$$  \hspace{1cm} (5)

where: $L_{jc}$ - distance from the control plane to the joint plane of the joined pipes (to the edge of the surface to be monitored); $\psi_1$ - the angle of inclination of the axis of the first pipe with the axis of control [9, 10].

To determine the order of angle values $\psi$, combinations of sizes and tolerances on a typical case are considered: pipe lengths of about 1000 mm, lengths of centering thickening 1 and centering thickening 2 - about 80 mm, maximum allowable radial runout of the average centering thickening 3 - 0.5 mm, from where the permissible curvature of the body axis is 0.25 mm.

Figure 3 defines:

$$\sin \psi_1 \approx \sin \psi_2 = \frac{TEFd_{wobf}}{L},$$  \hspace{1cm} (6)

where: $L$ - pipe length.

Substituting the numerical values of the components (6) into the equation, we obtain the maximum possible value $\sin \psi_1 \approx \sin \psi_2 \approx \frac{0.25 \cdot 1000}{1000} = 0.00025$. given that at small angles the functions of the sine, tangent, and angles in radians are equal, we get $\psi_1 \approx \psi_2 \approx \psi_3 = 0.00025 \, \text{radian} = 0.143^\circ$.

$EFd_{wobf1} \approx EFd_{wobf2} \approx 0.00025 \cdot 40 = 0.01 \, \text{mm}$. 

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Similarly, we find this by the formula (5) - $EFd_{0reh} \approx 0.01 \text{ mm}$. In this case, the total error of measurement of the size of the entry caused by the misalignment of the axes of the pipes of the housing is determined from the expression:

$$EFd_{0reh} = 0.5(EFd_{0reh1} + EFd_{0reh2}) + EFd_{0reh3},$$

substituting into which the maximum possible values of the components $EFd_{0reh1} \approx 0.01 \text{ mm}$, we get $EFd_{0reh} \approx 0.02 \text{ mm}$.

As a rule, we set the real value of the angles $\psi_1$ and $\psi_2$. In practice, it is impossible; therefore, it is possible to take into account the measurement error only using the calculated limiting angles $\psi_1$ and $\psi_2$, tightening size tolerance $TEFd_{0reh}$ when setting up the device.

To reduce the measurement errors of the case entry size $d_{0reh}$ during control, prisms should be installed as close as possible to the edges of the case. However, they should not go beyond it; therefore, the distance from the edge of the base centering bulges is taken to be at least 2-3 mm, which usually corresponds to the error $EFd_{0reh1,2} \approx 0.001 \div 0.00075 \text{ mm}$.

4. Conclusion

A study of the design and technological support for the assembly of extended thin-walled cases allowed us to develop a new way to control the size of the entry of thin-walled buildings, showing that the existing ovality of the centering bulges has a significant effect on the size of the controlled size, but do not affect the accuracy of its measurement.

When using the traditional arrangement of supporting prisms, approximately in the middle of the length of the extreme centering bulges, the skewness of the axes of the bodies significantly affects the error in measuring the size of the entry. With the maximum permissible radial runout of centering thickenings, a measurement error of up to 0.02 mm is obtained.

To reduce the control error, it is necessary to place the elements as close as possible to the edges of the parts to be joined. When testing, it is recommended to use an extended contact, which should overlap the joint to determine the size of the entry on two adjacent surfaces (two parts or one).

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