Cost analysis in injection moulded plastic parts designing

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Abstract. One of the major problem in plastic part design consists in the cost optimization. The designer should take into consideration some relevant aspects that are related to the functional role of the part, the mechanical and thermal loads, and the part cost. The part cost depends on three main components: the mould cost, the equipment operation cost and the material cost. The injection cycle time, the part volume and the material nature can estimate the last two components of the part cost. The mould cost is more difficult to estimate, and current CAD software did not integrate such a feature. The paper present a methodology to estimate the mould cost, taking into consideration the part geometry and its dimensional prescriptions. In addition, a spreadsheet is provided in order to estimate the mould cost.

1. Introduction. Part costing
One of the major problem in parts design consists in the cost optimization [1, 2]. According to the design for manufacturing paradigm, in the field of plastic parts the designer should take into consideration some relevant aspects that are related to the functional role of the part, the mechanical and thermal loads, and the part cost. As a rule, several designs are made, while the designer should keep in mind both the functionality, manufacturability and cost of the part. The last two terms are very close related, usually a good manufacturability will ensure a low part cost [3].

The injection moulded part cost, $K$, depends on three main components: the mould cost, the equipment operation cost and the part material cost [3]:

$$K = \frac{K_d}{N} + K_e + K_m$$  \hspace{1cm} (1)

where the terms refer to:

- $K_d$ – the mould (die) cost;
- $N$ – the production volume;
- $K_e$ – the equipment operation cost;
- $K_m$ – the part material cost.

The last two terms of formula 1 are quite easy to estimate, as follows [3]:

- The equipment operation cost $K_e$ depends on the machine hourly rate, $C_h$, and the effective cycle time of the process, $t_{eff}$, according to the following formula:
\[ K_e = C_h \cdot t_{eff} = C_h \cdot \frac{t}{Y} \]  

(2)

The effective cycle time of the process, \( t_{eff} \), depends on the process cycle time, \( t \) (which can be estimated using moulding process simulation software), and the production yield, \( Y \).

- The part material cost \( K_m \) depends on the part volume, \( V \), and the volumetric material cost \( K_p \), according to formula:

\[ K_m = V \cdot K_p \]  

(3)

As it is shown in figure 1, the costing module of the CAD environment let the designer [4]:

- to choose the material type; the CAD software will compute the part volume, then the part material cost can be calculated;
- to enter the value of the process cycle time (it should be previously determined by injection moulding simulation); then costing module can estimate the equipment operation cost;
- to enter the mould cost;
- to enter the production volume.

![Figure 1. An injection moulded part design in CAD environment with costing module.](image)

Finally, the costing module will compute the estimated total cost per part (see figure 2), with the distribution of the three components of the part cost:

- Part material cost – absolute and percentage;
- Equipment operation (manufacturing) cost – absolute and percentage;
- Mould (die) cost per manufactured part \( (K_d/N) \) – absolute and percentage.

2. The mould cost estimation

The only problem of the described procedure is that the cost of the mould is not rated by the CAD environment; it must be entered by the designer as an input data in the part cost calculation module [4].
Figure 2. Costing module window [4]:

- **Input data:**
  - Type of plastic material
  - Material cost
  - Mould runner system type
  - Maximum wall thickness
  - Injection cycle time
  - Mould cost
  - Production volume

- **Output data:**
  - Estimated cost per part
  - Part material cost
  - Equipment operation (manufacturing) cost
  - Mould cost per manufactured part.

Because the cost of moulds is very high, its correct estimation is of great importance even from the design phase of the injection moulded parts. The following procedure will estimate the mould cost taking into consideration the most relevant part design data.

2.1. *The mould cost estimation methodology*

The present approach uses a methodology that is based on the estimation of so-called relative cost, $C_d$, which is defined as a ratio of expected mould cost, $K_d$, to the mould cost for a reference part, $K_{d0}$ [3]:

$$C_d = \frac{K_d}{K_{d0}} = \frac{K_{dc}+K_{dm}}{K_{dc0}+K_{dm0}}$$

(4)

where $K_{dc}$ and $K_{dm}$ refer to mould construction cost and mould material cost for the designed part, and $K_{dc0}$ and $K_{dm0}$ refer to mould construction cost and mould material cost for the reference part, which is a plastic washer with the following dimensions: thickness = 1 mm, outer diameter = 72 mm and inner...
diameter – 60mm. The approximate cost of the mould for the reference part is about 7000 USD (mould construction cost – 6000 USD, mould material cost – 1000 USD).

Equation 4 can be written as follows:

\[ C_d = \frac{K_{dco}}{K_{dco} + K_{dm}} \cdot C_{dc} + \frac{K_{dm}}{K_{dco} + K_{dm}} \cdot C_{dm} = A \cdot C_{dc} + B \cdot C_{dm} \quad (5) \]

where the terms refer to:

- \( C_{dc} \) – the relative mould (die) construction cost;
- \( C_{dm} \) – the relative mould (die) material cost;
- \( A \) – the weight factor of the reference mould construction cost;
- \( B \) – the weight factor of the reference mould material cost.

The industrial experience of the mould-makers indicates the following average values for the weight factors: \( A = 0.8 \); \( B = 0.2 \). So the relative mould cost can be estimated by the simplified formula:

\[ C_d = 0.8C_{dc} + 0.2C_{dm} \quad (6) \]

2.1.1. The relative mould construction cost can be estimated as a product of three cost factors [3]:

\[ C_{dc} = C_b C_s C_t \quad (7) \]

where the terms refer to:

- \( C_b \) – The basic relative cost;
- \( C_s \) – A multiplier that takes into account the subsidiary factors that describe the part complexity;
- \( C_t \) – A multiplier that takes into account the part tolerance and surface finish.

![Figure 3. The basic relative cost \( C_b \) [3].](image)

The basic relative cost \( C_b \) depends on the following aspects (see figure 3):
• The part overall dimensions;
• The part geometrical shape (box or flat);
• The part dividing surface type;
• The part peripheral height to the dividing surface;
• The part internal undercuts, which required a mould with split cores or form pins;
• The part external undercuts, which required a mould with side cores or cavities.

Figure 2 shows the values of the basic relative cost $C_b$, for both flat or box-shaped parts.

The multiplier for subsidiary complexity factors, $C_s$, takes into account the part features that add some complexity – ribs, bosses, holes, lettering and other geometric entities that are aligned with the mould closure direction – as well as the complexity of the external undercuts, if they are present.

First, the total penalty of cavity complexity must be calculated using table 1 [3], then the part can be described having a low, moderate, high or very high cavity complexity, as it is shown in table 2 [3].

**Table 1.** The total penalty.

| Feature                                | Number of features ($n$) | Penalty per feature | Penalty |
|----------------------------------------|--------------------------|---------------------|---------|
| Holes or depressions                   |                          |                     |         |
| circular                               | 2                        | 2n                  |         |
| rectangular                            | 4                        | 4n                  |         |
| irregular                              | 7                        | 7n                  |         |
| Bosses                                 |                          |                     |         |
| solid                                  | 1                        | n                   |         |
| hollow                                 | 3                        | 3n                  |         |
| Non-peripheral ribs / walls / rib clusters | 3                          | 3n                  |         |
| Side shutoffs                          |                          |                     |         |
| simple                                 | 2.5                      | 2.5n                |         |
| complex                                | 4.5                      | 4.5n                |         |
| Lettering                              | 1                        | n                   |         |

Total penalty, $TP = \Sigma \ldots$

**Table 2.** The cavity complexity.

| Overall dimension | Total penalty | Cavity complexity |
|-------------------|---------------|-------------------|
| $L \leq 250$ mm   |               |                   |
| $10 < TP \leq 20$ | Moderate      |                   |
| $20 < TP \leq 40$ | High          |                   |
| $TP > 40$         | Very high     |                   |
| $TP \leq 15$      | Low           |                   |
| $250 < L \leq 480$ mm |               |                   |
| $15 < TP \leq 30$ | Moderate      |                   |
| $30 < TP \leq 60$ | High          |                   |
| $TP > 60$         | Very high     |                   |
| $TP \leq 20$      | Low           |                   |
| $L > 480$ mm      |               |                   |
| $10 < TP \leq 40$ | Moderate      |                   |
| $40 < TP \leq 80$ | High          |                   |
| $TP > 80$         | Very high     |                   |

The multiplier for subsidiary complexity factors, also, takes into account the presence and complexity of the external undercuts, as it is shown in table 3 [3]. The external undercuts are considered as extensive if they are not unidirectional holes or depressions.
Table 3. Multiplier for subsidiary complexity factors.

| C_s | Parts without extensive external undercuts | Parts with extensive external undercuts |
|-----|------------------------------------------|---------------------------------------|
| Cavity complexity | 1.00 | 1.25 |
| Low | 1.25 | 1.45 |
| Moderate | 1.60 | 1.75 |
| High | 2.05 | 2.15 |

The multiplier for part tolerance and surface finish, $C_t$, takes into account the dimensional tolerances and surface finish class. Table 4 shows the values of this multiplier [3]. It is assumed that the dimensional precision class is high if the tolerances are up to ISO 7 inclusive. Bigger tolerances are considered in the normal precision class. The surface finish is classified by Society of Plastic Engineers (SPE) as follows [3]:

- SPE 1: parts with high transparency, with low surface distortions and blemishes, i.e. optical lenses;
- SPE 2: parts with good transparency – near the lenses transparency, and parts having high gloss, without scratches, i.e. bearings;
- SPE 3: parts with low roughness, without high surface gloss;
- SPE 4: parts with medium roughness; no special aesthetic requirements;

Table 4. Multiplier for part tolerance and surface finish.

| C_t | Normal precision class | High precision class |
|-----|------------------------|----------------------|
| SPE 3-4 | 1.00 | 1.05 |
| Textured | 1.05 | 1.10 |
| SPE 1-2 | 1.10 | 1.15 |

2.1.2. The relative mould material cost depends on the overall part dimensions (figure 4).
The notations in figure 4 refer to [3]:
- \( L_m \) – the part length;
- \( B_m \) – the part width;
- \( H_m \) – the part height;
- \( M_{wf} \) – the thickness of mould core plate:

\[
M_{wf} = 0.04L_m^{4/3}
\]  

(8)

- \( M_t \) – the mould base thickness:

\[
M_t = 2M_{wf} + H_m
\]  

(9)

- \( M_{ws} \) – the thickness of the mould side walls:

\[
M_{ws} = (0.006CH_m^4)^{1/3}
\]  

(10)

The factor \( C \) in formula 10 is obtained from figure 5 [3].

![Figure 5](image)

**Figure 5.** Factor \( C \) in formula 10.

The relative mould material cost \( C_{dm} \) depends on the mould base thickness \( M_t \) (see figure 6) and the projected area of the mould base, \( M_a \) [3]:

\[
M_a = (2M_{ws} + B_m) \times (2M_{ws} + L_m)
\]  

(11)

![Figure 6](image)

**Figure 6.** The relative mould material cost \( C_{dm} \).
3. Spreadsheet for mould cost estimation
A software spreadsheet for the mould cost estimation was developed. It is presented in figure 7.

![Spreadsheet for mould cost estimation](image)

**Figure 7.** The relative mould material cost spreadsheet.

The designer should introduce the input data, such as the part overall dimensions, the number of internal/external undercuts, the type of the dividing surface, the complexity elements etc., and the spreadsheet will calculate the following outputs:

- The relative mould construction cost;
- The relative mould material cost;
- The relative mould cost;
- The mould cost.

4. Conclusion and further developments
The presented methodology and the developed software spreadsheet allows the estimation of the mould cost, helping the designer in the plastic parts conception to minimize the parts cost. Further developments will be focused in the software integration of the developed spreadsheet into the CAD environment, in order to facilitate the design process.

5. References
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