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SEARCH PROCEDURE FOR OPTIMAL DESIGN AND TECHNOLOGICAL SOLUTIONS TO ENSURE DIMENSIONAL AND GEOMETRIC ACCURACY OF CASTINGS

The object of research in the work is the technology of manufacturing shaped castings in disposable sand molds.

The existing problem is that the imperfection of design and technological solutions at the stage of developing the technology of a single sand mold casting leads to deviations in the dimensions and geometry of the castings after their manufacture from the requirements of technological documentation. This can lead to an irreparable shortage of casting.

To develop measures to eliminate or minimize the event, which consists in the formation of a shortage of castings in terms of dimensional and geometric accuracy, a procedure for searching for optimal design and technological solutions is proposed.

A hypothesis has been put forward that a significant factor that leads to deviations in the dimensional and geometric accuracy of castings from the requirements of technological documentation is the imperfection of the gating system design. It is demonstrated on specific castings how this factor can influence the formation of uneven wall thickness.

The proposed procedure, which includes 10 consecutive steps, allows to build a plan for a complete factorial experiment and obtain a regression equation for it, linking the parameters of the gating system with indicators of dimensional and geometric accuracy. The presence of such equations provides the possibility of further experimental optimization and determination of design and technological solutions for the development or improvement of casting systems that minimize the deviations of the dimensional and geometric accuracy of castings from the requirements of technological documentation. This also minimizes the likelihood of an event consisting in the formation of an irreparable shortage of castings.

The presented study will be useful for machine-building enterprises that have foundries in their structure, where shaped castings are made in disposable sand molds.

Keywords: *shaped castings, dimensional accuracy, geometric accuracy, gating system, design and technological solutions.*

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1. Introduction

The design of molded parts plays an important role both in terms of meeting operational requirements and in terms of its ability to be replicated at the technological level. This leads to the need to analyze the complexity of the design [1, 2]. To do this, computer-aided design analyzes the geometry and evaluates the complexity of the product [3]. In turn, the need for complexity analysis requires the introduction of quantitative estimates. Thus, in [4], an index of the complexity of the casting process was proposed for early product design and cost estimation. It is also of interest to analyze the factors that contribute to ensuring the specified quality of cast parts, taking into account their great design and technological complexity. In the technologies of one-time sand molds, one should take into account many factors of a constructive and metallurgical nature that affect the formation of quality. Such quality indicators include the continuity of the casting body, for example, the absence of defects in the form of cracks, surface quality, dimensional and geometric accuracy. In turn, defects arise as a result of incorrect design of the working cavity, which leads to inhibition of shrinkage in certain parts of the mold from the side of its elements, or as a result of an incorrect choice of alloy composition. For example, the chemical composition of an alloy determines not only the structure and mechanical properties [5, 6], but also casting properties, such as fluidity [7]. Melt crystallization processes also affect the formation of quality, and this effect is of a complex nature [8]. Moreover, an important factor influencing the resulting castings is the accuracy of forming models for the manufacture of casting molds [9]. It is impossible to take into account all these factors, however, the control of some of them makes it possible to assess their influence on the required indicators, at least indirectly, by identifying those factors that lead to deviations from the requirements of technological documentation for castings [10, 11]. All this makes it possible to speak about the expediency of studies that develop the theme of the influence of design and technological factors on the quality indicators of castings.

The object of research is the technology of manufacturing shaped castings in disposable sand molds.

The aim of research is to develop a procedure that allows determining the optimal design and technological solutions in the process of developing or improving foundry equipment.

2. Materials and Methods

The object of research is a shaped casting of a body with a predominant geometry in the form of a cylinder, which has defects in geometry, dimensions and continuity, as well as a technological solution for a mold developed as part of the design at the Department of Foundry of the National Technical University «Kharkiv Polytechnic Institute» (Ukraine).

The hypothesis of the study was that the results of a technological audit of serial castings can make it possible to purposefully select design and technological solutions to reduce the likelihood of defective shaped castings in terms of dimensional and geometric accuracy.

3. Results and Discussion

To demonstrate the idea in Fig. 1 shows a defective casting with a gating system affected by gas shells. Red arrows show the direction of melt movement during pouring. The casting is made by mold casting, the inner cavity is made with a sand core, and the mold is vertically split. A general view of a casting of high quality in terms of continuity with a cut-off gating system is shown in Fig. 2.

As a result of the pressure of the melt in the process of filling the mold, the part of the rod farthest from the entry point of the feeder can be displaced, which causes uneven wall thickness of the casting (Fig. 3).

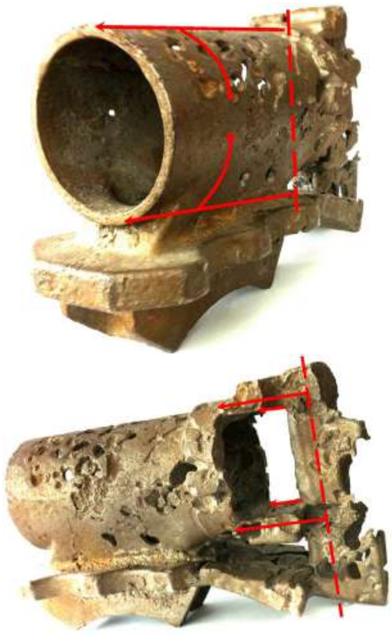

Fig. 1. Defective casting with uncut gating system

Fig. 2. Casting of high quality in terms of continuity without gating system

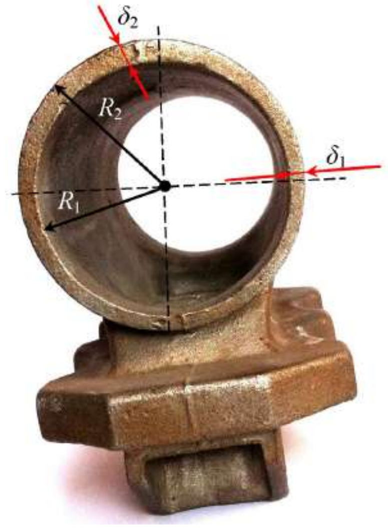

Fig. 3. Demonstration of the non-uniformity of the wall thickness along the back of the casting plane from the melt supply point: R_1 – the inner radius, $R_1 \neq$ const; R_2 – the outer radius; δ_i – the wall thickness, $\delta_i \neq$ const

As follows from Fig. 3, the wall thickness is described by a general equation $\delta = f(\varphi)$, where φ is the current angle, and $\delta = f(\varphi) \neq \text{const}$.

If the dimensions of the casting and its geometry require more complex technological solutions, the probability of deviations in dimensions and geometry increases. This is due to the fact that the use of additional elements of casting equipment causes inaccuracies at the stage of mold assembly, and also causes a more complex dynamic effect of the melt flow in the working mold cavity. An example of one of these technological solutions is shown in Fig. 4, 5.

As a result of the pressure of the melt, the elements of the mold can be deformed or blurred, which leads to deviations from the geometric shapes and dimensions of the casting. The main influence on these deviations is exerted by the dynamics of the melt movement and the forces created by the hydrodynamic pressure (Fig. 6).

In Fig. 6, the following designations are accepted: h_0 – the initial height of the melt surface (at the entrance from the feeder into the mold); $h_{\max}$ – the final height of the melt surface (the upper plane of the casting); h_i – the current height of the melt surface. The red arrows show the direction of the melt flow and its effect on the mold walls and cores.

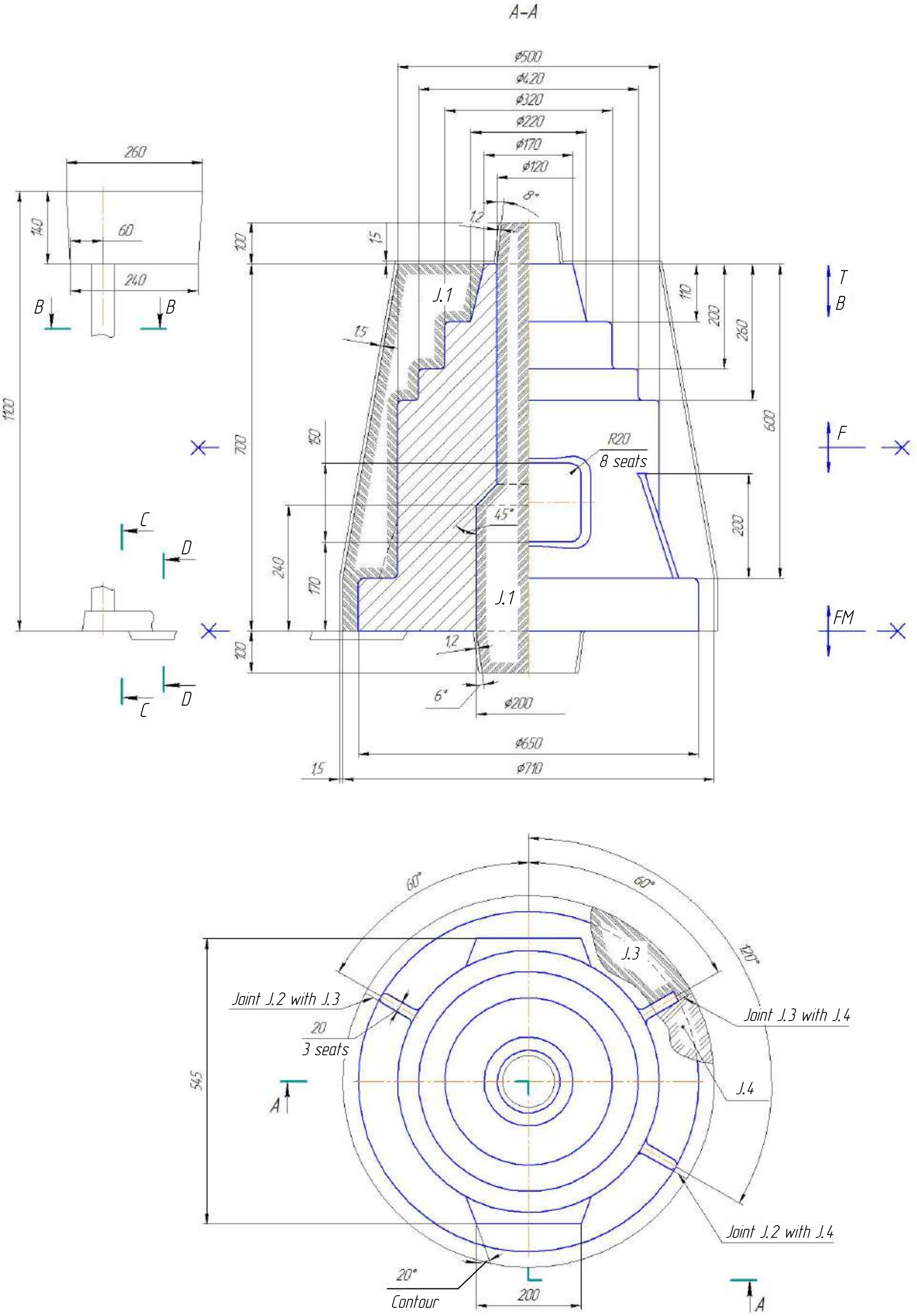

Fig. 4. Technology of body casting type «Lid» with two connectors

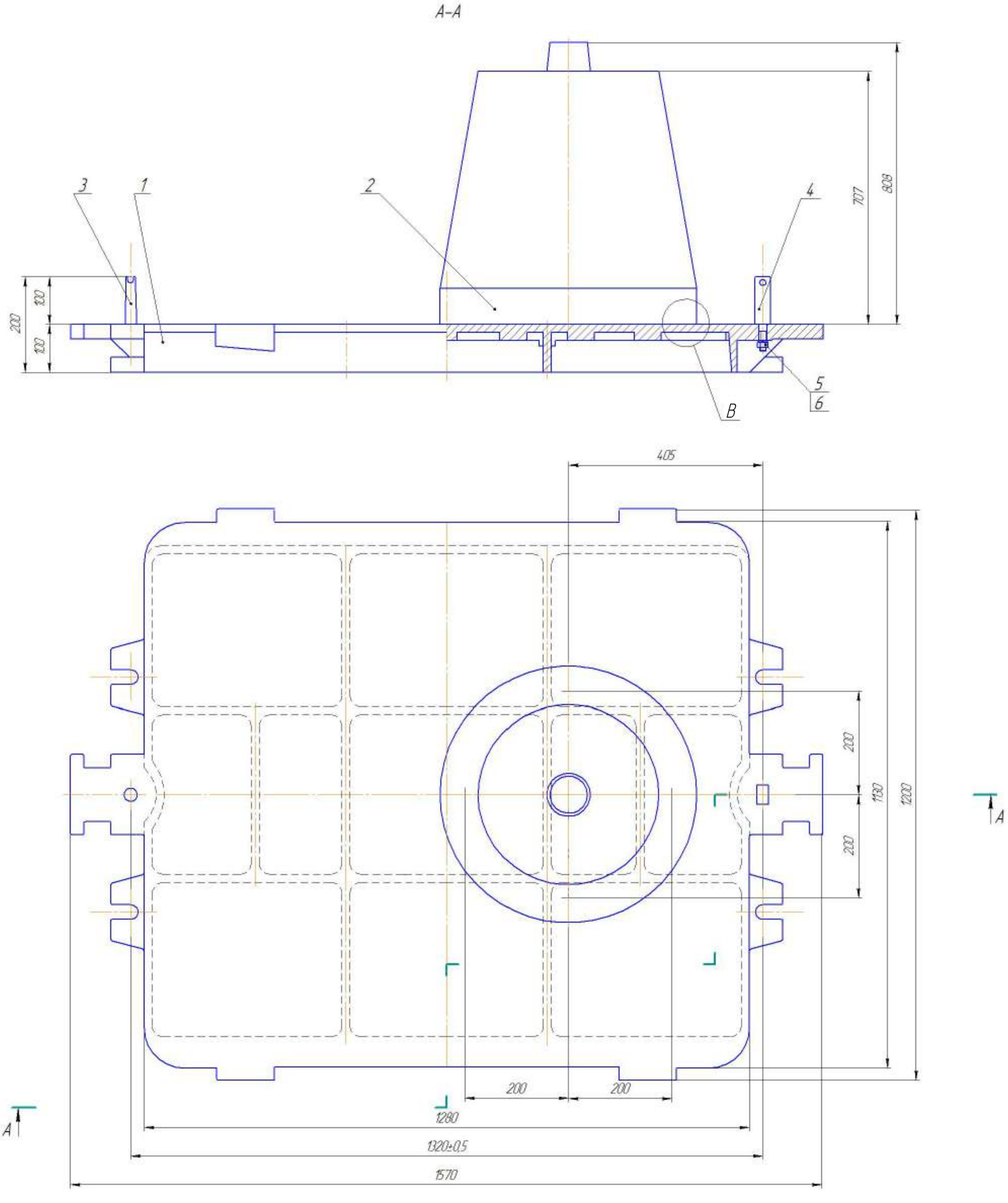

Fig. 5. Model on model plate: 1 – model plate; 2 – model; 3, 4 – stand; 5 – nut; 6 – washer; 7 – screw

Given these factors, it seems possible to control the quality of the casting in terms of geometry and dimensions. Such control can be carried out by purposeful changes in the method of supplying metal and the geometry of the elements of the gating system. To do this, it is proposed to construct a regression equation that relates the geometric characteristics of the gating system and the magnitude of deviations for each controlled parameter of the size and geometry of the casting. This idea is shown in Fig. 7.

The input variables in this consideration are: the length of the i-th feeder (l_i), the angle of inclination of the i-th feeder with respect to the Y axis (α_i), the cross-sectional area of the i-th feeder (F_{gi}), the height of the feeder supply in the case of a tiered gating system (H_i), Fig. 8.

The output variables are the dimensions and geometry of the castings, subject to control in accordance with the requirements of technological documentation.

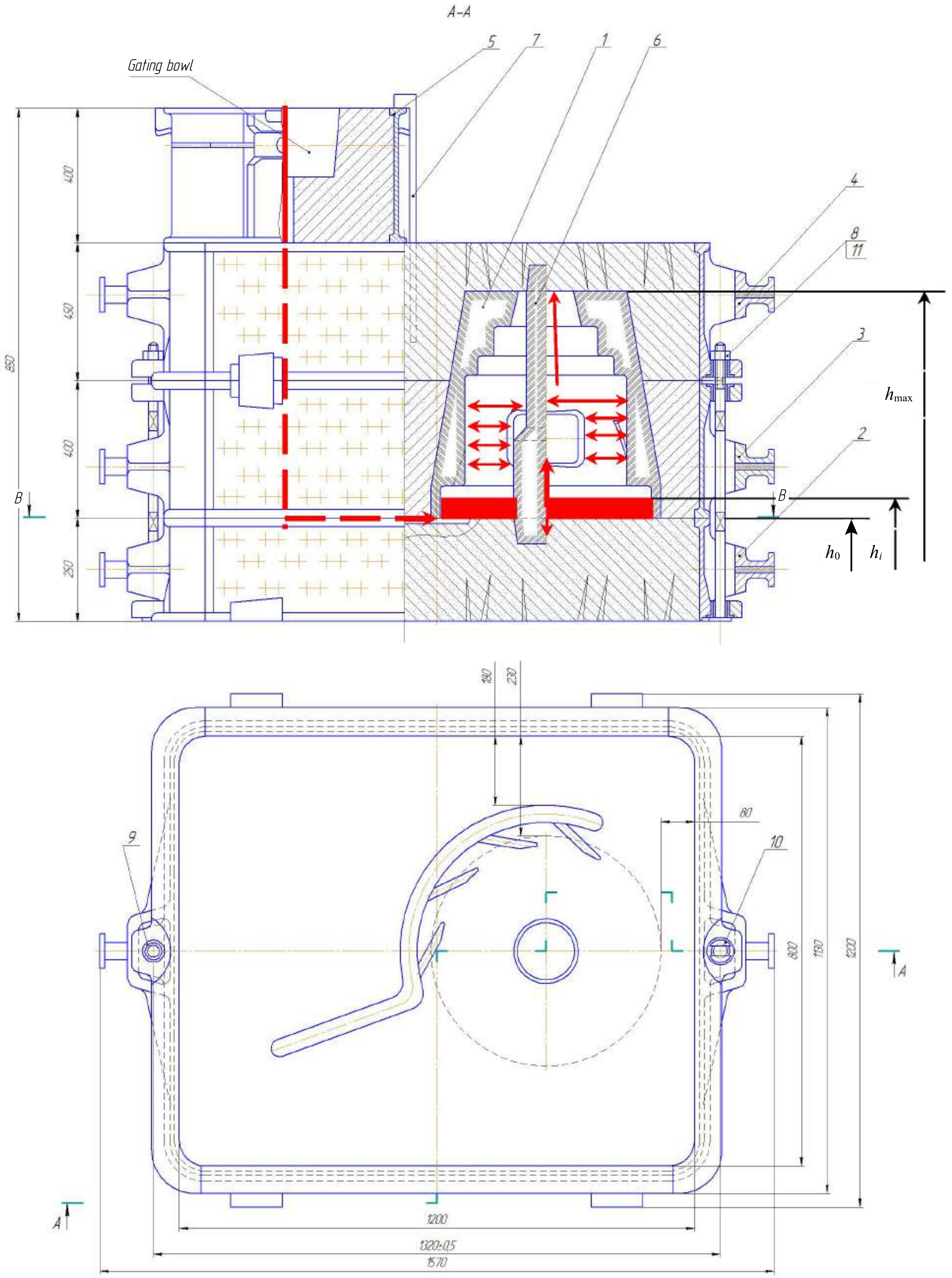

Fig. 6. Form assembly: 1 – rod; 2–5 – flask; 6 – rod; 7 – clamp; 8 – pin; 9 – centering sleeve; 10 – guide sleeve; 11 – nut

In contrast to the accepted simplifications, when choosing the cross-sectional area of feeders for reasons of their equality, satisfying condition (1), it is proposed to consider the area of each feeder as a variable. This can be justified by the fact that feeders are brought to different places of the casting and at different angles, while changing the cross-sectional area affects the rate of melt entry into the mold cavity:

$$F_g n = F_{g\Sigma} = \frac{\sum G}{\gamma\tau\mu\sqrt{2gH_p}}, \qquad (1)$$

where F_g – the cross-sectional area of one feeder, m^2; $F_{g\Sigma}$ – the total cross-sectional area of all feeders, m^2; n – the number of feeders; ΣG – the mass of poured metal, including the mass of all castings placed in the mold and the mass of the gating system, kg; γ – the density of the alloy, kg/m^3; μ – the coefficient that depends on the form resistance and is taken equal to 0.25–0.5, depending on the pouring method and form resistance. When pouring dry, $\mu=0.3$–0.5 (0.3 – high resistance – two turns of the jet by 90°, 0.38 – medium resistance – one turn, 0.5 – low resistance); when pouring wet $\mu=0.25$–0.42 (0.25 – high resistance – two turns of the jet by 90°, 0.32 – medium resistance – one turn, 0.42 – low resistance); τ – the pouring time, s, determined by formula (2) or (3), depending on the type of alloy – steel or cast iron, respectively:

$$t = S\sqrt[3]{\delta G}, \qquad (2)$$

$$t = S\sqrt{\delta G}. \qquad (3)$$

In formulas (2), (3): S – the coefficient depending on the fluidity of the metal (normal or increased) and the method of supplying metal (from below by siphon into the thick-walled parts of the casting $S=1.3$ with normal fluidity, $S=1.4$–1.45 with increased fluidity; by 0.5 heights or with a stepped, combined method of pouring $S=1.4$ with normal fluidity, $S=1.5$–1.6 with increased fluidity; uniform supply from above into the thin-walled parts of the casting $S=1.5$–1.6 with normal fluidity, $S=1.6$–1.8 with increased fluidity), δ – the predominant or average wall thickness of the casting, cm.

The static head taken into account in formula (1) is determined by the formula:

$$Hp = H - \frac{P^2}{2C}, \qquad (4)$$

where H – the height of the riser from the place of metal supply to the mold, corresponding to the height of the upper flask in the case of one mold connector, mm; C – epy casting height, mm; P – the height from the parting line to the top point on the casting, mm.

In this case, condition (1) can be written as:

$$\sum_{i=1}^{n} F_{gi} = F_{g\Sigma} = \frac{\sum G}{\gamma\tau\mu\sqrt{2gH_p}}, \qquad (5)$$

where F_{gi} – the cross-sectional area of the i-th feeder.

The areas of all other elements of the gating system (slag trap and riser) are traditionally determined by various ratios $\Sigma F_{g\Sigma}:F_s:F_r$ from empirical considerations.

Variables l_i, α_i, F_{gi}, H_i form a matrix of input variables x_i.

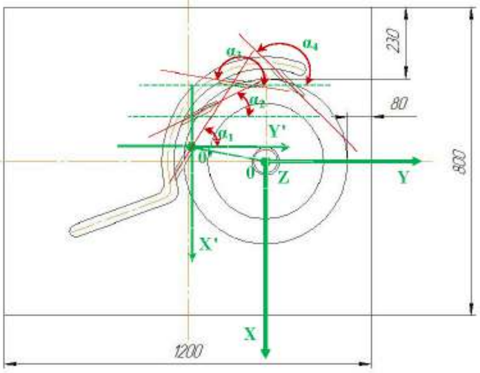

Fig. 7. The principle of choosing input variables – the parameters of the gating system

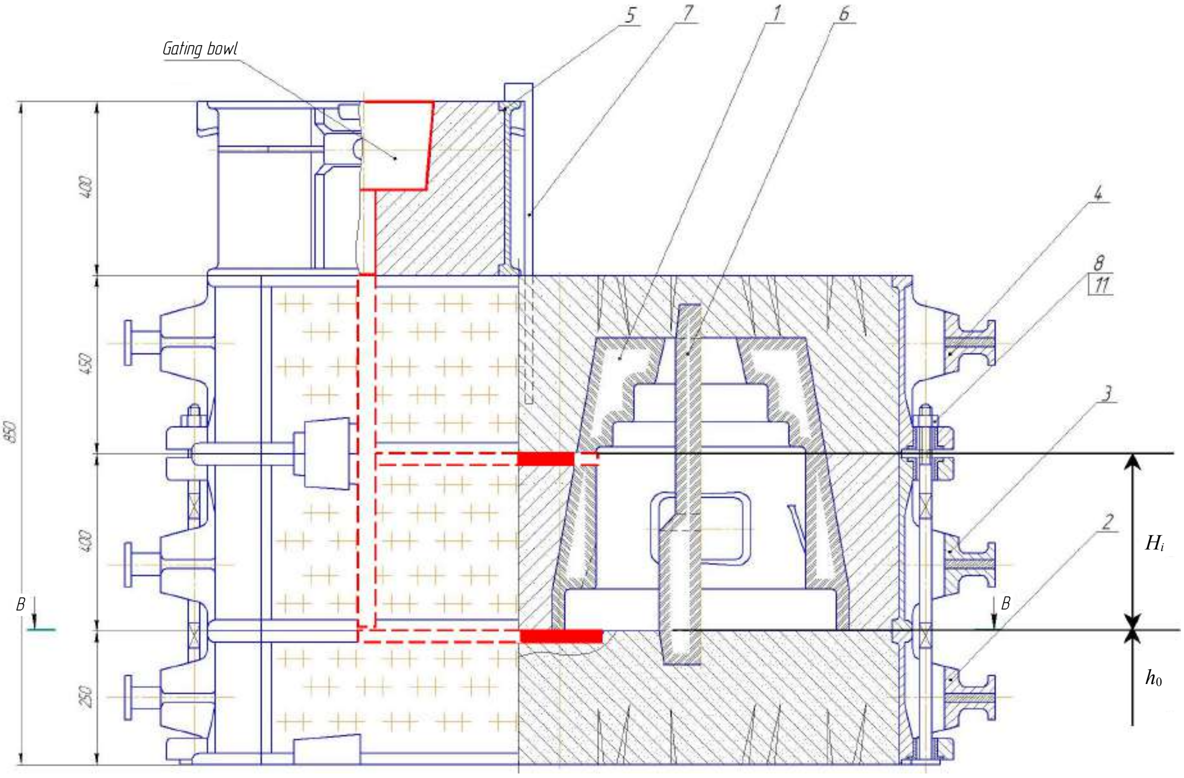

Fig. 8. Input variable «feeder inlet height» in the case of using a tiered gating system (the slag trap is conventionally not shown)

The proposed procedure, focused on quality control of castings by geometry and dimensions, consists of the following steps:

1. The choice of input variables – the geometric characteristics of the gating system in the selected coordinate system, the origin of which can be associated with the center of the casting in the plane of the parting of the mold.

2. The choice of intervals of variation of input variables and their normalization according to the formula:

$$x_i = \frac{2x_i^* - \left(x_{i\max}^* + x_{i\min}^*\right)}{x_{i\max}^* - x_{i\min}^*},$$

$$i = 1,..,N,\ j = 1,.,n,\ x_{i\max}^* = \max_j x_{ji}^*,\ x_{i\min}^* = \min_j x_{ji}^*, \qquad (6)$$

where the symbol * denotes the natural value of the input variables.

3. Manufacture of foundry equipment and n molds for this equipment.

4. Filling n forms.

5. Technological audit of the process, including:

5.1. Control of the sizes and geometry of the received castings.

5.2. Statistical processing of the obtained data in order to determine the following sample functions:

– mathematical expectation:

$$M(Y) = \frac{\sum_{s=1}^{N} Y_s}{N}, \qquad (7)$$

$$S(Y) = \sqrt{\frac{\sum_{s=1}^{N}\left(Y_s - M(Y)\right)^2}{N-1}}, \qquad (8)$$

where N – the number of measurements of the j-th dimension on the casting.

6. Checking the distribution law and, if it corresponds to the normal one, fixing the result for the selected set of values of the input variables corresponding to the first point of the full factorial experiment plan.

7. Go to p. 3–6, respectively, to the second point of the plan of the full factorial experiment, etc. until the end of the formation of the complete data table for calculating the coefficients of the regression equation $Y = \varphi(x_1,\ x_2, ...,\ x_m)$.

8. Verification of adequacy and statistical analysis of accuracy for the obtained linear regression equation [12].

9. Steep ascent along the response surface to reach the stationary region [13].

10. Study of the stationary region by canonical transformation of the response surface [14] or by ridge analysis [15].

The optimal values of the input variables found as a result of the procedure 1–10, which minimize deviations in the dimensions or geometry of the castings, can be included in the final tooling.

The limitation of the proposed procedure is due to the possible large number of input variables. In this case, the procedure cannot be implemented, starting from point 3 of their economic considerations. In this case, the physical experiment can be replaced by a computer experiment using specialized software products that allow modeling the filling and cooling processes. After obtaining the optimal parameters of the gating system, industrial verification will be necessary and, if necessary, adjustments.

The development of this research is possible in the direction of finding optimal solutions for specific castings.

4. Conclusions

A hypothesis has been proposed that modeling the influence of gating system parameters on the dimensional and geometric accuracy of castings can make it possible to find optimal design solutions in terms of creating casting equipment.

The proposed procedure for finding solutions for choosing a gating system that minimizes deviations in the dimensions and geometry of castings from those specified by the technological documentation allows optimizing the tooling, achieving an increase in the quality of shaped castings.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has no associated data.

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