LABOR PRODUCTIVITY IN INJECTION MOLDING PROCESS

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Abstract— The productivity of an injection molding machine is the quantity of parts made in unity of time on a particular model of mold. The quantity of injected parts in unit time is directly proportional with the injection cycle time. The cycle time is composed of filling time, opening-ejection-closing time, cooling time inside the mold. Of these three time, the first two are constant values. Filling time depends by the rheological properties of thermoplastics, and the opening-ejection-closing time depends by mechanical characteristics of the injection molding machine. Cooling time is variable and is determined by the shrinkage of injected molded piece, or deviation from nominal dimension. Low value of shrinkage cause a higher quality of injection parts, but lower values for productivity.

Keywords— cycle times, injection molding process, injection molded piece quality, labor productivity,

I. INTRODUCTION IN INJECTION MOLDING TECHNOLOGY

Injection molding process involves placing under the pressure of plastic melt inside the mold cavity, where after cooling time take the form of processed cavity.

Injection molding process is a cyclical phenomenon. The main phases of the injection cycle, without clearly defined, are:

- dosing stage,
- melting the plastic material,
- mold closing,
- placing under the pressure of melting inside the mold,
- cooling and solidification of melting inside the mold,
- opening the mold and molded part removal,

The graphic of screw motion and mold motion are represent in fig. 1.

II. THEORETICAL ASPECTS OF LABOUR PRODUCTIVITY IN INJECTION MOLDING PROCESS.

The labor productivity of an injection mold machine is the amount of injected parts performed in unit time on a particular model of mold. In mold should be taken into account the number of processed cavities, total volume of cavities and injecting network. All this, add up, will determine the default volume and mass of injected melt. Depending on the amount of injected melt will be different levels of labor productivity.

Working time calculation in injection molding process will be made by summing up time for each phase, added time for production preparation-wind up of production. In the injection molding process, preparation-wind up time is composed from time needed to heat the cylinder, and if necessary, time for change the thermoplastic material, or the color.

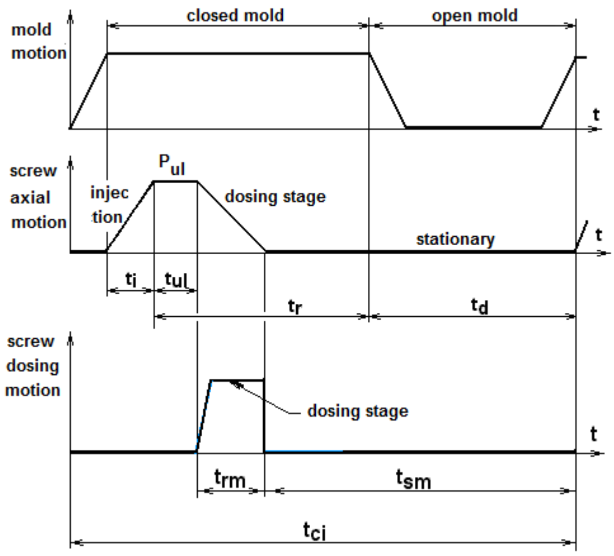

Fig. 1. Screw and mold motion graphic.

Preparation-wind up time is divided to the total number of injected parts proposed for manufacturing, having relatively small values.

Time scales, n_t, to produce one piece is given by the formula:

$$\mathbf{n_t = t_{pw} / n_{p.lot} + t_{ci} / n_c} \quad (1)$$

where: - t_{pw} – preparation-wind up time,
- $n_{p.lot}$ – number of injection parts,
- t_{ci} – injection cicle time,
- n_c – number of holes from the mold,

Time scales for all pieces will be given the amount of time:

$$\mathbf{N_t = \sum_{i=1}^{I} n_{ti}} \qquad (2)$$

Considering a process of continuous injection, three shifts, one type of material, t_{pw} –preparation-wind up time, will low-end.

The total value of the injection molding cycle time, figure 1, is constant and is given by the formula:

$$\mathbf{t_{ci} = t_i + t_r + t_d} \qquad (3)$$

where: - t_i – filling time,

- t_r – cooling time,
- t_d– opening-ejection-closing time,

For one hour, the labor productivity in injection molding process is given by the formula:

$$\mathbf{W_h = 60' / (t_{pi} / n_{p.lot} + t_{ci} / n_c)} \qquad (4)$$

From this formula results the determinative factors of the injection molding process productivity.

Analyzing figure 1, with closed mold we have filling time, packing time and cooling time. After packing pressure begins the dosing motion of the screw, but without influence over the cycle time. The dosing motion time of the screw is more little that the cooling time inside the mold.

Value of the filling time represents approximately 5…10% from the injection cycle time. Real values of this time is difficult to determine with classical methods, unable to read or deducted from the injection mold machine or screw motion. Filling time should be as small as possible. The injection mold simulation program, Moldflow, offers very good value induced for this time.

Packing time determination, t_p , called in same references "frozen time" or "sealing time", can be determinate using Moldflow simulation program. Without Moldflow is possible to determinate packing time measuring weight of injection molded piece for different value of packing time, and will consider the optimal time were is piece with maximum weight.

One of the most important factors of the injection molding process is the cooling time inside the mold. Cooling time, the longest time inside the cycle time, have very important influence over the quality of injected piece, especially on the shrinkage, warpage and internal tensions.

For the determination of cooling time, t_r, is using the heat balance equation, the melt temperature being transferred to the mold, [4],

$$\mathbf{t_r = (S^2/a\cdot\pi^2).ln[8(T_T - T_M)/ \pi(T_P - T_A)]} \qquad (5)$$

where:

- S - the thickness of the wall of injection molded piece, [m]
- a - thermal diffusivity, [m/s]
- T_T – melt temperature, [K]
- T_M – mold temperature, [K]
- T_P – maximum core piece temperature in ejection moment, [K]
- T_A – medium piece temperature in ejection moment, [K]

Depending on the quality required cooling time can be reduced, detrimental qualities, but increasing the labor productivity. The optimum cooling time must to be set in function depending on functional requirements of the injection molding pieces.

Good value of labor productivity are obtained for injection molded pieces with thin walls, especially for household items and industrial injection piece where are not require special mechanical properties.

Related to melt temperature that should be at optimum rheological properties, not at highest work temperature, so as to have a rapid cooling. The mold temperature must to be at an optimum value to facilitate the flow of melt, correct filling of the mold with minimum filling time, with tendencies toward optimum minimum values.

Opening-closing time for ejection of the injected piece start after cooling time, and have a constant value, depending by the characteristics of injection mold machine.

The number of holes from mould is limited. For determination of holes numbers inside the mold should be considered technical and economical criteria. From technical criteria the most important are: injection machine capacity, clamping force, size of the injection machine plate, length of the injection way, rheological properties of the melt.

Economical criteria are based on cost analysis: administration cost, with injection mold machine, with mold, etc.

The values which influence the productivity of the injection molding process are given the time scales expressed by the relation (1). Thus by minimizing preparation-wind up time, calculate an optimal value for the total cycle time of injection we achieve maximum productivity in terms of requirements quality.

Constructive size of mold is limited, so the number of holes of the matrix is limited, so the total cycle time value of the injection mold process has decisive influence on the productivity of the injection process.

Number of holes inside the mold can be determinate considering quality criteria, delivery time, injection machine technical data, number of injection pieces to fabricate. Determining the optimal number of holes inside the mold is the first step in mold design. For this is taken into account technical and economic criteria.

Among the technical criteria specified:

- injection molding machine plasticizing capacity,
- clamp force,
- size of injection machine plates,
- capacity of the injection machine utilization factor,
- rheological conditions for mold holes filling,

Economic criteria are based on the cost analysis:

- the base cost of the company, (production, supply, sale, etc..)
- the cost with the injection molding machine, (depreciation, maintenance, electricity, utilities, etc..),
- the matrix cost, (design, material, construction, etc..)
- indirect costs with matrix, (installation, testing and maintenance),

The case of empirical determination of the number of holes is used when we have information of the injection piece geometry, the material to be injected and the approximate number of pieces injected. To determine the number of holes is used the diagram presented in fig. 2.

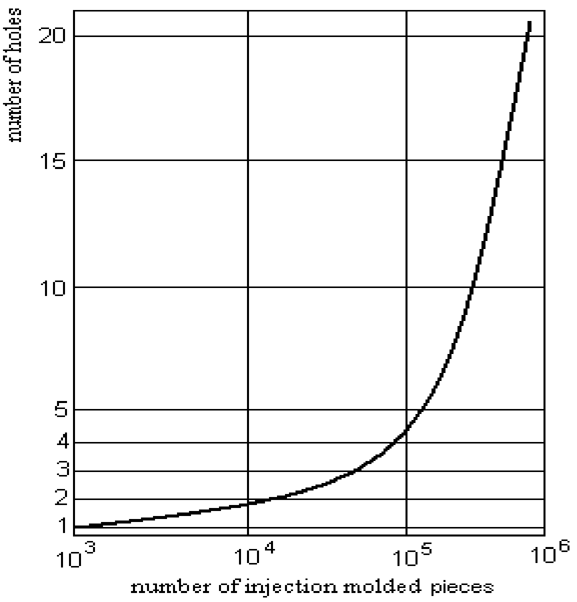

Fig. 2. Holes number diagram determination.

If is require a firm delivery date, the holes number is determined by the next formula, [3]:

$$N_1 = \frac{12k\,Zt_t}{3600n(t_0 - t_{em})}, \tag{6}$$

where:

- k-coefficient that takes into account the number of rejects,
- Z- number of molds,
- t_t - the total time of the injection cycle,
- n - the number of hours worked per year,
- t_0 - the time required to achieve control,
- t_{em} - mold execution time,

The holes number inside the mold, N must be greater than that calculated,

$$N \geq N_1 \tag{7}$$

If exists a significant difference between the holes number determined by calculating and the number determined empirically, have occurred on the number of molds or the date of delivery.

The number of holes inside the mold can be determinate considering the characteristics of injection molding machine. Thus, in view of the closing force of the injection machine can determine the number of holes in relation, [3] :

$$N_c = \frac{10c_d F_i}{S_{pi}} \tag{8}$$

where:

- c_d - factor of safety against openness, (c = 1.2...1.5),
- F_i - clamping force injection machine [kN],
- S_{pi} – projected area of the injection molding piece, and injection network, in direction of clamping force, (cm ^{2}),

Holes number can be determined taking into account the melting capacity of injection machine, [3]:

$$N_c = \frac{V}{1{,}2(V_p + V_r)} \tag{9}$$

where:

- V- melting capacity of injection machine, [cm ^{3}]
- $V_p + V_r$ - injection molded piece and network volume,[cm ^{3}]

The number of holes may be calculated, taking into account the rheological properties of the melt of thermoplastic material data. This method is applicable when the mold have a large number of filling, arranged in a way that requires a long way of the melt of material. The pressure applied to the molten material must overcome the resistance to flow through the nozzle of the injection machine nozzle, injection grid, filling the mold cavity and sealing of the melt. In this case a calculation is the road taken by molten material and an assessment of the number of holes given the travel covered melt [3]:

$$L_{max} = \frac{\pi R^2 \Delta p}{8 \cdot 10^6 \eta Q} \tag{10}$$

In injection molding process, injection time t_i and opening-ejection-closing time t_d are constant during an injection cycle. Injection time depend by the rheological properties of the injected material and opening-ejection-closing time depend by mechanical characteristics of injection machine.

Considering labor productivity of injection molding process as a function given by equation (1), its graphic representation is reduced to grade 1 math equation. Labor productivity mathematical graphics in function of cycle time is present in fig. 3.

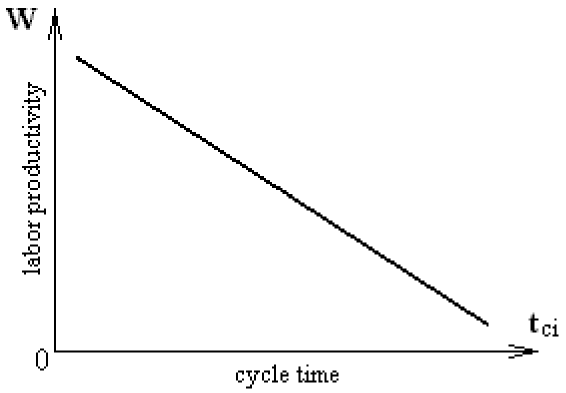

Fig. 3. Graphics of labor productivity function of cycle time.

Cooling time inside the mold t_r have an very important influence over the quality of injected piece, which will implicitly influence the labor productivity of the injection process.

Injection molding piece quality is given by formula, [2] :

$$Q_{lt} = \frac{1+C_3(1+\frac{4}{\pi}\bullet\frac{1}{e^{C_2 tr}})}{C_3(1+\frac{4}{\pi}\bullet\frac{1}{e^{C_2 tr}})} \tag{11}$$

$$C_2 = \frac{a\pi^2}{S^2} = ct. \tag{12}$$

$$C_3 = \alpha_v^{k_{pi}}(T_m - T_M) \tag{13}$$

Replacing relation (12) into (3) we obtain the injection cycle time function of quality of injection molded part, that:

$$tci = \frac{1}{C_2}\ln\frac{4}{\pi}\bullet\frac{C_3(C_{lt}-1)}{1-C_3(C_{lt}-1)} + ti + td \tag{14}$$

To express the labor productivity substitute (14) into time scales formula(1), then in labor productivity for one hour (4).

Time scales becomes:

$$n_t = \frac{t_{pi}}{n_{p.lot}} + \frac{\frac{1}{C_2}\ln\frac{4}{\pi}\bullet\frac{C_3(C_{lt}-1)}{1-C_3(C_{lt}-1)}+t_i+t_d}{n_c} \tag{15}$$

For one hour labor productivity in injection molding process is given by the formula:

$$W_h = 3600'/(\frac{t_{pi}}{n_{p.lot}} + \frac{\frac{1}{C_2}\ln\frac{4}{\pi}\bullet\frac{C_3(C_{lt}-1)}{1-C_3(C_{lt}-1)}+t_i+t_d}{n_c}) \tag{16}$$

Defining quality as an inversely with the size of the shrinkage the graphical representation of one hour labor productivity, we consider formula (16) as a function quality of injection piece as a variable. Also we consider a simplified form of the mathematical expression for productivity tool to facilitate analysis. Thus we consider constant: preparation-wind up time, number of parts in the batch, the number of holes inside the mold, opening-ejection-closing time, and variable cooling time.

Labor productivity graphics in function of injection pieces quality is present in fig. 4.

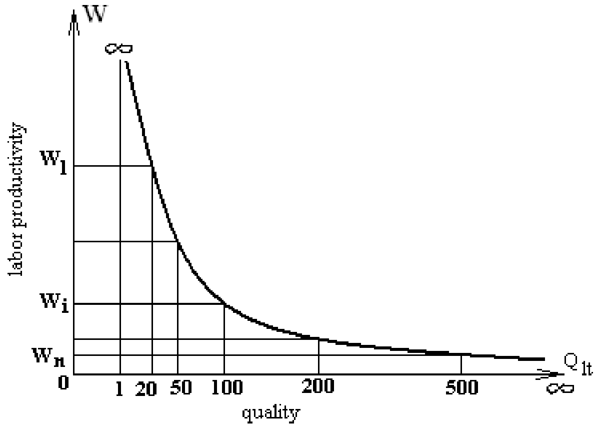

Fig. 4. Graphics of labor productivity function of injection pieces quality.

Vertical asymptote corresponds to the point where we have the worst quality of injection molded piece, and the horizontal asymptote corresponds to a very good quality of injection molded piece.

III. CONCLUSIONS

In injection molding process the labor productivity depends by cycle time, a short time of cycle time offer very good labor productivity, but in the same time a low quality of injection molded piece. For good quality of injection molded piece we need a long time for cooling time inside the mold, with direct influence over the cycle time.

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