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The Research on CAD Design System of Shaper Cutter Based on VB and Matlab

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Abstract

To solve the problem of low efficiency in the design of shaper cutter, a design and calculation system of shaper cutter is developed by using Matlab and VB mixed programming. The structure parameters of shaper cutter are calculated by using Matlab, and the system interface is developed by VB. The example shows the feasibility of the design method.

Keywords: *Shaper cutter, Matlab; VB*

1 Introduction

Gear as the basic parts in the entire machinery industry are widely used in aerospace, automotive industry, machine tools, engineering machinery and other fields. At present the main gear processing method is the generating method, this method is based on the principle of gear meshing to process the gear, including the gear shaping, hobbing, planing, shaving, grinding and other methods. As the most commonly used involute cylindrical gear machining method, the gear shaping method ranks only second to the hobbing method in the entire gear processing system, and is widely used for machining internal gears, racks, herringbone gears, gears with shoulder and Dual or multiple gears with slot cutter groove References are cited in the text just by square brackets With the improvement of productivity, the shortcomings of the traditional design method of shaper cutter are more prominent. But the development of CAD / CAM technology provides the conditions for rapid design. So in recent years, more and more researchers have begun to pay attention to the fast design system for shaper cutter. With the help of the computer's powerful computing ability, the shaper cutter design method become more flexible, and the design efficiency is greatly improved, but the manual calculation error is greatly reduced. In this paper References are cited in the text just by square brackets [1], a practical method of involute shaper cutter CAD is proposed, which realizes the professional design of involute shaper cutter. Paper[2] starts from the design theory of shaper cutter and hobbing cutter, proposed a overall design of gear cutter CAD system, based on the Visual Basic as a development platform, developed a gear cutter design system, and an example is given to demonstrate the correctness and feasibility of the design method.

To design a shaper cutter, the most difficult part is to calculate maximum and the minimum displacement coefficient of the shaper cutter. Matlab as a good mathematical software, with efficient numerical calculation and symbolic computing functions, as well as the complete graphics processing functions, so the calculation of the displacement coefficient of this part is mainly completed by Matlab References are cited in the text just by square brackets [3]. But Matlab also has its own limitations, in general, the program finished by Matlab can not run apart from the software alone, and its interface production function is relatively weak. Visual Basic as a good visual programming software, can easily create a friendly user interface, with an open object-oriented architecture, and can easily use other applications to provide the function References are cited in the text just by square brackets [4]. So this paper combines the two software, using Visual Basic to

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develop the interface of the design system, the use of Matlab as the core of the data processing, and finally developed a user-friendly, powerful gear cutter CAD design software References are cited in the text just by square brackets [5].

2 Principle of Shaper Cutter

2.1 Principle of gear shaping

It is well know that the gear shaping process is achieved through the generating principle, as shown in figure 1, in the generating process, the main movement of the gear shaping is the shaper cutter reciprocating along the tool axis. The machined gear is engaged with the shaper cutter to generate the involute tooth profile.The engagement moment can be decomposed into a circular feed movement and a dividing movement. the transmission ratio equals with the gear engagement.

When shaping the internal teeth, the cutter and the workpiece rotating in the same direction of rotation, and the direction is opposite when shaping the external teeth. The shaper cutter should be relieved during the escape motion to reduce the friction between the cutter and the tooth surface. Finally, the workpiece should have the radial feed movement until the workpiece is cut into the desired depth.

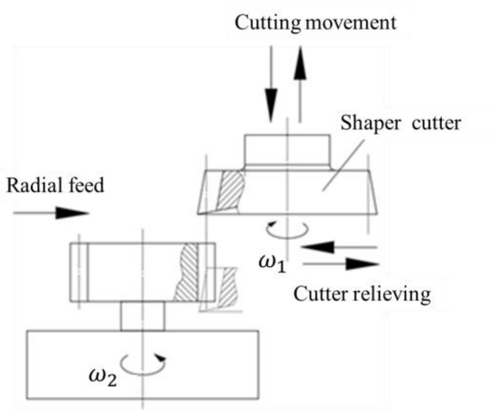


Figure 1 Principle of gear shaping

2.2 The structure of shaper cutter

The geometric structure has almost never changed since the shaper cutter was invented. Here use the helical gear shaper cutter as an example to illustrate the main structure of the shaper cutter. As shown in figure 2, a cutter tooth is composed by two side blades, a top edge, a rake face, two side flanks, and a top flank face.

Due to the presence of the relief angle, the radius of the top edge of and the tooth thickness at the reference circle are continuously reduced in the end profile from the rank face. Currently, when designing a shaper cutter, the tooth profile at the original section is first constructed. The top edge radius and the tooth thickness at the reference circle in the tooth profile are the standard values.

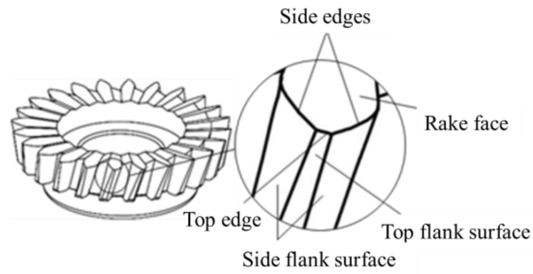


Figure 2 The Structure Of Shaper Cutter

The tooth profile in each end profile from the original section to the rank face is equivalent to the tooth profile of the gear with positive correction. And the modification coefficient gradually increases from the original section to the initial rank face. The tooth profile on the cross section from the original section to the last sharpening end face is equivalent to the tooth profile of the gear with negative correction. And the modification coefficient gradually decreases from the original section to the end face. as shown in figure 3.

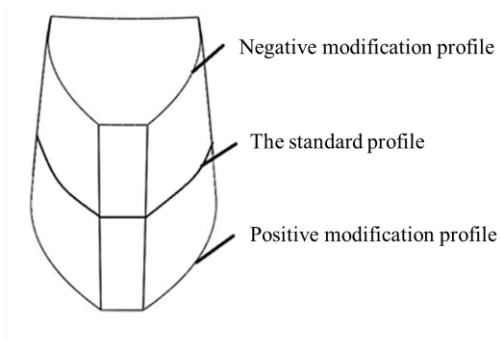


Figure 3 The modification diagram of the shaper cutter

3 Design Steps of Shaper Cutter

When designing the shaper cutter, the first step is to calculate the design parameters. The design parameters are composed of the basic parameters and structure parameters. The basic parameters are determined according to the workpiece parameters. The workpiece parameters are shown in Table 1:

Table 1 The Basic Parameters

	Workpiece	Match gear	Cutter gear
Modulus	m1	m2	m
Pressure angle on pitch circle	α_1	α_2	α
The original modification coefficient	x1	x2	x
Aaddendum coefficient	h_{a1}^{*}	h_{a2}^{*}	h_a^{*}
Tip clearance coefficient	c_1^{*}	c_2^{*}	

According to the basic design requirements of shaper cutter, m=m1=m2, α=α1=α2,h *α1=h* α2,c*

1=c* 2. The original modification coefficient shown in Table 1 refers to the modification coefficient of the workpiece. If the workpiece is a gear with addendum modification, the original modification coefficient of the shaper cutter is equal to the original modification coefficient of the cutter gear according to the principle of gear shaping,which is x=x2=-x1. As the shaper cutter teeth should cut out the workpiece tooth profile and the tooth top clearance, so the addendum of the shaper cutter should be higher than the standard involute gear tooth addendum, then the addendum coefficient of the cutter gear is:

$$h^*\alpha=,h^*\alpha 1+c^* 1 \tag{1}$$

The main structural parameters of the design of the shaper cutter are shown in Table 2:

Table 2 The Structural Parameters

Number Of Teeth	Rake angle of the top edge[°]	Relief angle of the top edge[°]	The max modification coefficient	The min modification coefficient
Z	γ	α_e	x_{max}	x_{min}

The parameters shown in the table are the basis for the design of the shaper cutter, and are all indispensable. They must be accurately calculated in order to ensure the correctness of the final shaper cutter.

3.1 The cutter teeth

Currently, to determine the number of cutter teeth on the shaper cutter, the first step is to select the nominal diameter of the reference circle, China's standard GB / T6081-2001 regulate the nominal diameter of 75mm, 100mm, 125mm, 160mm, 200mm. The most commonly used nominal diameter are 75mm, 100mm and 125mm. The main reason for selecting the standard nominal reference circle diameter is to standardize the shaper.

In general, the diameter of the shaper cutter should be as large as possible under the allowable conditions of the gear shaping machine and the gear grinding machine, which can effectively improve the cutter life and reduce the interference of the transition curve. But this will increase the cutter manufacturing cost. In addition, due to the current shaper cutter manufacturing process mainly rely on the generating gear grinding method, with the restriction of the involute cam plate on the grinding machine, extra checking should be involved according to involute cam plate parameters. After choose nominal reference circular diameter, the number of teeth on the shaper cutter:

$$Z=d'0/m_1 \tag{2}$$

Z should be rounded, m1 means the modulus of the machined gear, and d' 0 means the diameter of the reference circle.

3.2 The rake angle and relief angle of the top edge

The reasonable rake angle and relief angle is necessary to ensure the normal cutting of the shaper cutter. According to the structure of the shaper cutter, the rake angle on the side edge will increase when the rake angle on the top edge is increased, and the increase of the rake angles could effectively improve the surface quality of the workpiece.

There is a relief angle on the top edge of the shaper cutter, and two side flank faces on each tooth are actually two involute spiral surfaces which in the same angle, but the opposite direction. And this structure makes the cutter has the side edge relief angle. Studies have shown that increasing the relief angle of the shaper can effectively increase the durability of the shaper cutter.

However, for the current shaper cutter, increasing the rake and relief angle of the shaper cutter will lead to increased tooth profile error, reduce the number of sharpening. Therefore, the current design method stipulates that the rake angle on the top edge is 5 °and the relief angle is 6 °.

3.3 The modification coefficient

The maximum and minimum modification coefficient of the shaper are limited by a number of factors, so it is necessary to consider these factors to determine the maximum and minimum modification coefficient of the shaper cutter.

The maximum modification coefficient xmax. Increasing the maximum modification coefficient of the shaper cutter, the number of sharpening of the shaper cutter can be increased, and the tool life can be improved effectively. At the same time, the addendum of the shaper cutter under the large modification coefficient is higher, the curvature radius of the cutting edge is larger, so that the processed gear has the small surface residual and high surface quality. However, the excessive increase in the maximum modification factor of the shaper cutter will cause the addendum to become sharp and reduce the tool life, and the gear processed by the large modification shaper is easy to have the transition curve interference problem. So it is necessary to check these two issues when choosing the maximum modification coefficient.

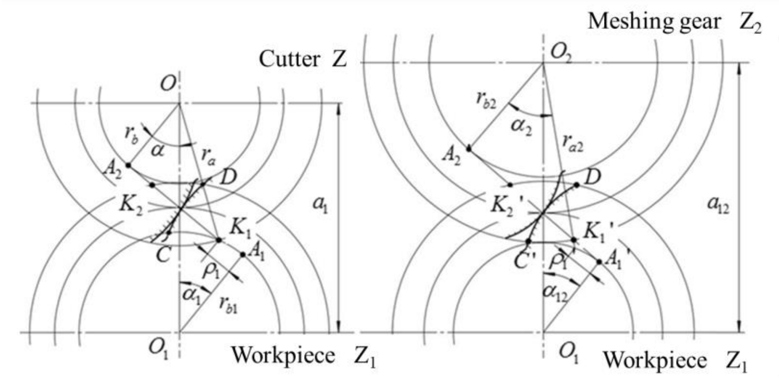
According to the current shaper cutter design theory, the actual addendum width Sa of the shaper should not be less than the minimum allowable width [Sa], but [Sa] is determined according to the shaper cutter modulus m, the tip strength, the cooling capacity and the tool durability, here is the empirical equation:

$$[Sa]=-0.0107m^2+0.2643m+0.3381 \tag{3}$$

The actual addendum width:

$$s_a=\left[\frac{\pi+4x_{max1}\tan\alpha}{z}+2\left(inv\alpha-inv\alpha_a\right)\right]r_a \tag{4}$$

αa means the pressure angle on the addendum circle. According the equation (4), the maximum modification coefficient xmax1 could be figure out.



(a)the shaper cutter and the workpiece (b)the workpiece engaging with the gear

Figure 4 Checking Of The Transition Curve Interference When Machining The Workpiece

The transition curve interference may occur between gears machined with positive modification shaper cutter. As shown in figure 4, when the tooth is machined, only the CD segment on the tooth profile of the workpiece is involute tooth, and the line between point C and dedendum is not the involute but the transition curve. The profile of the transition curve is actually the trajectory of the top edge and the side edge of the cutting blade relative to the workpiece. The transition curve is tangent to the involute tooth profile at point C, and the point C is the starting point of the involute on the tooth profile, but also the starting point of the transition curve.

The curvature radius of the involute at the point C ρ1 equals to the line A1K1, and can be calculated by the equation:

$$\rho_1 = A_1A_2 - K_1A_2 = a_1 \sin\alpha_1 - \sqrt{r_a^{\ 2} - r_b^{\ 2}} \tag{5}$$

After careful analysis, the greater of radius curvature is, the higher starting point of the transition curve has.

When the finished workpiece z1 engaging with the gear z2, as shown in figure 4 (b), the effective meshing line is K’ 1K’ 2, and the working part of the tooth profile on z1 is C’D, that is, above the point C’, the tooth profile should be the involute to ensure the normal engagement. If the starting point C is lower than the point C, the gear meshing can be carried out normally, otherwise the transition curve interference problem occurs.

It is necessary to ensure that CD ⩾ C’D to avoid the interference between the tooth root transition curve of the workpiece with the mating gear, which is the curvature radius ρ1’ larger than ρ1. To express this relation in a different form:

$$a_{12} \sin\alpha_{12} - \sqrt{r_{a2}^{\ 2} - r_{b2}^{\ 2}} \geq a_1 \sin\alpha_1 - \sqrt{r_a^{\ 2} - r_b^{\ 2}} \tag{6}$$

α1 is the engagement angle during the gear shaping, a1 the center distance when the final radial feed is completed during gear shaping, α_{12} and a_{12} is the engagement angle and the matching center distance between the worlpiece and the engaging gear. α1 and a1 could be figure out by the following equations:

$$inv\alpha_1 = \frac{2\left(x_1 + x_{\max 2}\right)\tan\alpha}{z_1 + z} + inv\alpha \tag{7}$$

$$a_1 = \frac{m\left(z_1 + z\right)}{2} \cdot \frac{\cos\alpha}{\cos\alpha_1} \tag{8}$$

In the equation (7), x1 is the original modification coefficient of the workpiece.

According to equation (7), a maximum modification coefficient xmax2 can be obtained under the condition that no transition curve interference occurs.

Finally, to compare xmax1 with xmax2, the small one is the final modification coefficient the shaper cutter should have.

The minimum modification coefficient xmin. With the grinding of the shaper cutter, the modification coefficient could be gradually reduced, in general, when the tooth thickness is ground to the final allowance, the ideal state is the modification coefficient is the minimum permissible coefficient xmin. In this way, the shaper cutter can be ground most times and have the longest life. But when the shaper cutter is in the negative modification, the tooth thickness become thinner, the tooth strength can not fulfill the requirement, may also lead to the undercutting or end cutting.

In the process of gear shaping, if the modification coefficient of the cutter is too small, as shown in figure 5, the tooth tip of the shaper may be cut into the involute profile of the workpiece, this phenomenon is called undercutting, so when designing the shaper cutter, the checking of the minimum modification coefficient to prevent from undercutting is very important.

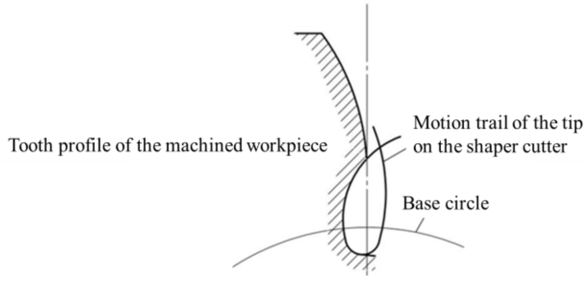


Figure 5 Diagram Of The Undercutting

According to the requirements mentioned above, ρ1 ≥0,which is:

$$a_1 \sin\alpha_1 - \sqrt{r_a^2 - r_b^2} \ge 0 \tag{9}$$

$$inv\alpha_1 = \frac{2\left(x_1 + x_{\min 1}\right)\tan\alpha}{z_1 + z} + inv\alpha \tag{10}$$

$$a_1 = \frac{m\left(z_1 + z\right)}{2} \cdot \frac{\cos\alpha}{\cos\alpha_1} \tag{11}$$

According to the equation (9) and the parameters of the shaper cutter and the workpiece, the undercutting phenomenon can be checked with the selected minimum modification coefficient. If the phenomenon still exist, increase the modification coefficient and check it again until the phenomenon do not happens anymore, in this way, the minimum modification coefficient xmin1 can be determined.

When the modification coefficient of the shaper cutter is small, the tooth height of the shaper cutter is small too, in the gear shaping process, the tooth root of the cutter may be interfere with the addendum of the machined workpiece, and the tip of the workpiece could be cut down, and this phenomenon is called end cutting.

As is shown in figure 6, to prevent the end cutting phenomenon, one condition need to be achieved,O1K1≤ O1A2, which is:

$$r_{a1} \le \sqrt{\left(a_1 \sin\alpha_1\right)^2 + r_{b1}^2} \tag{12}$$

In the case of no end cutting:

$$\tan\left(\alpha_1\right)_{\min} \ge \frac{2\sqrt{r_{a1}^2 - r_{b1}^2}}{m\left(z_1 + z\right)\cos\alpha} \tag{13}$$

According to the gear meshing principle:

$$inv\alpha_1 = \frac{2\left(x_1 + x_{\min 2}\right)\tan\alpha}{z_1 + z} + inv\alpha \tag{14}$$

In the case of no gear end cutting:

$$x_{\min 2} = \left[inv\left(\alpha_1\right)_{\min} - inv\alpha\right] \cdot \frac{z_1 + z}{2\tan\alpha} - x_1 \tag{15}$$

According to the equation (15), the minimum allowable modification coefficient xmin2 of the shaper cutter can be obtained without the end cutting.

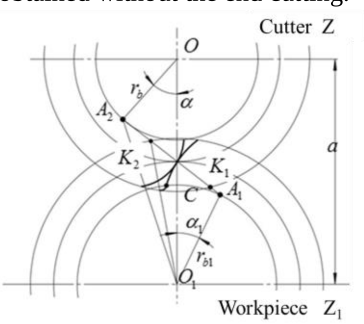


Figure 6 Diagram Of The End Cutting Checking

Finally, compare the xmin1 with xmin2, and choose the bigger one as the minimum modification coefficient xmin.

In summary, the main structure of the shaper cutter can be obtained after the calculation of all the parameters.

4 CAD System of Shaper Cutter

From the above, the shaper cutter design needs to calculate a series of parameters, and the parameter calculation process is quite complex, the manual calculation prone to errors, resulting in the final design failure. So in order to ensure the correctness and efficiency of the design results, the application of Matlab programming to finish the basic parameters calculation. At the same time, to develop the shaper cutter design system, Matlab interface production function is weak and can not run away from the Matlab environment, which is pretty inconvenient, so this article seeks a reliable way to solve this problem, that is, using Matlab and VB mixed programming way to achieve the function of the software.

4.1 System function module

Since the functional structure of the design system must be clear and reliable, this design of the system using modular design ideas, the design system is divided into three modules, human-computer interaction interface, design and calculation and the results display.

Human-computer interaction interface. For a design software, a good human-computer interaction interface is necessary. A good user interface should be simple and clear, so most of the man-machine interaction modules described in this chapter use a concise graphical user interface, as is shown in figure 7:

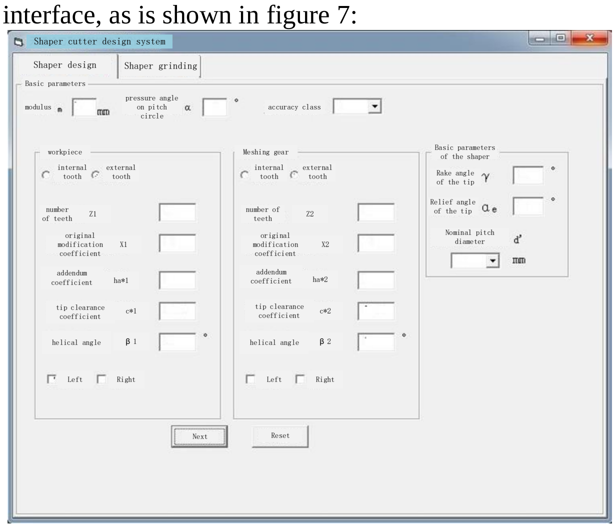


Figure 7 The Interface Of The Shaper Cutter Design System

Design and calculation module. The design calculation module is the core module of the whole shaper cutter design system, bearing the most important calculation task in the system. In the design process, this module gain the design parameters from the human-computer interaction interface module, and finish the main structure data calculation task according to the design theory and algorithm of the shaper cutter. The calculation result of this module directly determines the correctness of the shaper cutter.

Results display module. The results display module is designed to show the design results visually after the end of the design, so that the user can directly observe the design results. The module is actually integrated in the human-computer interaction interface, will be demonstrated in the follow-up design examples.

4.2 The realization of the main functional module[6]

This shaper cutter design system is the use of Matlab and VB mixed programming to achieve its function. The system uses Matlab as the core of calculation, with VB to achieve human-computer interaction and the results display function. Actually, in this system the interface developed by VB as the main program, the Matlab algorithm as a subroutine, the subroutine is called through VB to achieve a combination of the two mixed programming.

In general, VB calls the Matlab files in the forms of intermediate file transfer, dynamic data exchange (DDE), ActiveX automation services, DLL dynamic link library and COM components. But the first three methods are too tedious and can not be separated from the Matlab environment to run. DLL dynamic link library requires third-party compiler software to compile the Matlab file into a DLL file, and now the software has been stopped. COM components as a common object interface can be directly called by VB, and the Matlab version used in this design system integrated with deploytool, the use of the tool can compile Matlab files into COM components for VB calls. And the most important thing is the use of COM component technology helps the mixed program does not need to run in the Matlab environment, and no need to switch the environment which is greatly improving the system speed. So this chapter mainly uses COM component technology to realize the mixed programming system development and the main process is as follows:

Write the Matlab program. The COM component creation requires that each M file is written in the form of a function to facilitate the transfer of parameters between VB and Matlab.

According to the design principles described above, the M function file of the parameter calculation sub-module in the design calculation module is written first, named Parameter.m, and the calculation flow of this module is shown in figure 8:

The creation and calls of the COM components. Use the deploytool tool in Matlab to create the COM components containing the above M function file. Firstly, create the COM component project and add a new class in the project, then add the M function file that runs through to the class, finally compile and generate the dynamic link DLL file. After the three steps mentioned above, the M function file are written into the COM components.

When VB calls COM components, there should be a reference, to add the COM component to the VB project. When writing the main program, the use of CALL statement to call the M function packaged in the COM component. The call form is "Call class name. Function name (parameter)" which can achieve the function of the shaper cutter design system.

4.3 The design example

In order to verify the degree of functional realization of the design system, the design parameters shown in Table 3 are taken as an example, and the design system is used to design the shaper cutter.

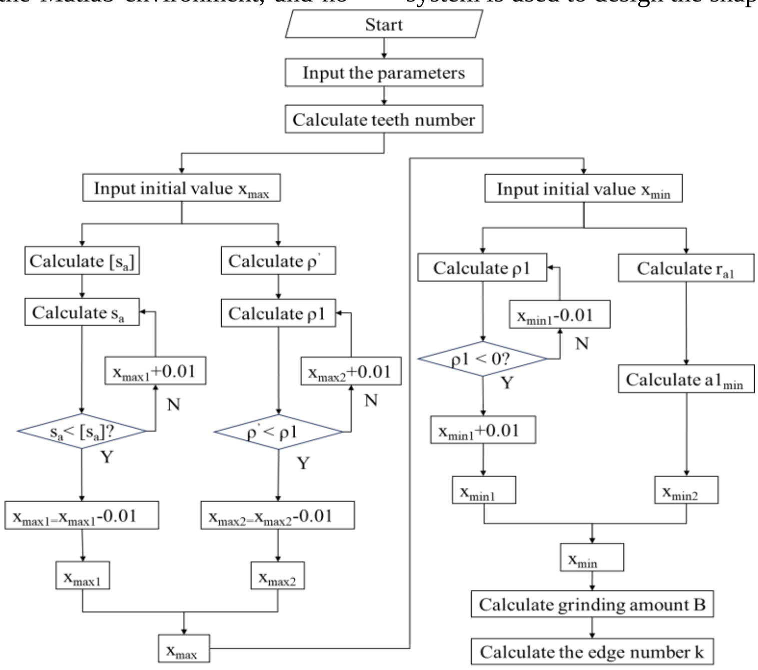


Figure 8 Calculation Process Of All The Parameters

Table 3 The Parameters Of The Workpiece

Basic parameters	Workpiece	Meshing gear
Modulus[mm]	2	2
Number of teeth	30	30
Pressure angle on pitch circle[°]	20	20
addendum coefficient	1	1
tip clearance coefficient	0.25	0.25
The modification coefficient	0	0
Helical angle[°]	15(left)	15(right)

Launch the system, enter the workpiece parameters in the initial operation interface, select 5° as the rake angle on the tip edge, and 6°as the relief angle on the top edge. The nominal pitch circle diameter is 75mm. Start the calculation and the results shown in figure 9:

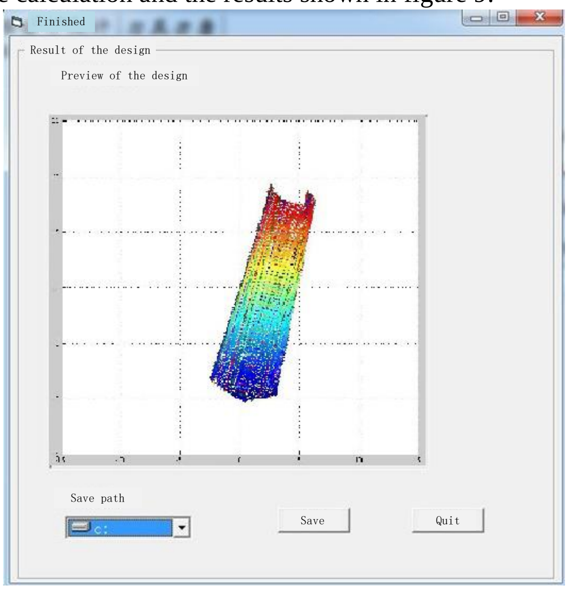


Figure 9 The design result

5 Summary

Based on the basic design theory of the shaper cutter, this paper developed a CAD system of shaper cutter design by using VB and Matlab mixed programming. This design system can finish the shaper cutter design based on the parameters of the workpiece, and the feasibility of the system is verified through a design example.

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