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Knowledge – based method for gate and cold runner definition in injection mold design

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1. Introduction

The quantity of plastic parts in mechanical and electronic industry during past 2-3 decades has a tendency to grow up. Mechatronics systems, in particular, apply many parts of plastic materials. A plastic, which is one of the most versatile materials in the modern age, is widely used because this is an easiest way to get parts of complicated geometrical form and properties. The injection molding process is the most common process for making plastic parts. In plastic parts manufacturing business the three types of small and medium enterprises (SMEs) are involved: 1) design, manufacturing engineering and production of injection molds, 2) production of plastic parts, 3) development of products and components from various plastic materials. These enterprises, in general, are located in different towns, even countries and are very specialized and must survive with high work productivity because they feel strong competition. The work productivity of mentioned SMEs depends on the created value, therefore, the intelligent systems related to design and manufacturing of plastic parts and appropriate techniques allow increasing work value. It involves the minimization of plastic parts and molds dimensions, mass and improvement of design and manufacture processes.

There are many research publications related to the developments of knowledge-based and object oriented approaches of injection molds and their design features as feed system, cooling system, ejection system and whole mold construction. An object-oriented approach to computer-aided design (CAD) of a plastic injection mold [1] considers the design of mold feed system. There was developed CADFEED to efficiently design the type, location and size of a gating system injection mold. It generates acceptable solutions at a lower cost than the most traditionally and commercially available analysis packages. The developed system can be used to verify designs proposed by the design engineers. CADFEED, unfortunately, was oriented to the AutoCAD and 2D input of a product, which are not competitive in new manufacturing environment. An interactive knowledge-based CAD system for mold design in injection molding processes [2] presents a practical prototype of artificial intelligence design method in molding manufacture. The application of case-based reasoning in die-casting focuses die design [3] on storing the knowledge and experience as cases, and modifies the previous case to satisfy a new situation. The proposed framework is also generally adaptable for injection mold design. A parametric controlled cavity layout design system for plastic injection mold [4] considers a methodology for designing the cavity layout by controlling geometrical parameters using a standard template. The standard template for cavity layout design consists of the configurations for the possible layouts. This ensures that the required configuration can be loaded into the mold assembly design very quickly, without the need to redesign the layout. An object-oriented design tool for associative cooling channels in plastic-injection molds [5] describes an associative design approach embedded in cooling channel module of mold design software package. It gives a set of comprehensive object definitions for cooling circuits, and addresses balanced or unbalanced design. Optimization of gate location with design constraints [6] considers an automated gating synthesis, taking advantages of the functionality of both CAD and CAE systems. Design of the runner and gating system parameters for a multi-cavity injection mold using FEM and neural network [7] presents the simulation method of optimal runner system minimizing the warp of injection mold.

Since for plastic parts and manufacturing techniques are raising distinctly higher claims, the purpose of this work is to develop knowledge-based method for gate and cold runners definition of injection mold. The engineering data and facts available in various references and companies involved in molding plastic parts as well designing and producing molds is systemized. Developed knowledge – based **(**KB) method is oriented towards personal computer and standard CAD systems (Solid Works, Solid Edge) and is able surely define the gate and cold runners of injection mold, because most of reviewed methods can work only with specialized mold design systems or software.

2. Knowledge – based method for gate and cold runner design

2.1. Gate design

The developed KB method for gate and cold runner design is attached to the artificial intelligent area. The purpose of mentioned KB is to replace routine work of human experts by artificial intelligent method, which would solve gate and cold runner's definition problem of injection mold design. There are several opinions why it is in use:

- for the purpose to decrease the amount of routine work
- the beginning engineer in the field could be prepared quickly to use injection molds design methodology
- expert can not always be in his or her workplace
- the working area of expert became complex.

The benefit of KB is that the data, which expert imputed into data base (DB), can always be verified and supplemented avoiding big misunderstandings. Inference engine and knowledge base provide solutions to the user via user interface. There is a dual possibility of data control – automatic from data file and manual. With individual interface component, it is always possible to start design in every design stage, i.e. when required data for further designing is available. In different areas KB clashes with limitations. If the method proposes wrong solution, which can not be verified with the help of human, then time and financial expenses for the correction and removal of the method errors becomes very high and expensive.

The present demand of injection molds was taken in consideration before designing KB method. The decision was made, that KB is the most useful for the design of precision parts injection mold, while currently the manufacture of precise parts is increasing. It was also assumed that the parts will only be manufactured from thermoplastics. The input data for injection mold design is production volume and delivery time of the part, its geometrical form, dimensions, mass and quantitative-qualitative parameters and molding machine characteristics as well. According to these data the parameters of injection mold gates and cold runner are defined. Making reference to the course of injection mold design the KB method of gates and cold runners was proposed. The gates and cold runner system often is named as molding system of injection mold. Molding system is one of the mold main characteristics, on which the quality of molded parts depends. The purpose of molding system is to provide the molding mass into mold cavities of injection mold. Taking into account the peculiarities of molding system design [8-12], the algorithms were developed for the definition of gates and runners and for the calculation of their parameters (Figs. 1 and 2).

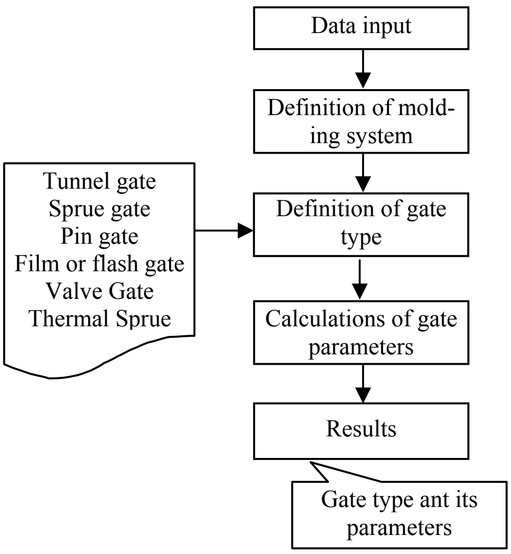


Fig. 1 Algorithm of gate type automated definition

Injection mold gates are classified into cool and hot types. Cool gates are divided into sprue, tunnel, cone, diagram, film, ring, point and multipoint (Table 1), while hot gates – into valve and sprue ones [8]. Hot gates for molding complex plastic parts are used because cold gates are not able to fill mold cavities of such parts. The design of molding system depends on molded part characteristics, such as dimensions and geometrical form, also on cavities layout and gate separation method from molded part. Therefore, the advantages and disadvantages of mentioned gate types (Table 2) are applied for molding system design. Molded parts were classified into three groups according to the methodology described in source [13]: 1) simple – when the number of design features (DF) is 1-5, 2) medium, when DF number is 6-9, and 3) complex when the number of DF is more than 10. Taking into account the above-mentioned peculiarities the rules of gate type selection have been developed. Fragment of the rules is presented in Table 3.

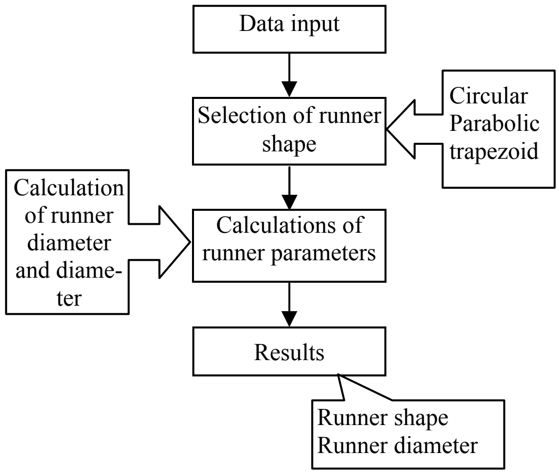
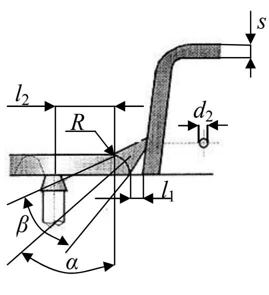
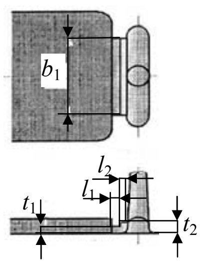


Fig. 2 Algorithm of runner type selection and parameters calculation

The tunnel type gate (Table 1) is widely used in mold design practice during past decade [9]. The main advantages of this gate type are its easy separation from the molded part and the possibility to modify available tunnel type gate ease to any mold runners. Taking into account these tunnel gate advantages the deeper development of KB method is considered in this research.

Table 1

Gate types and parameters

Tunnel gate		Film gate	
			
Parameter	Title	Parameter	Title
d_2	Gate diameter	b_1	Gate length
l_1	Gate length	t_1	Gate height in part side
l_2	Distance to tool	t_2	Gate height in gate side
α	Angle between gate and runner	l_1	Gate length in part side
β	Gate tilt angle	l_2	Gate length in gate side
R	Radius between the gate and the runner		

Continuation of Table 1

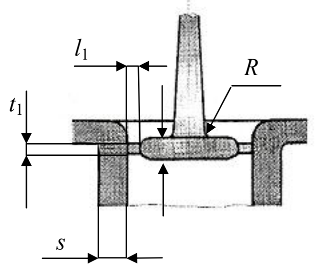
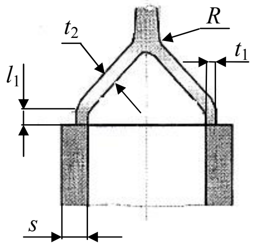
Diaphragm gate		Cone gate	
			
Parameter	Title	Parameter	Title
l_1	Gate height	l_1	Gate length
t_1	Gate length	t_1	Gate height
t_2	Gate thickness	t_2	Gate height
R	Radius between the gate and the runner	R	Radius between the gate and the runner

Table 2

Gates advantages and disadvantages

Type	Advantages	Disadvantages
Cold gate	Lower mold price Simplest mold design	Additional work after part withdrawal from mold Longer work cycle time
Hot gate	Molding material saving Shortened molding time Automated take out process of the part from mold	High manufacturing cost Potential part thermal damages for plastics that are sensitive to molding process

Table 3

The fragment rules of gate type selection

Gate type	Rules
Tunnel	if ((separation=automatic)) and ((material=ABS) or (material=PS)) and ((part_complexity=simple) or (part_complexity=medium)) and ((layout=row) or (layout=circular) or (layout=mirror)) and ((part_shape=flat) or (part_shape=circular))
Film	if ((seperation=non_automatic)) and ((material=ABS) or (material=PS)) and ((part_complexity=simple) or (part_complexity=medium)) and ((layout=row) or (layout =mirror)) and ((part_shape=flat)
Diaphragm	if ((separation=nonautomatic) and ((material=ABS) or (material=PS)) and ((part_complexity=simple) or (part_complexity=medium)) and ((layout=row) and (part_shape=circular))

Various methodologies of gate and molding parameters definition are described [8-12]. Therefore, it was decided to calculate the gate diameters applying several different methodologies and after that to find arithmetical mean value of the considered methods. The mean value of gate diameter d_2

$$d_2 = \frac{d_{2a} + d_{2b}}{2} \tag{1}$$

where d_{2a} is gate diameter according to the methodology described in literature [11]; d_{2b} is gate diameter according to the methodology described in literature [12].

The tunnel gate d_{2a} parameters, recommended in literature source [11], are given in Table 4. Within very small interval, it was accepted that part mass $m = 0$ g, gate diameter $d_{2a} = 0.5$ mm, and when $m = 5$ g, $d_{2a} = 0.62$ mm. From this proportion, with reference to the equation of straight line, the equation for the calculation of gate diameter d_{2a} was derived when the parts get into very small interval

$$d_{2a} = 0.024m + 0.5 \tag{2}$$

Accordingly, the equations were derived, when the parts get into very small (3), small (4), small to medium (5), medium (6), intervals

$$d_{2a} = 0.026m + 0.49 \tag{3}$$

$$d_{2a} = 0.025m + 0.5 \tag{4}$$

$$d_{2a} = 0.0125m + 0.75 \tag{5}$$

$$d_{2a} = 0.0042m + 1.08 \tag{6}$$

where d_{2a} is gate diameter according to the methodology described in literature [11]; m is part mass.

Table 4

Suggested dimensions for tunel gate diameter

Product size	Mass (gram)	Gate diameter
Very small	0 - 5	0.5
Small to very small	5 - 10	0.62
Small	10 - 20	0.75
Small to medium	20 - 40	1
Medium	40 - 100	1.25

The following method for the calculation of gate diameter d_{2b} was proposed in literature [12]

$$d_{2b} = ks \tag{7}$$

where s is inner wall thickness; k is coefficient which depends on wall thickness $k = 0.5 - 0.8$.

The variation of coefficient k is the most difficult to automate in equation (7). The equation of straight line was used for the definition of this coefficient also, because literature source [12] gives gate diameter d_{2b}, which varies from 0.8 to 2 mm. It was stated, when s = 0 mm, so $k = 0.8$, and when $s = 4$ mm, so $k = 0.5$. The equations of coefficient k and gate diameter d_{2b} were derived with reference to the equation of straight line

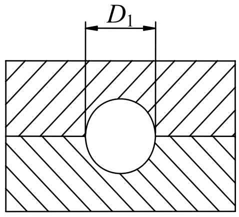
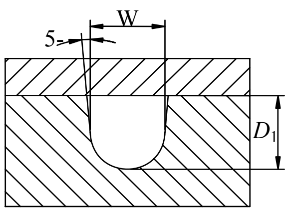
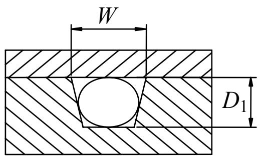
$$k = -0.075s + 0.8 \tag{8}$$

Accordingly, all other parameters of tunnel gate and the rest gates were determined.

2.2. Runner types and parameters definition

The advantages and disadvantages of various runner types [8-12] are presented in Table 5. More attractive is circular channel runner is in mold design practice, while A-line channel type runner is going out in application.

Table 5
The advantages and disadvantages of various runner types

Circular channel 	Advantages smallest surface relative to cross-section, slowest cooling rate, low heat and frictional, center of channel freezes last therefore effective holding pressure Disadvantages Machining into both mld halves is difficult and expensive
Parabolic form channel 	Advantages best approximation of circular cross section, simpler machining in one mold half only (usually movable side for reasons of ejection) Disadvantages more heat losses and scrap compared with circular cross section
A-line form channel 	Advantages Alternative to parabolic cross section Disadvantages more heat losses and scrap than parabolic cross section

Runners are also calculated with reference to several methodologies and arithmetical mean value is also computed

$$d_1 = \frac{d_{1a} + d_{1b} + d_{1c}}{3} \qquad (9)$$

where d_{1a} is diameter of the runner according to the methodology described in literature [8], d_{1b} is diameter of the runner according to the methodology described in literature [9], d_{1c} is diameter of he runner according to the methodology described in literature [12]. According to the latter sources the runner's diameter d_{1a} is defined as follows:

$$d_{1a} = 1.5 + s_{max} \qquad (10)$$

where s_{max} is maximum wall thickness of the molded part

The automation of runner diameter d_{1b} calculation is analyzed bellow. Such course of runner calculation, using Fig. 3, Fig. 4, is described in literature sources [8, 9]:

1. to find casting part mass m and average wall thickness s;
2. to find coefficient D_r under appropriate masses, using Fig. 3;
3. to find runner length;
4. to find coefficient L_f, using Fig. 4;
5. to find runner diameter.

$$d_{1b} = D_r L_f \qquad (11)$$

With reference to the course mentioned above and Fig. 3, Fig. 4, the expressions were defined.

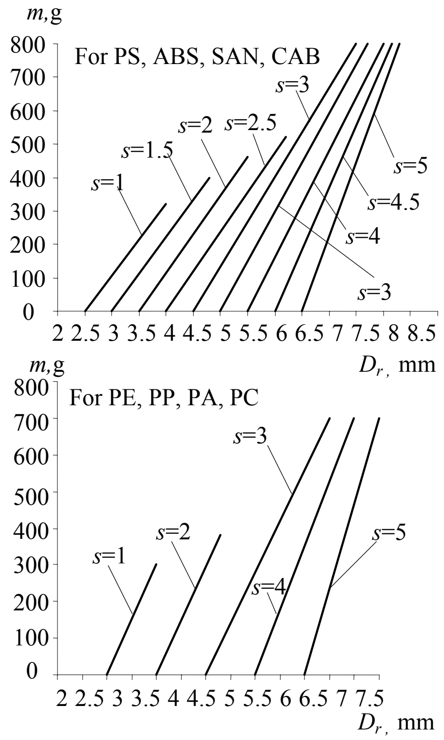


Fig. 3 Runner diameter chart for several materials

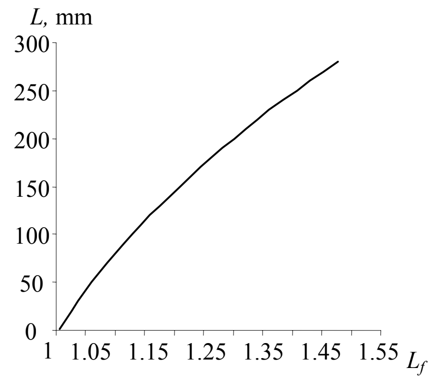


Fig. 4 Effect of runner length and length coefficient on diameter

If molding material is PS, *ABS*, *SAN*, *CAB* and s = 1-3 mm, then coefficient D_r is calculated as follows

$$D_r = \frac{(1.25m + 3.75) - (s+2)m + m_{max}(s+2)}{m_{max}} \qquad (12)$$

where m_{max} is maximal part mass.

If wall thickness $s =$ 1-2 mm, then $m_{max} = 100s +$ $+250$ and if $s =$ 2-3 mm, then $m_{max} = 250s - 50$.

If molding material is *PS*, *ABS*, *SAN*, *CAB* and s = 3-5 mm, coefficient D_r is calculated as follows

$$D_r = \frac{((0.2m+7)-(s+2))m + m_{max}(s+2)}{m_{max}} \qquad (13)$$

where m_{max} =700 g.

If molding material *PE*, *PP*, *PA*, *PC*, *POM* and s = 1-3 mm, then coefficient D_r is calculated as follows

$$D_r = \frac{(1.75m+2.25)-(s+1.5)m + m_{max}(s+1.5)}{m_{max}} \qquad (14)$$

where m_{max} = 800 g.

If molding material *PE*, *PP*, *PA*, *PC*, *POM* and s = 3-5 mm, then coefficient D_r is calculated as follows

$$D_r = \frac{(0.75m+5.25)-(s+1.5)m + m_{max}(s+1.5)}{m_{max}} \qquad (15)$$

where m_{max} = 800 g.

The variable L_F using approximation data presented in Fig. 4 are defined.

Runner diameter d_{1c} [12] is calculated as follows

$$d_{1c} = 1.5s + K \qquad (16)$$

where s is wall thickness of the part, mm; coefficient K depends on the runner length, part wall thickness and gate type, $K = 0-3$ and is defined experimentally.

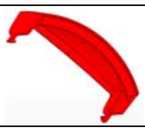
Applying presented research the knowledge-based method for molding system of injection mold has been developed and tested.

3. Case Study

The developed method is tested using experimental data of seven molded plastic parts in company X. The tested parts data are presented in Table 6.

Table 6

Experimental data of considered molded parts

Considered part numbers	Part 3D CAD model	Part mass *m*, g	Wall thickness *s*, mm	Length of runner to cavity *L*, mm
D_1		0.242	1	32
D_2		0.42	1.8	121
D_3		0.944	1.9	65
D_4		23.8	2	75
D_5		7.08	4.46	75

Continuation of Table 6

Considered part numbers	Part 3D CAD model	Part mass *m*, g	Wall thickness *s*, mm	Length of runner to cavity *L*, mm
D_6		1.46	1.8	50
D_7		5.5	2	97

Applying parts data and Eqs. 1-8 the diameters of gates' d_{2a}, d_{2c}, d_2, and runners' $d_{1a}, d_{1b}, d_{1c}, d_1$ are defined by Eqs. (9-16). The defined diameters were compared with practical gates d_{2p} and runners' d_{1p} data. Testing results in Figs. 5 and 6 are illustrated.

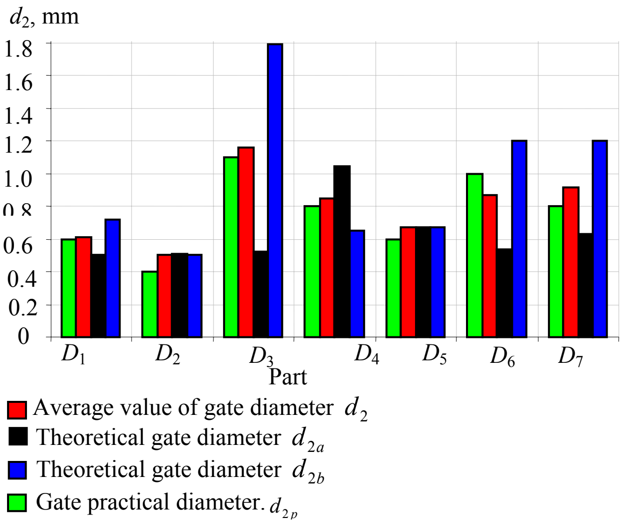


Fig. 5 The comparison of practical and theoretical gates diameters

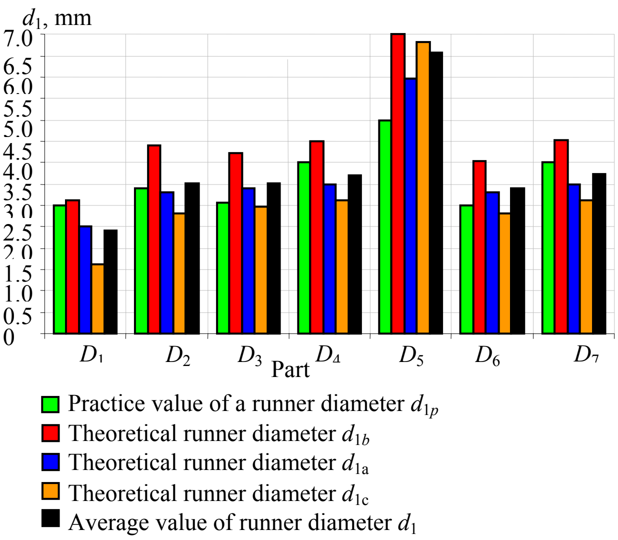


Fig. 6 The comparison of practical and theoretical runners diameters

4. Conclusions

The developed knowledge-based method for the definition of molding system and the calculation of its parameters is useful for SMEs that keep injection molding business. Testing results of the developed method show errors in the scale of 5-20 %. On the other hand developed KB system is useful in scholastic institutions or companies for the education employees.

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ŽINIŲ BAZIŲ METODO SUKŪRIMAS LIEJAMOJO PRESAVIMO FORMŲ LIEČIŲ IR LIEJIMO KANALŲ PARAMETRAMS NUSTATYTI

R e z i u m ė

Straipsnyje nagrinėjamas intelektualių sistemų taikymas liejamojo presavimo formoms projektuoti. Plačiau yra tiriamas sukurtos žinių bazės modulis, skirtas šių formų liejimo sistemai parinkti. Tam tikslui buvo susisteminti žinomi teoriniai liečių ir liejimo kanalų parametrų apskaičiavimo metodai, faktai bei sukurtos liejimo sistemos parinkimo taisyklės, naudojant ekspertų žinias. Liečių ir liejimo kanalų parametrų apskaičiavimo tikslumas žinių bazės metodu buvo testuotas, lyginant gautus rezultatus su eksperimentinių tyrimų duomenimis.

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KNOWLEDGE–BASED METHOD FOR GATE AND COLD RUNNER DEFINITION IN INJECTION MOLD DESIGN

S u m m a r y

This paper deals with the application of intelligent system for injection mold design. The molding system of the developed knowledge-based module for injection molds more detail is considered. For this aim the known theoretical methods of gates and runners definition as well facts and rules were systematized using experts' knowledge. The calculation accuracy of gates and runners were tested by the developed knowledge-based method comparing it with practical data.

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РАЗРАБОТКА МЕТОДА БАЗ ЗНАНИЙ ДЛЯ ВЫБОРА СИСТЕМЫ ЛИТЬЯ ПРИ ПРОЕКТИРОВАНИИ ЛИТЕЙНЫХ ПРЕСС-ФОРМ

Р е з ю м е

В статье рассматривается использование интеллектуальных систем в процессе проектирования литейных пресс-форм. Шире исследуется модуль созданных баз знаний для упоминаемого подбора литейной системы. С этой целью используя экспертные знания была выполнена систематизация теоретических знаний и фактов созданы правила для определения параметров литника и распределительного канала. Соответствие созданного метода знаний для выбора литника и распределительного канала была проверена и подтверждена путем экспериментальных исследований.

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