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 with internal coaxial and intersecting holes in an analytical form. Determine the effect of the parameters of precision machining holes on the error of their relative position in the part. Consider the possibility of reducing the error with the use of modern technologies for the manufacture 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 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 $n \in \{n_1, n_2, n_3, \ldots n_i\}$ in the line to put the vector $\vec{R}$ passing through the pole (the center of the hole) O_i when $r \in \{r_1, r_2, r_3, \ldots r_i\}$ (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 $m \in \{m_1, m_2, m_3, \ldots m_i\}$ can be put into accordance the vector $\vec{F}$ passing through the pole (the center of the hole) O_m when $f \in \{f_1, f_2, f_3, \ldots f_m\}$.
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 $m_i$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 $\vec{R} = \sqrt{(r_1^2 + r_2^2 + r_3^2 + \cdots r_i^2)}$ and $\vec{F} = \sqrt{(f_1^2 + f_2^2 + f_3^2 + \cdots f_m^2)}$ inside of the M_r. With respect to every detail in accordance with its design, you can put the specified parameters $\{n_i\}$, $\{r_i\}$, $\vec{R} = \sqrt{(r_1^2 + r_2^2 + r_3^2 + \cdots r_i^2)}$, $\vec{F} = \sqrt{(f_1^2 + f_2^2 + f_3^2 + \cdots f_m^2)}$ 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 $\vec{R} = \sqrt{(r_1^2 + r_2^2 + r_3^2 + \cdots r_i^2)}$, $\vec{F} = \sqrt{(f_1^2 + f_2^2 + f_3^2 + \cdots f_m^2)}$ inside of the M_r (1):

$$\xrightarrow{\Delta M_r} \begin{cases} \varepsilon_R = \sqrt{(\varepsilon_{r1}^2 + \varepsilon_{r1}^2 + \varepsilon_{r1}^2 + \cdots \varepsilon_{ri}^2)} \\ \varepsilon_F = \sqrt{(\varepsilon_{f1}^2 + \varepsilon_{f1}^2 + \varepsilon_{f1}^2 + \cdots \varepsilon_{fm}^2)} \end{cases} \quad (1)$$

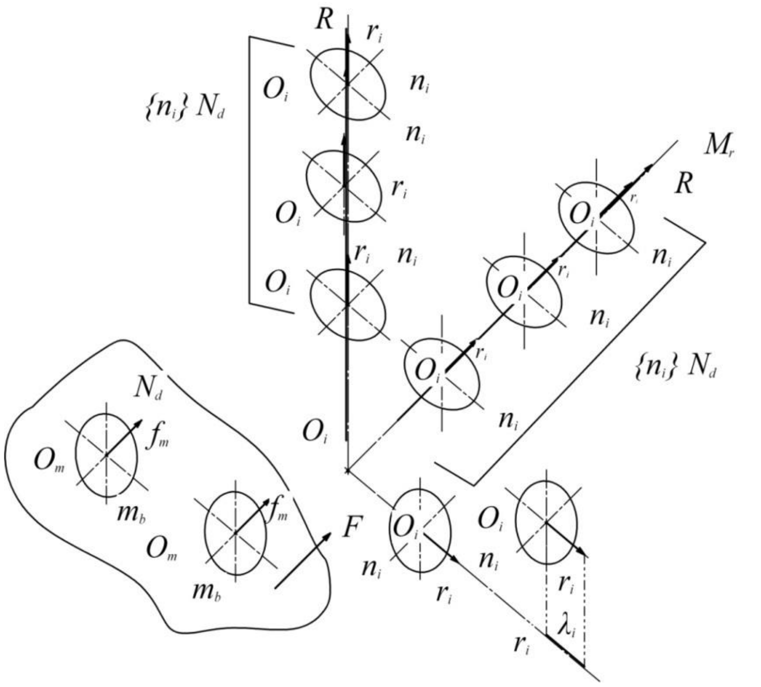

Figure 1. Vector scheme for calculating the hole location error for body parts.

Expression (1) shows that each error element ε_R and ε_F is a projections γ_r, γ_f of the vectors $\{r_i\}$, $\{f_i\}$, on the axis of the direction of calculation of N_r (2):

$$\Delta M_{Nr} \triangleq \begin{cases} \gamma_r = \sqrt{(\gamma_{r1}^2 + \gamma_{r2}^2 + \gamma_{r3}^2 + \cdots \gamma_{ri}^2)} \\ \gamma_f = \sqrt{(\gamma_{f1}^2 + \gamma_{f2}^2 + \gamma_{f3}^2 + \cdots \gamma_{fm}^2)} \end{cases} \quad (2)$$

Where a projections γ_r, γ_f is the scalars $|\varepsilon_R|$ and $|\varepsilon_F|$ of the vectors $\vec{R}$ и $\vec{F}$ on the axis of the direction of calculation of N_r:

$$\gamma_r = |\varepsilon_R| \cdot \cos\varphi \quad (3)$$

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$$\gamma_f = |\varepsilon_F| \cdot \cos\omega \tag{4}$$

φ and ω angles of slope for vectors $\vec{R}$ и $\vec{F}$ 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)^

$$\Delta M_{Nr} \triangleq \begin{cases} \gamma_r = \sqrt{(\gamma_{r1}^2 + \gamma_{r2}^2 + \gamma_{r3}^2 + \cdots \gamma_{ri}^2)} \\ 0 \end{cases} \tag{5}$$

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).

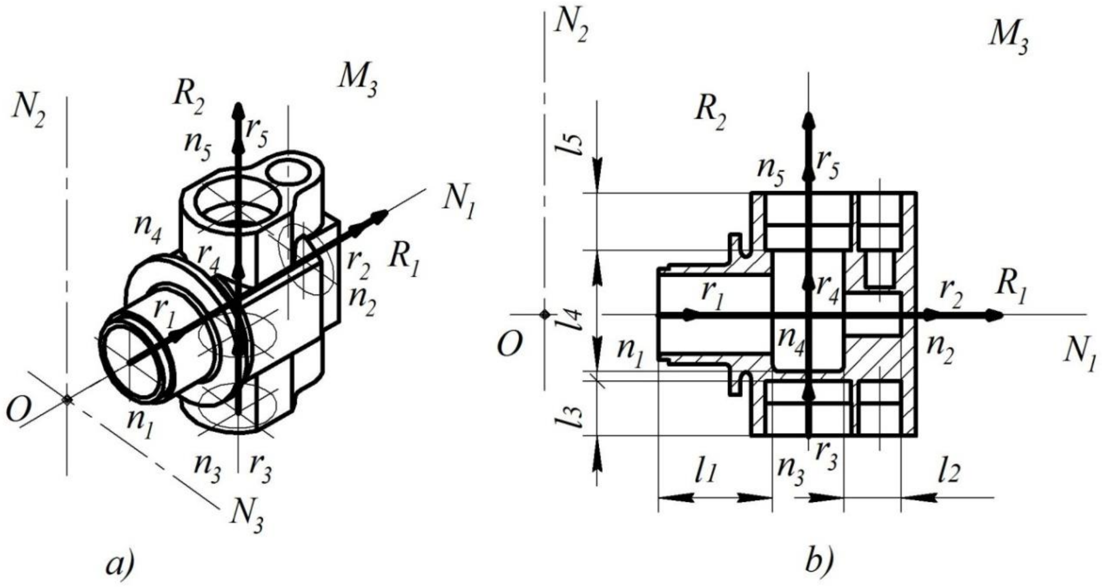

Figure 2. Vector scheme for calculating the hole location error for «Body» part.

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).

$$\Delta M'_{N\,1,2} = \begin{cases} \gamma_{R1} = \sqrt{(\gamma_{r1}^2 + \gamma_{r2}^2)} \\ \gamma_{R2} = \sqrt{(\gamma_{r3}^2 + \gamma_{r4}^2 + \gamma_{r5}^2)} \\ 0 \end{cases} \quad (6)$$

Where γ_{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):

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

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

$$\gamma_{ri} = l_{ri} \quad (8)$$

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:

$$L_{ri} \in (l_1, l_2, l_3, l_4, l_5) \in M_r \quad (9)$$

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

$$\Delta M'_{N\,1,2} \ll \Delta M''_{N\,1,2} \quad (10)$$

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 φ and ω - 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].

References

[1] Johnson R L and Leven M M 1977 Stress concentration factors at intersecting and closely approaching orthogonal coplanar holes *Experimental Mechanics* **1** 1-6

[2] Salvati E, Livieri P and Tovo R 2013 Mode I Stress Intensity Factors for triangular corner crack nearby intersecting of cylindrical holes *Frattura ed Integrità Strutturale* **26** 80-91

[3] Pastirčák R, Ščury J, Brůna M and Bolibruchová D 2017 Effect of Technological Parametrs on the AlSi12 Alloy Microstructure during Crystallization under pressure *ARCHIVES of FOUNDRY ENGINEERING* **17** 75-8

[4] Hilpert E, Hartung J, Risse S, Eberhardt R and Tünnermann A. 2018 Precision manufacturing of a lightweight mirror body made by selective laser melting *Precision Engineering* **53** 310-7

[5] Siddique S, Imran M and Walther F 2017 Very high cycle fatigue and fatigue crack propagation behavior of selective laser melted AlSi12 alloy *International Journal of Fatigue* **94** 246-54

[6] Yang Y, Gu D, Dai D and Chenglong M 2018 Laser energy absorption behavior of powder particles using ray tracing method during selective laser melting additive manufacturing of aluminum alloy *Materials and Design* **143** 12-9

[7] Siddique S, Imran M, Wycisk E, Emmelmann C and Walther F 2016 Fatigue Assessment of Laser Additive Manufactured AlSi12 Eutectic Alloy in the Very High Cycle Fatigue (VHCF) Range up to 1E9 cycles *Materials Today: Proceedings* **3** 2853-60

[8] Rahman Rashid R A, Ali H, Palanisamy S and Masood S H 2017 Effect of process parameters on the surface characteristics of AlSi12 samples made via Selective Laser Melting *Materials Today: Proceedings* **4** 2724-30

[9] Vora P, Mumtaz K, Todd I and Hopkinson N 2015 AlSi12 in-situ alloy formation and residual stress reduction using anchorless selective laser melting *Additive Manufacturing* **7** 12-19

[10] Rashid R, Masood S H, Ruan D, Palanisamy S, Rahman Rashid R A, Elambasseril J and Brandt M 2018 Effect of energy per layer on the anisotropy of selective laser melted AlSi12 aluminium alloy *Additive Manufacturing* **22** 426-39

[11] Battaglia E, Bonollo F, Ferro P and Fabrizi A 2018 Effect of Heat Treatment on Commercial AlSi12Cu1(Fe) and AlSi12(b) Aluminum Alloy Die Castings *METALLURGICAL AND MATERIALS TRANSACTIONS A* **49A** 1631-40

[12] Hofer P, Kaschnitz E and Schumacher P 2012 Simulation of distortion and residual stress in high pressure die casting – modelling and experiments *IOP Conf. Series: Materials Science and Engineering* **33** 1-8

[13] Hofer P, Kaschnitz E and Schumacher P 2014 Distortion and Residual Stress in High-Pressure Die Castings: Simulation and Measurements *JOM* **66** 1638-46

[14] Baitimerov R, Lykov P, Zherebtsov D, Radionova L, Shultc A and Konda G. P. 2018 Influence of Powder Characteristics on Processability of AlSi12 Alloy Fabricated by Selective Laser Melting *Materials* **11** 1-14

[15] Vrana R, Koutny D, Palousek D, and Zikmund T 2015 Impact resistance of lattice structure made by selective laser melting from ALSI12 alloy *Science journal* **1** 852-5

[16] Ponnusamy P, Masood S H, Ruan D, Palanisamy S, Rahman Rashid R A and Kariem M A 2018 High strain rate behaviour at high temperature of AlSi12 parts produced by selective laser melting *IOP Conf. Series: Materials Science and Engineering* **377** 1-7

[17] Ponnusamy P, Masood S H, Ruan D, Palanisamy S and Rashid R 2018 High strain rate dynamic behaviour of AlSi12 alloy processed by selective laser melting *The International Journal of Advanced Manufacturing Technology* **97** 1023–35

[18] Ogin P A, Levashkin D G and Yaresko S I 2017 Block-Modular Principle of Build Composition

Automatically Changeable Laser Modules for CNC Machines *Procedia Engineering* **206** 1298–302