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Research paper

Highlights methodology of time characteristics optimization for plastic products production

Rami Matarneh [1] *, Svitlana Sotnik [2], Zhanna Deineko [3], Vyacheslav Lyashenko [4]

[1] Department of Computer Science, Prince Sattam Bin Abdulaziz University, Al-Kharj, Saudi Arabia
[2] Department of Computer-Integrated Technologies, Automation and Mechatronics, Kharkiv National University of Radio Electronics, Kharkiv, Ukraine
[3] Department of Media Systems and Technology, Kharkiv National University of Radio Electronics, Kharkiv, Ukrain
[4] Department of Informatics, Kharkiv National University of RadioElectronics, Kharkiv, Ukraine
**Corresponding author E-mail: ramimatarneh@gmail.com*

Abstract

Basic elements of casting process and its main stages are considered. Features of time characteristics for production of plastic products are investigated. The main stages in the methodology of time optimization characteristics for the production of plastic products are given. The proposed methodology allows to increase productivity and optimize the time characteristics of the process of production of plastic products, taking into account the preservation of the quality of plastic products which is achieved by reducing the casting cycle. At the same time the considered methodology considers plunger time forward and backward, the "course" of the nozzle time, the time of extraction of the product from the matrix during the production of plastic products.

Keywords: *Injection Casting of Plastic; Strategy; Optimization; Time Characteristics; Cycle Time of Injection Casting.*

1. Introduction

Currently, the production of plastic products is a leader [1–3]. Injection casting of plastics (ICP) is one of the most progressive and developed methods for the production of plastic products (Fig. 1).

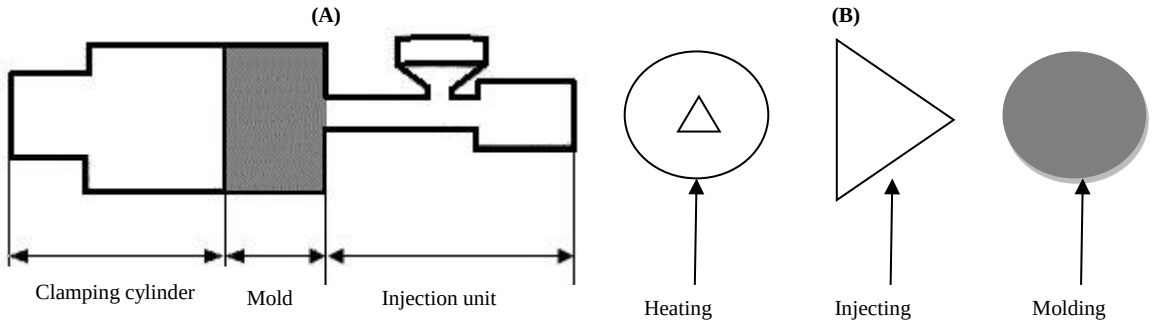


Fig. 1: Injection Casting: a) the Basic Elements of ICP; b) Basic Stages of ICP.

In recent years, significant progress has been made in the field of injection molding technology; in particular, the range of thermoplastics has significantly expanded [1]. This method of ICP has a number of advantages over extrusion of plastics.
The main advantages of plastic products manufacturing ICP are [2]:

- High productivity due to the heating of the plastic from the mold (IM), which allows to inject the melt into a continuously cooled mold, high dimensional accuracy and purity of finished products.
- minimal additional processing, which is reduced only to remove traces of the gate, as products do not have burrs (burrs) on the partial surface of the mold of the injection mold with high dimensional accuracy and purity of finished products.
- Cost effectiveness achieved due to small wear of the IM (due to the lack of moving parts, except pins and columns), and smaller IM (compared to punching), which facilitates the operations for their installation on the injection casting machine (ICM).
- The possibility of manufacturing articles of complex shape, thin-walled, with weak armature, with a long formative marks, as the closure of IM occurs before filling it with material.
- Possibility of full automation of production process.

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- Temporal characteristics for the manufacture of plastic products include the time to perform [4–7]: closing the mold, approach and pressing of the injection unit to the sprue bushing, injection of the plasticized mass to mold holding under pressure, curing in the mold, set the next dose of material, withdrawal of the injection unit, disclosure of the mold and eject the finished product into the tray attached to the frame. A sequence of such operations depends on the selected operation mode of the injection casting machine, which generally is the cycle time of the injection casting.

Cycle time ICP has a big impact on the cost and performance characteristics of casting products from thermoplastic materials. The cycle time of ICP depends on the temperature of the melt in the cylinder and the whole plasticizing process, so they can be considered intermediate variables, although they can be set arbitrarily. All cycle time ICP is even for large items of no more than 1.5-2 min [8]. Therefore, in order to reduce the cost of production, it should be possible to optimize the cycle time of ICP while maintaining satisfactory quality of the product. Thus, the problem of optimizing the cycle time of plastic products manufacturing has an important place and influences the products manufacture of any complexity.

2. Materials and methods

2.1. The main directions of researches in the field of time characteristics for production of plastic products

The authors believe that the problem of reducing the cycle time is mainly in evaluating all the difficulties of the casting process when designing the main stages of casting and the design of the mold. Thus, the management of these processes to achieve optimal design is necessary for the basic stages of molding and mold design. Therefore, for this purpose, in [1] software systems are considered that provide computer simulation of the casting process.

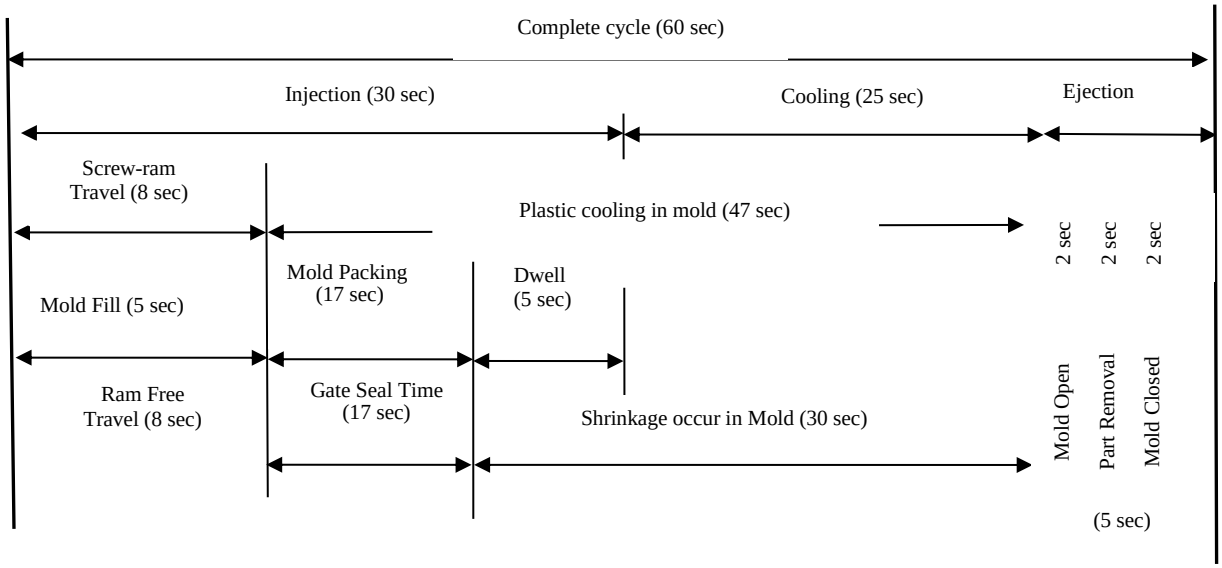


Fig. 2: Example of an Injection Casting Cycle.

The author of Gingery V. R. examines in detail the basic constructions of the injection molding machine [2]. In [2], the main principles of casting with a description of the process of designing a mold and detailed instructions that reveal the secrets of building a small inexpensive desktop injection molding machine are given. In [2] also found the basis for calculating the process parameters of ICP. In the work of Gingery V. R., the principles of minimizing the casting cycle time based on rational material selection and ICM are considered [2].

In [3] Kamar M. R. considers that the cycle of casting includes three main stages: putting the cured pitch, closing and hardening the mold and extracting it from the mold. In work [3] the author briefly considers features of a compression mold for injection Welding, thin "bedding" in shape, etc. Formulas for determination of the sprue channels sizes and a basis of the choice like an ingate are given. Kamar M. R. describes a casting cycle as the time spent of material in ICM and plastication time of material in a mold [3].

The comprehensive guide [4] emphasizes the relationship between the assembly methods, materials and manufacturing processes of plastics, thus allowing to determine rational method of product design/assembly. J. Rotheiser believes that the design of the product, when the amount of material cannot be further reduced, it is necessary to reduce the amount of material used in the technique known as "thin wall". Despite the fact that the aim of the method "thin wall" is to reduce costs, it also has the advantage of being able to reduce the cycle time during molding. That is, the author considers all aspects of a solution to the problem of achieving the "thin wall" of the product.

2.2. Features of time characteristics for production of plastic products

A cycle is the complete repeating sequence of operations in a process or part of a process. One cycle time is the time period, or elapsed time, between a certain point in one cycle and the same point in the next cycle; it is the time to mold a part (Fig. 2) [1].

If to generalize the concept "time characteristics", then it consists of concepts casting cycle time directly and they can be characterized by a ratio [5]:

$$\tau_c = \tau_{clo} + \tau_{cool} + \tau_{ope} + \tau_p + \tau, \quad (1)$$

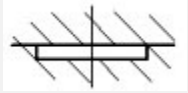
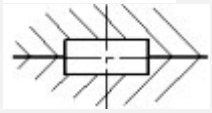
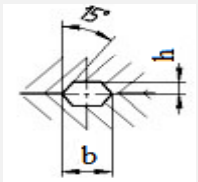
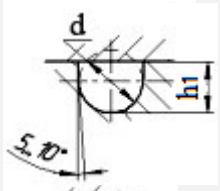
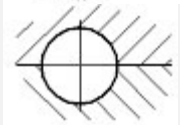
Where τ_{clo} – closing of a mold, sec.; τ_{ope} – opening of a mold, sec.; τ_{cool} – cooling of a mold, sec.; τ_p – pause time (service of a mold), sec.; τ – speed of a current of coolant, m/sec.

Implementation of the specified requirements allows to ICP optimize. For this purpose, it is necessary to make:

1) Rational choice of type of gate

For example, a point the gate freezes faster finger, so in such molds it is possible to reduce the casting cycle, and the necessity of holding pressure almost completely eliminated [2, 7] and it increases the productivity of the manufacturing process of plastic products. A recommendation on choosing the right type of gate is presented in Table 1 [5].

Table 1: Recommendations for Use of Channels with Different Cross-Sectional Shape of

№	Sketch	Section form of the parting channel	Characteristic channel	Note
1		Flat	Located in one plate. Promote rapid cooling of the melt.	Aren't allowed
2		Segmental	On the product of possible junctions, traces of flux etc.	
3		Rectangular	Rectangular duct is made in two plates, trapezoidal – in one plate	
4		Trapezoidal	A relatively large surface. The disadvantages of the previous sections was to a lesser extent	Are undesirable
5		Trapezoidal	The trapezoidal channel is executed in two plates, segment – in one plate	Are recommended
6		Segment	Provide a good current of melt and small losses of warmth	
7		–	Optimum form	Are preferable

2) To balance the inlet channels – is one of the ways to regulate and equalize resistors when filling in gains at different distances from the central sprue. Balancing gating system (GS) channels used with success, mainly for the simultaneous filling of the nests shape, which also affects the optimization of the temporal characteristics of ICP.

When calculating diameters of inlet channels use the characteristic size of a product which is determined by the expression [6]:

$$H = \frac{2 \cdot V_p}{S_p}, \quad (2)$$

Where V_p – product volume;

S_p – Surface area product.

3) To choose a rational design of a mold.

Depending on H, determine the diameter d_i and length of the first inlet channel [6]:

$$d_1 = d_i, d_2 = \frac{d_1 \cdot k_1 \cdot \sqrt{L_2}}{\sqrt{L_1}}; \quad (3)$$

$$d_3 = \frac{d_2 \cdot k_2 \cdot \sqrt{L_3}}{\sqrt{L_2}}; \quad (4)$$

Where d_1, d_2, d_3 – diameter of the first, second and third inlet channels (IC); L – distance from an axis of the central ingate (or from randomly the carried-out axis parallel to an axis of the central ingate) to an axis of channels d_1, d_2, d_3 (Fig. 3) [5]; k – correction coefficients, for example $k_1 = 0{,}86$; $k_2 = 0{,}89$; $k_3 = 0{,}95$; $k_4 = 0{,}98$; $k_5 = 1$; $k_6 = 1$; $k_7 = 1$; ... . Are chosen depending on the relation of sprue channels L_{ch} / L_{ch-1} (in a generalized view).

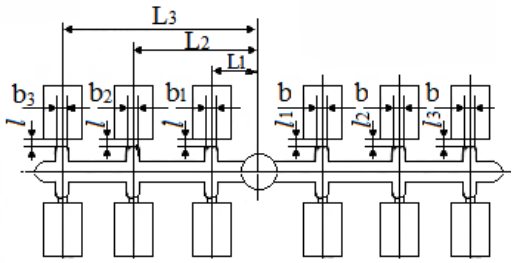


Fig. 3: Balancing Scheme of Inlet Channels.

4) Choose a rational number of gains

After defining the parting plane locations and the number of inlet channels is determined the optimal number of gains on the grounds of which is the appropriate size selection and number of ICM to ensure the casting tempo.

At the optimum cycle time of a casting is affected by the choice of the number of gains shape, which also affects to ensure maximum productivity. The share of cycle per one slot is defined by the following expression [1]:

$$\tau_{co_1} = \tau_{gen} n^{-1}, \quad (5)$$

Where τ_{gen} – the general duration of a cycle in a multiple nested mold; n – quantity of nests in injection mold.
Time abbreviation upon transition from a single-cavity mold to multiple nested mold can be presented by expression [5]

$$\tau_{opt} = \tau_{c_1} - \tau_{co_1} = (\tau_{c_1} - \tau_{pl_1})(n-1)n^{-1}, \quad (6)$$

Where τ_{c_1} – cycle time in an single-cavity mold; τ_{pl_1} – plasticization time of a melt dose in an single-cavity mold; τ_{co_1} – cycle duration in an single-cavity mold.
Recommendations about determination of gains quantity in IM are presented in Table 2 [5].

Table 2: Recommendations about Determination of Gains Quantity in IM

Product accuracy	Mass of a product	Quantity of gains
3 and 3a class	до 5 г	4 – 6 gains
products of usual accuracy (the 4-5th class)		16 – 20 gains
products of usual accuracy (the 4-5th class)	12 – 16 г	8 – 12 gains
products of usual accuracy (the 4-5th class)	50 – 100 г	6 – 10, 16 – 32 и 24 – 48 gains

There are three definition ways of gains number [5].

a) The number of IC (gains) can be found proceeding from the weight of injection of ICM and is defined by the following expression:

$$n = \frac{G_w}{k_1 \cdot G_p}, \quad (7)$$

Where G_w – the weight of injection of ICM (it is provided in the passport of ICM); G_p – weight of one product; k_1 – the coefficient considering the weight of gating system concerning the weight of one product (Table 3).

Table 3: Values of the Coefficient k_1 Considering the Weight of Gating System

Weight of one product, g	k_1	Weight of one product, g	k_1
Up to 0,5	1,5	Over 10 to 20	1,1
Over 0,5 to 2	1,3	Over 20 to 30	1,05
Over 2 to 10	1,2	Over 30 to 50	1,03

b) The number of gains (VK) can be found proceeding from the plasticizing productivity of the ICM material cylinder [5], [7]

$$n = \frac{A(\tau_{pr} G_p + \tau_{lm})}{k_1 \cdot G_p}, \quad (8)$$

where A – plasticizing productivity of the ICM material cylinder (it is provided in the passport of ICM, when processing of the crystallizing plastic it is necessary to accept value $\frac{A}{2}$); τ_{pr} – pressurization (endurance of a detail in IM per 1 gram of product weight) approximately is accepted equal 1 sec.; τ_{lm} – lost motion (idling of a cycle) which includes time of a closing the mold, disconnection of IM, pushing out of a product, plastic injection etc. (according to Table 4).

Table 4: Size Values of Idling Duration τ_{lm}

Weight of one product, g	Idling	Note
Products simple configuration without undercut, reinforcement, etc.	$\tau_{lm} = 0,4 \cdot \tau_{pr} \cdot G_w$	Time not less than 10 sec. for ICM with an injection weight to 50 g. Time not less than 20 sec. – for ICM with a big weight of injection
Articles of complex configuration with undercut, reinforcement, etc.	$\tau_{lm} = \tau_{pr} \cdot G_w$	Time not less than 20 sec.

c) The number of gains (IC) can be found proceeding from effort of a closing the mold of ICM [5]

$$n = \frac{P}{1,25 \cdot p_0 \cdot k_2 \cdot F}, \quad (9)$$

Where P – clamping force IM (it is provided in the passport of ICM); p_0 – unit pressure plastic in the impression gain (the equal $500 kg \cdot sec/cm^2$ approximately are accepted); F – area of a detail in the plan (without openings); k_2 – coefficient considering the area of GS (is accepted equal 1, 1).
Then time of plastication can be defined by means of expression [8]:

$$\tau_{pl} = \tau_{\text{cool w/p}} + \tau_{clo} + \tau_{ope} \approx (0,7 \div 0,8)\tau_m. \quad (10)$$

Where $\tau_{\text{cool w/p}}$ – cooling time without pressure. Cooling without pressure finishes process of product formation in shape. At this stage the speed of cooling is higher, than in the period of endurance under pressure of [1], [8].

$$\tau_{pl} = V_o \rho (QK_1)^{-1}, \quad (11)$$

Where ρ – density of material, kg/m^3; V_o – the casting volume of a product with ingates; Q – plastication productivity of the IMC, kg/sec: K_1 – correction coefficients.

At further increase in mass of a product multiple nested molds are applied seldom. In case of casting products 7 – the 9th class of accuracy the maximum n increases against specified in tab. 2, and for 4 – the 5th accuracy classes to 50% [9].
The analysis of duration of a casting cycle allows to define their dependence on n. Thus, it is defined, as τ_{clo} and τ_{ope} doesn't depend on n, also doesn't depend on n. The general duration of injection in all gains, though depends on n, on in view of its own insignificance making for average ICM 1,5-2 sec., influence of the share of injection falling time on one gain τ_{spr-1} as size extremely small can be neglected. The same extremely small size in molds for runnerless casting is the share τ_{hup} falling on one gain $\tau_{hup} \cdot n^{-1}$. At increase in diameter or length of a product the number of admissions increases.

5) To determine the number of injection casting machines and their rational size

ICM is a universal equipment for piece goods made of polymers [10], [11]. First we need to determine the amount of ICM that is needed. To do this, you must understand that the casting of products from plastics, the uninterrupted production which can produce products 24 hours a day, 7 days a week, with very few inter-

ruptions (e.g. for maintenance). That is, the amount of ICM is determined by perceived performance [12].
As each manufacturer produces ICM in several sizes, differing injection volume and other parameters, then the rational size of ICM for each product is chosen so that it is guaranteed to achieve the required quality of products and provide the best technical and economic indices of production [13]. The main parameters that determine rational size include: clamping force of moulds, injection volume and plastication performance. But also faced with a number of other tasks related to the casting technology, the design feature of future products, economics, etc.

3. Results and discussion

The target of the temporal characteristics optimization problem for the manufacture of plastic products reduce the cycle time of ICP can be expressed in the form: $\tau_c \to \min$ with restrictions $QI_i \geq QI_i^{tar}$ where QI_i – the product quality index, which must meet requirements and be not worse than specified QI_i^{tar}.

In order to optimize time characteristics will introduce them in the

$$\tau_c = \tau_m + \tau_{hup} + \tau_{cool} + \tau_e, \quad (12)$$

Where τ_m – machine time which includes time closing the mold, time of melt spray process in IM and time opening the mold; pause time (service of a mold), etc.; τ_{hup} – hold time under pressure; τ_{cool} – cooling time of the mold; τ_e – extraction time of a product from a matrix.
Each of these process steps (see Fig. 4) performs strictly certain function and influences both casting process control, and optimization of cycle time ICP.
The first stage for optimization of time of cycle ICP – a choice of product material [14] as, from properties of material further will be depends both quality of a product, and cycle ICP time.
Further the product type – a plane disk, a flat rectangular plate, a rectangular or round box, the sleeve open is defined. The type of a product influences layout of mold opening plane and therefore if the mold opening plane is not correctly located, then there will be difficulties with extraction of a product that will affect its quality. Difficulties with extraction of a product can affect also for the period of deleting casting from a matrix that will increase cycle ICP time.

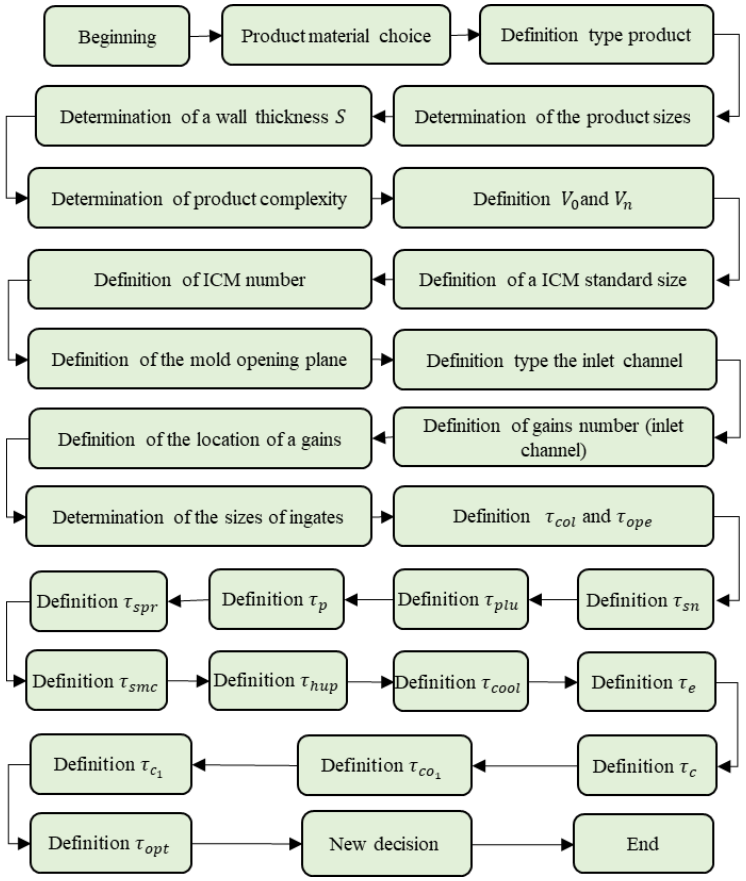


Fig. 4: Flowchart of Decision-Making Process of Time Characteristics Optimization.

Machine time can be expressed as:

$$\tau_m = \tau_{clo} + \tau_{spr} + \tau_{ope} + \tau_p + \tau_{sn} + \tau_{plu} + \tau_{smc}, \quad (13)$$

Where τ_{sn} – "course" time of a nozzle (supply);

τ_{plu} – "course" time of a plunger;

τ_{smc} – estimated time of melt stay in the cylinder.

As the tool by means of which it is possible to solve a problem of time characteristics optimization (12) for production of plastic products the algorithm which is presented in the form of the decision-making process flowchart (Fig. 4) is offered.
The system then determines the wall thickness S. Concept of product thickness is the ratio of the wall thickness of the product h to its surface S, it follows that $h/S = 0{,}0004$ – thin-walled products; $h/S = 0{,}001$ – the average thickness; $h/S = 0{,}003$ – thick-walled products [15]. That is, if the product has a different thickness, after cooling the degree of the molecules material orientation will be different and this will cause the appearance of residual stresses, which means that it will be of poor quality. At sites IM, where the wall thickness is large, the melt flows slower,

which affects the cycle time of ICP. At the increase of the product wall thickness increases the cooling time of the product. Therefore, it is necessary to correctly determine the wall thickness, to optimize the cycle time of ICP. The thickness of the walls depends on the temperature and pressure casting. After you have determined the thickness of the wall S, it is necessary to find the dimensions: length, width, height and optionally the diameter that affects the selection size of ICM. Irrational ICM will increase the cycle time ICP will lead to marriage.

If the wall thickness S is already computed, then proceed to the determination of the product complexity – the product of a simple shape or undercut, reinforcement, etc. as well as the shape of the product, definition of complexity affects the location of the mold opening plane, and thus the cycle time of ICP.

The next step is to determine V_o and V_n. Be conducted for selection of ICM, and determine the time of plasticizing. As in the proposed design expression (12) takes into account the parameter of machine time $\tau_м$, the value of which depends on the characteristics of the product and the technical characteristics of the ICM, so they are defined previously. Move on to the technical characteristics of ICM, one of which is the nominal volume of injection. It can be determined from the estimated volume of the casting products with the sprues,

$$V_o = \Sigma V_{cst} + V_{ic}, \quad (14)$$

Where V_{cst} – casting volume; V_{ic} – volume of inlet ingates.

Then nominal volume of injection of ICM [11]

$$V_n = V_o K, \quad (15)$$

where K – the coefficient considering compressibility of material and its leak on the plunger or a worm who for plunger machines is equal 1,2–1,3, and for worm 1,15–1,20 [12].

Next, you need to determine the number of ICM, and then choose a size of it that is realized by [12]:

1) Determine the diameter of the screw, the melt dose and route of dosing.
2) Determine the efforts of the closing of a mold.
3) Given the geometry of the screw.
4) Type nozzles.
5) Wear protection.

Thus, on the basis of (12) determined that to reduce the machine time necessary to reduce: closing of a mold time; melt spray in the IM process and time of opening of a mold; the pause time (service form); "course" time of a nozzle (supply); "course" time of a plunger; the estimated residence time of the melt in the cylinder.

After you have determined the type and size of the wall thickness and the complexity of the configuration, you can define the mold opening plane, the placement of which is carried out in accordance with the classical approaches [14].

As in most cases most of the cycle time of ICP is the process of molding products, the main points of which is a gating system and issuing the details, then the next block is the decision-making process determine the characteristics of GS. Gating system is a significant aspect in the optimization of cycle time ICP. To the gating system include the intake, inlet, breeders, and central sprues.

Let's start with determine the type of inlet channel [12]. You must choose a rational type, that is, for each specific material with its properties you need to choose the most appropriate form of the channel (point, finger, etc.).

Then we define the number of gains (IC). The calculation of the number of gains mold is associated with the choice of ICM according to the following parameters:

- Weight spray;
- Plastication performance;
- Clamping force.

It is proposed to use the estimated term plastication performance (expression 8), as it gives a more optimal result as determined in the course of the studies.

Knowing how many gains will be in IM, it is necessary to determine their location in the lateral surface, the bottom, etc. if you choose the wrong location of gates; it will complicate the path of the melt flow, which will affect the underfilling or slow down the filling time of IM.

The place of entrance of the inlet runners in the forming cavity of IM is defined by:

a) Configuration of the molded products;
b) Design of IM;
c) Requirement of least subsequent machining of the product.

An example of the definition of the IC location is given in Table 5 [13].

Table 5: The Inlet of the Inlet Channels and Their Dimensions

Product type	Inlet (inlet view)	Dimensions of inlet channels							
Flat rectangular plate	In the middle of a wide side face (band)	h	1	1,2	1,4	1,7	2,2	2,7	3,3
		b	3,5	4	5	6	7,5	9,5	12
		l	1	1	1	1	1	1,2	1,3
	In the middle of the narrow side faces h (belt)	h	1,1	1,2	1,4	1,7	2,2	2,7	3,3
		b	3,3	4	4,5	5,5	6,0	7,5	9
		l	1	1	1	1	1	1	1
	In the narrow face (slotted)	h	0,8	1,1	1,4	1,6	2,0	2,2	2,5
		b	50	60	90	100	150	210	300
	In the center of the plane (finger)	d	2	3	3,5	4	5	5,5	6
		l	5	8	13	15	20	25	30
	The outside diameter (fan)	h	0,8	1,0	1,3	1,6	1,8	2,0	2,3
		b	12	20	25	35	45	60	80
Flat disk	The outside diameter (tape)	h	1,2	1,3	1,4	1,5	–	–	–
		b	5	6	7	8	–	–	–
		l	1	1	1	1	–	–	–
	In the center of the plane (finger)	d	1,5	2,0	2,5	3,0	3,5	4,5	5,0
		l	5	8	13	15	20	25	30

Designs of gating channels are diverse. The presence of a large number of factors influencing their interaction with other molds systems, ICM, material, dimensional accuracy of the product and its purpose, the definition of the dimensions of gating channels (2, 3) an important point in optimization of cycle time ICP [14]. The correct choice of the dimensions of the gate, depending on the product thickness is an important condition for obtaining high-quality products. Depending on the plastics properties and requirements for dimensional accuracy of the product diameter cylindrical gate or the thickness of the flat inlet is usually in the range from 0.5 to 0.75 from the thickness of the product [5]. It is necessary to consider that at the stage of holding pressure, the cross-sectional dimensions of the gating channels or inlets, are an essential condition for the effective flow of the melt into the cavity of IM that is provided by the presence of a melt front of the screw tip in the material cylinder of ICM [8].

The next set of decision-making process determination of the parameters included in the machine time. Each block includes a number of stages. This unit will start with the definition stage τ_{clo} and τ_{ope}. You can define them in rapid and sustained displacement of the movable plate of the machine and moving the movable IM plate, they depend on the product design and shape. The definition does not depend on the number of gains [18 – 20].

In the proposed design expression (12) is introduced such time characteristics as time of "course" time of a nozzle (supply). This time characteristic can be calculated from the expression: $\tau_{sn} = \tau_{snf} + \tau_{snw}$, where τ_{snf} – the time feeding nozzle and τ_{snw} time the "withdrawal" of the nozzle is determined from the passport the ICM. It is important to consider the need to reduce speed "speed" nozzle immediately before the contact of the mold halves and when supply the nozzle to the sprue bushing to prevent premature wear and failure.

Also in the proposed design expression (12) is introduced such time characteristics "course" time of a plunger τ_{plu}, which is a parameter of machine time (13). The plunger pushes the molten plastic in the IM. To determine this time characteristic is possible by the expression: $\tau_{plu} = \tau_{pluf} + \tau_{p\,\mathrm{lub}}$, where τ_{pluf} – time plunger forward, $\tau_{p\,\mathrm{lub}}$ – time of turn, a plunger back.

Then define the following parameter of machine time – the duration of the pause. τ_p is the time between the opening and closing semi-molds. During the pause made cleaning forms, laying rebar or removable signs, etc. [21]. This parameter is introduced because the pause takes a significant period of time while ICM. If neglected τ_p, it will not allow you to optimize the time characteristics for the manufacture of plastic products.

The next phase is determining the spray time τ_{spr} in all gains depends on n, however, for the average ICM it is 1.5 – 2 sec.

The value τ_{spr} can be taken approximately depending on the volume of the spray as follows [17], [22]:

1) sec – for V_o to 63 cm^3;
2) sec – for V_o to 150 cm^3;
3) sec – for V_o to 400 cm^3;
4) sec – for V_o to 1000 cm^3.

To optimize the cycle time of ICP must be adjusted, if necessary, the spray time, that is, to choose the right spray speed. At low speeds the possible emergence of all sorts of defects in plastic products. At high speeds can be burned-on food, fin and degradation of plastics [22].

Previously identified the volume of the casting products with the gates V_o and the nominal volume of injection machine V_n, as they affect the determination of the size and number of ICM, and thus optimizing cycle time ICP [5].

To establish compliance V_o and V_n to account for such features:

1) the residence time of the material in the cylinder depends on the temperature range of casting and the start location;
2) increase the residence time of the melt in the cylinder leads to an increase in its temperature
3) estimated the residence time of the melt in the cylinder τ_{smc} calculated cycle τ_c are related by

$$\tau_{smc}^{-1}\tau_c = V_c V_n^{-1}, \qquad (16)$$

Where V_c – the volume of the cylinder channels.

Compliance V_o and V_n deemed satisfactory when $V_n = V_o K$, and for multiple nested mold $V_o n^{-1} = V_{o1}$, then $V_n = V_{o1} nK$, where K – coefficient taking into account the compressibility of the material and its leaking by the plunger or worm, which for motor machines is 1.2 – 1.3, and for the worm 1,15 – 1,20.

The following parameter is calculated for the expression (12) on the basis of which to optimize the time characteristics is hold under pressure (plasticizing) time τ_{hup} [8]. The necessary time of exposure to pressure can be determined by using successive weighting of the castings [9]. This is the simplest and reliable way. At constant casting modes, with the exception of the exposure time under pressure, which is changed to 1 – 2 seconds depending on the desired accuracy, consistently cast a few parts. Further, the pre-separating sprues, the parts are weighed on a laboratory balance and a schedule depending on the weight of items from τ_{hup}.

Best τ_{hup} is the minimum time after which the part weight no longer increases.

To optimize cycle time ICP hold under pressure time for each specific product correct and clarify experimentally. With insufficient time of hold under pressure after the "reset" pressure is the flow of the melt out of shape in the material cylinder of ICM, with the result that the casting is not compacted, there is a defective product.

The process of hold under pressure should the cooling process of the product. So next is the timing of cooling in the mold. The cooling time through the temperature at which it is removed from the matrix τ_{cool} depends on the following factors:

- The temperature at which the product of this design can be extracted from the matrix should reliably eliminate the danger of damage τ_{cool};
- The maximum temperature of the matrix at the beginning of the opening $t_м$ of the mold (it is higher than the temperature of the punch)
- The temperature of the melt at the time of admission to subject the cavity t_c;
- Thermal conductivity λ;
- Specific heat capacity $c_м$;
- Density p;
- Wall thickness of product 2 δ.

The relationship of these factors with the cooling time of the product in the form known from the below listed assumptions can be approximated by the thermal conductivity equation, which in one-dimensional heat flow has the following form [12], [15]:

$$\frac{t_{cool} - t_м}{t_c - t_м} = \frac{4}{\pi} e^{-\frac{\pi^2}{4}\frac{a\tau_{cool}}{\delta^2}}$$

Or

$$\frac{\pi}{4}\frac{t_{cool} - t_м}{t_c - t_м} = e^{-\frac{\pi^2}{4}\frac{a\tau_{cool}}{\delta^2}}, \qquad (17)$$

Where a – thermal diffusivity, equal to the ratio $(\lambda / \rho c_м)^1$.

Prelogarithmic both sides of equation (17) and solving it with respect to τ_{cool}, get [8]:

$$\tau_{cool} = -0,4\frac{\delta^2}{a}\ln\left(\frac{\pi}{4}\frac{t_{cool} - t_м}{t_c - t_м}\right). \qquad (18)$$

The different location of cooling channels; different temperature of the punch and matrix; if after holding pressure, due to shrinkage in thickness, between the product and the walls mold a gap, the heat transfer conditions deteriorate, the cooling is slowed down, thus increasing τ_{cool}. To increase τ_{cool} significant impact greater wall thickness of the product. Also a significant impact on required cooling time have the temperature of the IM walls (in most cases, the maximum intensity of the IM cooling, with the exception of IM with complex geometry of the gain and the problematic removal of articles) [16-18].

The next stage of the decision-making process, by definition, the cycle time of ICM with the target of optimization – introduced the parameter time extracting the casting from the die τ_e. To reduce the time of the product extraction, you can use IM with automatic ejection. Often applied, for example, robots in the manufacture of large products and products with mortgage the valve or in cases where the removal time less free time of deposition of the products [8]. When you define this parameter must be considered:

- Temperature of the product upon its removal from IM, which should be sufficient for extraction without undesirable deformation and breakage of castings;
- IM temperature when removing products;
- Cooling time, as too long cooling time leads to a problem of extraction of the product from IM (shrinkage on the punch or matrix).

Knowing all the components of the cycle time of ICP τ_c, determined by its expression (12).

Further, in order to optimize the cycle time of ICP in addition to the choice of rational parameters (process conditions, the gating system, drawing details, and directly ICM) and, if necessary, their correction, we introduce a "parameter" as a percentage of cycle per one gain τ_{co_1}. To calculate the percentage of the cycle, need to find the appropriate plasticizing degree of melting:

$$\tau_{hup_n} = (\tau_{c_1} - \tau_{hup_1}) + \tau_{hup_1} n \,. \quad (19)$$

So, plasticization in the mold of n gains τ_{hup_n} is directly proportional to the number of gains and equal $\tau_{hup_n} = \tau_{hup_1} n$. The cycle time in single-cavity mold is determined by the expression [8]:

$$\tau_{c_1} = (\tau_{c_1} - \tau_{hup_1}) + \tau_{hup_1}, \quad (20)$$

Where τ_{hup_1} – time of hold under pressure of a melt dose is single-cavity mold.

Thus, the cycle time in single-cavity mold $\tau_{c_1} = \tau_{c_1}$, if multiple nested mold, that for calculations have used the expression (12).

Then the general duration of a cycle in a multiple nested mold is determined by expression (12), and the cycle share falling on one gain it is possible to define as follows [18]:

$$\tau_{co_1} = \tau_{cp_1} n^{-1} = [(\tau_{c_1} - \tau_{hup_1}) + \tau_{hup_1} n] n^{-1}. \quad (21)$$

From the expression (21) shows that the value of the first term can be neglected, therefore, τ_{co_1} is determined by calculating the second term.

Therefore, cycle ICP time taking into account a cycle share, falling on one gain is defined by expression:

$$\tau_{opt} = \tau_{c_1} - \tau_{co_1} = (\tau_{c_1} - \tau_{hup_1})(n-1)n^{-1} \,. \quad (22)$$

Having the offered settlement expressions for definition of time characteristics which allow to optimize cycle ICP time for production of a plastic "product a flat rectangular plate" researches, results who are brought in Fig. 5 have been conducted. Basic data in Table 6.

Table 6: Values of Some Time Characteristics for Production of A Plastic Product

Product weight	19 g
Material	Polystyrene & rubber
τ_{smc}	2
τ_{clo}	2
τ_{pluf}	27
τ_{hup}	
$\tau_{p\ \mathrm{lub}}$	2
τ_p	3
τ_{ope}	
τ_{cool}	–
τ_e	1
τ_c	37

Also researches for the "product basis and the toddler for light switch" taking into account "course" time of a nozzle have been conducted, results are given in Fig. 6. Basic data in Table 7.

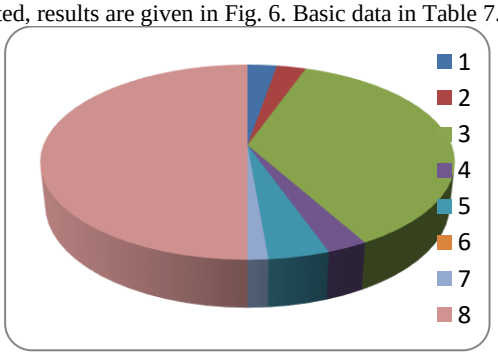


Fig. 5: Chart of Time Characteristics for Production of A Plastic "Product Flat Rectangular Plate".

– casting cycle time; – time of extraction of a product from a matrix; – time of a pause and mold opening; – time of turn, a plunger back; – time plunger forward and time of hold under pressure; – time closing the mold; – time of the melt in the cylinder.

Table 7: Values of Some Time Characteristics for Production of A Plastic Product

Product weight	15 g
Material	Atsetiltsellyulozny etrol
τ_{smc}	1
τ_{clo}	2
τ_{pluf}	25
τ_{hup}	
$\tau_{p\ \mathrm{lub}}$	2
τ_p	35
τ_{ope}	
τ_{cool}	–

τ_{sn}	3
τ_e	1
τ_c	69

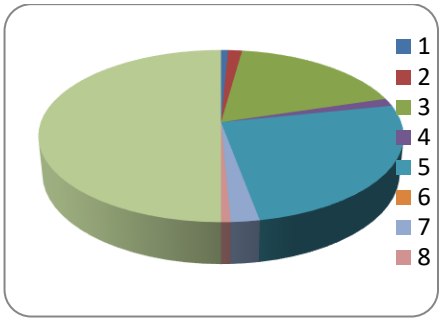


Fig. 6: Chart of Time Characteristics for Production of the Plastic "Product Basis and the Toddler for Light Switch".

– casting cycle time; – time of extraction of a product from a matrix; – the time feeding nozzle; – time of a pause and mold opening; – time of turn, a plunger back; – time plunger forward and time of hold under pressure; – time closing the mold; – time of the melt in the cylinder.

On the basis of constructed to charts it has been noted that by optimization of cycle time ICP plays a big role in holding time under pressure, pause time. But in the comparative study were selected products and materials which are preferably molded in a hot runner IM, but they are not necessary in the extraction of the gates from the mold, and consequently reduces the cycle time of ICP (for cooling of the sprues, additional time is required in comparison with the item). Moreover, today the hot runner IM is the most popular in the production of plastic products [9].

Thus, the basic steps of a methodology for the optimization of the time characteristics for the manufacture of plastic products different from the existing ones, that takes into account the running time of the plunger back and forth time of feeding nozzle, removing the products from the matrix. This methodology allows to increase the productivity of the manufacturing plastic products process by reducing cycle casting.

Diagrams allow to visualize the time characteristics of cycle casting. On the basis of these diagrams it can be concluded that a large part of the casting process is the hold under pressure time and the pause time is the time between the opening and closing semi-molds. During the pause made cleaning molds, laying rebar or removable signs, etc.

4. Conclusion

In result of the conducted researches it is determined that the hold under pressure time is the main part of the casting process and usually is 10 – 30 sec.

Cooling time, which is an important part of the casting process depends on the thickness of the same material and casting mode and does not depend on the number of gains. Increase in number of gains in shape leads to reduction of the casting falling cycle share on one product.

It is determined that the time characteristics (cycle time of the casting; time of extraction of a product from a matrix; time feeding nozzle; time of a pause and mold opening; time of turn, a plunger back; time plunger forward and time of hold under pressure; time closing the mold; time of the melt in the cylinder) most often as much as possible depend from:

- Type of material.
- Type of ICM.
- Sizes and form of ingates.
- Quantities of gains.

As summarized by the block diagram of the decision-making process stages problems of time characteristics optimization for the manufacture of plastic products. This block diagram allows to identify the most significant factors that impact on the maintenance of satisfactory product quality the and reduction in cycle time ICP. Given the estimated expression time characteristics for the manufacture of plastic allow you to optimize the casting cycle, including due to the choice of rational expressions to determine the number of gains (including plastication performance).

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