

Cutting Parameter Optimization Based on Experience and Rules

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Abstract: To reduce cutting time and costs, an optimized model of cutting parameter is proposed. Constraints like lathe and cutting tool are fully considered. The objective function is aiming at the target of profit margins. Some empirical indexes are used in the constraints and the objective function since the special properties of cutting process. The Fuzzy Comprehensive Evaluation Method is used to build an evaluation model, which provides an evolutionary path for cutting parameter. The evaluation matrix R in the model is determined by operators who use the cutting parameter to cut. A cutting parameter database system of B/S structure was developed by JAVA language based on the optimization model and helped a company improved profit margins successfully.

Keywords: Constraints, Cutting parameter, Database, Evaluation, Optimize, The profit margins.

1. INTRODUCTION

Cutting is the basis of mechanical manufacturing. Appropriate cutting parameter will improve production efficiency, processing quality, production profits and reduce production costs. The scholars all over the world have never been stopping to research the optimization of cutting parameter since TAYLOR in 1907 [1] proposed the problem. And a series of important progresses have been made in theory. Dozens of optimization models and solving methods were established. Here are some famous researches. TANDON established optimization model of cutting parameter with the highest production efficiency [2]. H. Juan made research on the relationships between cutting parameter (cutting speed, feed per tooth, and axial depth of cut) and tool life based on a polynomial network [3]. Reference [4] studied the relationship between material and cutting parameter. Othmani R made the prediction of the optimal values of cutting speed to minimize both time and cost of dye production in 2.5 D NC milling [5]. Xiaolong Li researched the relationship between cutting tools and cutting parameter [6]. References [7-10] used some algorithm like Genetic Algorithms and Particle Swarm Optimization to calculate cutting parameters. In China, Ni Qi-min formulated a fuzzy model for multi-objective optimization of machining parameter for end milling [11] Chen Zhitong proposed a new cutting parameter optimization model for single cutting pass process based on the statistics principle and analyzed in detail for solving the parameter coupling problem [12]. With the development of science and technology, computer technology is widely used in machining. A lot of countries established cutting database system to store the cutting data and information according to certain rules using the computer. So far, about 12 countries such as Germany, the

United States, Sweden, United Kingdom, Japan, Norway, Belgium and Hungary, established more than 30 cutting database systems. CUTDATA and INFOS are the most famous cutting database systems. CUTDATA is the world's first metal cutting database which contains a large number of cutting test data and can provide cutting parameter for more than 3750 species of materials, 22 kinds of processing methods and 12 kinds of cutting tool materials. German established INFOS in 1971. The INFOS stores more than two million materials information. It is the most complete cutting database system and its service ability is the strongest [13]. Here are a lot of studies about how to establish a cutting parameter database system. Reference [14] proposed a cutting parameter database system which can optimize cutting parameter. Reference [15] proposed a cutting database system which can optimize turning cutting parameter. But there were two shortages in the existing models and database system:

- The existing models did not include empirical indexes. Many factors in the process of machining at present could not be accurately controlled and quantized. So the empirical indexes gotten from experts and operators should be taken into consideration when people establish an optimized model of cutting parameter. They can improve the practicability of cutting parameter significantly.
- The existing cutting parameter database systems did not include an evaluation model of chosen cutting parameter. Because due to not enough refining of processing conditions, the existing cutting database provides only feasible data, not the optimal cutting parameter. It is necessary to set up an evaluation model to get the optimal cutting parameter.

In this paper, after interviewing cutting tools manufacturers and enterprise operators and professors in the university, a cutting parameter database system was established based on experience and rules, and the Fuzzy

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Comprehensive Evaluation model was used to establish an evaluation model for cutting parameter which provided an evolutionary way for cutting parameter.

2. THE OPTIMIZATION MODEL OF CUTTING PARAMETER

2.1. The Influencing Factors of Cutting Parameter Selection

Workpiece are made of a large number of different materials. Each material has its own unique features because of the influence of alloying elements, heat-treatment patterns and hardness. And this greatly affected the selection of cutting parameter. So the material grades, hardness index, heat-treatment pattern, and the tensile strength must be taken into consideration when selecting cutting parameter.

In order to improve profit margins, extending cutting tools' life is important. The three kinds of main cutting parameter, cutting speed, feed per tooth and cutting depth will influence the cutting tools' life, especially the cutting speed. The tool wear, and tool deformation are different with different structures and materials of cutting tools. And for some clip-type cutting tools, the model number of cutting tools will influence cutting parameter too. So, before choosing a cutting parameter, people must make sure which cutting tool will be used.

The traditional cutting parameter is used to manufacture rigid workpiece with simple structure, not fit for workpiece with weak rigidity and curved surface. Geometric features and mechanical properties of the workpiece have important influence on the cutting process. Before choosing a cutting parameter, serious deformation and vibration will appear if the structure is not considered in manufacturing weak rigid workpiece. So the features of workpiece are important when choosing cutting parameter.

Station-keeping ability, clamping ability and the biggest spindle torque, the biggest cutting power, the largest feed force provided by machine tool would influence cutting parameter directly. Designers should take machine tool information into consideration.

The cutting parameter must match the processing method and machining allowance of the procedure.

Finally, good cutting parameter should meet the requirements of surface roughness, shape and position accuracy of workpiece.

2.2. Model for Cutting Parameter Optimization

In the past, different optimization models of cutting parameter were established based on the actual production environment, and process conditions. In this paper, the objective function is aimed at the highest profit margins. A cutting parameter optimization model which takes all constraints into consideration was established. Because many factors in the process of machining at present could not be accurately controlled and quantized, this paper used some empirical indexes in the objective function and constraint conditions to reflect them. But because of not enough refining of processing conditions and the value of

some empirical indexes were a scope, the cutting parameter was not good enough. People needed an evolutionary path for cutting parameter. The Fuzzy Comprehensive Evaluation model was used to build the evolutionary path. The operators mark each index in the evaluation matrix according to the result of processing after using cutting parameter, and computer would improve the priority of cutting parameter of high scores. The model for cutting parameter optimization is as shown in Fig. (1).

2.3. Determination of Variables

After the workpiece, cutting tool, machine tool are determined. The main factors which influence the production efficiency are cutting speed, feed per tooth, cutting depth (axial cutting depth) and cutting width (radial cutting depth). Operators get cutting depth and cutting width according to the requirement of machining allowance and the actual process. People don't need to optimize them and regard them as known. So this paper regard cutting speed (v_c), and feed per tooth (f_z) as variables.

2.4. Determination of Constraints

The following six constraints will determine the maximum and minimum values of cutting parameter after the workpiece, cutting tool, processing craft, processing system, and the requirements of quality are determined. There are some empirical indexes in the formulas.

Cutting speed constraint

$$\pi DS_{\min}/1000 \leq v_c \leq \pi DS_{\max}/1000 \quad (1)$$

In the formula, S_{\min} represents minimum spindle speed of machine tool; S_{\max} represents maximum spindle speed of machine tool.

Feed per tooth constraint

$$\pi DV_{F\min}/1000Zv_c \leq f_z \leq \pi DV_{F\max}/1000Zv_c \quad (2)$$

In the formula, $V_{F\min}$ represents minimum feeding speed of machine tool; $V_{F\max}$ represents maximum feeding speed of machine tool. Z represents number of teeth of cutting tool

The largest feed cutting force constraints.

$$y_1(v_c, f_z) = C_1 \frac{f_z^G a_e^H a_p^Q}{D^M v_c^N} Z \leq F_{\max} \quad (3)$$

In the formula, C_1 represents empirical coefficient; G, H, Q, M, N represent empirical indexes; F_{\max} represents the largest feed cutting force.

Processing power constraint

$$y_2(v_c, f_z) = C_2 \frac{f_z^G a_e^H a_p^Q}{D^M v_c^{N-1}} Z \leq P_{\max} \quad (4)$$

In the formula, C_2 represents empirical coefficient; P_{\max} represents the largest processing power.

Spindle torque constraints.

$$y_3(v_c, f_z) = C_3 \frac{f_z^G a_e^H a_p^Q}{D^{M-1} v_c^N} Z \leq T_{\max} \quad (5)$$

In the formula, C_3 represents empirical coefficient; T_{\max} represents the largest spindle torque.

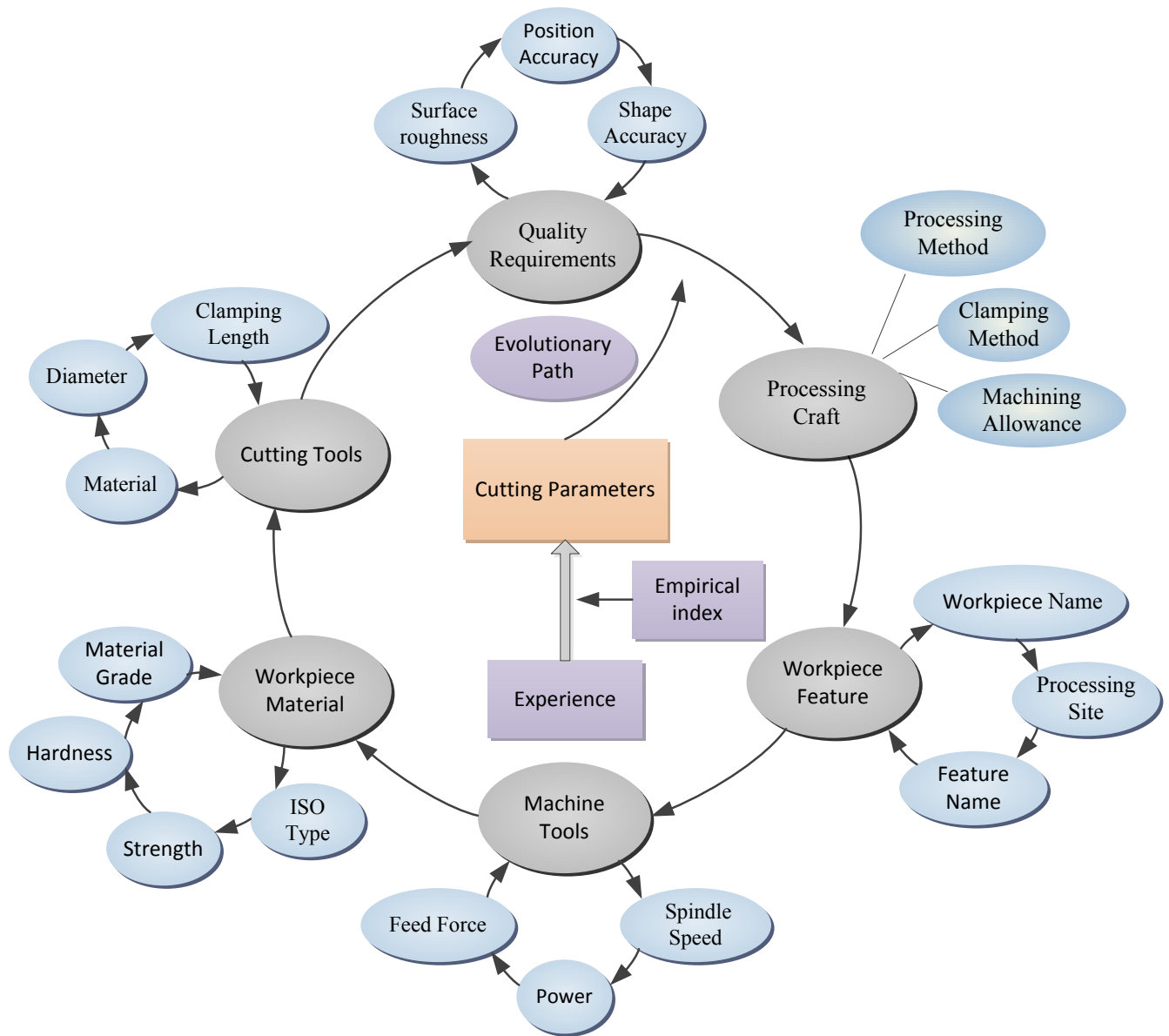


Fig. (1). Optimization model of cutting parameter.

Workpiece surface roughness constraints.

$$y_4(v_c, f_z) = C_4 \frac{f_z^2}{D} \leq R_{Amax} \tag{6}$$

In the formula, C_4 represents empirical coefficient; R_{Amax} represents the largest surface roughness.

2.5. Determination of the Objective Function

Manufacturing process is a technical and economic process. People use some technology to achieve other technology goals in order to benefit from the process. People want to get return when they put into something. The same for cutting process, different enterprises have the same goal called profit margins (the profits per unit time).

Production time per workpiece.

$$M_1(v_c, f_z) = T_A + T_B + T_C T_A / T_D \tag{7}$$

$$T_A = \pi(d + p)D / 1000Zv_c f_z \tag{8}$$

$$T_D = \frac{C_0 D^{m_1}}{a_e^{m_2} a_p^{m_3} v_c^{m_4} f_z^{m_5} Z^{m_6}} \tag{9}$$

In the formula, T_A represents cutting time; T_R represents auxiliary time; T_C represents tool change time; T_D represents cutting tool life; d represents the length of workpiece; p represents the total cutting depth; C_0 represents empirical coefficient; m_1, m_2, m_3, m_4, m_5 represent empirical indexes.

Cost per workpiece.

$$M_2(v_c, f_z) = M_1(v_c, f_z)G_1 + T_A G_2 / T_D \tag{10}$$

In the formula, G_1 represents cost of unit time; G_2 represents cost of material and grinding of cutting tool.

Profit margins.

$$M_3(v_c, f_z) = [P_W - M_2(v_c, f_z) - G_0] / M_1(v_c, f_z) \tag{11}$$

In the formula, P_W represents price of workpiece; G_0 represents material cost.

After constraint conditions and the objective function are determined, this paper uses GA (Genetic Algorithm) to calculate cutting parameter.

2.6. The Evaluation Model

Without evaluation indexes, the traditional cutting parameter database system did not have an evolutionary path for cutting parameter. An evaluation model which provided the way was built by the Fuzzy Comprehensive Evaluation model. The Fuzzy Comprehensive Evaluation model is a comprehensive evaluation method which uses the principle of fuzzy relationship synthetic to quantify some factors with fuzzy boundary. It quantifies the fuzzy indexes which reflect evaluated things by constructing grade fuzzy subset. Then it concludes all indexes by using fuzzy transformation principle. The main steps are as follows.

Determining the set of factors. U_m represents the evaluation element.

$$U = \{U_1, U_2, U_3 \dots U_m\}$$

Determining the set of comments. V_n represents the comment.

$$V = \{V_1, V_2, V_3 \dots V_n\}$$

Determining the evaluation matrix. r_{ij} represents the membership degree of U_m to V_n .

$$R = (r_{ij})_{m \times n}$$

Determining the weight vector. A_m represents the proportion of evaluation elements.

$$A = \{A_1, A_2, A_3 \dots A_m\}$$

Determining the appropriate synthesis algorithm to calculate evaluation vector B .

$$B = A * R$$

In this paper, U , V , A for cutting parameter were got through interviewing experts in the universities and enterprises and cutting tool manufacturers like SANDVIK, URMA, KOMET, Dijet, WALTER.

$U = \{\text{shape and position accuracy of workpiece, surface roughness of workpiece, cutting tool life, cutting deformation, cutting force}\}$.

$V = \{\text{very bad, bad, ordinary, good, very good}\}$.

$$A = \{0.2, 0.3, 0.25, 0.1, 0.15\}$$

For the determination of evaluation matrix R , a combo box was set for each evaluation element U_m in the system. The operators should choose a comment after using cutting parameter. Then the server responds with the corresponding r_{ij} plus one. The matrix R will be more precise if the amount being used by people is bigger. Besides, each line of R needs to be normalized.

In order to make full use of evaluation vector B , this paper uses a column vector called C to take U and B into comprehensive consideration.

$$C = (3, 4, 5, 6, 7)^T$$

In this paper, dot product is used as synthesis algorithm. Then:

$$B = A * R = (0.2, 0.3, 0.25, 0.1, 0.15) \begin{bmatrix} r_{11} & \dots & r_{15} \\ \vdots & \ddots & \vdots \\ r_{51} & \dots & r_{55} \end{bmatrix} = (b_1, b_2, b_3, b_4, b_5) \quad (12)$$

$$P = B * C = (b_1, b_2, b_3, b_4, b_5) * (3, 4, 5, 6, 7)^T \quad (13)$$

P is a real number. It represents the cutting result of chosen cutting parameter. The priority of cutting parameter is higher if the value of P is bigger.

3. CUTTING PARAMETER DATABASE SYSTEM

3.1. The System Flow

There are three kinds of roles, administrators, common users, and senior users in the system. Common users are cutting operators. They use the system to choose appropriate cutting parameter. First, they choose constraints, then search and get cutting parameter. After cutting, they should evaluate the cutting parameter. The administrator's work is to maintain information. Senior users always are experts who need to check cutting parameter. The flow is as shown in Fig. (2).

3.2. System Architecture

The system is based on software of B/S structure developed by JAVA language and can be easily deployed to Windows, Linux, HP-Unix, and IBM-Aix. The system is divided into three layers (view layer, business logic layer and data persistence layer). VIEW layer is used to display data and receive input from users. It is for interaction. Business logic layer is used to handle business logic and implement system design related to business needs, such as making rules for business, business process implementation, etc. It is the core value of system architecture. Data persistence layer is used to handle affairs (e.g. accessing database, CRUD operations etc.). Some open source components were used in the system. They are as shown in the Fig. (3).

3.3. Database Design

This paper used MySQL to store data because it is fast, and can be maintained easily and the volume of MySQL is small. In the database design, this paper used Navicat Premium and Power Designer to build the object relationship in the database. Before developing the database, this paper did the work about information collection, classification and organization, and then created effective tables by analyzing relationship between relevant data. Designer needs to find out the core data and the structure of tables before creating tables and then used the Power Designer to build UML model according to the relationship of entity one to one correspondence with data table as well as inner relationship of entity.

In the cutting parameter database, cutting parameter table is the core table. There are some relevant tables in the database, such as cutting blade table, cutter body table, workpiece material table, workpiece table, cutting medium table, and machine tool table. Appropriate major key and foreign key were set in each table.

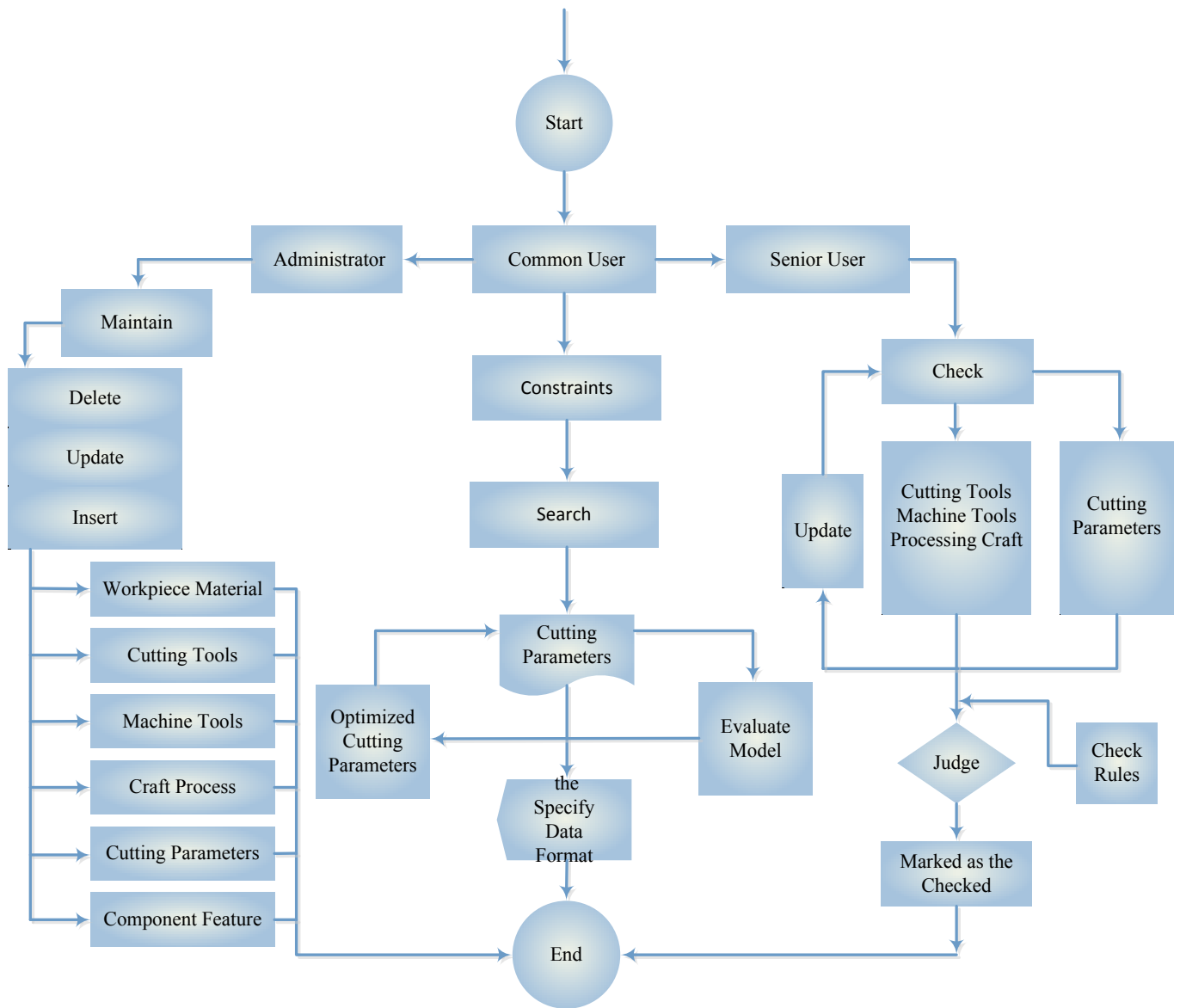


Fig (2). Cutting parameter database system flow.

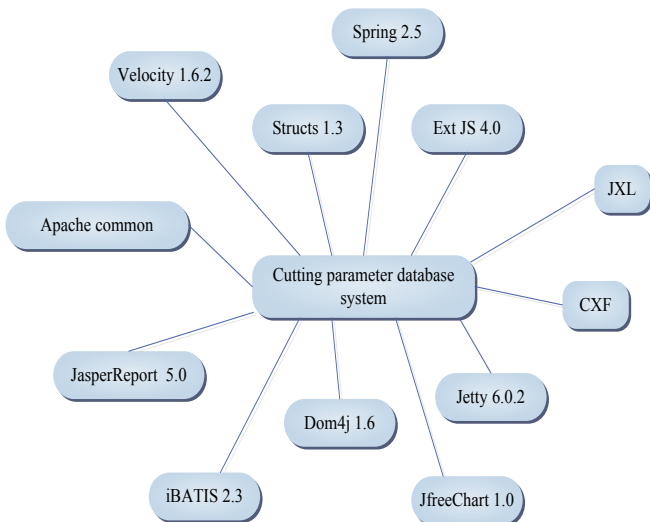


Fig (3). Open source components.

3.4. System Interface

The browser side development scheme of this system mainly included the Ext JS library, the custom tag library, report (Excel, Applet, PDF), chart (Flash, JFreeChart), controls interaction, and technologies about HTTP uploads and downloads. Ext JS V 4.0 is used for JavaScript language. The system interface is as shown in Fig. (4).

A company improves processing efficiency successfully and reduces processing costs by using the cutting parameter database system. The profit margins increased.

CONCLUSION

According to the actual production situation and experts' advices, this paper proposes an optimization model of cutting parameter, which describes requirements of choosing cutting parameter quantitatively, and qualitatively describes constraints on cutting speed (v_c) and feed per tooth (f_z). The

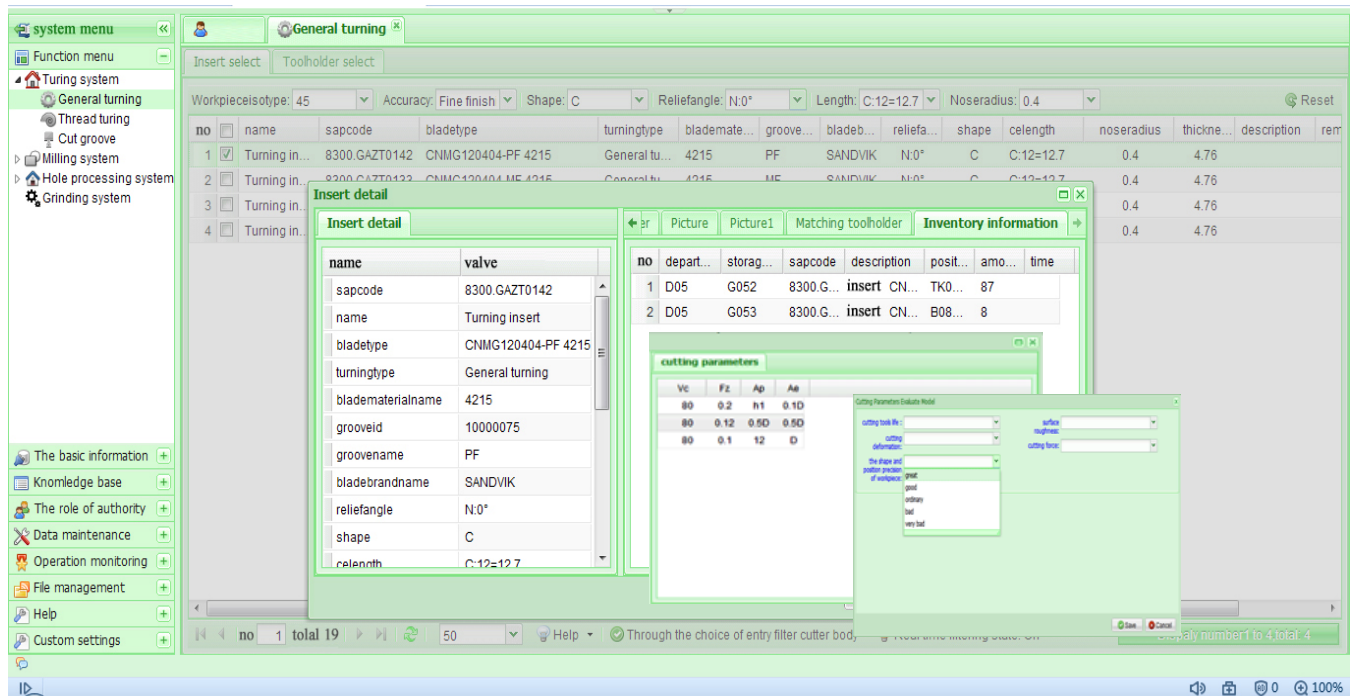


Fig (4). Cutting parameter database system interface.

objective function is aimed at the highest profit margins. The Fuzzy Comprehensive Evaluation model is used to build an evaluation model, which provides an evolutionary path for cutting parameter. Then a cutting parameter database system is established based on the optimization model by Java language.

However, since the constraints and the objective function are very complicated, this paper used Genetic algorithm to calculate. It is not very accurate. Future work can be done to research on some other algorithm for the optimization model.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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