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The mould as the central part of production unit. Part II*)

Summary — The development of technical, particularly manufacturing sciences, has resulted in a scientific knowledge added to underlie toolmaking and enabling increasingly difficult tasks to be solved. The work of the tool designer can be reintegrated with the work of the toolmaker. For some types of tools, Ropohl's [6] morphological classification has been redeveloped and the previously developed method using morphological boxes for designing moulds for injection moulding of thermoplastics has been theoretically supported. Separation of the activities of tool designing and toolmaking is shown to have unsatisfactory consequences. The expanding share of computers and computer software in modern toolmaking makes reintegration of the two fields of activity desirable.

Key words: toolmaking, natural and artificial tools, moulds, philosophy of toolmaking, mould production and design.

Part I [2] has discussed some historical and current considerations regarding toolmaking, which can be described as the beginnings of the toolmaking philosophy. The position of tools in the culture has been described and the term production defined. In particular, the philosophy of the bond between the design and production has been approached and explanation has been given why tools are the central element of production lines. We assume the time has come for toolmaking to be re-engineered in two directions, *viz.*, in the designer's and in the toolmaker's work [3].

By its very content, the term "re-engineering" implies continuous re-examination and improving of activities in numerous areas. In Part I [2], the methodology of re-engineering and systemic theory of technics has been used to prove the old thesis that the mould is the central part of the line for the production of polymeric parts [2]. The intention is now to discuss two possible applications of the basic ideas derived from the philosophy of technics. First, the mould design for primary shaping by using a morphological matrix will be described. Secondly, the application of the general assembly theory in toolmaking will show us the importance of the connection between the mould design and the mould manufacturing. But first of all, it is necessary to present a morphological systematisation of tools.

RE-ENGINEERING IN MOULD DESIGN

This part will discuss the morphological systematisation of tools, injection mould design using a morphological matrix and systemic development models of polymer mouldings and appropriate injection moulds.

Morphological systematisation of tools

Table 1 shows the characteristics of some tools [4, 5] which follows the methodology developed by Ropohl [6a], except that one more column has been added to characterise the most sophisticated tool, the natural one, *viz.*, the hand with its most important part, the fist, and the number of characteristics has been extended to include sensoring and degrees of freedom.

Certain characteristics and forms from Table 1 should be explained in more detail. Field 3 explains the relation between the system and the environment. If interactions between the system and the environment are nonexistent, the system is a closed system [7]. If such interactions do exist, the system is open; and if such interactions exist, but are insignificant such as those within the system itself, then the system is a relatively isolated system [7]. For example, the environment influences the operation of the mould in injection moulding of polymers through such parameters as pressure, temperature and humidity. However, the interactions within the cavity itself are more important for the mould injection process than the interactions between the mould (housing) and the environment. Therefore, the mould for injection moulding is **relatively isolated**. A similar situation occurs with stamping tools, whereas the lathing tool represents an **open system**.

Field 4 describes the hierarchical level of certain systems. If the system is an element of a superior system,

*) This text is based on [1].

T a b l e 1. Morphological classification of some tools

Characteristics	Occurrences of form characteristics								
						Hand	Lathing tool	Mould for injection moulding of polymers	Stamping tool
1. System exists as	concrete	abstract				concrete	concrete	concrete	concrete
2. System originates from	nature	artificial (culture)				nature	artificial	artificial	artificial
3. System relation to environment	closed	relative isolate	open			open	open	relative isolate	relative isolate
4. Level of system hierarchy	supersystem	system	subsystem			system and/or subsystem	subsystem	system and/or subsystem	system and/or subsystem
5. Type of system	production system	manufacturing system	reactive processing	processing	working machining	processing*)	working machining	processing or reactive processing	working machining
6. Shaping/forming	primary	secondary				secondary forming*)	secondary	primary	secondary
7. Manufacturing of objects with simultaneous	chemical building of material	physical building of material with possible cross linking	change of state			change of state	change of state	chemical and/or physical building of material and/or change of state	change of state
8. Time dependent (function)	static	dynamic				dynamic	dynamic	dynamic	dynamic
9. Attribute value within a time interval	continuous	discrete				continuous	continuous	continuous	continuous
10. Type of function	linear	nonlinear				nonlinear	nonlinear	nonlinear	nonlinear
11. Degree of determination	deterministic	stochastic				stochastic	stochastic	stochastic	stochastic
12. Time dependence of structure	rigid	flexible				flexible	rigid	rigid and flexible	rigid and flexible
13. Number of subsystems	simple	complicated	very complicated			very complicated	simple	very complicated	complicated
14. Number of relations	simple	complex	very complex			very complex	simple	very complex	complex
15. Behaviour	unstable	stable	ultrastable			stable	stable	stable	stable
16. Shape of structure	no feedback	feedback	partial feedback			feedback	yes/no feedback	yes/no feedback	yes/no feedback
17. Sensoring	yes	no				yes*)	no	no	no
18. Degree of freedom	no of DOF					28	≤2	≤4	≤2

*) Only first.

it is called a subsystem, and if the system is composed of several subordinate systems, then it forms a supersystem [7]. For example, the mould for injection moulding of polymers can be a system in itself. But, if it is considered an element of the system for injection moulding comprising an injection moulding machine, mould and a heat exchange device (thermolater), then the mould becomes a subsystem of that supersystem.

Field 5 describes the types of systems. These are the production, manufacturing, reactive processing, processing, and work machining systems. The production system comprises converting a substance into a material and manufacturing of a product [7]. The manufacturing of a product includes primary shaping, reshaping (machining), bonding, coating and imparting characteristics properties to the product. The physical processing system includes primary shaping of the material into a preform, which can be a final product, and the reactive-processing system includes reactive primary shaping of reactive substances into a **preform**. The work machining system includes machining of the **preform** into a **working part** [7]. For example, a mould for injection moulding of polymers represents a processing or a reactive-processing system, which performs the primary shaping of the material or reactive substances into a preform (moulded part). The moulding part sometimes needs to be additionally machined, *e.g.* by particle separation machining (removal of flash or rest from the runner system), and to be modified on the surface, *e.g.* by painting.

Field 7 describes occurrences related to product manufacture. It is possible to distinguish manufacturing of products involving simultaneous chemical conversion, physical formation, and modification of the state of materials [7]. In a mould for injection moulding of polymers all, or only some of these occurrences, may occur simultaneously. For example, a mould that serves as a charge reactor, and simultaneously for the manufacture of the product, involves chemical conversion of a material (polymerisation). On the other hand, injection moulding of rubber compounds comprises networking and crosslinking of rubber (material). In mould injection of thermoplastics, mainly the state of the material is changed, *i.e.*, the thermoplastics material is melted in order to be injected into the cavity, and later it re-solidifies to form a moulding that is demoulded.

Field 8 describes system parameters in relation to time. If system parameters change with time (*e.g.* pressure and temperature in the cavity), the system is a dynamic system. If system parameters are fixed, the system is static [7]. This means that the mould for injection moulding of polymers is the dynamic system.

Depending on the occurrence of certain attributes in a time interval, it is possible to distinguish continuous and discrete systems (Field 9) [7]. If there is a related system attribute characteristics for every point in time, we speak of a continuous system [7]. If such conditions are lacking, the system is a discrete system. It should be pointed out that the pair of terms "continuous/discrete" is not synonymous to the pair "analogue/digital" [7]. According to this definition, the mould for injection moulding of polymers represents a **continuous** system.

Field 10 describes the type of function. The system is linear if functions of the system can be described only by linear equations relating system attributes [7]. If this is not possible, the system is non-linear [7]. It may be concluded, by the analysis *e.g.* of pressure and temperature changes occurring in the cavity, that the mould for injection moulding of polymers is a **non-linear** system.

If it is known with certainty that the attributes describing the system either do or do not exist, then the system is deterministic, *i.e.* all the system characteristics may be assigned the value of zero (0) or one (1) [7]. If the system can be described by assigning to some or all of the system parameters the values between 0 and 1, this is a stochastic system (Field 11) [7]. The mould for injection moulding of polymers is a **stochastic** system.

Unlike Field 8, which describes time-dependent functions, Field 12 describes the time dependence of the structure of the system. This means that, within a period of time, the system can take on various forms, *i.e.* some relations may become eliminated and others added and the structure of the subsystems may change with time, *etc.* [7]. Such systems are flexible and the systems with a fixed structure are rigid [7]. Generally, the mould for injection moulding of polymers is a **rigid** system, since it is designed so that it can produce only one type of moulded part. However, great efforts have recently been made to increase the mould flexibility. Therefore, the mould can be either a rigid or a **flexible** system.

In Fields 13 and 14, the terms complicated and complex should be explained. The term complicated is connected with the absolute number of subsystems and is a measure of complication (variety). A system can be simple or complicated [6b]. The term complex means a number of relations occurring between system elements, and complexity is a measure of the number of relations. The system can be simple, complex or very complex. The mould for injection moulding is a **very complicated** and **very complex** one.

Field 15 refers to the stability of the system. The system is stable if its parameters are amplitude-limited time functions. The stable system always tends towards equilibrium as a target. On the other hand, there are systems, which after being disturbed cannot return to the original equilibrium but rather remain in another state of equilibrium. Unstable systems are ones which after having been disturbed do not return to the same state of equilibrium [7]. According to these definitions, the mould for injection moulding of polymers is a **stable** system.

The structure of the system is described in Field 16. According to this division, there are systems with no feedback, systems with a partial and systems with a full feedback [7]. To decide this question is currently most difficult, therefore Table 1 includes both possible answers.

New characteristics are added in Fields 17 and 18. The fist can act as a sensor and the hand has in total 28 degrees of freedom.

Injection mould design using morphological matrix

The concept of mould designing by using a morphological matrix has been developed at the Chair for Polymer Processing, University of Zagreb [8, 9].

In order to successfully design a given moulded part, the overall function of the mould needs to be divided into partial functions. Table 2 shows the morphological matrix for designing the moulds for injection moulding of thermoplastic melts [8]. It includes an example of a possible solution for each partial function. The morphological matrix-aided design has been repeatedly checked. There are slight differences in the solutions tested in practice and those introduced by young, as a rule unskilled, mould designers using this design method.

After a decade it seems wiser to form an addition theoretical basis for such a result [10]. Such a case is a typical case in production technics. Practitioners find out some solution, by experience or test, and production scientists give some theoretical explanation.

One very fine idea comes from a German philosopher Friedrich Dessauer [11]. Eekels [11] has quite correctly pointed out that there is not only one ideal form that can fulfil a given end. "One can pave a road with brick, with concrete and with hot rolled asphalt, one can write a fountain pen and with a ballpoint, one can heat a house by means of coal, oil, gas or electricity. We feel, therefore, that every technical problem has at least several, but generally many good solutions". The idea is that "the ideal solution is approached asymptotically". Our comparison of mould design solutions by practitioners and those by young designers applying the morphological matrix method to design moulds for injection moulding of thermoplastics has resulted in a similar experience [*cf.* 10]. Our practice shows this by the fact that a technical product such as a mould, appears in less and less fundamentally different solutions as the technical development of this product is progressing.

Catalogues of standard mould base parts and other mould elements formed the basis for developing workable solutions of partial functions of moulds for injection moulding of thermoplastics. And for this there is also a philosophical explanation given by Dutch philosopher Hendrik van Riessen [11].

Characteristic for technical products like machines, tools, mould, devices *etc.* that may be regarded as systems, is their "neutralising division" [11]. Technical products usually consist of subsystems that are becoming less and less specific. At the same time, the subsystems become more and more general in terms of their intended functions. Until we finally end up with system ele-

T a b l e 2. **Methods of conceptual design realisation of mould for injection moulding of polymers partial functions shown by means of a morphological matrix**

Partial functions		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	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	Primary shaping of matter and distribution	E_{21}																
C_3	Regulation of mould temperatures	E_{31}	E_{32}	E_{33}	E_{34}	E_{35}	E_{36}	E_{37}	E_{38}								...	
C_4	Injection shot demoulding	E_{41}	E_{42}	E_{43}	E_{44}	E_{45}	E_{46}	E_{47}	E_{48}	E_{49}	E_{410}						...	
C_5	Mould element centering 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	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	Mould clamping on the machine	E_{71}	E_{72}														...	
C_8	Loads taking over and transmission	E_{81}	E_{82}	E_{83}	E_{84}												...	
C_9	Mould elements joining	E_{91}	E_{92}	E_{93}	E_{94}	E_{95}	E_{96}	E_{97}									...	
C_{10}	Special functions	E_{101}	E_{102}	E_{103}	E_{104}	E_{105}											...	

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.

ments like ejector pins or guide pins. It could be said the these parts are neutral or indifferent with regard to the purpose of the technical product, here the mould. For they could have found a place in totally different tools with a completely different purpose. This is where the systemic approach to mould design, a project being carried out by D. Godec, could offer great help [10].

The "neutralising division" has been confirmed also in mould designing for the injection moulding of thermoplastics. That is looking for an optimal solution by means of "decision diagrams". However, it proved possible to generalise such diagrams by improved organisation to reduce the number of questions as well as possibilities of errors, and to include explanations with application examples in the diagrams. At the moment, we are trying to generalise such diagrams and make decisions with the aid of a computer [10, 12].

Systemic development models of polymer mouldings and appropriate injection moulds

Many activities during the development of mouldings and the appropriate mould are carried out simultaneously [10, 12]. Therefore, designing is a very tough exercise especially for inexperienced mould designers.

The modern approach to the development and manufacture of each product, and therefore also to polymer mouldings, requires a certain synergy in the activities of professionals engaged in the project of development and production. It is precisely this co-operation which makes it all the more difficult to separate production from the development, especially since many activities in developing a moulding and the related processing equipment (*e.g.* the mould) are carried out simultaneously, referred to by the term simultaneous engineering. We have discussed this bond earlier. Therefore, the development and production of polymer mouldings needs to be considered a system. In order to achieve the best results of such an approach, that is, the production of an optimal moulding with the lowest possible costs and in the shortest possible time, all the activities during the development and production of polymer moulding need to be defined, co-ordinated, and organised. One of the possible tools in solving this task is the systemic theory of technics [13, 14]. First, the basic concepts of systemic analysis must be described, as well as the possibilities of their application in developing a systemic model of polymer mouldings and the appropriate mould for injection moulding of polymers as the basic element of the processing equipment.

Generally, three basic systemic concepts may be mentioned: hierarchical, functional, and structural [6c]. The hierarchical concept of the injection moulding system is presented in Figure 1 [13, 14].

The hierarchical concept emphasises the circumstance when the elements of one system, *e.g.* injection moulding system, represent the systems themselves, *e.g.*, a mould for injection moulding [6c]. At the same time, this systems is the element of a superior system (*e.g.* injection blowing system) [13, 14]. The next concept is the functional one (Figure 2) [13, 14].

In the functional concept of the system, its elements (subsystems) are presented as "black boxes". The relations of its external characteristics denote a "black box". These are inputs and outputs, which can take the form of matter, energy and information [6c]. Thus, the state parameters (pressure, temperature, *etc.*) are described. The best known is the structural concept (Figure 3). Characteristically, the system is regarded as a whole of interrelated elements [6c].

A simplified systemic model of developing and manufacturing the polymer moulding will be presented. The system for developing the appropriate mould represents a part of the system for developing the processing equipment. In this case, the moulding is an element of a complex product (Figure 4) [10, 12].

First, in Figure 4, the basic phases included in the development of the moulding and the appropriate mould need to be defined in general. This statement is supported, among others, by Griffiths in the following sentence: "the mould is the sole channel between product design and the eventual end product" [15].

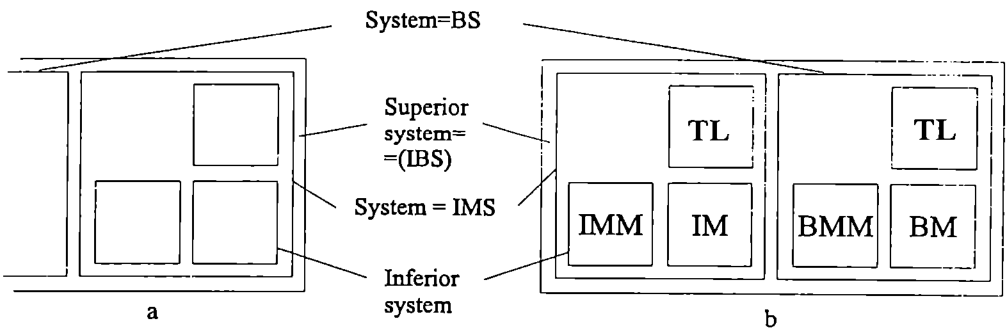

Fig. 1. The hierarchical concept of injection moulding system: BS-blowing system, IMS-injection moulding system, IBS-injection blowing system, IMM-injection moulding machine, IM-injection mould, TL-thermolater, BMM-blow moulding machine, BM-blow moulding

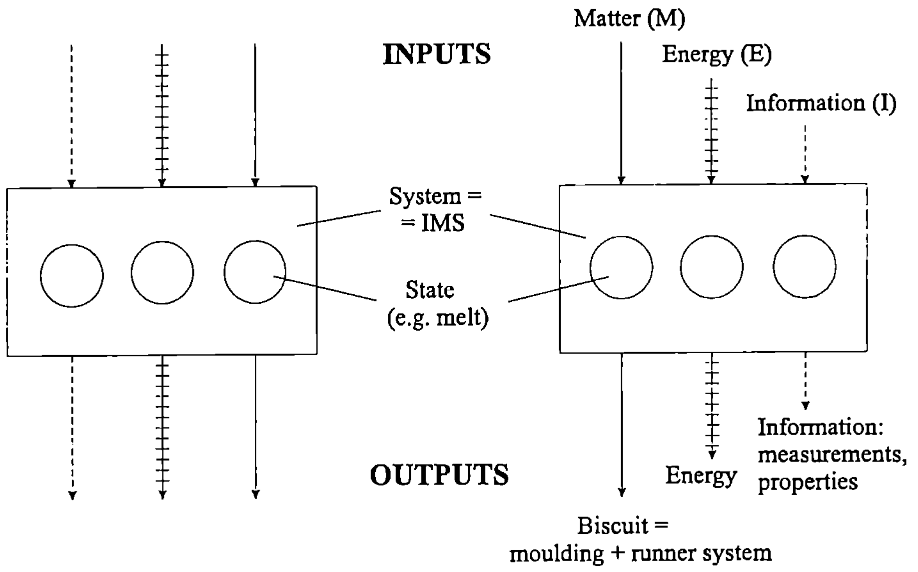

Fig. 2. Functional concept

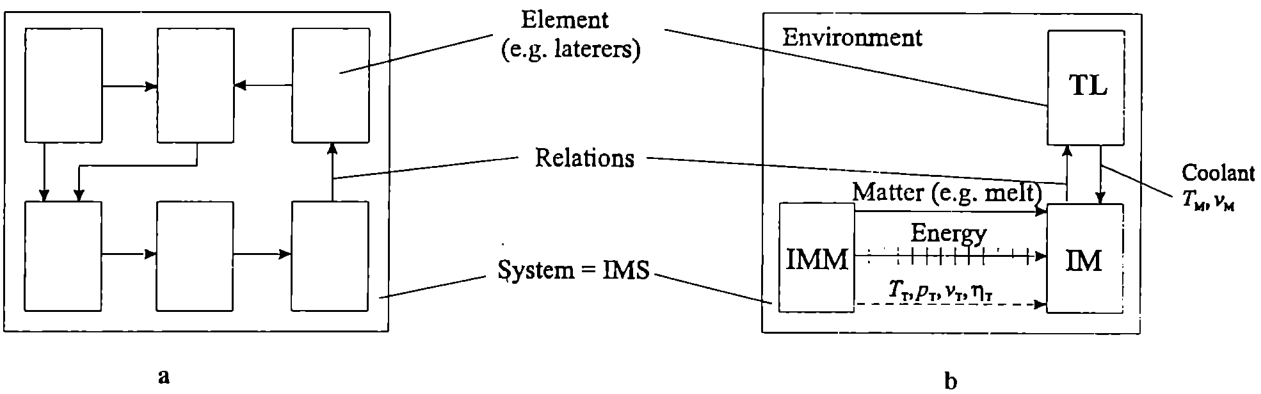

Fig. 3. Structural concept: IMS-injection moulding system, IMM-injection moulding machine, IM-injection moulding, TL-thermolater

The first phase in the development of the moulding is the conceptual design. This phase follows the market research phase and the conceptual design of the complex and complicated product based on the given requirements. Next are the activities related to the selection of material, and then follows the constructional design of the moulding (both in production and in service).

After the constructional design, the efficiency and production feasibility need to be checked. These are all the basic phases in the development of the moulding.

The development of the processing equipment, in this case the mould and the production of the mouldings, starts by planning the processing method of injection moulding, as well as the analysis of the mould operation principles (conceptual design of the mould). Then follows the calculation of the mould, and the adequate design and production documentation. The final phase in developing a mould is its production, followed by the pilot production of mouldings, their testing, elimination of possible faults and, eventually, the injection moulding. The finished mouldings are then assembled into complex and complicated products. After the basic phases in the development and production of polymer mouldings have been defined, the basic concepts of the systemic analysis need to be applied to achieve the systemic development and production model of polymer injection mouldings [10, 12].

The application of the hierarchical concept leads to the conclusion that the system of polymer moulding development and production consists of the moulding and appropriate mould design section, toolshop (toolmaking department), processing section, and the moulding quality control as subsystems. All the development phases represent elements of these subsystems, and are their subsystems. For example, the conceptual design of a moulding is a subsystem of the moulding and mould development system.

According to the functional concept, each of the mentioned subsystems and development phases may be regarded as "black boxes" with inputs and outputs. And

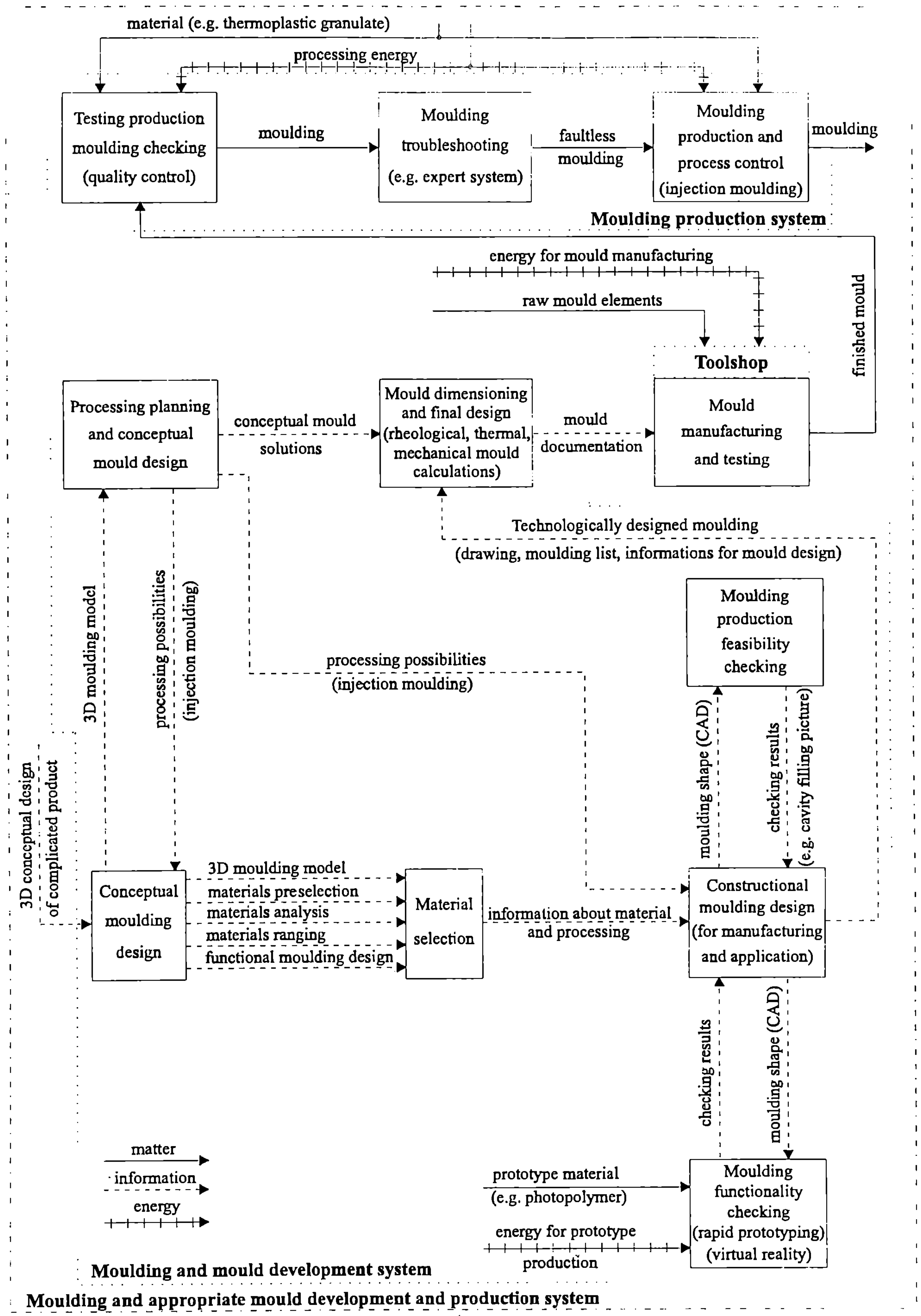

Fig. 4. A simplified systemic model of polymer moulding and appropriate mould development and production system

according to the structural concept, the whole system of developing and manufacturing polymer mouldings consists of a certain number of "black boxes" that interact by adequate relations [10, 12].

Thus, the input into the polymer moulding development and production system is an information represented by a 3D model of the complex product, as well as the moulding technical requirements. Besides, the system needs energy in order to operate (*e.g.* electrical energy for computers, tooling machines, prototyping, *etc.*), and material inputs (*e.g.* standard mould elements, photopolymer for prototyping, *etc.*). The output is in the material form, *i.e.* faultless moulding [10, 12].

There are certain relations between the phases in the development. Thus, within the moulding conceptual design, the 3D model of the moulding is defined, the polymeric materials are preselected, analysed, and classified, and the mouldings are predimensioned. The data obtained during these activities are the information input for the subsequent activity, *i.e.* selection of the moulding material. Since it is possible to simultaneously develop a conceptual design of the appropriate mould, the 3D model of the moulding is the information input into this phase of mould development. Data on the selected polymer material are in turn the information input into the phase of moulding constructional design, including the moulding dimensioning. The final form of the moulding as information input (computer model) is used to check its production feasibility and its functioning. And the final results of these activities are the design, list of mouldings, and information on the moulding, which is then built into the mould. The same data are the input into the mould dimensioning phase and the phase of the design and production documentation, which is also the information input into the toolshop where the mould is produced. The mould is the material input into the department of moulding processing and quality control. Apart from the mould, the material input includes also *e.g.* thermoplastic granulate. The output is the finished moulding [10, 12].

Such a model has several functions. It includes all the basic phases of the development and production of polymer moulding, giving an overview of all the activities during development. Also, the relations between individual departments and the "black boxes" within the departments are defined, and they in turn define the cooperation principles. In this way, each department knows who to cooperate with, from whom to expect appropriate information, and whom to give the results of their activities. Therefore, this model may be applied as an organisational model. The power of systemic analysis lies in the fact that its application is universal. Therefore, even this model, with certain modifications, may be applied in the development and production of any product.

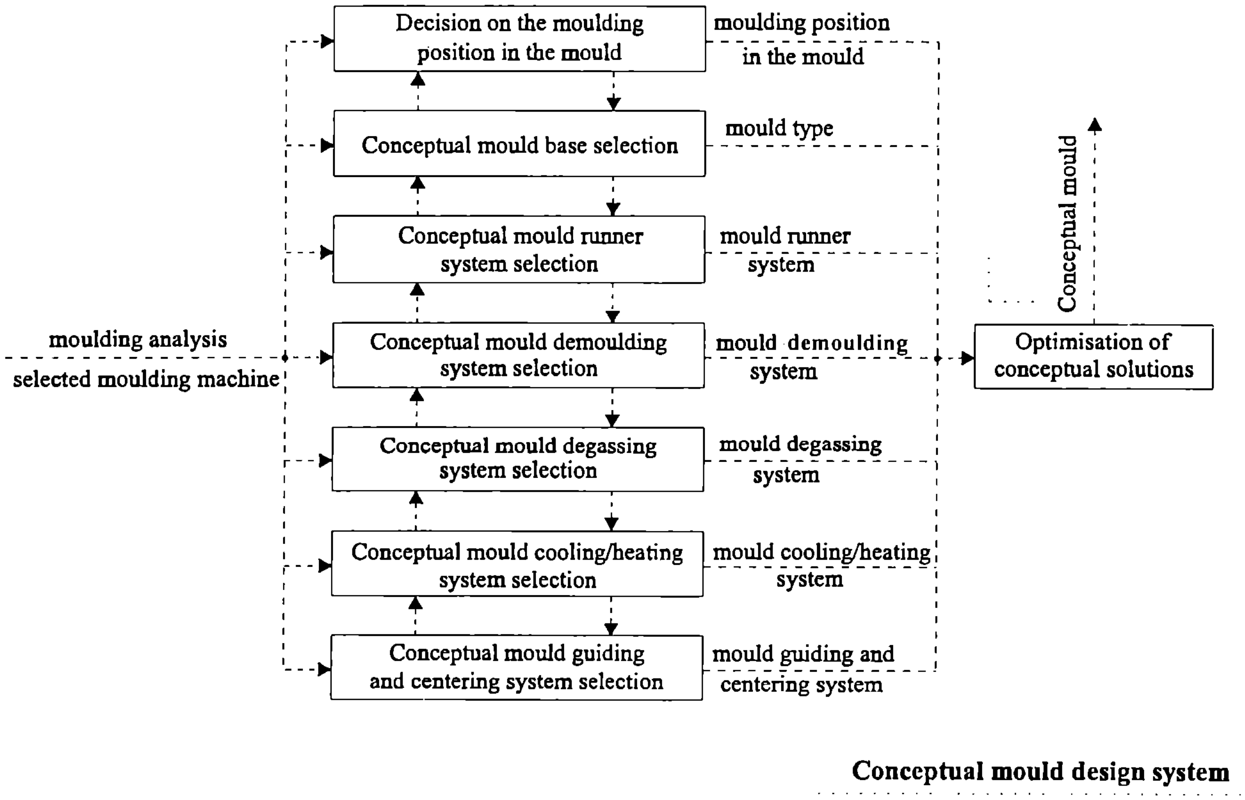

Fig. . The model of conceptual mould design system

The systemic model may be extended, *i.e.*, certain activities during the development of moulding and the appropriate mould may be analysed in detail. Thus, as already mentioned, the mould development consists of several basic phases: conceptual mould design, dimensioning, and design and production documentation. Each of the mentioned phases which can be regarded as systems, consists of several activities or subsystems (Figure 5) [10, 12].

During the conceptual mould design phase, the number and arrangement of mould cavities are determined, and the principal solutions for individual partial functions of the mould are defined, made possible by the application of the decision diagrams and the morphological mould matrix. This number of mould cavities is the information input in the activities of determining the type of the mould base, gating system and gate, demoulding system and degassing system, and this data is used to determine also the approximate mould dimensions.

The mould calculations include rheological, thermal, and mechanical calculations of the mould, and each of the calculations, or systems, consists of an appropriate number of blocks or subsystems, which are interconnected. Thus, the thermal mould calculation can be divided generally into 4 blocks: calculation of the injection moulding cycle time and appropriate temperatures, thermal balance of the mould, calculation of dimensions and mould cooling/heating system parameters, cooling/heating optimisation.

The input in the thermal calculations are the data about the moulding shape and dimensions. Then the input are the shape and dimensions of the gating system obtained by the rheological calculation and thermal and mechanical properties of the mould plate material and the polymeric material. Then follow the intervals of significant temperatures (melt, mould cavity, surrounding), and limitations such as the permissible deflection, pressure, minimal and maximal mould cavity wall thickness. The information output from the first block is the cooling time of the moulding and the injection moulding cycle time, as well as the temperature and thermal characteristics of the mould and the cooling/heating medium. The result of the mould thermal balance calculation are the values of the heat brought to the mould by thermoplastic melt, heat exchanged with the cooling/heating medium and with the surrounding.

The next block determines the number and arrangement of cooling/heating channels. As well as their diameter, maximum flow rate of the cooling/heating medium, wall thickness between the cooling/heating channels and the mould cavity, input and output temperature of the cooling/heating medium, and the power of the pump (Figure 6).

The last block determines the optimum temperatures of the melt and of the mould cavity wall, and the optimal positions of thermocouples in the mould. The optimal position of the thermocouples in the mould is described in paper [16]. These data are sufficient to develop a simplified systemic model of the mould thermal calculation presented with inputs and outputs in Figure 6. In the same way, it is possible to define models for all the other phases in the mould development, thus gaining insight in all the activities that need to be carried out, and their sequence. Also, it defines which in-

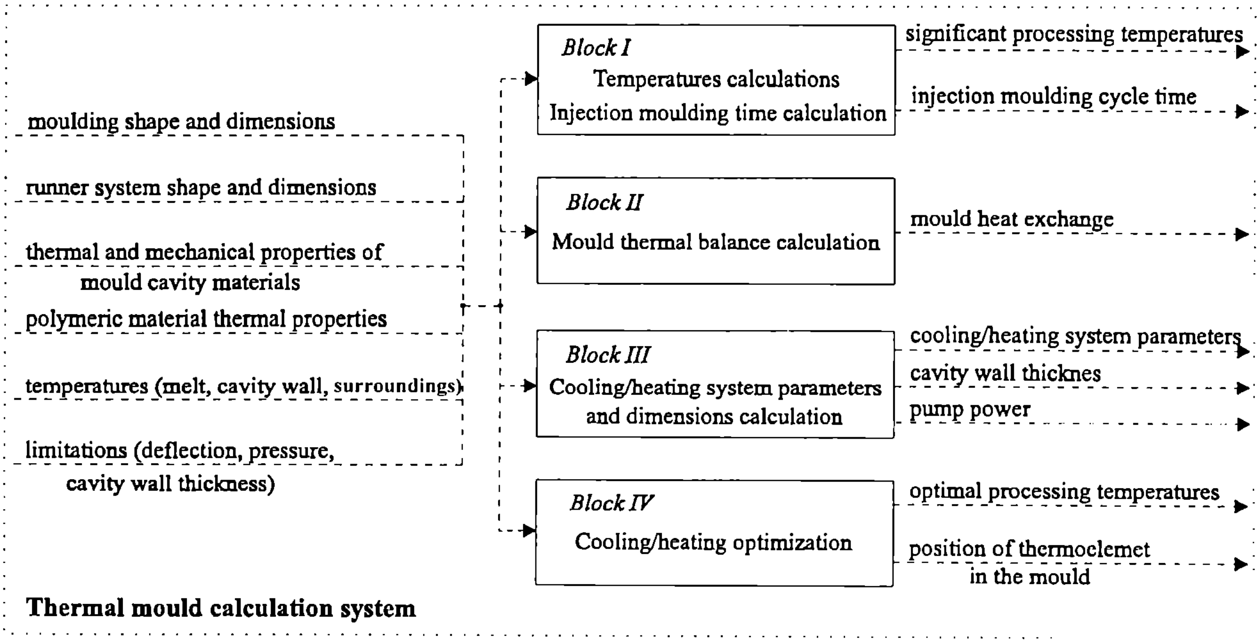

Fig. 6. The model of thermal mould calculation system

put data are necessary for certain activities, and what is expected as a result of the activity as the output.

From this analysis it follows that the mould design for polymer injection moulding needs to be considered with special attention, since the mould is the central element of the injection moulding system. Some activities during the development do not receive due attention, *e.g.* the conceptual design and mould calculations, so that they are based on designer's experience. However, the modern approach to the mould design for polymer injection moulding requires an engineering approach to be taken and various analytical and/or numerical methods to be applied to solve a given task(s). Therefore, it is very important, especially for the young and inexperienced designers, to develop a design process to describe in detail all the activities and their sequence. Systemic models present one of the ways in which this can be achieved, thus obtaining the appropriate guidelines for the polymer injection mould design.

From this description it follows once again that the systemic analysis is a very powerful tool not only to model various systems, but also to model occurrences and activities. For young designers, it is particularly important to develop a model that will include all the activities and define their sequence in order to create guidelines for the polymer injection mould design.

RE-ENGINEERING IN MOULD MANUFACTURING

In mould manufacturing a considerable progress has been achieved during only a few years. This means not only the introduction of CAD/CAP/CAM, but particularly rapid prototyping and rapid tooling. Rapid tooling introduced into mould making means not only a new set of producers, but also numerous new people who are not educated to be mouldmakers. They learn from practice, not so bad, but this is not an optimal solution. At the same time, as predicted by Griffiths [15]*), this group of specialists can be the leading group of the future tool manufacturing.

To discuss the application of the general assembly theory in toolmaking [17, 18], it is worth reminding that at the beginning of the 1960s, Duraševič showed what could happen in the production line when the design was separated from the function of making. He proved that the system of allowed departures, known as the system of unit bores or unit axle, is not natural [19]. This system, which for the assembly tolerance uses abbreviations such as *e.g.* H7/g6, has proved especially inadequate in mould manufacturing [17, 18].

*) Griffiths [15] has drawn attention to certain trends in the future development of mouldmaking. Interested Readers are invited to consult the original reference.

It follows from the general assembly theory that, if tolerances are prescribed, equal tolerance is needed both for the bore and for the axle. This is true in general. However, some other possibilities are offered to toolmaking, those that were known to toolmakers practitioners. The general assembly theory plans that the required allowance or interference and assembly tolerance should be prescribed. With the problem set in this way, there is the question of the level of probability whether the set assembly allowance will be realised, if only one assembly is made, which is not rare in toolmaking. We will discuss the possible achievement of the prescribed assembly tolerance on the concrete example of cutting plate and punch, or guide pin and guide bush 25 mm in diameter (Figure 7) [17].

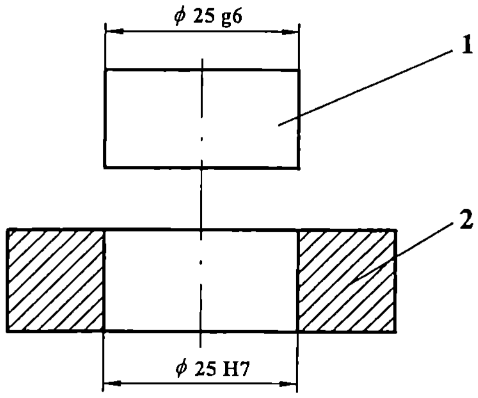

Fig. 7. The punch and cutting plate: 1 — punch, 2 — cutting plate

By adding the normal distributions, the probability of achieving the prescribed assembly tolerance was found to be lower than 20%. Therefore, the toolmakers have always adjusted the assemblies, independently of the prescribed part tolerances.

Our experiments have shown that it is worth adjusting up to four or five assemblies, and then to perform programmed assemblying (for details see [17]). Table 3

Table 3. Results of random and programmed assemblying

Number of elements in fit	Number of fit	Number of fit classes random/ programmed assemblying		Tolerance of fit random/ programmed assemblying
2	50	9	3	3.0
2	21	8	3	2.7
2	8	5	2	2.5
3	10	5	2	3.5
3	6	4	2	5.5
4	8	6	3	7.3
6	8	7	1	8.3

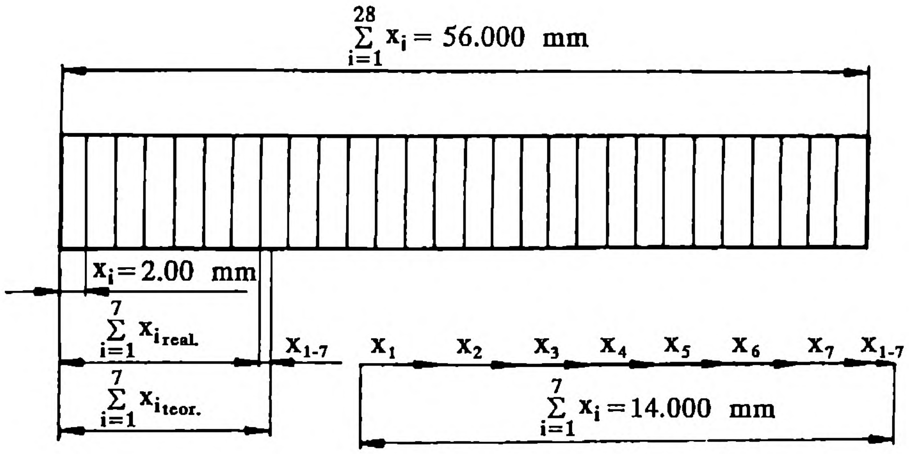

Fig. 8. The punch consisting of 28 lamellas programmed assemblies

summarises our experiments with two to six parts assemblies [17].

The most interesting example is shown in Figure 8 [18]. By programmed assemblying, identical assemblies at four punches consisting of 28 lamellas each (real manufacturing of lamellas, by grinding, were ±3 μm), have been achieved. The assembly tolerance was within 1 micrometer, even after each 7 lamellas the tolerances were the same.

TOOLMAKER — THE PRODUCT CREATOR

We wish to discuss now two points, the position of toolmaker in the modern production of goods and some aspects of toolmaker's work.

In the late 1980s a general model was presented for injection moulding [2]. This model depends neither on the type of polymeric material (plastics or rubber compounds), nor on the nature of the matter processed (polymers, metals, ceramics, and combinations) nor its state (solid or liquid). The model is based on the systemic theory of technics and deals with the flows of matter, energy and information.

A graduate mechanical engineer started a discussion on the adequacy of such presentations [2]. He considered his task to be the "design of moulds that function, *i.e.* provide mouldings of the required shapes". We wish to explain now a generalised presentation of injection moulding [19].

For some time, it could be really said that mould design has outgrown the phase of experience-based approach. Mould designers should understand not only how the moulding primary shape comes into being. They are also responsible for the primary structure of the part, at the molecular and supramolecular level, and that during processing of thermoset and elastomeric matter chemical reactions take place in the mould which can be directly influenced by the part and mould designer, *etc.* [20].

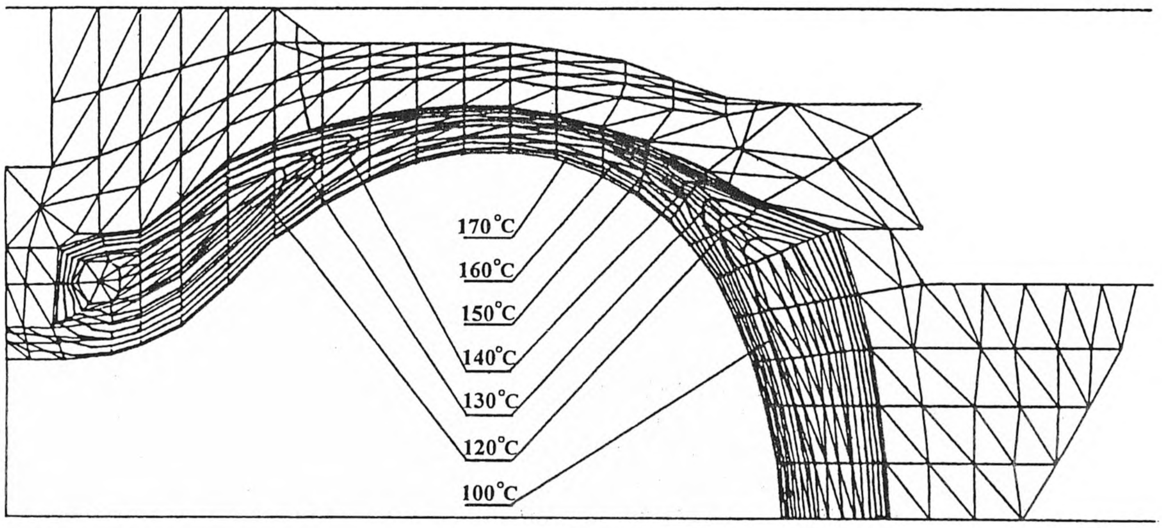

Fig. 9. The optimum heat exchange field in the mould

Just one example from rubber industry: how, by using FEM, the mould designer can optimise the cross--linking process during transformation of rubber compound into vulcanised rubber (Figure 9 [21]).

In the history, the toolmaker has been, first of all, the designer and the maker, all in one person. In this century, separation took place of what is called the technical forming. According to van Riessen, the modern industrial forming process is characterised by "function division", which also has a neutralising influence like division of technical products (*e.g.* casting, milling, assemblying, *etc.*), *cf.* [11]. This is the basis for function division of all the activities, which brought about increased specialisation in the 1950s, already discussed. Simultaneously, it coincided with the division of the mould manufacturing process into three function specialists: the mould designer, function makers of mould elements (lathe-, milling- and grinding operators, *etc.*) and the assemblying-, mounting-operators, all called the toolmakers.

It seems that the advent of computers has introduced significant changes and new redistribution of tasks. The mould designer uses the computer more and more (CAD): in planning, designing, drawing, selecting optimal materials for mould manufacturing, calculating or simulating the cavity filling phase, heat exchange in moulds, mechanical calculating of single elements. The CAD phase is more and more often followed by the mould manufacturing-planning phase (CAP), which includes also the software development for NC-equipment (CAM). Due to the introduction of NC-equipment the function element makers started to disappear, *i.e.* the separated functions started to reintegrate. They become metal, or more and more often materials machining-operators, very precisely the machining-operators of materials preforms. As early as 1988, the Berstoff Company (Germany) was granted the permission to educate and train metal machining-operators, instead of conventional lathe-, or milling-operators, *etc.* Does this suppress the significance of the mould, or generally tool assemblers? No. The toolmaker has not only to assemble the tool or the mould, but also to adjust it so that it makes the required product reliably and permanently. The toolmaker remains the "homo faber", man — the maker who realises the "conceiving creativity" (idea, concept and design), in material reality, which is a feature of "production creativity".

At ANTEC in Atlanta (1998) [22], the opportunity was given to learn more. Problems in plastics and rubber industry always start with mechanical engineers. Why? The answer is very simple. Mechanical engineers are mostly educated how to design a product made of metals. In principle, their knowledge about designing by using other materials and particularly about the production of parts is insufficient. In the plastics and rubber industry this fact means that it is not sufficient to know how to shape the macrogeometrical shape of the part, but it is necessary to know also how to produce the material endowed with the necessary properties (reactive primary shaping). At the same time, a modern product can be a combination of parts made of metals, plastics, rubber, ceramics and some other materials. Let us take the car as an example. Plastics engineers have insufficient knowledge about other materials and their level of knowledge on machining, joining, surface coating and heat treatment is very poor. All this depends on the education systems. The education in the European countries and in USA is quite different. In Croatia, we have a model similar to that observed in Central European countries, particularly Germany. At the University of Zagreb, we have a school named *Fakultet strojarstva*. It is impossible to translate the term *strojarstvo* into English. But in German there is the term *Maschinenwesen*. Under the term *strojarstvo*, our students are educated in the fundamentals of mechanical, production, industrial and material engineering. But, in this country designers, mechanical engineers, and particularly architects are more than scarce in production engineering. If you have mechanical engineers poorly educated in plastics, rubber and polymeric composites, you have problems.

Another problem is connected with the overall neglect of education in tooling. Even though the tool is the central part of each production unit, at the university education level only poor attention is paid to the field of tooling. To be the avant-garde in the field of tooling like design and manufacturing of mould for plastics and rubber industry, we need the university level of education. Consider only the methodology for rheological or thermal calculations of the mould.

In August 1998, at the Regional Meeting of the Polymer Processing Society, Canada, several interesting and at the same time severe problems arose. The introduction of CAD into the design bureau and the use of ample software, has changed the working area of the mould designer. Mostly, the mould, and naturally in general tool design, is the case of a variant design. In this case there is only little creative work in mould design, the mould designer is mostly a "transport worker". He "transports", by using the "mouse", the "boxes" from one side of the display to any other. Or he must put only some measures into the software as input to receive as the output the drawings *e.g.* of the runner system. We can even expect very soon that only one click on the mouse will be sufficient to pick up the whole mould design for most today's polymeric products. The computer does that "all alone". The time for repeating the same operation is now growing shorter, and the mental stress is rising. "Modern times" have arrived again. Instead of workers at the assembly line in Chaplin's famous movie, we have new "workers", this time at the computer as the "assembly line". Problems are now more difficult, because, instead of the combination of mental and physical stress, we have now mostly only mental stress. This problem will certainly be the one that will call our attention in the future.

Two additional question are also open. It is known that women are very good at handling computers. Will this fact result in a growth of the number of women engaged in tool design? Maybe it will, since in Japan, in one design bureau, only women were employed in tool design (about 20 of them) [23]. The second question is a very important one: who will want to work for long as a tool designer under the mentioned conditions? And the success in the work of a designer does not depend only on software support, but also on experience.

CULTUROLOGICAL APPROACH TO TOOLMAKING

We have indicated elsewhere [4] that the given considerations show the phrase *technics to technicians*, and therefore *toolmaking to toolmakers* to be no longer satisfactory. There are not many modern vocations and occupations which, like toolmaking, contribute to spreading of most diverse products all over the world. Toolmaking is a part of technics, and technics is a part of culture, with all the consequences of regarding human activities in such a way. In the concept of the culturological development of the product and the production, toolmaking, in its widest sense, plays a significant role in the success. The requirements imposed upon modern toolmaking are such that people working in this field deserve that the name of their vocation and occupation be written with capital T. But neither toolmakers can neglect the fact that a tool has not only a form and properties. Tools must also serve for making of products, which affect in a very diverse manner those who use them. Therefore, the toolmakers have to understand also all the relations between toolmakers as technicians and their environment. "Those who understand that, can become very successful entrepreneurs", wrote Gellert [24].

THE MESSAGE

The question may be asked as to what is the message of our two papers? Toolmaking deserves maximum attention, because it is the basis for the modern product manufacture. Over a million years, toolmaking has probably lived through many changes, from designer and maker in one person, to specialisation in production and its new restructuring. The toolmaker has over the history been, first of all, the designer and the maker in one and the same person. Then, in this century, separation took place of what is called technical forming and so we have the division of the mould manufacturing process into three function-specialists: the mould designer, the mould function makers and the assemblying operators (mouldmaker). It seems that the introduction of computers caused significant changes and new redistribution of tasks, and is connected with a very high mental stress. The mould designer is combining CAD and CAP. We even assume that the product designer would serve as mould designer in the cases of variant mould. Due to the introduction of NC-equipment, the separated functions of mould making started to reintegrate. Does this reduce the significance of mould assemblers? The answer is negative.

Toolmaking has ceased to be an experience-based activity, and is becoming over time a scientifically based activity, connecting the scientific knowledge with the piled-up experience. However, toolmaking also deserves its own philosophy — the philosophy of toolmaking as a part of the philosophy of technics. But technicians can only give incentives for its development. Technicians have to realise that the phrase *technics to technicians* is a thing of the past, that technics is part of the culture with all the consequences that result from such an attitude.

For these reasons mould also, or more generally the tool design and making must once again be re-engineered and restructured.

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