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Improving the Quality of Additive Methods for Forming the Surfaces of Odd-Shaped Parts with the Application of Parallel Kinematics Mechanisms

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Abstract

The article considers the possibilities for the development and transfer of additive technology for selective laser melting. It undertakes the analysis of the trajectories of formation processes movement. The paper proposes a scheme of forming odd-shaped parts surfaces based on the use of parallel kinematics mechanisms. The application of this scheme will make it possible to improve the quality of surfaces of additive technologies products.

Keywords: additive manufacturing, technology transfer, parallel kinematics, geometric theory.

INTRODUCTION

At present, additive manufacturing is quite diverse and has many advantages. Applying such technologies leads to cost and time savings, etc. Additive technology is able to significantly simplify the production process of making parts. The possibilities of this are that in the near future instead of a production workshop with huge units and workers there will be one department with several units for selective melting and two or three engineers. However, despite all the obvious advantages of additive technologies application, we do not see any mass adoption of them in technological processes of industrial enterprises. Their use is limited to industrial 3-D prototyping and consulting services in the field of 3-D printing. This fact can be explained by the high cost of equipment for additive manufacturing, poor addressing the issues of domestic materials and equipment systems development and the introduction of additive technologies. Therefore, the issues of additive technologies transfer and development of domestic materials and equipment complexes remain open.

PROPOSED METHOD

Traditional formation of parts by additive methods is characterized by high values of shape error. This is due to the fact that forming the surface layer of an odd-shaped part is being carried out line by line (in layers), and the orientation of a movable operating element, for example, the extruder of an additive unit is fixed and independent of the magnitude of the formed surface curvature. To reduce the value of workpiece surface distortion it is necessary to ensure the orientation of the operating element along the normal at the point of surface while forming its points. The solution to this problem is possible via the use of the Stewart platform on the movable element of which there will be the formation of a part. When moving closer the operating element of an additive unit to the surface, the platform will change the orientation of a part, ensuring the coincidence of the working body axis and the normal with the surface of a part in the formed point. It is necessary to calculate the values of controlled parameters of the Stewart platform (the lengths of guide bars). Owing to them, there will be obtained the desired position and part orientation.

RESULTS AND DISCUSSION

For this purpose, we will use a generalized model of mechanisms with parallel kinematics proposed in [1-9] (Fig. 1).

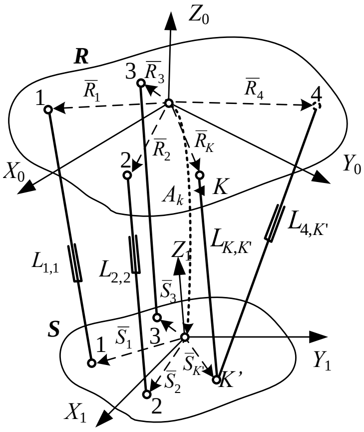

Figure 1: Generalized block diagram of mechanisms with parallel kinematics [1]

The generalized model is described by a system of equations in matrix form [1]

$$L_{ij}\left(b_{ij1}, b_{ij2}, \ldots, b_{ijN_{ij}}\right) = \left|\overline{R}_i\left(a_{i1}, a_{i2}, \ldots, a_{iN_i}\right) - A_k \overline{S}_j\right|, \tag{1}$$

where A_k – transformation matrix from the coordinate system of the base in the coordinate system of the movable part;

$\overline{R}_i$ – vector defining the position of the joint i in the coordinate system of the platform stationary base;

$a_{i1}, a_{i2}, \ldots, a_{iN_i}$ – parameters determining the position of the joint i where N_i – the number of parameters.

$\overline{S}_j$ – vector specifying the position of the joint j in the coordinate system of the moving platform;

L_{ij} – the distance between the related joints i and j;

$b_{ij1}, b_{ij2}, \ldots, b_{ijN_{ij}}$ – parameters determining the distance between joints i and j;

N_{ij} – the number of parameters for related joints.

In our case, in relation to the Stuart platform, we have it as follows (1)

$$\begin{cases} L_{1,1} = \left|\overline{R}_1 - A_k(u,v)\overline{S}_1\right|; \\ L_{2,2} = \left|\overline{R}_2 - A_k(u,v)\overline{S}_2\right|; \\ \vdots \\ L_{6,6} = \left|\overline{R}_6 - A_k(u,v)\overline{S}_6\right|, \end{cases} \tag{2}$$

where $A_k(u,v)$ – transformation matrix of the coordinate system of the moving platform when forming the point of the part surface with parameters u and v;

$L_{1,1}$, $L_{2,2}$, …, $L_{6,6}$ – the lengths of guide bars 1-6, respectively.

Vector $\overline{R}_i$, defining the position of the joints of the platform fixed base (Fig. 2) we have as follows

$$\begin{gathered} \overline{R}_1 = \left[H_1 \quad -h_1/2 \quad 0 \quad 1\right]^{\mathrm{T}}, \\ \overline{R}_2 = \left[H_1 \quad h_1/2 \quad 0 \quad 1\right]^{\mathrm{T}}, \\ \overline{R}_3 = A^6(120°\pi/180°)\overline{R}_1, \\ \overline{R}_4 = A^6(120°\pi/180°)\overline{R}_2, \\ \overline{R}_5 = A^6(-120°\pi/180°)\overline{R}_1, \\ \overline{R}_6 = A^6(-120°\pi/180°)\overline{R}_2. \end{gathered} \tag{3}$$

where $A^6(\theta)$ – matrix that takes into account the rotation of the workpiece around axis Z by angle θ

$$A^6(\theta) = \begin{vmatrix} \cos(\theta) & -\sin(\theta) & 0 & 0 \\ \sin(\theta) & \cos(\theta) & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix};$$

Vector $\overline{S}_j$, defining the position of the joints in the coordinate system of the moving platform we have as

$$\begin{gathered} \overline{S}_5 = \left[-H_2 \quad -h_2/2 \quad 0 \quad 1\right]^{\mathrm{T}}, \\ \overline{S}_4 = \left[-H_2 \quad h_2/2 \quad 0 \quad 1\right]^{\mathrm{T}}, \\ \overline{S}_6 = A^6(120°\pi/180°)\overline{S}_4, \\ \overline{S}_1 = A^6(120°\pi/180°)\overline{S}_5, \\ \overline{S}_3 = A^6(-120°\pi/180°)\overline{S}_5, \\ \overline{S}_2 = A^6(-120°\pi/180°)\overline{S}_4. \end{gathered} \tag{4}$$

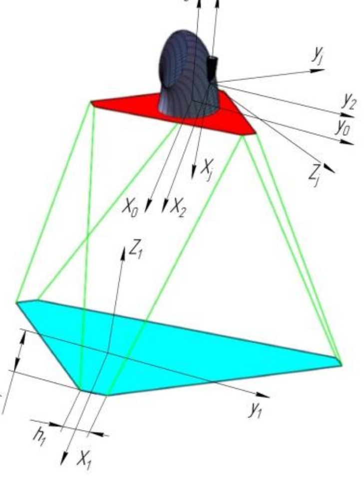

Figure 2: The initial position of the Stewart platform with a part being formed

Fig. 3 shows a part having a surface of Liming with the equation (Fig. 3.)

$$\bar{r}_0(u,v)=\left[\begin{matrix}\big(\big(2v\cos(2u)+10\big)\cos(u)+2v\sin(u)\sin(2u)+100\big)\cdot\\ \cdot\cos(\pi v/20)+\sin(\pi v/20)v+90\end{matrix}\right., \\ 2\sin(u)(v-5), \\ \left.-\cos(\pi v/20)v-20+\left(\begin{matrix}\big(2v\cos(2u)+10\big)\cos(u)+2v\sin(u)\cdot\\ \cdot\sin(2u)+100\end{matrix}\right)\cdot \\ \cdot\sin(\pi v/20), 1\right]^{\mathrm{T}} \tag{5}$$

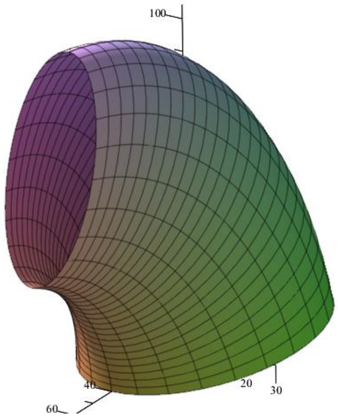

Figure 3: Surface of Liming

Matrix $A_k(u,v)$ is calculated in the following way

$$A_k(u,v)=A_{01n}A^1(\bar{i}_k\cdot\bar{r}_0(u,v))A^2(\bar{j}_k\cdot\bar{r}_0(u,v))\cdot \\ \cdot A^3(\bar{k}_k\cdot\bar{r}_0(u,v))A_{0k}(u,v),$$

where A_{01n} – transition matrix from the coordinate system of the base ($X_0Y_0Z_0$) in the coordinate system of the moving platform ($X_1Y_1Z_1$) in the initial position $A_{01n}=A^3(H_n)$, where H_n – the distance between the base and the movable platform in the initial position; $A^3(z)$ - transition matrix along the axis Z

$$A^3(z)=\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&z\\0&0&0&1\end{bmatrix};$$

$A^2(y)$ – transition matrix for Y axis

$$A^2(y)=\begin{bmatrix}1&0&0&0\\0&1&0&y\\0&0&1&0\\0&0&0&1\end{bmatrix};$$

$A^1(x)$ – transition matrix along X axis

$$A^1(x)=\begin{bmatrix}1&0&0&x\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix};$$

$\bar{r}_0(u,v)$ – vector of the part surface;

$A_{0k}(u,v)$ – transition matrix from the coordinate system of the base in the coordinate system ($X_kY_kZ_k$) of the surface point $\bar{r}_0(u,v)$ in the initial position

$$A_{0k}(u,v)=\begin{bmatrix}\bar{i}_0\cdot\bar{i}_{k0} & \bar{j}_0\cdot\bar{i}_{k0} & \bar{k}_0\cdot\bar{i}_{k0} & \bar{i}_0\cdot A_{01n}\bar{r}_0(u,v)\\ \bar{i}_0\cdot\bar{j}_{k0} & \bar{j}_0\cdot\bar{j}_{k0} & \bar{k}_0\cdot\bar{j}_{k0} & \bar{j}_0\cdot A_{01n}\bar{r}_0(u,v)\\ \bar{i}_0\cdot\bar{k}_{k0} & \bar{j}_0\cdot\bar{k}_{k0} & \bar{k}_0\cdot\bar{k}_{k0} & \bar{k}_0\cdot A_{01n}\bar{r}_0(u,v)\\ 0&0&0&1\end{bmatrix},$$

where $\bar{j}_{k0}=A_{01n}\dfrac{\partial\bar{r}_0(u,v)/\partial u}{\left|\partial\bar{r}_0(u,v)/\partial u\right|}$;

$$\bar{k}_{k0}=A_{01n}\frac{\partial\bar{r}_0(u,v)/\partial u\times\partial\bar{r}_0(u,v)/\partial v}{\left|\partial\bar{r}_0(u,v)/\partial u\times\partial\bar{r}_0(u,v)/\partial v\right|};$$

$$\bar{i}_{k0}=\bar{j}_{k0}\times\bar{k}_{k0}.$$

Figure 4. shows the calculation result of a new position of the Stewart platform with a part being formed.

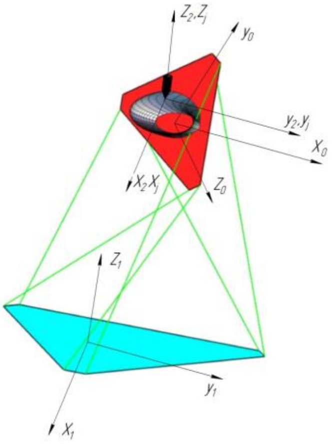

Figure 4: New position of the Stewart platform with a part being formed

CONCLUSION

Thus, using the platform to change the orientation of formed parts will ensure coincidence of the operating element axis of an additive unit and the normal to the surface of a part in the point being formed. This will allow minimizing the errors of forming odd-shaped parts. It will also improve the quality of shaped surfaces.

The resulting model can be applied in the design of equipment for additive manufacturing. This will bring the quality of domestic equipment systems to a higher competitive level, enhance their attractiveness and ensure the effective transfer of additive technologies in the industrial complex.

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