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Industrijska uporaba računalniško podprtega inženirstva

Industrial Use of CAE for Product Manufacturing

VOJKO ROGELJ - BLAŽ NARDIN - BOŠTJAN ŠMUC

Pri načrtovanju procesa izdelave izdelkov s tehnologijo injekcijskega stiskanja naletimo na vrsto problemov, ki jih moramo, če želimo obvladovati proces, poznati ter jih predvideti. Prispevek obravnava postopek analize procesov v orodjih za polimerne materiale, od zasnove modela do analize polnjenja, hlajenja ter nadzora krčenja in zvijanja izdelka. Opozarjamo tudi na ustrezne podatke o lastnostih materiala, brez katerih je praktično nemogoče dobiti zanesljive rezultate računalniških simuliranj procesa. Z uporabo računalniške analize imamo možnost izbire optimalnih parametrov injekcijskega stiskanja, ki so bistveni za obvladovanje procesa, na primer stroj, material in tehnologija.

Ključne besede: stiskanje injekcijsko, analize procesov, CAE, izbor parametrov

In planning the process of product manufacturing by the injection moulding technology we come across a number of problems which have to be known and predicted in order to be able to control the process. This paper focuses on the procedures of analysing the processes in moulds for polymeric materials, comprising the mould design, cooling, warpage and shrinkage analyses. We also points out the relevance of adequate data on the material characteristics, since this information is indispensable for obtaining reliable results from process simulations on a computer. The computer analysis offers us the possibility of choosing optimum injection parameters - such as the machine, material, technology - which are essential for controlling the process.

Keywords: injection moulding, process analysis, CAE, choosing parameters

0 UVOD

Prizadevanja po ohranjevanju konkurenčne prednosti različnih dobaviteljev avtomobilski industiji narekujejo hkratno povečanje kakovosti in zmanjševanja stroškov. Zahtevnost izdelave polimernih izdelkov in orodij zanje za potrebe avtomobilske industrije se stalno zvečuje. Zaradi vse bolj zapletenih izdelkov, postajajo tudi orodja vse bolj zahtevna in dražja, povečuje se tveganje izdelave orodja, hkrati pa obstaja velika nevarnost, da izdelek na koncu ne bo kakovosten. Povečanemu stroškovnemu pritisku se je mogoče upreti le s širokimi ukrepi racionalizacije proizvodnje in povečani produktivnosti strojnega parka.

Aktivno izpolnjevanje obeh ciljev je mogoče z uporabo sodobnih računalniških tehnik za simuliranje procesnega dogajanja v oblikovnih orodjih. Že v fazi razvoja izdelka in orodja lahko daje analiza zapolnjevanja in ohlajanja modela, ki je podprta z metodo končnih elementov, kakovostne in v marsičem najboljše rešitve.

Zanesljivost navedenih simuliranj in majhno odstopanje rezultatov v primerjavi z dejanskim procesom daje takšnemu načinu razvoja in optimiranja orodja povsem nov pomen. Povezanost konstrukcije orodja s hkratnim upoštevanjem smernic za vodenje procesa injekcijskega stiskanja skrajšuje čase in tveganja uvajanja novih izdelkov.

0 INTRODUCTION

In order to maintain their competitive advantage in the car industry it is essential for the suppliers to increase the quality of the products while keeping the costs as low as possible. The manufacturing of polymeric products and their moulds for the needs of the car industry is becoming increasingly demanding. With increasingly complex products, the complexity and costs, and thereby the risk of mould manufacturing increase as well, together with the risk that the product may not meet the quality requirements in the end. The pressure of ever-increasing costs can be successfully dealt with only by global rationalisation of the production and the increased productivity of the machines.

With the use of up-to-date CAE techniques for the simulation of the processes occurring in moulds the above two goals can be successfully realised. The analysis of filling and cooling of the model, which is supported by the finite element method, can offer viable and in many respects optimum solutions already at the design stage of the product and the mould.

The reliability of such simulations, and the low deviations of the results in comparison to the results measured in the actual process, opens a completely new perspective onto such an approach to the development and optimization of the mould manufacturing. Because the design of the mould and the parameters involved in the injection moulding process are inter-related and simultaneously analysed, the production time and the risk of introducing new products are decreased.

V nadaljevanju bomo obravnavali le področje računalniških simuliranj tečenja termoplastičnih materialov v oblikovnih orodjih. Trenutno je na voljo kar nekaj programske opreme, ki rešuje probleme na tem področju. Sami uporabljamo programski paket IDEAS MS 2.1, Plastic Processing Package, podjetja SDRC iz ZDA. Z uporabo tega paketa lahko simuliramo polnjenje orodne votline s polimerno talino, ohlajevanje izdelka v orodju ter analizo zvijanja in skrčkov. Zanesljivost rezultatov je za polnjenje in hlajenje velika, medtem ko pri sami analizi zvijanja in skrčkov rezultatov ne smemo jemati kot absolutne, temveč bolj kot usmeritve. Trenutno je mogoče izvajanje anizotropne, viskoelastične analize do izmetavanja izdelka iz orodja. Smeri razvoja programske opreme na tem področju gredo v:

1) bolj zanesljivo napovedovaje zvijanja in krčenja izdelka,
2) povečanje števila materialov in materialnih dodatkov, ki so pomembni za injekcijsko stiskanje,
3) dodajanje novih postopkov injekcijskega stiskanja, kakršni so: večkomponentno injekcijsko stiskanje, injekcijsko stiskanje z uporabo plina in drugo.

The rest of the paper focuses on the computer simulations of the flow of thermoplastic materials in moulds. At present there are quite a few programmes available for solving problems in this area. We use the IDEAS MS 2.1, Plastic Processing Package produced by SDRC, USA. This programme package performs the simulations of mould filling with polymeric melt, cooling of the product in the mould, and the warp and shrink analysis. The reliability of the filling and cooling results is considerable, whereas the results of the warp and shrink analysis are not as reliable and should therefore be taken as trends. At the moment it is possible up to do anisotropic, viscoelastic analysis on the ejection of the product from the mould. The software development trends in this area follow the directions below:

1) more reliable warp and shrink predictions,
2) an increased number of materials and their additives important in the injection process,
3) application of new injection methods such as co-injection moulding, gas-assisted injection moulding, etc.

1 PRIKAZ PROBLEMATIKE

Za simuliranje polnjenja potrebujemo tridimenzionalni model izdelka. Za vse izdelke, ki jih izdelujemo s postopkom injekcijskega stiskanja, lahko trdimo, da so tankosteni izdelki. Zato potrebujemo samo površinski model izdelka, na katerega postavimo ploskovno mrežo končnih elementov.

Model običajno pred simuliranjem poenostavimo. To naredimo iz več razlogov, kakor sta:

- kakovostnejša mreža končnih elementov, zaradi česar se izboljša tudi kakovost rezultatov,
- zaradi manjšega števila elementov se skrajša čas reševanja problemov, kar pomeni prihranek stroškov.

Pri poenostavljanju modela je treba biti pazljiv. Običajno poenostavljamo kakšna manjša rebra, čepke, ki funkcijsko nimajo velike vloge pri izdelku. Poenostavljamo tako, da s poenostavitvijo dobimo za sam proces izdelave zahtevnejši model. Rezultati takšne analize pomenijo bolj kritičen problem kakor v praksi.

Vstopne podatke, potrebne za analizo, delimo v pet večjih sklopov:

1) geometrijski podatki o izdelku,
2) geometrijski podatki o orodju (samo v primeru analize hlajenja),
3) podatki o materialu izdelka in orodja,
4) podatki o brizgalnem stroju,
5) podatki o postopku.

Glede na to, da vseh materialov in strojev ni v bazi podatkov, imamo možnost, da nove podatke vstavimo sami, da bodo ti čimbolj podobni dejanskim razmeram naročnika.

1 PRESENTATION OF THE PROBLEM

For the simulation of the filling, a 3-D model of the product is necessary. We shall assume that the products produced by the injection moulding technology are thin shell products. Thereby only the surface model of the product is needed, on which a shell mesh of the finite element is set.

The model is usually simplified before the simulation. This is done e.g. for two reasons:

- the mesh of finite elements is of higher quality, which consequently increases the quality of the results;
- due to the smaller number of elements, the problem solving time is shorter, which results in cost reductions.

The simplification of the model should be done with great care. Usually minor ribs and bulges which have no functionally important role in the product are simplified. The simplification is carried out in such a way that a more complex model for the production process is arrived at. The results of such an analysis present a problem which is more critical than in reality.

The input data needed for the analysis can be classified into five major groups:

1) geometrical data on the product,
2) geometrical data on the mould (only for the purpose of the cooling analysis),
3) data on the product and tool material,
4) data on the injection moulding machine,
5) process data.

Since not all the data on the materials and machines can be found in the database, it is possible to input new data in order to achieve the maximum resemblance to the actual conditions of the customer.

2 IZBIRA STROJA ZA INJEKCIJSKO STISKANJE

Za potrebe avtomobilske industrije izdelujemo z injekcijskim stiskanjem celo vrsto izdelkov, ki jih dodatno praviloma sploh ne obdelujemo.

Že v fazi prve kalkulacije proizvodnje injekcijskega stiskanja je treba izbrati ustrezno velikost stroja, ki bo zadostil posameznim orodnim in materialnim zahtevam. Običajno se ta izbira opravlja na podlagi splošnih enačb, ki pa pri zahtevnem gospodarjenju s stalnim zniževanjem stroškov že lahko pomenijo določeno tveganje.

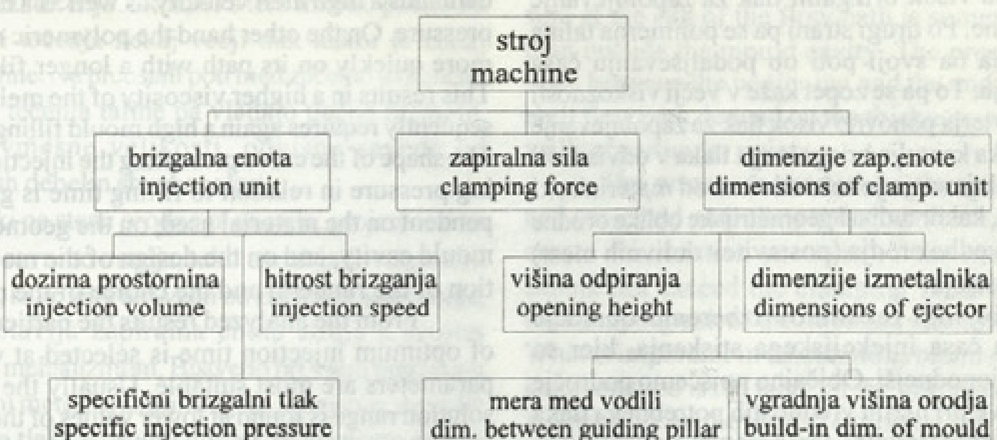
Na strojih za injekcijsko stiskanje ločimo dve povezani funkcijski enoti: brizgalno in zapiralno enoto. Obe sta za stroj enako pomembni, zato v standardizirani označbi navajamo brizgalno enoto in nato še zapiralno, npr. 1300/250. Prva številka pomeni količino vbrizgane mase v gramih polistirola (PS) pri vbrizgovalnem tlaku 1000 bar. Druga številka enostavno označuje zapiralno silo stroja v tonah.

2 THE CHOICE OF THE INJECTION MOULDING MACHINE

For the needs of the car industry a considerable number of products are produced by the method of injection moulding, which usually needs no subsequent processing.

It is important to choose the right size of the machine already at the precalculation stage of the injection moulding production so that the mould and material requirements can be met. Usually the choice is made on the basis of general equations, which can, however, present a certain risk in the constant cost reduction economy.

The injection moulding machine consists of two related functional units: the injection and the clamping unit. Both units are equally important for the machine. A standard way of referring to them is by making reference first to the injection and then to the clamping unit, e.g. 1300/250. The first number represents the quantity of the injected material: polystyrol (PS) in grams at an injection pressure of 1000 bars. The second number refers to the machine clamping force in tons.



Sl. 1. *Razčlenitev stroja za injekcijsko stiskanje glede na značilne veličine*

Fig. 1. *A detailed presentation of the injection moulding machine with characteristic parameters*

Glede na vse večjo zapletenost izdelkov iz polimerov, ki jih narekuje predvsem avtomobilska industrija, se vse bolj že v fazi razvoja izdelka uporablja programska oprema, ki omogoča simuliranje injekcijskega stiskanja teh materialov. Z njimi se optimirajo celotni razvojno-proizvodni proces brizganih izdelkov. Te programe uporabljajo za napovedovanje vpliva konstrukcije brizganega izdelka, konstrukcije brizgalnega orodja in pogojev procesa injekcijskega stiskanja ter tudi za pravilno izbiro potrebne strojne opreme. Tu je najpomembnejši program, ki analizira tečenje taline polimernega materiala v ogreto orodje z upoštevanjem temperature in hitrosti tečenja. Na kratko ga imenujemo program zapol-

Since increasingly complex polymeric products are required, especially by the automobile industry, software for the simulations of the injection moulding of polymeric materials is being increasingly used already at the design stage of the product. It optimises the entire design and production process of plastic products. It can predict the effects of the design of the product and the injection moulding machine as well as the conditions during the injection process. It can also assist us in making the correct choice of the machine equipment needed. The most important programme analyses the flow of polymeric melt into the heated mould with regard to the temperature and the flow velocity. It is simply referred to as the njevanja modela in temelji na uporabi metode končnih elementov. Tako je celotna prostornina kanalnih tokov korakoma izpolnjena s podanim prostorninskim deležem in iz iterativnega opazovanja izgub tlakov vzdolž poti tečenja ugotavljamo čelo taline.

Na podlagi simuliranja zapolnjevanja modela lahko izvedemo kakovostno in količinsko analizo. Analiza kakovosti, imenovana tudi slika polnjenja, posreduje informacije o položaju dolivkov, polnjenju ter legi hladnih zvarov in zračnih vključkov. Količinska analiza je izračun tlakov, temperatur, strižnih hitrosti in napetosti, srednje temperature izdelka in potrebne zapiralne sile stroja. Količinska analiza temelji na postopku optimizacije. S spreminjanjem predelovalnih parametrov, geometrijske oblike in tudi materiala dosežemo optimalno rešitev.

Primer za takšno spreminjanje je določitev optimalnega časa injekcijskega stiskanja. Če prikažemo tlak, potreben za zapolnjevanje v odvisnosti od časa, velja za brizgalno stiskanje tipična krivulja v obliki črke U z najmanjšo vrednostjo zahtevanega brizgalnega tlaka ob srednjem času zapolnjevanja (sl. 2.) Ta krivulja ima obliko črke U zato, ker po eni strani kratek čas zapolnjevanja terja veliko hitrost taline in tako visok brizgalni tlak za zapolnjevanje orodne votline. Po drugi strani pa se polimerna talina hitreje ohlaja na svoji poti ob podaljševanju časa zapolnjevanja. To pa se zopet kaže v večji viskoznosti taline in tako terja ponovno visok tlak za zapolnjevanje orodja. Oblika krivulje brizgalnega tlaka v odvisnosti od časa zapolnjevanja je zelo odvisna od materiala, ki je uporabljen, kakor tudi od geometrijske oblike orodne votline in izvedbe orodja (postavitev dolivnih mest) ter od izbire stroja.

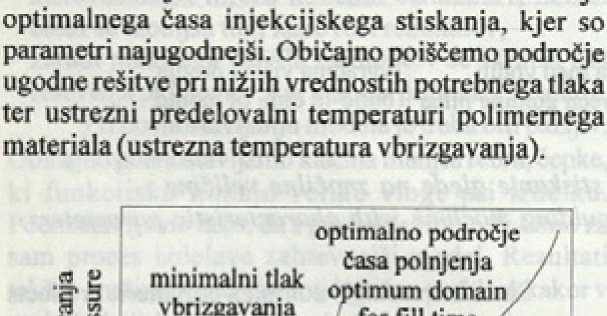
Iz dobljenih rezultatov izberemo območje optimalnega časa injekcijskega stiskanja, kjer so parametri najugodnejši. Običajno poiščemo področje ugodne rešitve pri nižjih vrednostih potrebnega tlaka ter ustrezni predelovalni temperaturi polimernega materiala (ustrezna temperatura vbrizgavanja).

mould filling programme and is based on the finite element method. In this way the entire volume of the flow is gradually filled with the given volume quantity. From the iterative observations of pressure losses along the flow path, the front line of the melt can be established.

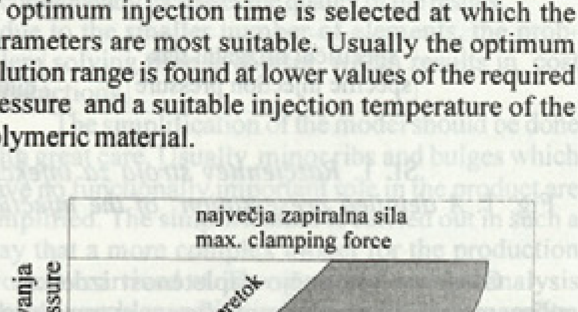
On the basis of the mould filling simulation, qualitative and quantitative analyses can be conducted. Qualitative analysis provides information on the filling, the position of the runners, weldlines and air gaps. The quantitative analysis is a calculation of the pressure, temperature, strain rate, stress, average temperature of the product, and the needed clamping force. The quantitative analysis is based on the optimisation method. By varying the process parameters, geometry and the material, the optimum solution can be reached.

An example of such a variation is the establishment of the optimum injection time. If the filling pressure is presented in relation to the filling time, a typical U-shaped curve presenting the injection moulding pressure is obtained with the minimum occurring at the average filling time. The curve is U-shaped because on the one hand the short filling time demands a high melt velocity as well as a high filling pressure. On the other hand the polymeric melt cools more quickly on its path with a longer filling time. This results in a higher viscosity of the melt and consequently requires again a high mould filling pressure. The shape of the curve presenting the injection moulding pressure in relation to filling time is greatly dependent on the material used, on the geometry of the mould cavity, and on the design of the mould (position of the runners) and the choice of the machine.

From the analyzed results the particular range of optimum injection time is selected at which the parameters are most suitable. Usually the optimum solution range is found at lower values of the required pressure and a suitable injection temperature of the polymeric material.



Sl. 2. *Tlak vbrizgavanja v odvisnosti od časa*
Fig. 2. *The injection pressure in relation to time*



Sl. 3. *Procesno izdelovalno okno*
Fig. 3. *Process scan window*

Iz navedene krivulje potrebnega najmanjšega tlaka lahko napravimo hitro primerjavo s podatki za ustrezni največji tlak vbrizgavanja, ki ga lahko zagotovi brizgalna enota določenega stroja. Navedena krivulja s svojima končnima točkama hkrati določa še dva druga omejitvena kriterija proizvodnosti, ki izhajata iz izbire ustreznega stroja.

Poleg tega je s tem diagramom določen tudi najmanjši potrebni čas zapolnjevanja orodne votline, ki ga določa največji tlak vbrizgavanja. Na sliki 3 je ta čas predstavljen s presečiščem krivulje najmanjšega tlaka in premice, ki ponazarja največji pretok taline skozi šobo stroja. Ordinatna vrednost tega presečišča pomeni tako vrednost potrebne prostornine oziroma na podlagi simuliranja z izbranim materialom maso celotnega brizga.

Druga končna točka pomeni največjo mogočo višino potrebnega tlaka, ki se še kaže v dopustni razpiralni sili. Drugače povedano je največji vbrizgovalni tlak tisti tlak na začetku celotne poti taline, ki je potreben, da pripeljemo čelo taline na konec največje poti tečenja. Skladno s tem imamo potem na koncu poti tečenja nekaj večji tlak kakor je zunaj orodne votline. Na preostali poti med začetno in končno točko poti tečenja taline pa vladajo tlačne razmere, ustrezne vmesne velikosti, odvisno seveda od posameznih debelin sten kanalov.

Tlaki na stene orodnega gnezda, projecirani na razpiralno ravnino orodja, tako ustvarjajo razpiralni tlak orodja, ki ne sme biti večji od zapiralne sile orodja, ki jo zagotavlja zapiralna enota stroja s svojim zapiralnim mehanizmom. Bistveno pri vsem preračunu po navedeni metodi s simuliranjem je dejstvo, da vpliv padajočega tlaka v orodni votlini na površine orodja (integriranje po površinah) brez težav opravi že sam program, tako da si izračun razpiralne sile orodja v odvisnosti od časa lahko predstavimo v obliki diagrama.

3 PRIMER

Simuliranje je bilo izvedeno za okrov meglenke za nov Fiatov model Multipla. Na sliki 4 je prikazan površinski model meglenke z dolivkom, medtem ko je na sliki 5 predstavljen diagram zapiralne sile, ki je bil določen z uporabo računalniškega simuliranja tečenja plastične mase v orodju. Z uporabo tega diagrama pa lahko izberemo stroj, ki ga bomo uporabili za injekcijsko stiskanje.

Using the above curve of the minimum necessary pressure a comparison can easily be made with the data for the maximum suitable injection pressure provided by the injection unit of a machine. The above curve with its two extreme points presents two other criteria of production limit, which depend on the choice of the machine.

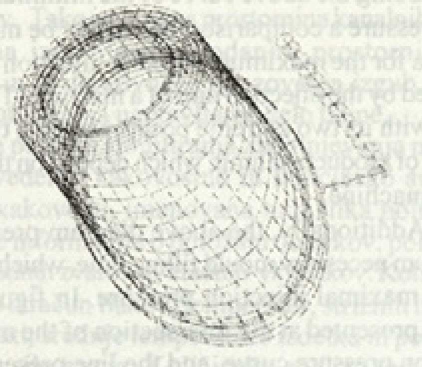
Additionally, the above diagram presents the minimum necessary mould filling time, which depends on the maximal injection pressure. In figure 3 this time is presented at the intersection of the minimum injection pressure curve and the line presenting the maximum melt flow through the machine nozzle. The ordinate value of the intersection represents the required volume or the weight of the injected material obtained in the computer simulation with a specific material.

The other extreme point represents the maximal required pressure which still results in the allowable reaction force. In other words the maximal injection pressure is the pressure required at the beginning of the melt path to bring the melt front line to the end of the maximum flow path. Consequently the pressure at the end of the flow path is somewhat higher than outside the mould cavity. The pressure conditions between the beginning and the end point of the melt flow path depend on the thickness of the runner walls at particular points.

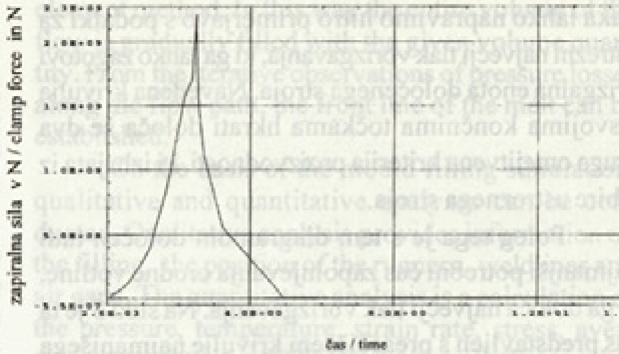
The pressures exerted on the mould surface and projected onto the parting surface of the mould create the reaction pressure of the mould, which should not exceed the clamping force provided by the clamping unit of the injection moulding machine. What is important in calculations based on the simulation method is the fact that the influence of the falling pressure in the mould cavity on the parting surfaces of the mould can easily be predicted by the computer so that the relation of the reaction force of the mould in relation to time can be presented in the form of a diagram.

3 EXAMPLE

A simulation was conducted for the production of a housing of the fog lamp for the new Fiat model Multipla. Figure 4 presents the surface model of the fog lamp housing with a runner. Figure 5 presents a diagram of the clamping force obtained on the basis of the computer simulation of the plastic material flow in the mould. Such a diagram can be very helpful in choosing the injection machine.



Sl. 4. *Model okrova meglenke*
Fig. 4. *A model of the fog lamp housing*



Sl. 5. *Profil zapiralne sile*
Fig. 5. *Profile of the clamping force*

4 SKLEP

Simuliranje injekcijskega stiskanja ali analiza zapolnjevanja modela omogočata uporabniku zanesljivo oblikovanje izdelka, orodja, optimalno izbiro materiala in določitev optimalnih procesnih parametrov hkrati s strojem za brizganje.

V prihodnosti lahko pričakujemo, da bodo razvoj izdelkov, konkurenčnost in optimiranje proizvodnje narekovali obvezno uporabo paketov za analize procesov injekcijskega stiskanja in s tem tudi natančnejše določanje velikosti stroja za injekcijsko stiskanje za proizvodnjo določenega izdelka.

4 CONCLUSION

The injection moulding simulation, or the analysis of the mould filling, offers the user a reliable design for the product and mould, the establishment of the optimum process parameters, and the optimum choice of the material and the injection moulding machine.

We predict that in the future the development of products, together with the competitiveness and optimization of the production, will demand the indispensable use of programme packages for injection process analyses; these will enable a more precise determination of the size of the injection moulding machine for the production of a particular product.

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Naslovi avtorjev: Vojko Rogelj, dipl. inž.
Fakulteta za strojništvo
Univerze v Ljubljani
Aškerčeva 6
1000 Ljubljana

Blaž Nardin, dipl. inž.
TECOS, Razvojni center
orodjarstva Slovenije
Mariborska 2
3000 Celje

mag. Boštjan Šmuc, dipl. inž.
Saturnus Avtooprema
Letališka 17
1000 Ljubljana

Authors' Addresses: Vojko Rogelj, Dipl. Ing.
Faculty of Mechanical Engineering
University of Ljubljana
Aškerčeva 6
1000 Ljubljana, Slovenia

Blaž Nardin, Dipl. Ing.
TECOS, Slovenian Tool and the
Development Centre
Mariborska 2
3000 Celje, Slovenia

Mag. Boštjan Šmuc, Dipl. Ing.
Saturnus Avtooprema
Letališka 17
1000 Ljubljana, Slovenia

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