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FEATURES OF PROCESSING AND ASSEMBLY OF COMPOSITE PRODUCTS

Igor DERYABIN[1*], Viktor GUZEEV[2], Alexander KOZLOV[3], Dmitrii ARDASHEV[4]

[1,3]Zlatoust branch of South Ural State University, Department of Engineering Technology, Zlatoust, Russian Federation
[2,4]South Ural State University, Department of the Technology of Automated Mechanical Engineering, Chelyabinsk, Russian Federation

E-mail: deriabin-ip@susu.ru[1], guzeevvi@susu.ru[2], kozlovav@susu.ru[3], ardashevdv@susu.ru[4]

Abstract: The paper examines the assembling of cylindrical products consisting of sector parts with dihedral angles. A crucial issue in the assembly of such parts is the accuracy of dihedral angles during processing. Based on methods of analytical geometry, we proved that in order to achieve gapless assembly of three sectors, the sum of all dihedral angles of the sectors should be less than or equal to 360°. Since it is impossible to ensure the exact equality of the sum of all dihedral angles of 360°, characteristic "flatness deviation" is always formed during assembly. In order t obtain a gapless connection, we propose a new method for the selective assembly of sectors and developed a scheme of the dihedral angle controller. This selective assembly method will allow sectors to be selected in such a way that their "twist" angle in the assembled conditions is minimal.

Keywords: *assembly technology, sector parts, dihedral angle control, conditions for gapless connection of three sectors.*

Introduction. Product quality, reliability, and durability depend on the accuracy of mating parameters. This can be increased by:

– Increasing the accuracy (reducing tolerances) of the surface treatment of mating parts that form the product;

– Selective assembly based on the complete interchangeability method.

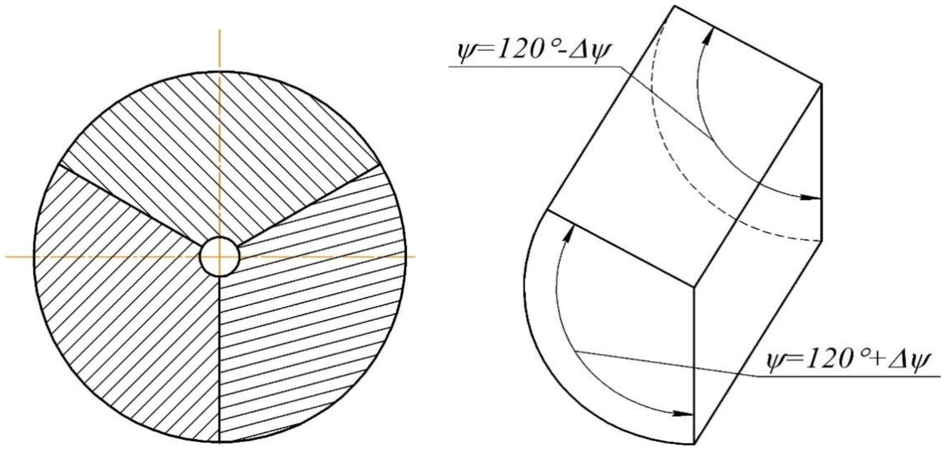
The first option is largely related to the resources of technological equipment. Therefore, in some cases, when these resources are exhausted, then selective product assembly is important. Its essential objectives are to complete and obtain assembly kits. Most of the existing methods are designated for the assembly of two shaft-sleeve parts, i.e., mating of the female face to the male face. The assembly of three or more parts is underexplored. Additional difficulties arise when mating open surfaces, for example, the planes of dihedral angles.

The processing of composite products has its own specific features associated with the errors of some parameters. This is relevant both for the parts themselves and the assembled product [1–4]. Such products include propellers, turbine blades, some types of projectiles, etc. Let us consider these features using the example of processing and assembly of a product consisting of 3-sector parts (hereinafter referred to as sectors) (Fig. 1a). The main sector processing errors which affect the product assembly are errors of the dihedral angle ψ ($\Delta\psi$ is the angle processing tolerance) and the errors of the arc radius R (Fig. 2b).

In order to determine the capabilities of the sector assembly process, let us analyze the conditions for the unambiguous positioning of the assembled form and the very capability of assembling sectors without a gap between the planes of the dihedral angle.

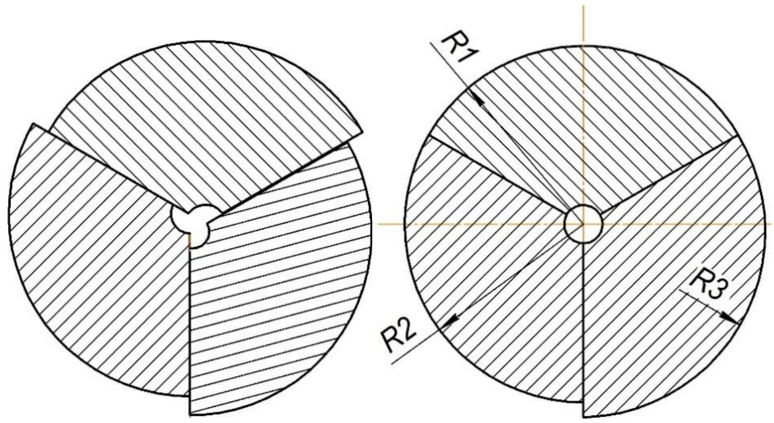
If all the dihedral angles of the sectors ψ are exactly equal to 120°, then we can assume that gapless binding is possible with small deviations from the flat surface accuracy of their side faces (Fig. 1a). In this case, the edges of the side faces are strictly parallel to each other. However, the gapless state during assembly does not per se mean that the mutual position is unambiguous (Fig.

2). Even in the ideal case, i.e. when assembling reference parts, complete unambiguity cannot be achieved either with a three-jaw chuck (Fig. 2a), or with hoops. For example, in the latter case, if the radius of one of the sectors is larger than the radius of the other sectors, then Fig. 2b is possible. When positioning in a three-jaw chuck, any of the positions shown in Fig. 2a can be fixed.



a) *b)*

Fig. 1. Composite product
a) – sector assembly b) – dihedral angle errors



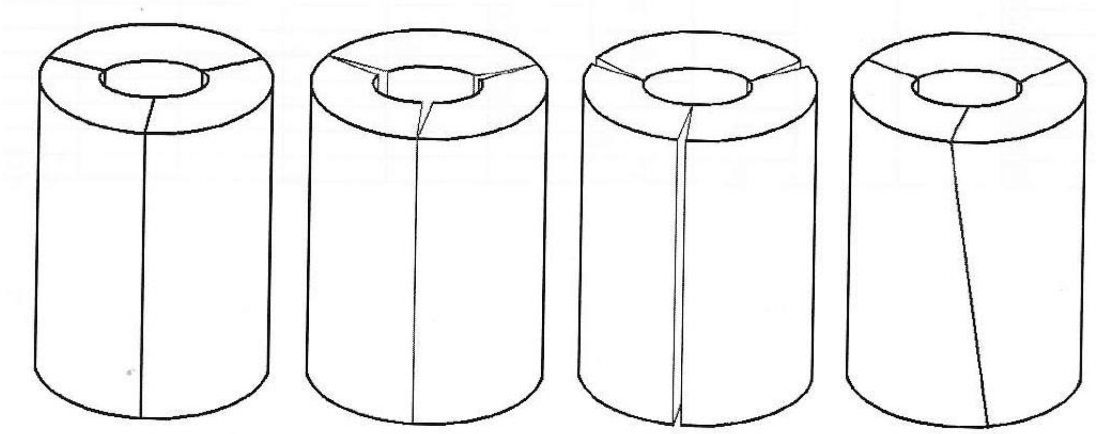
a) *b)*

Fig. 2. Sector assembly options
a) assembly of reference ("ideal") sectors, b) assembly of sectors with a radius error

Another sector assembly problem is the failure to make absolutely accurate dihedral angles, i.e. angles exactly equal to 120° [5–9]. Let us consider what happens, if the sum angle of the three sectors is less than or more than 360° (Fig. 3). If the sum angle exceeds 360° (Fig. 3b), then assembly is impossible, since it is impossible to ensure engagement of the dihedral angle planes. If the sum angle is less than 360° (Fig. 3c), then assembly is possible but with a noticeable twist angle or "flatness deviation" of the assembled sectors (Fig. 3d), as well as assembly ambiguity before and after processing.

It can be proved mathematically that with a total positive tolerance for sector angles, the product cannot be assembled, while with a total negative tolerance, the product can be assembled. All planes are guaranteed to be tightly stacked on top of each other, but strongly "twisted". This causes major problems both during assembly and control, as well as processing stages of the assembled product (in a satellite device) [10–20]. A dihedral angle controller can be designed based on this principle.

Product assemblability analysis. Gapless assembly does not always ensure the engagement of all three sectors with an angular dimension strictly equal to 120°. Let us assume that the side faces of the sectors are ideally flat. Without loss of generality and for convenient consideration, we can assume that two of the three sectors have dihedral angles exactly equal to 120°. The third sector has a deviation of 120° (Fig. 4) equal to the total defect of the angle of all the three real sectors. This assumption does not result in a significant error due to the small deviations of the angular dimensions of real sectors.



a) b) c) d)

Fig. 3. Assembly options at different tolerances for dihedral angles
a) 3ψ=360°; b) 3ψ > 360° c) 3ψ < 360° d) 3ψ < 360°

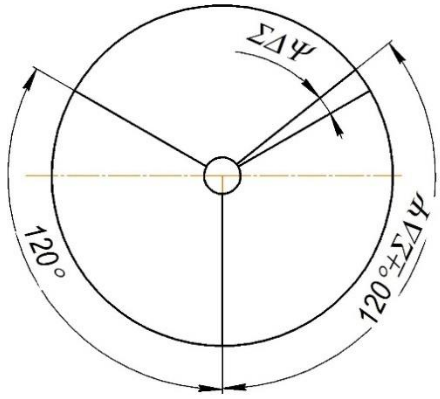


Fig. 4. Assembly with an angle error of one of the sectors

Let two sectors with angular dimensions of 120° contact along a common plane (Fig. 5a). If these sectors are given a small angle of rotation α along the contact plane, then the dihedral angle formed by the other planes of these sectors will differ from 120° (Fig. 5b). Therefore, the third sector with a dihedral angle different from 120° can have gapless contact with them.

Let us make the equations of nonadjacent planes of sectors 1 and 2:

$$3Z - \sqrt{3} \cdot Y = 0 \quad (1)$$

$$3Z + \sqrt{3} \cdot Y = 0 \quad (2)$$

Let us rotate sector 2 around the Y axis by the angle α. Then, in the new coordinate system related to this sector, the equations of non-adjacent planes will take the form:

$$3Z' - \sqrt{3} \cdot Y' = 0 \quad (3)$$

$$3(X' \sin\alpha + Z' \cos\alpha) + \sqrt{3} \cdot Y' = 0 \quad (4)$$

Let us find the dihedral angle between the non-adjacent planes using the analytical geometry formula:

$$\cos\psi = \pm\frac{0\times 3\times\sin\alpha + \sqrt{3}\times\sqrt{3} + 3\times\cos\alpha\times(-3)}{\sqrt{0^2+3^2+3}\times\sqrt{3^2\sin^2\alpha + 3 + 3^2\cos^2\alpha}} = \pm\frac{3-9\cos\alpha}{12} \tag{5}$$

Equation (5) implies that if α=0, $\cos\psi = -\frac{1}{2}$, and if α≠0, ψ <120°.

Thus,

$$\psi = \arccos\left(\frac{1-3\cos\alpha}{4}\right) \tag{6}$$

The rotation angle α is determined from the equation

$$\alpha = \arccos\left(\frac{1-4\cos\psi}{3}\right) \tag{7}$$

In the manufacturing of these products, the following tolerance was set experimentally. It was based on processing capabilities for the angle ψ = 119,5°±15′, i.e.. ψ_{max}=119°45′, ψ_{min} = 119°15′. At such values of the angle ψ, the rotation angle of the sectors is α ≈ 5°…10°.

Thus, in the case of gapless assembly of three sectors, the sum of all dihedral angles of the sectors should be less than or equal to 360°. Since it is impossible to ensure that the sum of all dihedral angles is exactly equal to 360°, a characteristic “flatness deviation” is always formed during assembly (Fig. 3d). Furthermore, the “propeller” can be twisted both clockwise and counterclockwise. When turning along the outer surface of the sector assembly, the tangential components of the cutting forces can “untwist” the assembly depending on the direction. Then the gap ΔS is formed on the outer surface of the product (Fig. 6).

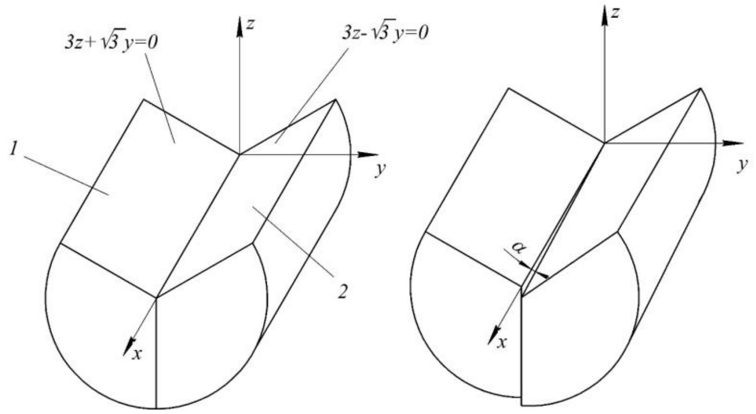


Fig. 5. Assembly of two sectors

For example, with the deviation of the angle of each sector of –10′, and the total deviation Δψ of –30′, a gap appears during untwisting

$$\Delta S = (R-r)\frac{0{,}5\pi}{360} \tag{8}$$

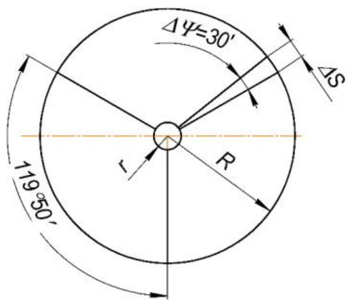


Fig. 6. The appearance of a gap when the assembly is “untwisted” during cutter turning

When assembling sectors with angles ψ < 120°, a radial motion variation ΔR may appear. This is due to the radial throw of the sectors (Fig. 7). When the angle is ψ = 119.5°±15′, the radial motion variation can reach ΔR = 0.43mm, exceeding the allowable value T = 0.2mm for these products.

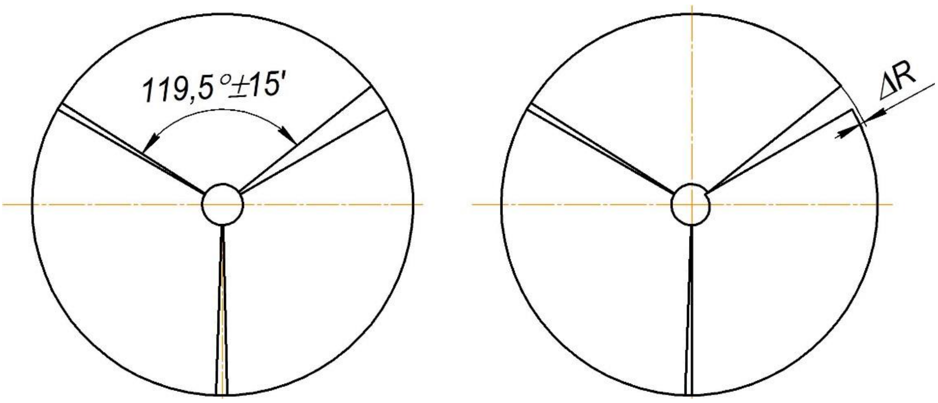


Fig. 7. Appearance of the radial motion variation during sector assembly
a) sector assembly at ψ = 119,5°±15′, b) radial throw of one of the sectors

Statistical studies carried out on a batch of 30 parts showed that the allowable value of the radial motion variation was exceeded in 27% of the parts (Fig. 8).

The following actions are essential to reduce the above-mentioned assembly errors:

1) Significantly reduce the tolerance for the dihedral angle in the manufacture of sectors;

2) Apply selective assembly using a special control device, which will significantly reduce the total defect of dihedral angles without reducing their processing tolerance.

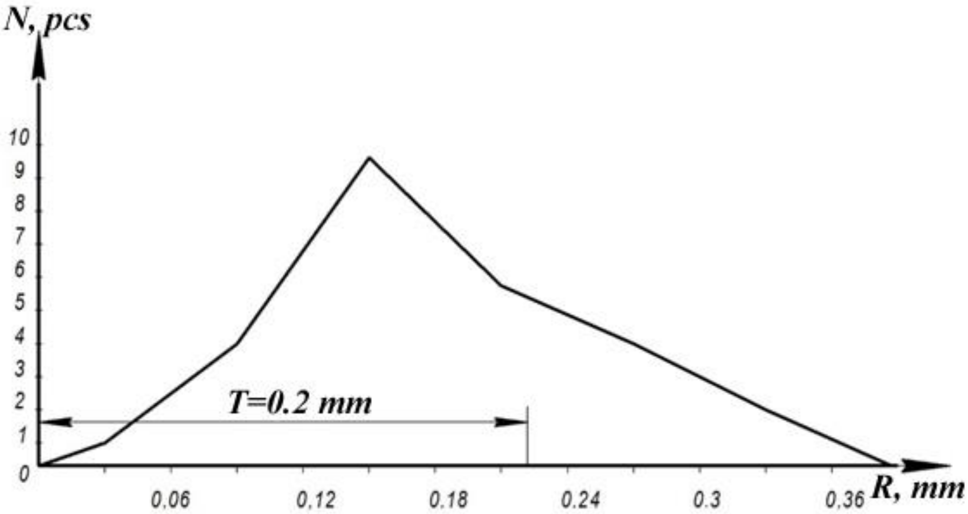


Fig. 8. Results of the radial motion variation measurement

Conclusion. We developed a scheme of a dihedral angle controller for selective assembly (Fig. 9). Sector 1 is mounted on a prism consisting of two “semi-prisms”: fixed 2 and rotary 3. By turning “semi-prism” 3 around axis 5, we obtain snug engagement of the planes of “semi-prism” 3 and sector 1. We fix the resulting position of “semi-prism” 3 using adjusting screw 4, and measure the angle of rotation with a goniometer or any other measuring device.

Such control and selective assembly will allow sectors to be selected in such a way that their “twist” angle in the assembled condition is minimal. In this case, when selecting sectors, we can set the clockwise or counterclockwise “twisting” direction, depending on the direction of the cutting forces.

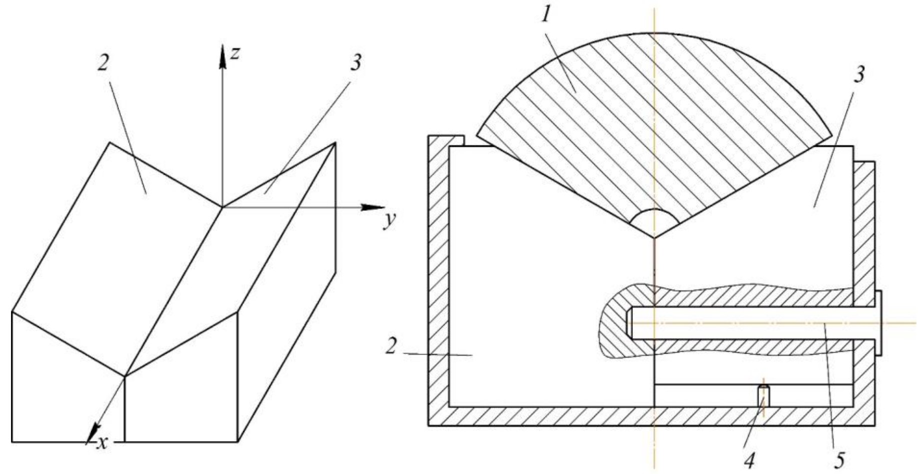


Fig. 9. Scheme of the dihedral angle controller
1 – sector, 2 – fixed "semi-prism", 3 – rotary "semi-prism", 4 – adjustable stop, 5 – axis

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