Vector approach in modeling the accuracy of body parts holes manufacturing in aspect of the additive technologies application

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Abstract. The article deals with the issues of ensuring the specified accuracy in the processing of the coaxial and intersecting body parts holes. Features of a details design this type body parts are considered. Parametric analysis was performed, and the key parameters affecting the accuracy of machining body parts internal holes were identified. It is offered at development of details production technology to use in the course of technological parameters system calculation of the vector equations which solution is the only combination of technological parameters of processing of body parts holes. The geometric parameters that determine the position of the basing holes in space are determined. In the vector form shows the influence of the location errors of the base holes and the intersecting and coaxial body parts holes during processing. A spatial calculation scheme for determining the error of the arrangement of the group of coaxial holes of the body part is presented. The work compares results of simulation of the processing errors of the body type parts holes of the for standard cycles for machining holes with the simulation results of the error processing errors of the body type parts holes of manufacturing processes based with additive technologies. It is established a significant impact on the accuracy of the holes location the rotation of details in the working area of the machine, as well as its reinstallation. The efficiency of application of hybrid technological cycles based on additive technologies in the production of coaxial holes in the body type parts is shown.

1. Introduction
More and more requirements to the body parts of modern mechanisms. Increasing the overall rigidity, weight reduction and individual approach to each product require a revision of the production concept and, as a result, the use of modern high-performance technologies. One of the most time-consuming tasks for body parts is to ensure the accuracy of the relative position of the internal coaxial and intersecting holes. In works [1,2] the analysis of technological features at production of similar details is given. Due to the presence of such holes for the body parts of this group is characterized by:

- The presence of additional technological bases, as a rule, are bosses and tides with holes for installing the part on the machine, which leads to the need to reinstall the part during its processing and as a consequence to a violation of the principle of unity and combination of design and technological bases.
- The need to rotate the part in space during processing, which leads to an error in the relative position of the internal coaxial and intersecting holes.
The use of expensive methods of die casting and centrifugal casting (under pressure) due to the complexity of the geometry of the part.

The inability to use a number of materials due to the large number of technological limitations.

Complexity and high requirements for technological equipment.

In the conditions of traditional technologies implementation of all requirements is impossible because of the wide range of body parts and variable program of their production. This leads to problems of ensuring the accuracy of the relative position of the internal coaxial and intersecting holes of the body parts and, as a result, reduce the quality of parts.

In this regard, the search for alternative solutions in the manufacture of internal coaxial and intersecting holes of body parts of this group is an urgent task. In the context of this problem, the paper proposes to consider from the point of view of the accuracy theory of the design of body parts, for example, using hybrid cycles of additive processing and technological equipment of progressive design.

2. Research methodology

Let us imagine a body part in the form of an arbitrary oriented in space $M_r$ holes system. There are coaxial holes and axis holes that intersect. Let the constructive part contain $n_i$ holes located on the $r_i$ directions inside the space $M_r$. Then, for each hole of the set $n \in \{n_1, n_2, n_3, ... n_i\}$ in the line to put the vector $\vec{R}$ passing through the pole (the center of the hole) $O_i$ when $r \in \{r_1, r_2, r_3, ... r_i\}$ (figure 1).

For each body part we are talking about a set of parameters $\{n_i\}$ and $\{r_i\}$, which determine the geometric location of the holes $\{n_i\}$ details inside the $M_r$. If for the sets $\{n_i\}$ and $\{r_i\}$, collinearity condition of the vector $\vec{R} = \sqrt{(r_1^2 + r_2^2 + r_3^2 + \cdots r_i^2)}$ passing through the pole $O_i$ is satisfied, then we are talking about the system of coaxial holes of the body part $\{n_i\}$.

One of the features of the body parts is the arrangement of the system of coaxial holes $\{n_i\}$ and $\{r_i\}$ in several interrelated directions $N_d$. Here the opposite statement is also true, that the body part consists of a set of $D_d$ coaxial holes $\{n_i\}$ of the body part and interrelated parameters $\{r_i\}$ inside the space $M_r$.

The relationship of coaxial holes of the part $\{n_i\}$ and $\{r_i\}$ inside the space $M_r$ is carried out by satisfaction a set of design conditions on the location of the vector $\vec{R} = \sqrt{(r_1^2 + r_2^2 + r_3^2 + \cdots r_i^2)}$ passing through the pole $O_i$ of each hole of the part $\{n_i\}$. To ensure high accuracy of processing of spatial body parts, it is necessary to comply with the principles of unity and preservation of technological bases, which in practice is realized by the use of additional technological elements in the design of the part – for example, holes. There are implementing a details basing scheme on the on the two ($m=2$), three ($m=3$) locating fingers of the two types (rhomb and cylinder forms).

Let the body part constructively contains $m_b$-based holes located at $r_i$-directions within the $M_r$. Then, for each hole of the set $m \in \{m_1, m_2, m_3, ... m_i\}$ can be put into accordance the vector $\vec{F}$ passing through the pole (the center of the hole) $O_m$ when $f \in \{f_1, f_2, f_3, ... f_m\}$. For each body part, we talk about a set of parameters $\{m_b\}$ and $\{r_m\}$, which determine the geometric location of the basing holes $m_b$ of the part inside the space $M_r$.

The interrelationship of $\{m_b\}$ and $\{r_m\}$ parameters inside the space $M_r$ implementation is by the set of design conditions for the location of the vector $\vec{F} = \sqrt{(f_1^2 + f_2^2 + f_3^2 + \cdots f_m^2)}$ which passes through the pole $O_m$ of $\{m_b\}$-holes and the pole $O_i$ of $\{n_i\}$ - holes.
The proposed method allows you to track the technological relationship of the processed holes and technological holes-bases throughout the technological process of manufacturing parts on the actual location of the groups of vectors \( \mathbf{R} = \sqrt{r_1^2 + r_2^2 + r_3^2 + \cdots + r_i^2} \) and \( \mathbf{F} = \sqrt{f_1^2 + f_2^2 + f_3^2 + \cdots + f_m^2} \) inside of the \( M_r \). With respect to every detail in accordance with its design, you can put the specified parameters \( \{n_i\} \), \( \{r_i\} \), \( \mathbf{R} = \sqrt{r_1^2 + r_2^2 + r_3^2 + \cdots + r_i^2} \), \( \mathbf{F} = \sqrt{f_1^2 + f_2^2 + f_3^2 + \cdots + f_m^2} \) inside of the \( M_r \).

In general, the accuracy of the machined hole is determined by the deviation from the specified position of the vectors \( \mathbf{R} = \sqrt{r_1^2 + r_2^2 + r_3^2 + \cdots + r_i^2} \), \( \mathbf{F} = \sqrt{f_1^2 + f_2^2 + f_3^2 + \cdots + f_m^2} \) inside of the \( M_r \).

Expression (1) shows that each error element \( \varepsilon_R \) and \( \varepsilon_F \) is a projection of the vectors \( \{r_i\} \), \( \{f_i\} \), on the axis of the direction of calculation of \( N_r \):

\[
\Delta M_r \rightarrow \begin{cases} 
\varepsilon_R = \sqrt{(\varepsilon_{r1}^2 + \varepsilon_{r1}^2 + \varepsilon_{r1}^2 + \cdots + \varepsilon_{ri}^2)} \\
\varepsilon_F = \sqrt{(\varepsilon_{f1}^2 + \varepsilon_{f1}^2 + \varepsilon_{f1}^2 + \cdots + \varepsilon_{fm}^2)}
\end{cases}
\]

Figure 1. Vector scheme for calculating the hole location error for body parts.

Where a projections \( \gamma_r \), \( \gamma_f \) is the scalars \( |\varepsilon_R| \) and \( |\varepsilon_F| \) of the vectors \( \mathbf{R} \) n \( \mathbf{F} \) on the axis of the direction of calculation of \( N_r \):

\[
\gamma_r = |\varepsilon_R| \cdot \cos \varphi
\]
\[ \gamma_f = |\varepsilon_f| \cdot \cos \omega \]  

\( \varphi \) and \( \omega \) angles of slope for vectors \( \vec{R} \) and \( \vec{F} \) on the \( N_r \) axis.

According to (2-4), the error in the arrangement of the base holes in the implementation of the principles of unity and constancy of the bases can be taken to be zero (5):

\[ \Delta M_{N_r} \triangleq \begin{cases} 
\gamma_r = \sqrt{\gamma_{r_1}^2 + \gamma_{r_2}^2 + \gamma_{r_3}^2 + \cdots + \gamma_{r_i}^2} 
\end{cases} 
\]

However, if the technological cycle of manufacturing contains reinstallation or rotation of the part, then the calculations should take into account the basing error, according to (2).

3. Practical significance

Let us consider a part of "Body" type for the cases according to (2) and (5) in space \( M_3 \in (O, N_1, N_2, N_3) \) (figure 2 a). Suppose that in the direction \( N_1 \) we have holes \( n_1, n_2 \) which position is determined by vectors \( r_1, r_2 \). Here the collinearity condition of vectors \( R_1 \in \{r_1, r_2\} \) is satisfied. In the \( N_2 \) direction position of holes \( n_3, n_4, n_5 \), determines the vectors \( r_3, r_4, r_5 \). Here the collinearity condition of vectors \( R_2 \in \{r_1, r_2, r_3\} \) is satisfied. Holes \( n_2 \) and \( n_3 \) are blind (figure 2b).

![Figure 2](image_url)  

**Figure 2.** Vector scheme for calculating the hole location error for «Body» part.

In practice, the blind holes axis centering with the holes \( n_1, n_4, n_5 \) axis is a time-consuming task. In this case, the condition (5) is not met, as for the processing of \( n_2, n_3 \) holes need to reinstall the parts in the fixture device and rotate the part relative to the pole \( O \in M_3 \). That according to (2) leads to the need to take into account in the calculations of the basing errors. This basing errors are absent in the case of obtaining this part on the basis of a hybrid additive processing cycle. It is possible to process groups of holes \( n_1, n_2 \) in the direction of vectors \( R_1, R_2 \), which corresponds to the conditions of the minimum error according to (5). For the case of obtaining the part "Body" based on a hybrid additive processing cycle expression (5) for the value \( \Delta M_{N_1,2} \) takes the form (6).
\[ \Delta M'_{N_{1,2}} = \begin{cases} 
\gamma_{R1} = \sqrt{(\gamma_{r1}^2 + \gamma_{r2}^2)} \\
\gamma_{R2} = \sqrt{(\gamma_{r3}^2 + \gamma_{r4}^2 + \gamma_{r5}^2)} \\
0 
\end{cases} \] (6)

Where \( \gamma_{ri} \) parameters are calculated according to (3). Otherwise, the expression (5) for the value \( \Delta M''_{N_{1,2}} \), taking into account (2) takes the form (7):

\[ \Delta M''_{N_{1,2}} = \begin{cases} 
\gamma_{R1} = \sqrt{(\gamma_{r1}^2 + \gamma_{r2}^2)} \\
\gamma_{R2} = \sqrt{(\gamma_{r3}^2 + \gamma_{r4}^2 + \gamma_{r5}^2)} \\
\gamma_{f} = \sqrt{(\gamma_{f1}^2 + \gamma_{f2}^2 + \gamma_{f3}^2 + \cdots + \gamma_{fm}^2)} 
\end{cases} \] (7)

If (6) and (7) the validity of the equation

\[ \gamma_{ri} = l_{ri} \] (8)

and \( l_{ri} \) the length of each hole \( n_1, n_2, n_3, n_4, n_5 \) set according with the detail drawing in the form of parameters \( l_1, l_2, l_3, l_4, l_5 \) (figure 2b), where (8) is necessary and sufficient that the condition:

\[ L_{ri} \in (l_1, l_2, l_3, l_4, l_5) \subseteq M_r \] (9)

then for expressions (6) and (7) the inequality will be performed (10):

\[ \Delta M''_{N_{1,2}} \ll \Delta M'_{N_{1,2}} \] (10)

4. Conclusions
The approach, considered in the work, on the basis of vector modeling of parameters of coaxial holes accurately distributed in space is effective for use in the production process based on a hybrid cycle of additive processing, since in this case the batch holes of each part in a given direction, in relation to which a mechanical process also takes place in the future. Providing the formation of a cylindrical surface of each hole in the additive cycle in the direction of its main axial vector \{\( r_i \)\} provides the principles of unity and preservation of bases. Knowing the parameters of the precision hybrid cycle additive processing for the equipment, significantly simplifies the calculation procedure of processing accuracy of holes of body parts due to minimization values of \( \varphi \) and \( \omega \) - angles of the vectors \( \vec{R} \) and \( \vec{F} \) axis direction \( N_r \). The proposed approach to modeling the accuracy of the distributed in the space of coaxial holes of the part is effective in solving the inverse problem—when the specified parameters of accuracy are determined by the method of calculation permissible errors of hole processing at each technological stage of manufacturing the body part. It provides ample opportunities for the design of effective from the point of view of ensuring the specified accuracy of the details of technological processes implemented on the basis of the additive processing hybrid cycle.

5. Judgments and prospects of research development
Additive technologies today are increasingly considered as an alternative to traditional procurement technologies (stamping (forging), various types of casting), including the use of aluminum alloys [3-17]. The workpiece obtained by this technology is, in fact, a finished part, with the exception of surfaces that have special requirements for accuracy, roughness, shape of the surface. It is important to provide the required spatial arrangement of the surface relative to the design base of the part, which can be provided with the application of the results of this work.
The profitability of the blanks obtained by additive technologies is higher, the more complex the configuration of the final parts, the greater their nomenclature and the smaller the annual production volume. The highest productivity in the application of additive manufacturing technologies can be obtained by integrating this technology into technological equipment for machining [18].

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