EXPERT SYSTEM FOR MOLD QUOTATION

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ABSTRACT

The biggest challenge for any company in the process of making an offer to a potential client is to determine the cost and the time required for item machining. This is especially apparent for mold tool calculation, because the production of only one part requires the development and design of several dozen items. Only a small portion of the quotations result in an order and this is the main reason why calculations must be done as quickly as possible, with minimal engagement of resources and all of this has to be done without a detailed tool design. Mold manufacturers usually “estimate” the tool price, with calculation methods based on previous experience, comparison with similar cases or by using some parameters, like mass, overall dimensions etc. This is a quick way of getting results, but it comes with a large estimation range, varying up to ± 50%. The most precise estimation method would be the one that includes a detailed calculation of all costs and the time required time for item machining. In this case, the estimation range can be as low as ± 5%. This is the main need in preparing and establishing a computer aided system for mold calculation and quote preparation, based on systematized knowledge that eliminates all subjective factors and the possibility of something being missed.

Key words: Mold quotation, mold calculation, computer aided mold quotation, expert system for calculation, expert system for mold quotation.

1. INTRODUCTION

The product lifetime in the contemporary market conditions is short and the biggest challenge the manufacturers face is to reduce the launching time of a new product, without quality implications. This is almost impossible, regardless of the product, without producing one or more tools. The tool planning and production make up a large percentage of the final price and time necessary for product development. Tool making is an important chain in the launching of products on the market, and estimating the time and price necessary for production is key for profitability.

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The determination of the tool price is related with previously acquired experiences, mostly nonsystematic, based on products technic specification only, without having in mind its structure or degree of complexity. Mold manufacturers usually estimate the tool price, with calculation methods based on previous experience, comparison with similar cases or by using some parameters, like mass, overall dimensions etc [11]. This is a quick way of getting results, but it comes with a large estimation range, varying up to ± 50% [3]. The most precise estimation method would be the one that includes a detailed calculation of all costs and the time required time for item machining. In this case, the estimation range can be as low as ± 5% [3].

2. CALCULATION METHODS AND SYSTEMS

Calculation methods can be divided in three groups: heuristic, statistical and analytical. Estimation accuracy is directly related to the data available at the moment of the quotation process. In practice, there are four methods for calculation and quote creation in the mold tool production industry [3], [4].

- **Intuitive estimation methods** are completely based on personal experience and knowledge of the tool design and production process. The accuracy is in the range of ±50%.
- **Analogue estimation methods** are based on time and cost data from previous cases, generated from previous tool production. These methods rely on an accurate database of previous projects, and become unreliable if such database is unavailable. The accuracy is in the range of ±35%.
- **Parameter estimation methods** use certain parameters for product design and with appropriate functions, the basic manufacturing times and costs are calculated. The parameters used can include mass and overall dimensions for example. This method is useful for rough estimation only.
- **Analytical estimation methods.** In this case, the subject is separated in parts and the method calculates the times and costs for the simplified components. This method application is relatively more time demanding, but with special skills and plenty experience, an expert generally can achieve an estimating range of ±5% while a beginner can go up to ±15%.

We recognize two approaches in determining the estimated tool price:

\[ a) \text{ data based systems} \]
\[ b) \text{ expert systems} \]

Data base systems include searching through the base of previous and similar projects and relating them with the current request. It is good when it deals with similar shape parts, and developing such a system demands acquiring a lot of data and tool sub calculations of completed tools, it is based on real values and can be effective only if the previous data is accurate.

Expert systems do not directly use the experience of previous projects in the new quotation. Acquired data is previously evaluated from an engineer or the company which develops the expert system, in order to define relations with costs similarities and costs modifiers. In this case the user does not have to do any elementary work, as to enter data, formulas etc. Different steps in the tool production chain are predicted in detail, for example, milling, eroding, assembling etc. and they are all based on algorithms necessary for calculating the tool's price. The procedure used by the expert system is repeated for every new tool. This expert system is called Computer Aided Calculation CAC.
3. DESIGNING THE EXPERT SYSTEM

The primary aim of the expert system for injection molding quotation tool offering is to determine two elements: the tool price and time necessary for tool production and delivery. *The tool price* is a multi-element sum. First of all, the manufacturing costs must be determined. They are divided into several groups. *Material costs* depend on the price of materials for the tooling inserts, electrodes, materials for the standard tools components, etc. *Machining costs* consists of the costs for mechanical machining, thermal and other treatments as well as other post-processing costs. Assembling expenses, prototype tooling and correction costs, designing costs, programming costs, overheads and other expenses are all added up to form the total material cost for the molding tool.

*Tool production time* is a sum of the times needed to manufacture the same elements mentioned before, plus the materials supply time, standard parts supply time, machining time (either in-house or in another capacity), assembling time, trial and correction time, design time, programming time etc.

Data input parameters are mostly values dependent on the plastic parts geometry and they differ from part to part. First of all, according the models form, the "parting line" and "parting surfaces" are determined. Afterwards they are used to establish the surfaces which define the two tooling segments: the mold core and mold cavity. In case of lateral holes or some similar undercuts placed perpendicular to the direction of pull, it is necessary to include side cores as tooling inserts as well. Cavity numbers are determined according to the planned production and the size of the production series. That in turn determines the number of tooling inserts that need to be machined. According to the total size of all segments, the mold base is either manufactured in-house or a standard mold base is selected and ordered from a supplier. If a standard mold base is used, there is a need to machine pockets and holes in the appropriate plates in order to mount the tooling inserts and to ensure that every tool system functions accurately.

Overall part dimensions are determined in the beginning (Fig. 1): $P_x$ – maximal part length, $P_y$ – maximal part width, $P_z$ – maximal part height in relation to the parting surface. Afterwards additional length, width and height is added in order to enable the machining of the tools cooling system. $P_x$, $P_y$ and $P_z$ are values that the system user inputs as data together with the coefficient of shrinkage of the plastic material. The additions can be either entered as external inputs as well, or the user can make a choice from the software's suggested values dialog. This determines the overall dimensions of the inserts.

![Fig. 1 - Defining the overall dimensions of the tooling inserts](image-url)
The number of cavities and therefore the number of tooling inserts are in function of production volume. If the tool has more cavities, the sum of the inserts measurements should be calculated as:

\[ X_t = nX_i + (n-1)A_x; \text{ and } Y_t = nY_i + (n-1)A_y \]

**Fig. 2 - Cumulative size of the tooling inserts**

The total length \( X_t \) and the total width \( Y_t \), as well as the heights \( R_i \) or \( V_i \) are values which determine the mold base dimensions and plate thickness (Fig. 2). Thereby some relations should be noted, for example, the ejecting plates’ stroke should be larger than \( R_z \) and the maximal mold core height, which will allow an uninterrupted part ejection from the mold.

**Fig. 3 - Defining a mold base in relation to the tooling inserts size**

When selecting a mold base, in addition to the segments being inserted, a few other systems and elements should be implemented. Some of them are mandatory for all tools, and some of them are used depending on the plastic part’s characteristics or the customer’s demands. On the injection molding tool (Fig. 4), made by Meusburger for standard mold bases, few systems are indicated: for guiding, for feeding, cooling, ejection etc.
The time necessary for data calculation and system implementation will be determined by decomposing the basic geometric features of all elements, systems and segments. Each geometric feature represents a geometric model, and for each geometric model a machining procedure needs to be predefined. For example, when an intake bushing is selected, its geometric model is a two-stage cylinder. To get the bushing, we have a predefined machining procedures in the database of the system. In this case the strategy for defining the two-stage cylinder is lathe machining a metal rod with a fixed diameter. The intake bush should be inserted in the fixed tool half, i.e. the geometric model of the two-stage cylinder is going to be treated as a hole and we will apply a machining strategy for drilling (or milling) a two-step hole in one of the plates and a cylindrical hole in the other plate. In both cases, we will get the necessary machining time.

*Fig. 4 - Components of a standard two-plate mold base with two cavities*
To successfully perform its functions, the expert system must have a database with material data, standard parts data, machining data etc. The idea is for the tool systems and the tooling segments to be decomposed into geometric features. (feature decomposition). Their implementation in the mold base means plate machining. For each geometric form and geometric feature, there is an appropriate machining model in the database, i.e. a machining procedure for obtaining the same shape in the respective plate. The necessary time calculation for the segments construction implements an algorithm which takes into account the part's form complexity including the volume, the segment's surface and the total length of each segment's contour lines. The total machining time necessary for all tool elements is a sum of the separate machining times of every geometric form in the tool systems and segments. The relations between the tool elements and systems are shown in Fig. 6. The rows show the selected tool plates and the columns contain the separate tool systems. Their cross-section shows the basic geometric feature, which has a predefined technology model in the system database.
4. PREPARATION EXPERT SYSTEM FOR INJECTION MOLDING TOOLS

In order to make a correct price/time/operation estimation during the tool production, the algorithm has to start with the specific tool's overall dimensions input and core numbers. After that comes the mold base selection, followed by a tooling systems and elements selection, up to the phase where the software through the implemented algorithms for time and price estimation, gives the user a final result. This report contains the estimated price and time data as well as series of operations, their individual machining times and individual prices for separated groups. If needed, the report could be even more detailed. The software should have the option to offer corrections of some input parameters and to check for some eventual changes of the final evaluation based on modifications of specific input values.

In the following paragraphs the functionality of the expert system and its procedures are described step by step, from the initial input, until the final result. Also, the input forms for the system are also presented according to each individual step.

Some of the following properties are derived from the 3D model and some depend on the manufacturing plans. All of this data is given to the expert. Expected production, material type and quality and other requests are entered in the "web-wizard" in the tool input.
Conceptually, the tool consists of a standard mold base, cavity inserts and different systems. Consequently, the functions the expert system represent this as well: the insert dimensions are defined, next a standard mold base is selected and finally each system is added.

In compliance with the expert system’s concept, in the next screen, the part’s length, width and height are entered, as well as the position of the parting line and the planned additions in all three directions. As a result, we get three basic dimensions for the mold core and cavity. They will be used in selecting the type and dimensions of the standard mold base. Previously, a calculation of the sum of segment dimensions is performed, in relation with the necessary number of plates and their required position. (Fig. 8, 9)
Defining the necessary machining time for the tool inserts is the most complex factor to evaluate and in the same time it has the biggest impact on the final price. The experimental method for estimating the inserts machining time developed specifically for this expert system presented in this paper uses a so-called complexity factor $f$. This factor is expressed as a function of the machining volume, the total surface of the part as well as the length of the part’s contour lines and the length of the parting line. In the shown screen in Fig. 10, the values of these parameters are entered in as initial input values and as a final result, the value of the complexity factor is calculated.

After the definition of the tooling insert, the type and dimensions of the standard mold base is determined (Fig. 11).
Fig. 11 - Selecting a mold base and defining plate dimensions

Fig. 12 - Selecting standard components
When adding the systems in the mold base, the "feature decomposition" principle will be applied, i.e. the geometry is separated into elementary machining features, so that for each feature there will be a so called machining component prepared with an operation plan and an algorithm for calculating the machining time. Finally, in Fig. 13 is the menu from which various reports for time, prices and operations can be generated.

![Table of Calculations Results](image)

**Fig. 13 - Generating a report**

The report can be generated as a PDF, Excel spreadsheet or in a similar format. It contains a wide variety of information for the product and for the tool as well. For example, it can be generate data for the material, dimensions and weight of the part. In case the customer demands a trial report, there is price data with or without delivery costs. Also, data can be generated for the tool material, its elements, surface machining, cavity numbers, tool price with or without a trial sample, delivery terms etc.
5. CONCLUSION

The use of contemporary software tools provides automation in the process of calculating and generating solutions without a human factor. Expert systems represent a fast and systematic approach for creating a tool calculation, based on a database of knowledge and they eliminate the human experience factors, thus excluding the possibility of something being missed. As a result the accuracy is increased and an approximation of the real price is made. The advantage of this approach is not only the prediction, but the options of optimization of the total costs, i.e. minimizing the expenses. Generating a fast and reliable quotation essential for market survival and development. With expert systems, calculation are made with a minimal engagements of the manufacturer’s resources, they are done in a short time and with a high evaluation accuracy. They are based on a knowledge database and they don’t depend on human factors and the experience of the operator.

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EKSPERTNI SISTEM ZA PROJEKTOVANJE KALUPA ZA INJEKCIONOJ PRESOVANJE

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REZIME

Jedan od značajnih problema koji se pojavljuje prilikom kreiranja ponude potencijalnim kupcima jeste definisanje cene (troškova) i vremena izrade tj. vremena isporuke proizvoda. Ovo se odnosi i na kalkulacije alata (kalupa) u procesima izrade plastičnih delova. Poseban problem predstavlja zahtev za kratkim vremenom izrade. U najvećem broju slučajeva proizvođači alata (kalupa) određuju cenu na bazi predhodnih iskustava, upoređenjem sa sličnim već urađenim alatima ili na bazi nekih parametara kao što je npr. težina alata. Ovo je brzi način određivanja cene ali na taj način moguća su odstupanja od realne (stvarne) cene i do 50%. Najprecizniji način određivanja cene bio bi onaj koji uključuje detaljan proračun svih troškova i vremena potrebnog za izradu alata. U tom slučaju se gore pomenuta odstupanja mogu svesti na nivo od 5%. Ovo je glavni razlog za pripremu i definisanje računarsko potpomognutog sistema za proračun alata i pripremu ponude, baziranu na sistematskom znanju, čime se eliminišu svi subjektivni faktori prilikom kalkulacije. U ovom radu prikazan je jedan takav sistem.