ABSTRACT
The paper shows that casting dimensions and their tolerance limits must be assigned by the technologist developing the technological process for machining. A foundry engineer must design the casting in accordance with the requirements for the respective technological process of casting, i.e. to design the casting slopes and roundings. That provides the opportunity for ensuring quality with a minimum consumption of material.

KEYWORDS: Casting, Design, Dimensional analysis

1. INTRODUCTION

The design of the castings has been considered in a number of literary sources, mainly textbooks and reference books [1-9]. In order to determine the dimensions of the castings, the machining allowances and dimensions tolerances are set [1,3,6,7,8]. Two important questions arise after analysis of this data:

1. In all the sources instead of tolerance $T_{EI}$ and upper $ES$ tolerance limits are assigned.

Tolerance $T$, however, is a field and a physically independent (value) (Figure 1a). In this case the tolerance margin is defined by the possibilities of technological process, used for making the casting. This tolerance restricts dispersion $D$ of errors $\Delta$, arising in the course of technological process, expressed by stray field $\omega$.

![Figure 1: Tolerance and stray field.](image)

The tolerance can be positioned in a different manner in relation to the nominal dimension. Its position is defined by mean deviation $EM$, position of the stray field – by mathematical expectation $m$ (Figure 1.b).
Mathematically the tolerance and the mean deviation are connected with tolerance limits $EI$ and $ES$:

$$T = ES - EI; \quad \text{(1)}$$
$$EM = \frac{EI + ES}{2}. \quad \text{(2)}$$

Whereas a mean deviation $EM$ is assigned by the designer for various reasons, tolerance $T$ is a preset value and cannot be changed. (There exist the concepts of attainable accuracy and economically effective accuracy. In manufacturing, economically effective accuracy is used. That, which can be achieved on an equipment in a good condition, by a worker with the needed qualification and when the preset economic criteria are met).

In fact, in literature lower $EI$ and upper $ES$ tolerance limits preset not only tolerance $T$, but also its position in relation to nominal dimension (through equation 2).

2. In all sources the lower tolerance limit is assigned with a minus sign, the upper one – with a plus sign. In fact the lower tolerance limit "consumes part of allowance" for embracing dimensions (Figure 2a), the upper tolerance limit does the same for the embraced dimensions (Figure 2b).

![Figure 2: Machining allowances and tolerances for castings dimensions.](image-url)

In order to provide the needed allowance $z_{\text{min}}$, we must preset $EI = 0$, $ES = T$.

If the workpiece dimension is $A = 300 \text{ mm}$, $z_{\text{min}} = 4 \text{ mm}$, $EI = -2 \text{ mm}$, $ES = 2 \text{ mm}$, then, from Fig. 3a, we will obtain:

$A_{\text{embracing}} = 304 \text{ mm}$, $z_{\text{residual}} = 2 \text{ mm}$.

In order to provide the needed allowance $z_{\text{residual}} = 2 \text{ mm}$, we must assign $EI = 0 \text{ mm}$, $ES = 4 \text{ mm}$.

2. DIMENSIONAL ANALYSIS

In the machining of the workpieces as a result of the need to do multiple operations and to change technological bases complex dimensional links arise. As a result of the casting dimen-
sions become different with the same allowances and tolerances, but with different variants of
technological process.
We will consider two variants of a technological process for machining of workpiece, shown on
Figure 3. Surfaces 1, 2 are machined by milling and 3 by boring. As a result of the machining
dimensions $D_1$, $D_2$, and $D_3$ must be obtained.

**Variant 1.** (Figure 4).
*Operation 1.* Milling of the surface 1. Tuning base – surface 2. Resulting dimension $A_1$ (Figure
4a).
*Operation 2.* Milling of the surface 2. Tuning base – machined surface 1. Resulting dimension
$A_2$ (Figure 4b).
*Operation 3.* Boring of the hole 3. Tuning base – surface 1. Resulting dimensions $A_3$ and $A_4$
(Figure 4c).

The dimensional scheme of technological process is shown on Figure 4d.

**Figure 3:** Workpiece “Body”

**Variant 2.** (Figure 5).
*Operation 1.* Milling of the surface 1. Tuning base – the axis of surface 3. Resulting dimension
$A_1$ (Figure 5a).
*Operation 2.* Milling of the surface 2. Tuning base – machined surface 1. Resulting dimension
$A_2$ (Figure 5b).
*Operation 3.* Boring of the hole 3. Tuning base – surface 1. Resulting dimensions $A_3$ and $A_4$
(Figure 5c).

The dimensional scheme of technological process is shown on Fig. 5d. The radius of hole
$D_3 = D_3 / 2$ is showed on the dimensional schemes. Respectively $T_{i3} = T_{i3} / 2$. Misalignments
of the axes of the cast and bored hole are marked with $e$. This misalignment leads to fluctuation
$\Delta z$ of allowance $z$ ($\Delta z = 2e$). Casting dimensions are indicated by $B_1$.

Input data:

$D_1 = 150^{+0.12}_{-0.11}$ mm, $D_2 = 230^{+0.20}_{-0.10}$ mm, $D_3 = 40^{+0.05}_{-0.10}$ mm
($2D_3 = 80^{+0.10}_{-0.10}$ mm), $z_{i\min} = 5$ mm,

$z_{i\min} = 4$ mm, $z_{i\min} = 3$ mm, $T_{j1} = 0.40$ mm, $T_{j2} = 0.30$ mm, $T_{j3} = 0.10$ mm,

$T_{i1} = 0.06$ mm, $T_{i2} = 2.0$ mm, $T_{i3} = 3.0$ mm, $T_{i4} = 2.0$ mm.
Intermediate technological dimensions $A_i$ and casting dimensions $B_i$ are determined by a specialized software program for dimensional analysis of technological processes.

The results for variant 1 are shown in table 1, for variant 2 – in table 2. As it can be seen dimensions $B_i$ and $B_i'$ have different minimum values (at the same tolerance) - $B_{i min} = 241.6 \text{ mm}$, $B_{i min}' = 239.6 \text{ mm}$. The dimension $B_{i min}'$ is larger than dimension $B_{i min}$ by 2 mm. In fact that is an increase of allowance by 2 mm.

Figure 4: Dimensional analysis - variant 1.
### Table 1: Variant 1.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Nominal dimension, mm</th>
<th>Lower tolerance limit, mm</th>
<th>Upper tolerance limit, mm</th>
<th>Dimension</th>
<th>Nominal dimension, mm</th>
<th>Lower tolerance limit, mm</th>
<th>Upper tolerance limit, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_1$</td>
<td>150.0</td>
<td>0.000</td>
<td>0.120</td>
<td>$A_1$</td>
<td>80.0</td>
<td>-0.610</td>
<td>-0.210</td>
</tr>
<tr>
<td>$D_2$</td>
<td>230.0</td>
<td>-0.100</td>
<td>0.200</td>
<td>$A_2$</td>
<td>230.0</td>
<td>-0.100</td>
<td>0.200</td>
</tr>
<tr>
<td>$D_3$</td>
<td>40.0</td>
<td>0.000</td>
<td>0.050</td>
<td>$A_3$</td>
<td>150.0</td>
<td>0.100</td>
<td>0.110</td>
</tr>
<tr>
<td>$z_1$</td>
<td>5.0</td>
<td>0.000</td>
<td>5.400</td>
<td>$A_4$</td>
<td>40.0</td>
<td>-0.005</td>
<td>0.055</td>
</tr>
<tr>
<td>$z_2$</td>
<td>4.0</td>
<td>0.000</td>
<td>2.700</td>
<td>$B_1$</td>
<td>154.0</td>
<td>0.810</td>
<td>2.810</td>
</tr>
<tr>
<td>$z_3$</td>
<td>3.0</td>
<td>0.000</td>
<td>2.860</td>
<td>$B_2$</td>
<td>239.0</td>
<td>2.600</td>
<td>5.600</td>
</tr>
<tr>
<td>$e$</td>
<td>0.0</td>
<td>0.000</td>
<td>0.800</td>
<td>$B_3$</td>
<td>37.0</td>
<td>-2.005</td>
<td>-0.005</td>
</tr>
</tbody>
</table>

**Figure 5:** Dimensional analysis - variant 2
Table 2: Variant 2.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Nominal dimension, mm</th>
<th>Lower tolerance limit, mm</th>
<th>Upper tolerance limit, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>D₁</td>
<td>150.0</td>
<td>0.000</td>
<td>0.120</td>
</tr>
<tr>
<td>D₂</td>
<td>230.0</td>
<td>-0.100</td>
<td>0.200</td>
</tr>
<tr>
<td>A₁</td>
<td>234.0</td>
<td>0.200</td>
<td>0.600</td>
</tr>
<tr>
<td>A₂</td>
<td>230.0</td>
<td>-0.100</td>
<td>0.200</td>
</tr>
<tr>
<td>A₃</td>
<td>150.0</td>
<td>0.100</td>
<td>0.110</td>
</tr>
<tr>
<td>A₄</td>
<td>150.0</td>
<td>0.050</td>
<td>0.110</td>
</tr>
<tr>
<td>z₁</td>
<td>5.0</td>
<td>0.000</td>
<td>3.400</td>
</tr>
<tr>
<td>z₂</td>
<td>4.0</td>
<td>0.000</td>
<td>0.700</td>
</tr>
<tr>
<td>z₃</td>
<td>3.0</td>
<td>0.000</td>
<td>4.860</td>
</tr>
<tr>
<td>e</td>
<td>0.0</td>
<td>0.000</td>
<td>2.800</td>
</tr>
</tbody>
</table>

Thus the depth fluctuation of the cut (in machining of one working movement is different for both variants (Table 3).

Table 3:

<table>
<thead>
<tr>
<th>Operation</th>
<th>Variant 1</th>
<th></th>
<th></th>
<th>Variant 2</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>tₘₘₘ, mm</td>
<td>tₘₘₘ, mm</td>
<td>ωₘ, mm</td>
<td>tₘₘₘ, mm</td>
<td>tₘₘₘ, mm</td>
<td>ωₘ, mm</td>
</tr>
<tr>
<td>Milling of upper surface</td>
<td>5.0</td>
<td>10.4</td>
<td>5.4</td>
<td>5.0</td>
<td>8.4</td>
<td>3.4</td>
</tr>
<tr>
<td>Milling of lower surface</td>
<td>4.0</td>
<td>6.7</td>
<td>2.7</td>
<td>4.0</td>
<td>4.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Boring of the hole</td>
<td>3.0</td>
<td>5.86</td>
<td>2.86</td>
<td>3.0</td>
<td>7.86</td>
<td>4.86</td>
</tr>
</tbody>
</table>

The depth fluctuation of cut on the hole circumference owing to misalignment e of the axes of cast and bored hole for the two variants is also different:

\[ e₁ = 0.8 \text{ mm}, \quad ω₁ = 1.6 \text{ mm} \]

\[ e₂ = 2.8 \text{ mm}, \quad ω₂ = 5.6 \text{ mm} \]

3. CONCLUSION

Casting dimensions and their tolerance limits must be assigned by the technologist developing the technological process for machining.
A foundry engineer must design the casting in accordance with the requirements for the respective technological process of casting, i.e. to design the casting slopes and roundings.
That provides the opportunity for ensuring quality with a minimum consumption of material.

4. REFERENCES
