# Correction Series 1.

## Exercice 1

| Process | Categorie | SubCategorie |
|---|---|---|
| electro discharge machining | subtractive | - |
| machining (milling, turning, ...) | subtractive | - |
| electro chemical machining | subtractive | - |
| plastic injection | replicative | non duplicative |
| sand casting | replicative | duplicative, expendable |
| deep drawing | replicative | non duplicative |
| classical sintering | replicative | non duplicative |
| galvanic moulding | replicative | expendable |
| vacuum casting | replicative | duplicative |
| investment casting | replicative | duplicative, expendable |

## Exercice 2

**a)** During the development phase of a product, the use of prototyping may be motivated by:

i) the need for **models**, especially:

- to eliminate interference and conflicts between moving parts,
- to assess the interactions between the product and its environment like:
  - its storage in the case of household products,
  - its incorporation into a complex system if the product is only a constituent element,
  - its aerodynamic or hydrodynamic behavior if the product is a vehicle,
  - ...
- to anticipate any assembly and disassembly problems of the product when it is repaired or recycled,
- to plan, as soon as possible, how to package the product,
- to motivate the employees in charge of the development project,
- ...

ii) the need for **conceptual prototypes** in order to make preliminary surveys in a community of experts and to evaluate the impact and the trade-related aspects of the product.

iii) the need for **fonctionnal prototypes** to judge the end design, and the way the product fulfills the detailed specifications imposed in the beginning of the development project,

iv) ...

Obviously the creation of prototypes is subject to a speed constraint which is essential to shorten the development time and to ensure

i) a longer lifetime to the product,

ii) a competitive advantage over similar products that could be marketed later.

**b)** The price of every prototypes will depend of the following elements:

i) the process,

ii) the volume of the part,

iii) the material,

iv) the post-processing(s),

v) the total number of needed parts.

For most additive processes, it should be mentionned that the price of a prototype **does not depend** (or very few) of its geometric complexity.

**Exercice 3**

The total cost $P$ of the production is the sum of three contributions:

- the price $P^{\text{mat.}}$ of the raw material,
- the price $P^{\text{init.}}$ for all the needed initiation of the machine between batches,
- the use cost $P^{\text{use}}$ for the use of the SLA station.

The three terms are calculated separately:

**Raw material price.**
The price of the raw material to produce $N$ parts is proportional to their mass. The mass of an individual part is $\rho V_{\text{part}}$ and the price of a gram of photresist is 0.1 Frs. We get:

$$P^{\text{mat.}} = N\rho V_{\text{part}} p_{\text{spec}} = N \times 0.8 \times 0.250 \times 0.1 = 0.02N \text{ Frs.} \tag{1}$$

**Initiation price.**
To determine the number $N^{\text{batches}}$ of batches which will be required, we need to introduce the *ceil function* $\mathcal{E}$:

$$\forall\, x \in \mathbb{R},\ \mathcal{E}(x) \text{ is the smallest integer greater than or equal to } x. \tag{2}$$

We actually get the following formula:

$$N^{\text{batches}} = \mathcal{E}(\frac{N}{n_{\text{plate}}}) = \mathcal{E}(\frac{N}{25}) \tag{3}$$

and the total initiation cost is

$$P^{\text{init.}} = p_{\text{init.}} N^{\text{batches}} = 200\mathcal{E}(\frac{N}{25}) \text{ Frs} \tag{4}$$

**Use cost of the SLA station**

To determine the use cost of the SLA station, one has first to evaluate the lasing time $T_{\text{lasing}}$ of a part as well as the total recoating time $T_{\text{recoat.}}$ of the resin layers:

i) The first step is to calculate the total recoating time. If $H$ is the height of the part and $e$ the thickness of an individual layer, one needs exactly $N_{\text{recoat.}} = \frac{H}{e} = \frac{30}{0.025} = 1200$ recoatings to realise the parts in a single batch. Taking into account that one needs $N^{\text{batches}}$ batches for the total production (see (3)) and the en indivdual recoating lasts $\tau_{\text{recoat.}} = 18\,\text{s}$, we conclude that the total recoating time is:

$$T_{\text{recoat.}} = N^{\text{batches}} N_{\text{recoat.}} \tau_{\text{recoat.}} = \mathcal{E}(\frac{N}{25}) \times 1200 \times 18 = 21'600\mathcal{E}(\frac{N}{25}) \text{ s}$$

i.e.

$$T_{\text{recoat.}} = 6\mathcal{E}(\frac{N}{25}) \text{ h.} \tag{5}$$

ii) The second and last step is to calculate the lasing time of the parts. This lasing time is proportional to the total mass:

$$T_{\text{lasing}} = \frac{\rho N V_{\text{part}}}{\dot{M}}, \tag{6}$$

where $\dot{M}$ is the **M**aterial **C**onsolidation **R**ate, i.e the quantity of mass that can be polymerized per unit of time. This quantity is equal to the ratio between the laser power and the polymerisation energy per unit of mass:

$$\dot{M} = \frac{P}{\varepsilon} = \frac{0.01}{17.5} \simeq 5.714 \times 10^{-4} \text{g/s}.$$

In this way, formula (6) for the lasing time gives:

$$T_{\text{lasing}} \simeq \frac{0.8 \times N \times 0.250}{5.714 \times 10^{-4}} \simeq 350N\, s \simeq 0.0972N \text{ h.} \tag{7}$$

As a matter of fact, the use cost of the SLA station for the total production are obtained by multiplying the total time $T_{\text{lasing}} + T_{\text{recoat.}}$ by the hourly rate $R$:

$$P^{\text{use}} = R(T_{\text{lasing}} + T_{\text{recoat.}}).$$

Using the values (5) et (7) of $T_{\text{recoat.}}$ and $T_{\text{lasing}}$ and taking into account that $R = 100\,\text{Frs/h}$, we find that

$$P^{\text{use}} \simeq 9.72N + 600\mathcal{E}(\frac{N}{25}) \text{ Frs.} \tag{8}$$

**Conclusions.**
Adding the contributions (1), (4) and (8), we find that the total price of the production is

$$P = 9.74N + 800.0\mathcal{E}(\frac{N}{25}) \text{ Frs.}$$

Consequently, the unit cost is:

$$p = \frac{P}{N} = 9.74 + 800\frac{1}{N}\mathcal{E}(\frac{N}{25}) \text{ Frs.} \quad (9)$$

Fig. 1 represents the evolution of $p$ as a function of the production size $N$.

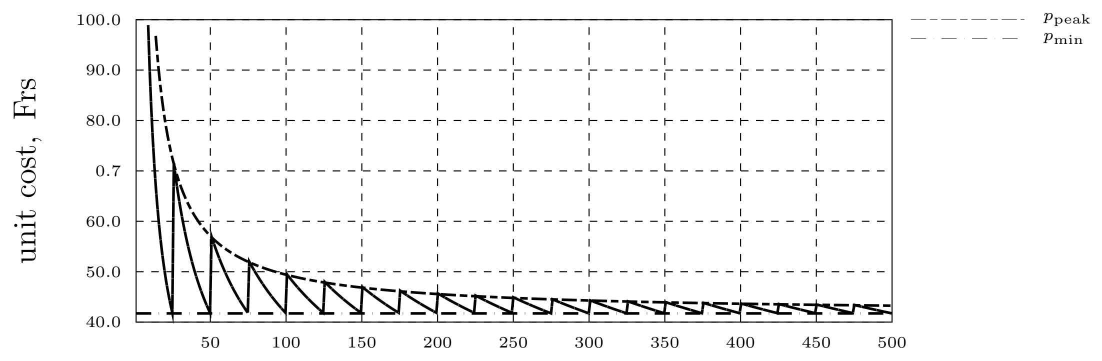


Figure 1: Unit cost as a function of the production size $N$.

Two remarks can be made:

i) As soon as $N$ is an integer multiple of 25 the base plate occupation is optimal and the unit cost is minimal:

$$p_{\text{min}} = 9.74 + 800\frac{1}{25} = 41.74 \text{ Frs.}$$

The first term of 9.74 Frs corresponds to the unit price for the raw material (0.02 Frs) and the unit cost of lasing (9.72 Frs)[1].
The factor 800 Frs in the last term corresponds to the use cost of the machine for realising an individual batch including the initiation price. In the formula for $p_{\text{min}}$, this value is divided by 25 because the use cost is shared by the $n_{\text{plate}} = 25$ parts which can be constructed in a same batch.

ii) When the production size $N$ is an integer multiple of 25 plus 1, the unit cost goes through a peak depending on $N$ (see Fig. 1):

$$p_{\text{peak}} = p_{\text{min}} + 32 \times \frac{24}{N} = 41.74 + \frac{768}{N} \text{ Frs.}$$

The additional term $32 \times \frac{24}{N}$ corresponds to the use cost for the 24 parts which **have not been constructed** on the last plate. These fees have to be shared by the $N$ other parts in

[1]In our case, the price of raw material is (almost) negligible.

the production.
It has to be observed that the unit cost for a single part is

$$p_{\mathrm{single}} = 41.74 + \frac{768}{1} = 809.74 \text{ Frs.}$$

It consists of the price for the raw material and its consolidation (9.74 Frs) and of the use cost for one batch (800 Frs)[2].

[2]The price for a single part is not much less than the price of the 25 parts which can be built in a batch: $25 \times p_{\mathrm{min}} = 1043.5$ Frs.