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Management of space orientation of the end effector of generation of geometry system five-axis manufacturing machinery for additive generation of geometry

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Abstract. The article is devoted to the investigation of the surface layer formation accuracy of engineering products by additive methods. The analysis of advantages and disadvantages of layered products synthesis technologies was carried out. It was revealed that, in additive shaping, the exact characteristics of the surface layer differ significantly from the accuracy characteristics of the surface layer of products obtained by the traditional methods. The analysis of domestic and foreign works on the topic of research was carried out. It is revealed that to increase the accuracy characteristics of products obtained by additive methods, it is necessary to realize dynamically the spatial orientation of the working element of the additive installation in the process of shaping. To control the spatial orientation of the working organ of additive equipment, a method is proposed. According to the proposed method, the controlled parameters of the additive installation are calculated on the basis of a 5-coordinate mechatronic system. The proposed methodology will allow to calculate the controlled parameters of the process equipment, to provide the required orientation of the working element of the additive installation to reduce the error of shaping (approximation), using 5-coordinate mechatronic system

1 Introduction

At present, additive technologies are positioned as technologies capable to replace the traditional approaches of complex geometric shapes parts manufacturing for a variety of purposes. However, the accuracy characteristics of parts obtained by additive methods are not identical to the characteristics of parts obtained by computational methods [1].

Formation of parts by additive methods is characterized by high values of the static component of the processing error, in particular, the magnitude of the error in shaping (approximation). This is due to the fact that the formation of the surface layer of a complex shape detail occurs in a row, and the orientation of the final element of the forming system of the additive installation is thus unchanged and independent of the curvature of the surface being formed.

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Increasing the accuracy of additive methods of shaping is an actual task, one of the solutions of which is to ensure the spatial orientation of the final link of the forming system of additive equipment along the normals at the point of the nominal surface of the formed part, which requires the creation of a new or expansion of the technological capabilities of existing additive equipment

2 Analysis of domain research

A large number of works have been devoted to improving the accuracy of additive methods of shaping [2,4,6,7,8,9,10], for example, in [6] to reduce the error in shaping (approximation), it is proposed to use the static orientation of the surface to be formed. The questions of the dynamic orientation of the final element of the formative system of additive equipment in the process of shaping by additive methods remain insufficiently studied. The use of dynamic orientation will reduce the magnitude of the error in shaping (approximation) of additive methods by reducing the curvature of the surface of the applied elementary layer at the point of contact with the nominal surface of the part.

In [4], a method of additive shaping using the Stewart platform was proposed, in which the orientation of the final link of the forming system of additive equipment will be provided in such a way that when it approaches the surface of the part to be formed, the platform will change the orientation of the part, ensuring the coincidence of the axis of the final link of the forming system and the normal to the surface of the part at the point being formed.

The use of mechatronic systems with parallel kinematics is justified by the need to ensure high accuracy in the functional control of the displacement and orientation of the output link of the basic component of the mechatronic device in the three-dimensional working space, the stiffness and compactness of this device under the action of dynamic loads. The disadvantages of mechanisms with parallel kinematics include a smaller working space, in comparison with classical sequential structures, a relatively small manipulation and a more complex mechanism design. In the process of operation of mechatronic devices with a parallel structure, the internal connections arise that limit their working spaces and can lead to loss of controllability by the mechanism. The presence of forces and moments of frictional forces in the kinematic pairs of the Stewart platform leads to the fact that in the vicinity of special positions the mechanism may become jammed, thus the mechanism will not be operable in the most special position, but in some neighborhood of this position [15].

Thus, to solve the problems of increasing the accuracy of additive form-building methods, the mechanisms with a sequential structure – multi-position robots – can be used as an alternative to mechanisms with parallel structure, the use of which will expand the working space of technological equipment, as well as the ranges of technological parameters control, which is a necessary condition for shaping of complex shape surfaces.

3 Construction of the forming system model of the 5-coordinate mechatronic system

To implement the dynamic spatial orientation of the final link of the formative system of additive equipment, consider the use of a 5-coordinate mechatronic system. To do this, it is necessary to solve the problem of calculating the controlled parameters of the robot, under which the necessary spatial orientation of its final link will be obtained (Fig. 1).

Let's describe the basic equation of the process of additive shaping using this robot, providing a spatial orientation of the final element of the forming system of the additive installation. The equation has the form:

$$\bar{r}_0(u,v)=A_{0\Sigma}\cdot A_{\Sigma}(\varphi_1,\varphi_2,h)\cdot\bar{e}, \qquad (1)$$

where $A_{0\Sigma}$ – matrix for setting the coordinate system of the detail in the working space of the technological equipment; $A_{\Sigma}(\varphi_1,\varphi_2,h)$ – matrix of the forming system of the technological equipment, corresponding to the values of the angles of rotation of the corresponding links of the 5-coordinate mechatronic system; φ_1 – the angle of the table relative to the axis OY; φ_2 – angle of the 2nd link rotation relative to the axis OZ; h – the distance between the plane and the axis of rotation of the table; $\bar{e}$ – radius vector of the point of origin; u,v – curvilinear coordinates of the formed detail.

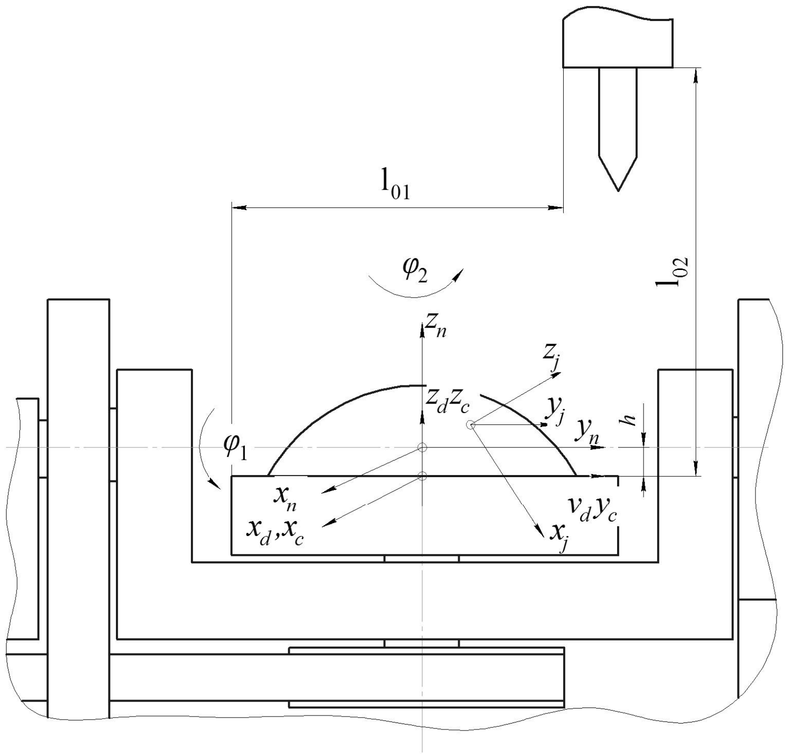

Fig. 1. Scheme of calculation of controlled parameters for formative element spatial orientation providing of the additive installation using a 5-coordinate mechatronic system.

The matrix for setting the coordinate system of the detail in the working space of the 5-coordinate mechatronic system has the form (see Fig. 1) [18]:

$$A_{0\Sigma}=A^{\{2\}}(l_{01})\cdot A^{\{3\}}(l_{02}), \qquad (2)$$

Where $A^{\{2\}}(l_{01})$ – matrix for setting the coordinate system of the detail in the working space of the 5-coordinate mechatronic system t along the axis OZ; $A^{\{3\}}(l_{02})$ – matrix for setting the coordinate system of the detail in the working space of the 5-coordinate mechatronic system along the axis OY.

The matrix of the forming system of the 5-coordinate mechatronic system has the form [18]:

$$A_\Sigma = A^{\{5\}}(\varphi_1)\cdot A^{\{3\}}(h)\cdot A^{\{6\}}(\varphi_2), \tag{3}$$

where $A^5(\varphi_1)$ – rotation matrix of the coordinate systems of the corresponding links relative to their initial position along the axis *OY*; $A^{\{3\}}(h)$ – displacement matrix of the coordinate systems of the corresponding links relative to their initial position along the axis *OZ*.

Parameters included in the matrix A_Σ, can be divided into controllable and uncontrolled (constructive) parameters of technological equipment.

To ensure the process of shaping, on the uncontrollable parameters of the 5-coordinate mechatronic system included in the shaping equation, it is necessary to impose a relationship of the form:

$$q_i = const\,. \tag{4}$$

Uncontrolled parameters include the lengths of the 5-coordinate mechatronic system's links, namely the elements of the matrix of the forming system: h_1.

To ensure the process of shaping, on five controlled parameters of the 5-coordinate mechatronic system', it is necessary to impose a relationship of the form

$$\begin{aligned} &q_1 = q_1(u,v);\\ &q_2 = q_2(u,v);\\ &\ldots\\ &q_5 = q_5(u,v). \end{aligned} \tag{5}$$

The controlled parameters include the rotation angles of the links around the corresponding axes *OY*, *OZ*: φ_1, φ_2.

When the *j*-th point of the surface of the detail is formed, equation (5) can be determined by solving the matrix equation

$$A_{0j}(u_j,v_j)\cdot A_{0\Sigma}\cdot A_\Sigma(\varphi_1,\varphi_2,h) = E\,, \tag{6}$$

where $A_{0j}(u_j;v_j)$ – matrix of the transition from the coordinate system of the formed detail to the coordinate system of the *j*-th point on the surface of the detail $\bar{r}_{0j}(u_j,v_j)$; E – identity matrix.

Matrix A_{0j} of the transition from the coordinate system of the formed detail to the coordinate system of the *j*-th point on the surface of the detail $\bar{r}_{0j}(u_j,v_j)$ is calculated according to the method described in [16-19], along the vectors which define the positive direction of the axis Z_j $\bar{k}_{j0} = \frac{\partial\bar{r}_{0j}}{\partial u}\times\frac{\partial\bar{r}_{0j}}{\partial v}\Big/\left|\frac{\partial\bar{r}_{0j}}{\partial u}\times\frac{\partial\bar{r}_{0j}}{\partial v}\right|$, axis Y_j $\bar{j}_{j0} = \frac{\partial\bar{r}_{0j}}{\partial u}\Big/\left|\frac{\partial\bar{r}_{0j}}{\partial u}\right|$ or $\bar{j}_{j0} = \frac{\partial\bar{r}_{0j}}{\partial v}\Big/\left|\frac{\partial\bar{r}_{0j}}{\partial v}\right|$, where: $\frac{\partial\bar{r}_{0j}}{\partial u}, \frac{\partial\bar{r}_{0j}}{\partial v}$ – partial derivatives of the vector $\bar{r}_{oj}$ with respect to the parameters u, v, as well as the vector $\bar{r}_{oj}$, specifying the origin of the coordinate system $X_jY_jZ_j$.

4 The results of the controlled parameters calculation

Let's consider an example of calculation of controlled parameters of a 5-coordinate mechatronic system forming the hemispherical surface by the additive methods (Fig. 2).

The equation of the hemisphere has the form:

$$r_0(\theta; z) = \begin{bmatrix} \sqrt{R^2 - z^2} \cdot \cos(\theta) \\ \sqrt{R^2 - z^2} \cdot \sin(\theta) \\ z \\ 1 \end{bmatrix} \tag{7}$$

where θ, z – curvilinear coordinates of the surface; R – radius of the sphere.

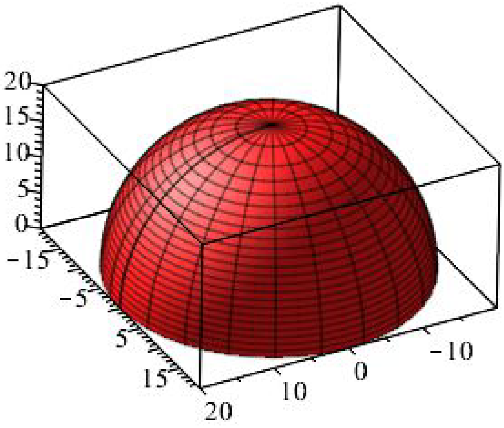

Fig. 2. Graphical representation of the formable surface.

In Fig. 3. the results of the graphical modeling of the position of the final link of the forming system during the shaping of the spherical surface are presented.

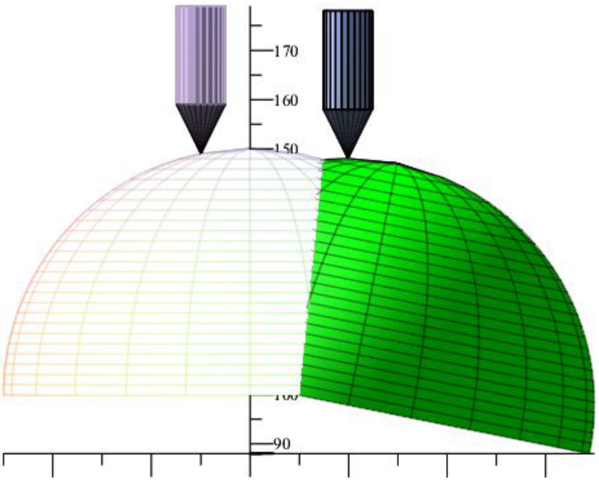

Fig. 3. The orientation of the extruder for the surface points.

5 Conclusions

The proposed method will allow to calculate the controlled parameters of the 5-coordinate mechatronic system in additive shaping of products. to provide the dynamic spatial orientation of the final element of the forming system of additive equipment, which will reduce the magnitude of the error in shaping (approximation). increase the productivity of the shaping process.

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References

1. M. Burns, *Automated Fabrication: Improving Productivity in Manufacturing* (PTR Prentice Hall, USA, 1993)
2. A. A. Saprykin, *Increasing the productivity of the process of selective laser sintering in the manufacture of prototypes.* Thesis of candidate of technical Sciences (Tomsk Polytechnic University, Yurga, 2006)
3. A. Pronikov, O. I. Averyanov, Yu. S. Apollo, *Designing of metal-cutting machines and machine tools,* **3** (MSTU them NE Bauman: Mechanical Engineering, Moscow, 1994)
4. V. V. Kuts, M. S. Razumov, A. N. Grechukhin, N. A. Bychkova, Int. J. Appl. Eng. Res., **11** (24), 11832 (2016)
5. L. M. Chervyakov, N. A. Bychkova, N. V. Yeliseyeva and others, *Transfer of additive technologies: the industry of the Kursk region* (ZAO «University Book», Kursk, 2016)
6. V. L. Dobroskok, L. N. Abdurayimov, S. I. Chernyshov, Scientific notes of the Crimean Engineering and Pedagogical University, 24, 13 (2010)
7. S. K. Singhal, A. P. Pandey, P. M. Pandey, A. K. Nagpal, Computer-Aided Design and Applications, **2** (1-4), 319 (2005)
8. H. S. Hong, K. H. Lee, Int. J. Adv. Manuf. Technol., **28** (3-4), 307 (2006)
9. H. S. Hong, K. H. Lee, Proc. of the 34th International Conference on Computers & Industrial Engineering, 426 (2004)
10. J. Hur, K. Lee, Manuf. Technol., **14** (4), 247 (1998)
11. J. Y. Kim, K. Lee, J. C. Park, Technical Report. Dept Mech Des Prod Eng (Seoul National University, Seoul), 356 (1994)
12. P. T. Lan, S. Chou, Y. Chent, L. D. Gemmill, Computer-Aided Design, **29** (1), 53 (1997)
13. S.H. Massod, W. Rattanawong, P. Iovenitti, J. Mater. Process. Technol, **139**, 110 (2003)
14. S. H. Masood, W. Rattanawong, Int. J. Adv. Manuf. Technol., 19, 209 (2002)
15. I. N. Egorov, *Position-force control of robotic and mechatronic devices* (Vladimir State University, Vladimir, 2010)
16. S. I. Lashnev, A. N. Borisov, S. G. Emelyanov, *Geometric theory of surface formation by cutting tools* (Kursk. state. tech. un-t., Kursk, 1997)
17. S. G. Emelyanov, *Development of the theory. methods and means of surface formation by assembled metal-cutting tools on the basis of system modeling of their design process* Thesis of doctor of technical Sciences (MGTU, Moscow, 2001)
18. V. V. Kuts, *Methodology of pre-project studies of specialized metal-cutting systems* Thesis of doctor of technical Sciences (Kursk State Technical University, Kursk, 2012)

19. V. V. Kuts, V. V. Ponomarev, Fundamental and applied problems of technology, 2(322), 110 (2017)
20. V. A. Grechishnikov, V. V. Kuts, M. S. Razumov, V. B. Romanov, P.M. Pivkin, A.N. Grechikhin, S. Yu. Yurasov, STIN, 4, 24 (2017)
21. V. A. Grechishnikov, V. B. Romanov, P. M. Pivkin, Russian Engineering Research, **37** (9), 824 (2017)
22. High-precision industrial 6-coordinate robot, access mode: //video.phim22.com/n535u234a405i3w5m5b3x5.html