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Podpora odločitvenih diagramov za projektiranje orodij za injekcijsko brizganje termoplastov

Decision Diagrams Aided Conceptual Mould Design for Injection Moulding of Thermoplastics

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Konstruiranje orodij za injekcijsko brizganje termoplastov postaja vse bolj zapleteno in zahtevno opravilo in tudi izkušeni konstrukterji lahko naletijo na težave. Ena izmed najbolj pomembnih faz pri konstruiranju orodij je projektiranje orodja, zato je treba temu delu konstruiranja posvetiti posebno pozornost. Navadno temelji postopek konstruiranja orodij na izkušnjah konstrukterja, kar lahko v osnovi vodi k napakam v konstrukciji. Ena izmed mogočih rešitev je uporaba odločitvenega diagrama, ki vodi k določitvi delnih orodnih funkcij. Odločitveni diagrami so posebej pomembni za mlade in manj izkušene konstrukterje orodij, kajti z uporabo diagramov se lahko izognemo napakam že v zgodnji fazi razvoja orodja.

(Ključne besede: brizganje polimerov, projektiranje orodij, diagrami odločitveni, termoplasti)

Mould design for injection moulding of thermoplastics is becoming a more complex and complicated task, where even experienced mould designers could have problems. One of the most important phase of mould design is conceptual mould design, thus the mould designer must pay special attention to this phase. The approach to this mould design phase is usually based on the designer's experience, which can lead to some raw mould design errors. One of the possible solutions for this problem is the application of decision diagrams which can guide to the solution for certain partial mould functions. Decision diagrams are especially important for young and less experienced mould designers, because with their application mould design errors can be avoided in an early phase of mould development.

(Keywords: injection moulding, mould design, decision diagrams, thermoplastic)

1 PREDSTAVITEV

Zmeraj večje zahteve po zapletenosti orodij za injekcijsko brizganje termoplastov na eni strani in skrajševanje razvojnih časov za optimalno konstrukcijo orodij na drugi strani terjajo metodološki in sistematični razvoj določenega orodja ([1] do [4]).

Osnovna predpostavka pri tovrstnem načinu konstruiranja orodij za injekcijsko brizganje termoplastov je, da razdelimo postopek na posamezne faze, znotraj katerih nato definiramo vse potrebne korake in njihovo zaporedje ([1] in [2]). Znotraj te razdelitve je najbolj pomembno, da določimo projektivno zasnovo konstrukcije orodja, oziroma t.i. delne funkcije [5]. Da se izognemo napakam v tej fazi razvoja orodja, so bili razviti ustrezni odločitveni diagrami, ki ponujajo preprosto metodo za zagotavljanje projektiranja orodja za injekcijsko brizganje polimerov [2]. Za zagotovitev maksimalne zanesljivosti odločitvenih diagramov jih je treba primerjati v orodjarnah na že znanih orodjih, ki preverjeno delujejo [6].

1 INTRODUCTION

The increasing degree of complicatednes and complexity of moulds for injection moulding of thermoplastics on the one hand, and requirements for minimum development time of the optimum mould for a given moulded part, on the other hand, require a methodical and systematical approach to its development ([1] to [4]).

The basic assumption to such an approach of mould development for the injection moulding of thermoplastics is the division of the whole process into single phases within which all the necessary activities are defined, as well as their sequence ([1] and [2]). Within the frame of such a division, the most important phase is the conceptual mould design within which the general solutions are determined, i.e. the mould partial functions [5]. In order to avoid making wrong decisions in this phase of the mould development, adequate decision-making diagrams have been developed which provide an easy and simple method of obtaining the concept of mould for the injection moulding of thermoplastics [2]. For the maximum reliability of the decision-making diagrams, it is necessary to check and test them in the toolshops on the already existing, verified mould designs [6].

2 PROJEKTIRANJE ORODIJ ZA INJEKCIJSKO BRIZGANJE TERMOPLASTOV

Vsak injekcijsko brizgan izdelek lahko izdelamo v več orodjih, katerih konstrukcije so različne. Kakorkoli že, obstaja vsaj ena konstrukcija, ki optimalno rešuje tehnične, ekonomske in vse druge zahteve za izdelavo posameznega izdelka [1].

S sistematizacijo korakov, ki jih je treba opraviti, pospešimo razvoj orodja in hkrati zmanjšamo možnost nastanka napak med razvojem orodja. Skrajšana predstavitev aktivnosti, ki jih je treba izvesti pri metodološkem konstruiranju, je prikazana na sliki 1 ([1] in [7]). Faza projektiranja orodij vključuje določitev delnih rešitev za zagotavljanje funkcij orodja. V fazi dimenzioniranja orodja pa določimo končne izmere orodja ([1] in [2]).

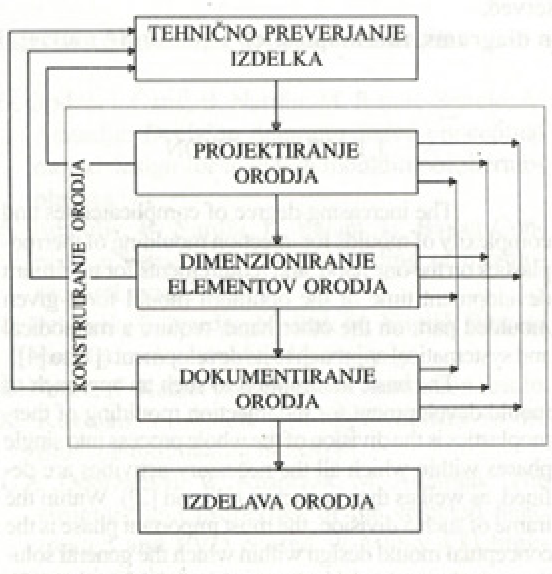
Ne glede na potek razvoja orodja, ponuja projektiranje orodij veliko podporo pri določanju ponudbe za izdelavo orodja, v fazi pridobivanja naročila. Orodjarji so namreč prisiljeni, da določijo ceno za izdelavo orodja v zelo kratkem času, navadno le na podlagi skice izdelka. Z uporabo projektiranja, seveda brez preverjanja izdelovalnosti izdelka, je mogoče zelo hitro povzeti, kakšno zamisel orodja bomo potrebovali. To znanje pa je temelj, na katerem lahko nato določimo ceno orodja glede na materialne in izdelovalne stroške [8].

2 CONCEPTUAL MOULD DESIGN FOR INJECTION MOULDING OF THERMOPLASTICS

Each moulded part can be fabricated in a number of moulds of various designs. However, there is always at least one design which best meets the set technical, economic and all the other requirements regarding the fabrication of the moulded part [1].

By the systematisation of steps that need to be carried out, the process of mould design is accelerated and the risk of reaching wrong decisions and bad design solutions is reduced. The shortened presentation of activities during the methodical mould design is shown in Fig. 1 ([1] and [7]). The phase of the conceptual mould design includes determining the principle solutions for fulfilling certain mould functions. During the dimensioning phase, these solutions are used to determine the final dimensions ([1] and [2]).

Apart from the process of mould development, the conceptual mould design phase is of great significance in forming the offers for manufacturing the mould, while still in the contracting phase. The toolmaker is in fact expected, to determine the costs of mould manufacture, in a very short time, usually only on the basis of a draft drawing of the moulded part. By applying the conceptual design phase - of course, in this case, without previously testing the technicality of the moulded part - it is possible to come very quickly to a conclusion regarding the type of mould in general. This knowledge is the basis for further estimation of costs regarding material and mould manufacture [8].



Sl. 1. *Skrajšan diagram metodološkega konstruiranja orodij ([1] in [7])*

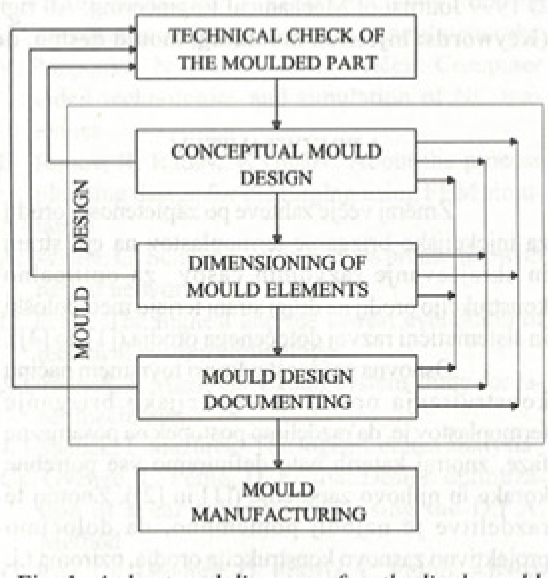
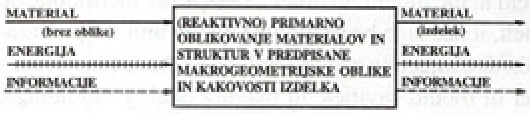


Fig. 1. *A shortened diagram of methodical mould design ([1] and [7])*

Če se želimo lotiti konstruiranja orodij metodološko in sistematično, je pomembno analizirati vse funkcije orodja. V tem primeru je termoplastična talina oblikovana v makrogeometrijskih oblikah v predpisanih zahtevah za

In order to approach the mould design methodically and systematically, it is necessary to analyse its overall function. In this case, the thermoplastic melt is primary shaped into the set macrogeometrical shape and prescribed properties of posamezni termoplastični izdelek. Izpolnjevanje teh funkcij je poglavitna zahteva orodja za injekcijsko brizganje polimerov (sl. 2) [5].



Sl. 2. *Osnovne funkcije orodja za injekcijsko brizganje polimerov* [5]

Kakorkoli že, vse funkcije orodja je treba razdeliti v tako imenovane delne funkcije orodja. Naslednji korak v projektiranju orodja je določitev primerne, poprej sistematizirane rešitve za posamezno delno funkcijo orodja, in jih kombinirati v optimalno konstrukcijo orodja za injekcijsko brizganje termoplastov. Vse aktivnosti pri določanju rešitev za vse delne funkcije so lahko izvedene zelo hitro, z uporabo t.i. odločitvenih diagramov ([1], [2] in [5]).

Faza projektiranja orodja je najpomembnejša faza v razvoju, saj že najmanjše napake v tej fazi lahko povzročijo velike napake in stroške pri izdelavi orodja. Če želimo povečati zanesljivost v tej fazi, je treba preveriti odločitvene diagrame na sedanjih orodjih, in sicer s pravilno in optimalno konstrukcijo [2].

3 DELNE FUNKCIJE ORODJA IN NJIHOVE REŠITVE

Med fazo projektiranja se določi lega izdelka v orodju, kakor tudi število in oblika gnezd, in tudi drugih rešitev za posamezne delne funkcije. Z željo po boljšem razumevanju delnih funkcij orodja, jih je treba na hitro razložiti.

Izbrana konstrukcijska rešitev, ki bo izpolnila potrebne delne funkcije, se mora združiti v celoto (v okrov orodja) in omogočiti nemoteno delovanje in ravnanje z orodjem. To je zagotovljeno z delno funkcijo združevanja elementov orodja. Orodje mora biti pritrjeno na stroj za injekcijsko brizganje. Zato je treba ustvariti delno funkcijo za pritrjevanje orodja na stroj. Med postopkom injekcijskega brizganja je orodje izpostavljeno velikim obremenitvam. Zato je treba določiti funkcijo, ki bo popisovala prevzem in vodenje sile s stroja na orodje. Preden se lahko grozd (izdelek in dolivek) sname iz orodja, je treba orodje odpreti. Pri odpiranju in zapiranju orodja je treba zagotoviti, da se gibajoči deli orodja dobro ujemajo, zato je treba definirati funkcijo vodenja in centriranja orodnih elementov. Termoplastična talina se mora v orodju

the thermoplastic product. The fulfilling of this function is the basic task of the mould for injection moulding of polymers (Fig. 2) [5].

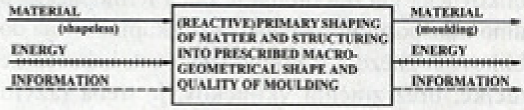


Fig. 2. *Basic function of mould for injection moulding of polymers* [5]

However, the overall mould function needs to be divided into the so-called partial mould functions. A further step within the mould conceptual design is to determine the adequate, previously systematised solutions for single partial mould functions, and to combine them into an optimum mould design for injection moulding of thermoplastics. The activities regarding determination of the solutions for partial functions can be carried out very quickly, with the help of the so-called decision-making diagrams ([1], [2] and [5]).

The conceptual mould design phase is the most important phase in the mould development process, since minor errors or omissions during that phase may result in gross faults on the finished mould. Therefore, in order to increase the reliability of this phase, it is necessary to check the already defined decision-making diagrams using practical examples, i.e. on the already finished and correct mould designs [2].

3 PARTIAL MOULD FUNCTIONS AND THEIR SOLUTIONS

During the phase of the conceptual mould design, the position of the moulding in the mould is determined, as well as the number and arrangement of the mould cavities, and the design solutions for single partial functions of the mould. In order to be able to understand better the partial functions of the mould, these features need to be briefly explained.

The selected solutions of design versions that will fulfil the partial functions need to be joined in to one whole (mould base), and provide undisturbed operation and handling of the mould. This is provided by the partial function of joining of mould elements. The mould has to be clamped onto the injection moulding machine. Therefore, it is necessary to realise the partial function clamping of the mould on the injection moulding machine. During the injection moulding process the mould is subjected to high loads that are transmitted from the machine. Thus, to provide regular operation of the mould, the partial function of taking over and transmitting force has to be realised. Before the biscuit (mouldings and runner system) is demoulded, it is necessary to open the mould. In opening and re-closing the mould, the moving parts of the mould must match precisely. It is necessary, therefore, to guide and centre the mould strditi v želeno obliko in z zahtevanimi lastnostmi. Zato je treba temperirni sistem v orodju popisati s funkcijo doseganja, vzdrževanja in krmiljenja temperaturnega polja v orodju. Za zapolnitev oblikovnega gnezda orodja je treba termoplastično talino transportirati od injekcijske skupine stroja do oblikovnih gnezd. Če želimo izdelovati kakovostne izdelke, brez zračnih vključkov, je treba razviti funkcijo odzračevanja v orodju. Potem ko je izdelek v orodju strjen, ga je treba izvreči iz orodja, za kar skrbi funkcija izmetavanja. Pri tem je treba omogočiti, da se bo izvrgel tako izdelek kakor tudi dolivek ([1], [2] in [9]).

Ne glede na tip orodja, morajo biti vse te funkcije popisane. Odvisno od specifičnih zahtev orodja je treba včasih rešiti tudi tako imenovane posebne orodne funkcije, ki pa so lahko zelo različne.

Za vsako delno funkcijo pričakujemo vsaj eno praktično rešitev. Tako je na primer za določeno funkcijo (vodenje in centriranje orodja), definiranih sedemnajst različnih mogočih rešitev. Zato je zelo pomembno, da sistematiziramo sedanje rešitve delnih funkcij, za potrebe hitre in zelo kakovostne izbire rešitve za posamezno funkcijo. Takšna sistematizacija se lahko izvede z uporabo morfološke orodne matrike (pregl. 1) [10].

Naslednji pomembni korak je pravilna izbira vsaj ene od ponujenih rešitev za posamezno delno funkcijo. V tem koraku je natančno določeno, da je treba imeti za vrhunsko kakovost in hitro projektiranje orodja uporaben diagram odločitev.

Primer: E_{12} - točkovni dolivek, E_{21} - orodna votlina, E_{37} - vodno hlajenje, E_{41} - izmetalniki, E_{58} - trapezno vodenje, E_{612} - skupina laminatnih slojev, E_{71} - pravokotne zapiralne plošče, E_{83} - podložna plošča, E_{94} - standardni sistem, tip N okrov orodja.

Na koncu faze konstruiranja je nujno potrebno kombiniranje načelno določenih rešitev posameznih delnih funkcij v optimalno konstrukcijo. Optimizacija je izvedena na podlagi informacij o tehničnih prednostih in pomanjkljivostih posamezne rešitve, medtem ko je gospodarno prednost posamezne konstrukcijske rešitve moč opisati le na grobo [1].

4 ODLOČITVENI DIAGRAM ZA PROJEKTIRANJE ORODJA

Iz analiz velikega števila znanih orodij, katalogov izdelovalcev standardnih delov in na podlagi dobrega sodelovanja z izkušenimi konstrukterji orodij, je mogoče določiti postopek za definicijo posamezne delne funkcije. Ti diagrami izberejo rešitev, ki je sistematizirana v morfološki

elements. The thermoplastic melt in the mould has to solidify into the required moulding shape of the prescribed properties. In order to achieve this, it is necessary to reach and maintain the controlled temperature field in the mould. In order to shape the thermoplastic melt, it needs to be brought from the unit for preparation and injection and distributed to the required number of mould cavities. In making quality mouldings, free of air voids, mould cavity degassing needs to be done. After the moulding is solidified, the biscuit needs to be reliably demoulded. The runner system is taken out of the feed cavity, and the moulds from the mould cavities. It is therefore, necessary to provide the partial function of biscuit demoulding ([1], [2] and [9]).

Regardless of the type of the mould, the mentioned functions have to be realised. Depending on the special mould requirements, there is often the need to solve also the so-called special mould functions which can be very different.

At least one principle solution has to be defined for each partial function. However, to select a solution, e.g. for the partial function of guiding and centring the mould elements, seventeen various solutions have been defined. Therefore, it is very important to systematise the existing known solutions of partial functions for the needs of a fast and top-quality selection of the solution for a partial function. Such systematisation can be done, e.g. by means of a morphological mould matrix (Table 1) [10].

The next important step is to make the right choice of at least one of the offered solutions for the partial function. It is precisely in this step that the adequate decision-making diagrams represent a precondition for the high-quality and fast conceptual mould design.

Example: E_{12} - pin gate feed system, E_{21} - mould cavity, E_{37} - water cooling, E_{41} - ejector pins, E_{58} - tapered leading (guiding), E_{612} - set of laminated sleeves, E_{71} - rectangular clamping plates, E_{83} - support plate, E_{94} - standard system, type N mould base.

At the end of this mould design phase, it is necessary to combine the principally determined solutions of partial functions into an optimised mould design. The optimisation is done on the basis of information about the technical advantages and disadvantages of certain solutions since economic advantages in this phase can be only roughly estimated [1].

4 DECISION DIAGRAMS FOR THE CONCEPTUAL MOULD DESIGN

The analysis of a greater number of the already existing moulds, catalogues issued by manufacturers of standard mould elements, as well as in co-operation with the very experienced mould designers, it is possible to define the appropriate decision diagrams for single partial functions. These diagrams are used to select the principal solutions

Preglednica 1. *Metode izvedbe projektiranja za orodja za injekcijsko brizganje polimerov, gledano z vidika delnih funkcij z uporabo morfoloških matrik [10]*

Table 1. *Methods of conceptual design realisation of mould for injection moulding of polymer partial functions shown by means of a morphological matrix [10]*

delna funkcija partial functions		projektna rešitev / conceptual design solutions																
		P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{11}	P_{12}	P_{13}	P_{14}	P_{15}	—	P_n
C_1	porazdelitev materiala matter distribution	E_{11}	E_{12}	E_{13}	E_{14}	E_{15}	E_{16}	E_{17}	E_{18}	E_{19}	E_{110}	E_{111}					.....	
C_2	primarno oblikovanje snovi in distribucija primary shaping of matter and distribution	E_{21}															.....	
C_3	krmiljenje temperature orodja control of mould temperatures	E_{31}	E_{32}	E_{33}	E_{34}	E_{35}	E_{36}	E_{37}	E_{38}								.....	
C_4	izmetavanje brizganca injection shot demolding	E_{41}	E_{42}	E_{43}	E_{44}	E_{45}	E_{46}	E_{47}	E_{48}	E_{49}	E_{410}						.....	
C_5	centriranje in vodenje orodja mould element centring and guiding	E_{51}	E_{52}	E_{53}	E_{54}	E_{55}	E_{56}	E_{57}	E_{58}	E_{59}	E_{510}	E_{511}	E_{512}	E_{513}	E_{514}	E_{515}	.....	
C_6	odzračevanje orodja mould cavity degassing	E_{61}	E_{62}	E_{63}	E_{64}	E_{65}	E_{66}	E_{67}	E_{68}	E_{69}	E_{610}	E_{611}	E_{612}	E_{613}	E_{614}		.....	
C_7	pritrditev orodja na stroj mould clamp on the machine	E_{71}	E_{72}														.....	
C_8	prevzem obremenitev in gibanja loads takeover and transmission	E_{81}	E_{82}	E_{83}	E_{84}												.....	
C_9	elementi za spajanje orodja mould elements joining	E_{91}	E_{92}	E_{93}	E_{94}	E_{95}	E_{96}	E_{97}									.....	
C_{10}	posebne funkcije special functions	E_{101}	E_{102}	E_{103}	E_{104}	E_{105}											.....	

matriki orodja ([2] in [10]). V takšnih diagramih lahko konstrukter odgovarja z DA ali NE in po določenem številu vprašanj ga diagram pripelje do rešitve za posamezno delno funkcijo. Do sedaj je bilo razvitih sedem odločitvenih diagramov. Odločitveni diagram je bil razvit za načelno določitev lege izdelka v orodju, za določitev velikosti in oblike orodne votline in za določitev tipa orodja ([1], [2] in [9]).

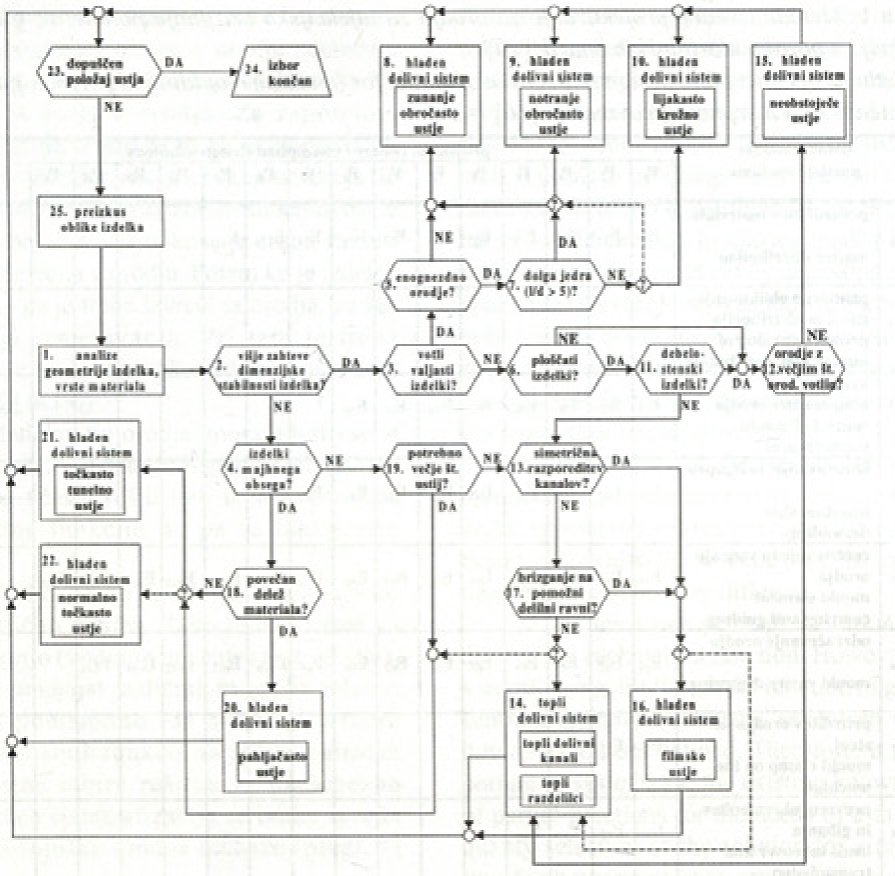
Okrov orodja, ki zagotavlja prevzemanje in prenos sile in povezuje orodne elemente, se prav tako določi z uporabo odločitvenih diagramov. Okrov orodja je neposredno odvisen od oblike in prostornine izdelka. Dimenzije okrova orodja so odvisne od potrebnega prostora za pozicioniranje izdelka. V zadnji izbiri okrova orodja je treba poznati podatke o standardnih orodnih elementih [1], [2] in [9].

Tip dolivnega sistema in dolivka, ki izpolnjuje zahteve za razdelitev polimerne taline do oblikovnega gnezda, prav tako izberemo z uporabo odločitvenega diagrama za načelno določitev dolivnega sistema in dolivnih točk (sl. 3). Diagram

systematised in the morphological matrix of the mould ([2] and [10]). In such diagrams, the designer mainly answers the questions with YES or NO, and after a certain number of questions this leads him to the principle solution for the single partial function. Seven different decision diagrams have been developed until now. The decision diagram has been developed for principle determination of the position of the moulding in the mould, thus completely defining the shape and size of the mould cavity, and the mould type ([1], [2] and [9]).

The mould base type that fulfils the function of takeover and transmitting forces, and joins the mould elements, is determined also by an adequate diagram. The base type depends directly on the shape and volume of the moulding that needs to be fabricated. The mould base dimensions depend on the necessary space for positioning of the moulding (the injection shot). In the final selection of the mould base type, the data on the standard mould elements are needed [1], [2] and [9].

The type of the runner system and the gate which fulfil the partial function of thermoplastic melt distribution to the required number of mould cavities is selected using the decision diagram for the principle defining of the runner system and gate (Fig. 3). The diagram is used to come to the conclusion as



Sl. 3. *Odločitveni diagram za projektivno določitev dolivnega sistema in ustja v orodju [11]*

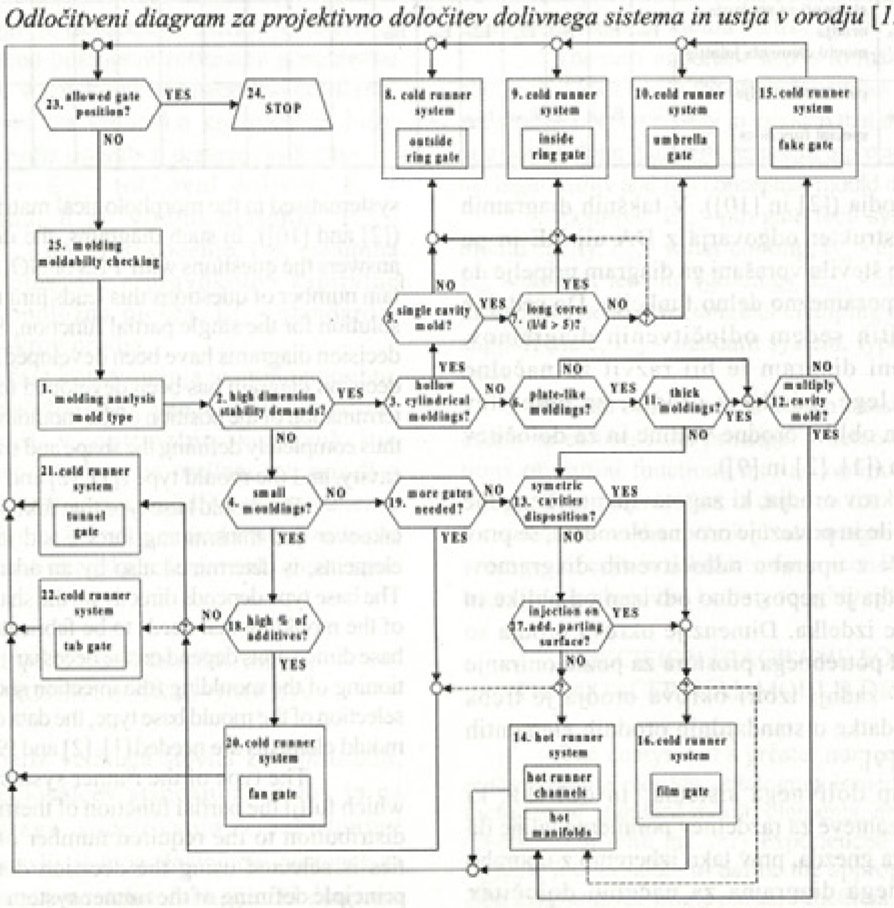


Fig. 3. *Decision diagram for conceptual determination of mould runner system and the gate [11]*

pomaga določiti, kateri tip dolivnega sistema naj uporabimo (topli ali hladni dolivek), prav tako pa definira, kateri tip ustja je najprimernejši za posamezen izdelek ([1], [2] in [9]).

Diagram za načelno določitev temperaturni krmilni sistem je oblikovan v prvi vrsti za orodja, pri katerih se temperatura uravnava z grelnim/hladilnim medijem oziroma za uporabo grelnikov ([1], [2] in [9]).

to whether the hot or cold runner system should be applied, and what gate would be the best selection for the adequate moulding ([1], [2] and [9]).

The diagram for the principle determination of the temperature control system is applied mainly to the moulds in which the temperature is controlled by means of the cooling/heating medium or by using the heater. The basic function of this diagram is to determine the cooling/heating method of the mould plates, and determine principally the position of the cooling/heating channels, i.e. heater ([1], [2] and [9]).

Preglednica 2. *Medsebojna povezava med orodnimi delnimi funkcijami* [5]
Table 2. *Interaction between mould partial functions* [5]

DELNA ORODNA FUNKCIJA PARTIAL MOULD FUNCTION		F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	porazdelitev termoplastične taline thermoplastic melt distribution			+		+		+	+	+	?
F2	primarno oblikovanje thermoplastic melt primary shaping	++		++		+	++	+	+	+	?
F3	krmiljenje temperaturnega polja v orodju control of mould temperature field				+	+				+	?
F4	izmetavanje grozda (izdelka in dolivka) biscuit ejection	++		++		++		+	+	+	?
F5	vodenje in centriranje orodnih elementov guiding and centering of mould elements				++			++	++	++	?
F6	odzračevanje orodja mould cavity degassing					+			++		?
F7	zapiranje orodja na stroju za injekcijsko brizganje mould clamping on injection moulding machine					++			++	++	?
F8	prevzemanje obremenitev in vodenje loads takeover and transmission					++		++		++	?
F9	elementi orodja za spajanje mould element joining					++		++	++		?
F10	posebne funkcije orodja special functions	?	?	?	?	?	?	?	?	?	

Legenda: ++ - močna interakcija
\+ - interakcija
? - interakcija odvisna od rešitve za posamezno orodno delno funkcijo
\- brez interakcije

Legend: ++ - big interaction
\+ - interaction
? - interaction dependent on solution for single mould partial function
\- without interaction

Nadalje je popisan tudi odločitveni diagram za določitev elementov izmetalnega sistema grozda iz orodja (izdelka in dolivka). Diagram upošteva elemente v orodju, na primer zobniške prenose v orodju, pa tudi sistem izmetavanja zunaj orodja, na primer manipulatorje ([1], [2] in [9]).

Načelna določitev sistema za vodenje in centriranje je treba na obeh straneh orodja, saj je potrebno zagotoviti dobro ujemanje obeh polovic, prav tako pa ta sistem zagotavlja centriranje orodja na stroj. Na osnovi opisov znanih metod vodenja in centriranja smo razvili diagram za določitev primernega sistema vodenja in centriranja posameznega orodja ([1], [2] in [9]).

The decision diagram for principle determination of the elements of the system for reliable demoulding of the biscuit from the mould. The diagram takes into consideration the elements within the mould, e.g. gears for demoulding of threaded mouldings, but also outside the mould, e.g. the demoulding manipulators ([1], [2] and [9]).

The principal determination of the elements of the mould guiding and centring is necessary so as to insure that both parts of the mould are positioned and match accurately, but also that the mould is centered on the injection machine plates. Based on the analysis and description of the known methods of mould elements guiding and centring, a decision diagram has been developed for the principal selection of the elements of the mould guiding and centring system ([1], [2] and [9]).

Med postopkom injekcijskega brizganja polimerna talina zapolnjuje orodno votlino in izpodriva zrak pred seboj, zato je treba v konstrukciji orodja zagotoviti sistem odzračevanja orodja. V ta namen smo za izbiro elementov odzračevanja orodja prav tako razvili odločitveni diagram ([1], [2] in [9]).

Načelna določitev posebnih orodnih funkcij in elementov ni tako preprosta, saj je pri posebnih orodjih nekaj prav posebnih funkcij, ki se glede na obliko izdelka, med seboj zelo razlikujejo. Zato odločitveni diagram za ta sistem še ni razvit ([1], [2] in [9]).

Po določitvi vseh delnih funkcij orodja, je treba te rešitve sestavljati v optimalno konstrukcijo orodja. Med tem sestavljanjem moramo biti pozorni na medsebojno učinkovanje med določenimi rešitvami za posamezne delne funkcije. Preglednica 2 prikazuje medsebojno povezavo med orodnimi delnimi funkcijami.

4.1 Testiranje in analiziranje odločitvenih diagramov

Glede na to, da se je postopek konstruiranja orodij od prvega pojava odločitvenih diagramov precej spremenil, saj so se pojavile določene nove konstrukcijske rešitve, je treba odločitvene diagrame neprenehoma obnavljati in modernizirati z analizo rešitev na novih orodjih. Tovrstno testiranje je treba izvajati v kar največjem številu orodjarn za kar največ različnih oblik izdelkov.

Sedanji diagrami odločitve so bili testirani v dveh slovenskih orodjarnah (Iskra OTC-Kranj in Gorenje Orodjarna-Velenje) in v treh orodjarnah na Hrvaškem (Novotec, TOZ in Elektrokontakt-Zagreb) v okviru projekta *Re-inženiring konstruiranja orodij za potrebe malih in srednje velikih podjetij*. Do sedaj je bilo analiziranih 22 orodij. Analize smo izvedli tako, da smo preverili diagram na posameznem izdelku in nato te rezultate zapisali, tako kakor da konstruiramo novo orodje. V naslednjem koraku smo te rezultate primerjali z dejanskimi preverjenimi rešitvami. V primeru, da je prišlo do razlik med določenimi rešitvami in dejanskimi, smo poskušali najti vzrok

During the injection of the thermoplastic melt into the mould cavity, air and gases remain there, and they prevent complete filling of the mould cavities, so they need to be removed. Therefore, a decision diagram has been developed for the selection of elements of the mould cavity degassing system ([1], [2] and [9]).

The principle determination of the special mould elements is not as simple as for the other mould functions, since special functions may be very different, depending on the mould shape characteristics. Therefore, the decision diagram for determining special mould elements has not been defined yet ([1], [2] and [9]).

After determination of all solutions for partial functions of the mould, those solutions should be optimized and combined into an optimum mould design. During this combination, the mould designer should be aware of interaction between certain solutions for mould partial functions. Table 2 represents interactions between mould partial functions.

4.1 Testing and analysing the decision diagrams

Since the approach to mould development has changed since the appearance of the first decision diagrams, and some new solutions have also appeared on the market, decision diagrams need to be constantly checked on the completed mould examples, and corrected and supplemented. Such tests and analyses need to be carried out at a maximum number of toolshops and for different shapes of the moulded parts.

The existing diagrams were tested at two toolshops in Slovenia (Iskra OTC-Kranj and Gorenje-Toolshop Velenje), and at three toolshops in Croatia (Novotec, TOZ, and Elektrokontakt-Zagreb) within the project *Re-engineering of mould design for small and medium enterprises*. Up to now, a total of 22 moulds have been analysed. The analysis was performed so that the decision diagrams were checked for a certain moulded part, and the solutions for mould partial functions were recorded. In the second step, those results were compared to the solutions of the already completed and verified moulds. In case of deviations of the actual solutions from those suggested by the diagrams, an attempt was made to find out the reason for this deviation. An analysis was also made to

Sl. 4. *Primer injekcijsko brizganega izdelka* [6]
Fig. 4. *Example of moulded part (cover)* [6]

Preglednica 3. *Rešitve delnih funkcij za izdelek na sliki 4* [6]
Table 3. *Solutions for partial functions of mould for cover* [6]

delna funkcija (2-gnezdno orodje) partial function (2-cavity mould)	rešitev iz diagrama odločitev solution from decision diagram	dejanska rešitev real solution
pozicija izdelka v orodju moulding position in mould	pravilna postavitev izdelka correct position of moulding	OK
okrov orodja mould base	drsniško orodje slide mould	OK
dolivni sistem in ustje type of runner system and gate	hladni dolivni sistem cold runner system	OK
	zunanji okrogli dolivek outside ring gate	filmski dolivek tab gate
vrsta izmetalnega sistema type of ejection system	paličasta izmetala ejector pin	OK + votlo izmetalo OK + hollow ejector
vrsta hladilnega/ogrevalnega sistema type of cooling/heating system	hladilni/ogrevalni sistem cooling/heating of cavity plates krog U U-circle krog Z Z-circle	OK
	"pravokotni" krog "rectangular" circle ALI/OR navadna delitev cevi s posameznim ali dvojnim vijačnim hlajenjem ordinary pipe partition with single-spindle or two-spindle thread. navaden delilni sistem z navojem (protismeren) ordinary partition wall with thread (counter-stream)	OK
vrsta centriranja in vodenja orodja type of centering and guiding system	centrirni obroč centering ring	OK
	vodilna puša guide pillar vodilni čep guide bush centrirni čep centering bush	OK
vrsta sistema za odzračevanje type of degassing system	doseganje potrebne hrapavosti na robovih orodja na delilni ravnini; achievement of necessary roughness of mould cavity plates on parting surface;	OK
	porozni sintrani vložki porous sintering inserts.	NE NO

za to. Nato smo analizirali ta primer in ugotavljali, ali je določena rešitev, ki smo jo dobili z uporabo diagrama, primerna za to orodje ali ne, oziroma katera od njiju je boljša. Eden izmed primerov je podan na sliki 4 in v preglednici 5 [6].

Med analiziranjem odločitvenih diagramov so prišli do sklepa. Diagrami so povsem sprejemljivi za manj zapletene izdelke, medtem ko je na izdelkih, kjer imamo zahtevno geometrijsko obliko treba diagrame preverjati. To pa je tudi pričakovano in očitno, saj smo diagrame razvili za srednje zahtevne izdelke in vsebujejo zelo splošno znanje. Tovrstni diagrami težko popišejo vse primere zahtevnih orodij, zato pa je to izziv za naše nadaljnje delo [6].

5 RAČUNALNIŠKI PROGRAM ZA PROJEKTIRANJE ORODJA

Z uporabo teh sedmih odločitvenih diagramov v obliki računalniškega programa, bi uporabo projektnega reševanja orodja še bolj oživili in hkrati ponudili tudi zanesljivejše rezultate. Kakorkoli že, z natančno analizo diagramov smo ugotovili, da se določena vprašanja podvojijo. Prav tako se konstrukterju postavi kar nekaj vprašanj, na katera mora odgovoriti z DA ali NE, kar zna biti

determine, whether the solution suggested in the decision diagram is applicable after all, i.e. which of the two solutions is the better one, the actual solution or the one in the diagram. An example of analysing the mould for injection moulding shown in Fig. 4 is given in Table 3 [6].

During analysis of the decision diagram one conclusion was made. The diagrams are fully applicable to the moulded parts of simpler shapes, whereas their application becomes difficult in case of very complicated shapes. This is obvious also because such diagrams have been intended for conceptual design of average moulds, and they have general contents. Such diagrams can hardly encompass all the cases of complicated mould forms, however, this can be an incentive for their further improvement [6].

5 COMPUTER PROGRAM FOR THE CONCEPTUAL MOULD DESIGN

By considering the seven mentioned decision diagrams, one cannot but think about organizing them into a computer program that would provide simpler and more convenient application for the mould designer than the decision diagrams themselves. However, careful analysis of the decision diagrams shows that certain questions are repeated. Also, the designer is expected to answer with YES or NO quite a number of times, and that can be very tiring [2]. Therefore, it was concluded that precej utrujajoče [2]. Zato smo povzeli, da je pametno združiti večino vprašanj v en splošen obrazec, v katerega vnesemo začetne podatke, ki jih mora konstrukter tako ali tako poznati (izmere izdelka, gostota termoplasta itn.) [13]. Z izpolnjevanjem teh vnesenih podatkov dobi nato konstrukter vnaprej odgovore na večino vprašanj iz odločitvenega diagrama, tako da računalniku ni treba zahtevati vseh odgovorov od konstrukterja, ampak jih prebere iz vnesenih podatkov [2]. Dodatna prednost računalniškega programa je možnost uporabe prek medmrežnega iskalnika, ki omogoča izris grafičnih rezultatov. Z uporabo računalniškega programa se izognemo vsaj enemu od zelo zapletenih opravil načrtovanju orodij in v ta namen odgovorimo le na nekaj standardnih vprašanj, na katera ni težko odgovoriti celo manj izkušenemu konstrukterju [13].

Pomanjkljivost tovrstnega računalniškega programa je v statičnem znanju, ki sloni na odločitvenem diagramu. V primeru, da pride do nove rešitve delne funkcije, ali se določene rešitve ne uporabljajo več, je treba ponovno programirati nov sistem. Nadaljnji trud bomo vložili v nenehno preverjanje odločitvenih diagramov v praksi in tako osveževali program in diagrame. Program bo tako način dopolnjen s slikami in primeri, kar bo za samo uporabo še laže.

6 SKLEP

Projektiranje orodja za injekcijsko brizganje termoplastov je najbolj pomembna faza v razvoju orodja in ji je zato treba posvetiti kar največ pozornosti. Z željo, da bi bilo čim manj napak v tej fazi, smo razvili ustrezne odločitvene diagrame. Ti diagrami pomagajo določiti pravilne konstrukcijske rešitve za posamezno orodje. Ti diagrami so nastali z analizami sedanjega znanja, v rešitvah že znanih orodij, v katalogih izdelovalcev standardnih delov in s sodelovanjem velikega števila strokovnjakov. Dodatni napredek v projektiranje je dosežen z vpeljavo diagramov odločanja v računalniški program, ki pospeši in poenostavi delo konstrukterja. Poleg tega pa omogoča kakovostno nadgradnjo aktivnosti v tej fazi razvoja orodja na nekoliko višjo raven.

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most of the questions can be joined into one general form into which the input parameters are entered, which the designer has to know anyway, (e.g. moulding dimensions, thermoplastic material density, etc.) [13]. By filling in the input form, the designer gives in advance the answers to the majority of questions in the decision diagram, so that the computer program does not have to require an answer from the designer but receives it from the input parameters. Not all questions are included in the existing input form, but the number of questions to the mould designer is reduced to a minimum [2]. The additional advantage of this computer program is the possibility of using it via any Internet searcher which can display the results in a graphical form. Using the computer program, one of the otherwise very complex tasks of mould designing is at least seemingly reduced to several standard questions that are not difficult to answer even for a less experienced designer [13].

The disadvantage of such a computer program lies in the static knowledge base, represented in fact by the decision diagrams. If, e.g. a completely new solution for a partial function appears, or a solution stops being applied, it is necessary to re-program the computer system. Further efforts will be also directed towards constant checking of the decision diagrams in practice, and to improving the appearance itself of the program, which will be supplemented by pictures and additional explanations, thus making it even simpler for the mould designer to work with the program.

6 CONCLUSION

The conceptual mould design for injection moulding of thermoplastics is the most important phase of the development, and thus requires special attention. In order to avoid taking wrong decisions and selecting bad design solution, adequate decision diagrams have been developed for the principle determination of the solutions of the single partial functions of the mould. These diagrams result from the analysis and systematization of the existing design solutions in the field of moulds, as well as based on the experience and knowledge of a greater number of experts. An additional improvement to the conceptual design phase is the organization of the decision diagram into an adequate computer program which speeds up and simplifies the work of the designer, and what is more important, provides a qualitative upgrading of the activities in this mould development phase to a higher level.

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