Part cost estimation in injection moulding

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Abstract. The part cost optimization is one of the major problems in plastics industry. The designers must take into account a lot of aspects regarding the functional role of the part, the mechanical loads, and least but not last, the part cost. The part cost depends on the mould cost, the equipment operation cost and the material cost. The paper presents a methodology to estimate the part cost, focusing on the equipment operation cost. In addition, a spreadsheet is provided in order to estimate the equipment operation cost.

1. Introduction. Part costing in injection moulding

One of the major problems in parts design consists in the cost optimization [1, 2]. The injection moulded part cost, $K$, depends on three main components: the mould cost, the equipment operation cost and the part material cost [3]:

$$K = \frac{K_d}{N} + K_e + K_m,$$

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.

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 $K_m$ can be calculated;
- to enter the value of the process cycle time (it should be previously determined); then costing module can estimate the equipment operation cost $K_e$;
- to enter the mould cost $K_d$;
- to enter the production volume $N$. 
Figure 1. Injection moulded part design in CAD environment with costing module.

So one of the problems in the described procedure is to estimate as accurate as possible the process effective cycle time, in order to compute the equipment operation, cost $K_e$.

2. The equipment operation cost estimation

The equipment operation cost $K_e$ depends on the machine hourly rate, $C_h$, and the effective cycle time of the process, $t_{ef}$, according to the following formula [3]:

$$K_e = C_h \cdot t_{ef} = C_h \cdot \frac{t}{Y}$$

(2)

The effective cycle time of the process, $t_{ef}$, depends on the process cycle time, $t$ (which can be estimated using moulding process simulation software), and the production yield, $Y$. As a rule, wasted parts are the result of dimensional or surface quality nonconformity. A large percentage of wasted parts will lead to an appropriate increase in the effective cycle time. Due to scrap, in practice it is possible to achieve increases of between 10% and 30% of the effective cycle time.

If there are no perceived estimates of the effective process cycle time (from the simulation of the process or normative), then the relative calculation of the processing cost $C_r$ is used [3]:

$$C_e = \frac{K_e}{K_{e0}} = \frac{C_h \cdot t_{ef}}{C_{h0} \cdot t_o} = C_{hr} \cdot t_r$$

(3)

where the terms refer to:

- $K_{e0}$ – the equipment operation cost in case of a reference part injection. The reference part is a plastic washer with the following dimensions: thick – 1 mm, outer diameter – 72 mm and inner diameter – 60mm;
- $C_{h0}$ – the machine hourly rate for the reference part injection. $C_{h0} = 27.53 \, \text{$/h$}$$
- $t_o$ – the effective cycle time in the case of injection of the reference part. $t_o = 16s$;
- $C_h$ – the machine relative hourly rate;
- $t_r$ – the total relative duration of the process cycle.

So, in order to estimate the relative processing cost $C_e$, two relative terms should be estimated: the machine relative hourly rate $C_{hr}$ and the total relative duration of the process cycle $t_r$. 
2.1. The machine relative hourly rate $C_{hr}$

The machine relative hourly rate is determined by the size of the injection machine, see table 1 [3].

Table 1. The machine relative hourly rate.

| Machine weight, $F_p$ [tons] | $C_{hr}$ |
|-----------------------------|---------|
| $\leq$ 99                  | 1.00    |
| 100... 299                 | 1.19    |
| 300... 499                 | 1.44    |
| 500... 699                 | 1.83    |
| 700... 999                 | 2.87    |
| $\geq$1000                 | 2.93    |

The required machine tonnage is determined on the basis of the section size of the injected part projected in a plane perpendicular to the direction of mould closure [3], $A_p [mm^2]$:

$$F_p = 0.005 \cdot A_p$$  \hspace{1cm} (4)

2.2. The total relative cycle time $t_r$

The statistical study of the equipment operation cost has shown that the length of the process cycle time depends essentially on the design details of the part. Thus, for the complex parts, there is the question of how the presence of ribs, bosses of complex form, etc. will increase the time of solidification and, implicitly, the length of the process cycle time.

Based on the experience gained by manufacturers of injection moulds, it was concluded that the total relative cycle time $t_r$ can be estimated by the formula [3]:

$$t_r = (t_b + t_e) t_p$$  \hspace{1cm} (5)

where the terms refer to:
- $t_b$ – the basic relative cycle time;
- $t_e$ – the additional relative cycle time due to the presence of inserts and/or internal threads;
- $t_p$ – the multiplying penalty factor that takes into account tolerances and surface quality of the injected part.

The additional duration due to the presence of inserts and/or internal threads $t_e$ is extracted from table 2, the penalty multiplier factor that takes into account tolerances and surface quality $t_p$ is extracted from table 3, and the relative basic duration of the work cycle $t_b$ is extracted from table 4 [3].

Table 2. The additional relative cycle time due to the presence of inserts and/or internal threads $t_e$.

| Parts without internal threads | Without moulded-in inserts | 0 |
|-------------------------------|---------------------------|---|
|                               | With moulded-in inserts   | 0.5* |
| Parts with internal threads   | Without moulded-in inserts | 0.1* |
|                               | With moulded-in inserts   | 0.1*/0.5* |

* The value must be multiplied by the number of inserts and/or internal threads. Thus total additional relative cycle time $t_e$ results.

2.2.1. The basic relative cycle time

The basic idea behind the analysis of the working cycle duration is that in most cases the pieces can be decomposed into so-called partitions or plates (see figure 2) that have their own cooling time so that the longest cooling time will greatly influence the duration of the work cycle for the part being analyzed [3].
Table 3. The multiplying penalty factor that takes into account tolerances and surface quality $t_p$.

| Plate surface requirements | Wall thickness $w$ [mm] | Tolerances not difficult to hold | Tolerances difficult to hold |
|----------------------------|-------------------------|---------------------------------|-----------------------------|
| Low                        |                         | 1.00                            | 1.00                        |
| 1≤w≤2                     |                         | 1.30                            | 1.20                        |
| 2≤w≤3                     |                         | 1.22                            | 1.43                        |
| 3≤w≤4                     |                         | 1.16                            | 1.37                        |
| 4≤w≤5                     |                         | 1.10                            | 1.32                        |
| High                      |                         |                                 |                             |

Table 4. The basic relative cycle time $t_b$.

| Parts with Lu/Bu≥10 or frames | Wall thickness, $w$ [mm] | (a) Slender partitionable parts, $S$ | Parts with Lu/2w<100 without lateral projections | Without ribs | With ribs | Difficult to fill or eject | Use foamed materials |
|-------------------------------|--------------------------|-------------------------------------|-----------------------------------------------|---------------|-----------|---------------------------|----------------------|
| Plates with Lu/2w≥100 and/or plates with lateral projections | w<1                      | Plates with Lu/2w<100 without lateral projections | Without ribs | 1.00  | 1.35  | 1.70  | 2.55  | Use foamed materials |
| Plates with Lu/2w≥100 and/or plates with lateral projections | 1≤w≤2                    | Plates with Lu/2w≥100 and/or plates with lateral projections | Without ribs | 1.15  | 1.55  | 2.00  | 2.85  | Use foamed materials |
| Plates with Lu/2w≥100 and/or plates with lateral projections | 2≤w≤3                    | Plates with Lu/2w≥100 and/or plates with lateral projections | With ribs | 1.15  | 1.55  | 2.00  | 2.85  | Use foamed materials |
| Plates with Lu/2w≥100 and/or plates with lateral projections | 3≤w≤4                    | Plates with Lu/2w≥100 and/or plates with lateral projections | With ribs | 1.15  | 1.55  | 2.00  | 2.85  | Use foamed materials |
| Plates with Lu/2w≥100 and/or plates with lateral projections | 4≤w≤5                    | Plates with Lu/2w≥100 and/or plates with lateral projections | With ribs | 1.15  | 1.55  | 2.00  | 2.85  | Use foamed materials |

(b) Non-slender partitionable parts, $N$

| Parts with Lu/Bu<10 | Plates with Lu/2w<100 without lateral projections | Plates with Lu/2w≥100 and/or plates with lateral projections | Difficult to fill or eject | Use foamed materials |
|---------------------|--------------------------------------------------|--------------------------------------------------|---------------------------|----------------------|
| Plates without significant ribs or significant bosses, with or without non-peripheral ribs or bosses | Without non-peripheral ribs | With non-peripheral ribs | 1.68  | 2.39  | 3.11  | 3.82  | Use foamed materials |
| Plates without significant ribs or significant bosses, with or without non-peripheral ribs or bosses | Without non-peripheral ribs | With concentric or cross ribbing | 1.96  | 2.67  | 3.39  | 4.10  | Use foamed materials |
| Plates without significant ribs or significant bosses, with or without non-peripheral ribs or bosses | Without non-peripheral ribs | With radial or unidirectional ribbing | 2.10  | 2.81  | 3.53  | 4.24  | Use foamed materials |
| Parts with rib and/or boss thickness less than the wall thickness | Ribs/bosses supported by gusset plates | Difficult to fill or eject | 2.24  | 2.96  | 3.67  | 4.39  | Use foamed materials |
| Parts with rib and/or boss thickness greater than or equal to the wall thickness | Ribs/bosses not supported by gusset plates | Difficult to fill or eject | 2.38  | 3.10  | 3.81  | 4.53  | Use foamed materials |

(c) Non-partitionable parts

| Parts which are not partitionable | Easy to cool | Difficult to cool | Easy to cool | Difficult to cool | Use foamed materials |
|----------------------------------|-------------|-------------------|-------------|-------------------|----------------------|
|                                  |             |                   |             |                   |                      |
Not all parts can be partitioned. Partitionable parts are those that can easily be broken down into a series of elementary plates. For each elemental plate, the work cycle will be determined. The plate with the longest cooling time will determine the part overall duration of the work cycle. Partitioned plates can be of several types:

- Slender or frame-like (S);
- Non-slender (N).

Figure 3 shows the definition of slender/non-slender plates. If $L$, $B$, and $H$ are the dimensions of the parallelepiped that circumscribes the part, then the part is considered to be of a slender type if:

$$\frac{L_u}{B_u} \geq 10$$  \hspace{1cm} (6)

where

$$L_u = L + B$$  \hspace{1cm} (7)

$$B_u = H$$  \hspace{1cm} (8)

The parts are considered to be non-partitionable either if they have a very complex geometry that does not allow decomposition into elementary plates, or they contain extremely difficult to cool entities because of the impossibility of using the baffles, bubblers or thermal pins [5]. This type of parts have injection cycle times longer than those of the partitionable parts.

2.2.2. The additional relative cycle time due to the presence of inserts and/or internal threads

To determine the additional relative cycle time, take into account the presence of internal threads and inserts. Inserts are metal components inserted into the mould prior to material injection. The value in
Table 2 must be multiplied by the number of inserts and/or internal threads of the part, so a total additional relative cycle time $t$, results.

### 2.2.3. The multiplying penalty factor

The multiplying penalty factor $t_p$, which takes into account the tolerances and surface quality of the injected part, takes into account the surface quality of the injected part and its dimensional and geometric tolerances. From the point of view of the injection cycle time, the surface quality requirements of the part are considered to be high if:

- Parts are produced from a mould having a surface finish SPE1-2;
- Sink marks and weld lines are not allowed on an untextured surface.

Other types of parts are considered to have low surface quality requirements.

To determine if a part has tolerances difficult to achieve, the following considerations are taken into account:

- The presence of external undercuts;
- Specification of tight tolerances on the separation surface;
- The thickness of the walls is non-uniform;
- The presence of more than 3 tight tolerances or 5 commercial tolerances.

### 3. Spreadsheet for equipment operation cost

A software spreadsheet for the equipment operation cost was developed. It is presented in figure 4.

![Figure 4. The equipment operation cost spreadsheet.](image-url)

The designer should select the input data, such as:

- The section size of the injected part – $A_p$;
The basic relative cycle time - \( t_b \);

The additional relative cycle time – \( t_e \);

The multiplying penalty factor – \( t_p \).

The spreadsheet will calculate the following outputs:

The machine relative hourly rate – \( C_{hr} \);

The total relative cycle time – \( t_r \);

The relative calculation of the processing cost – \( C_c \);

The equipment operation cost – \( K_e \).

4. Conclusion and further developments

The presented methodology and the developed software spreadsheet allows the estimation of the equipment operation cost, helping the designer in the plastic parts conception to minimize the overall 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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