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Research Article

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Intelligent design and simulation of roadheader cutting head

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ABSTRACT

The design method of cutting head of roadheader was studied in this paper, and aimed at the deficiency of the traditional design way, an intelligent design and optimization methods were proposed. This method took secondary development of ANSYS based on the Visual C++2010, and achieved the input of design parameters on the foreground interface. By using the APDL parametric design language we realized the parametric modeling, parametric analysis and parameter display results with the design parameters, and the optimization and adjustment of the structure of cutting head can be carried out according to the results of finite element analysis. With this design method can achieve intelligent design and optimization of cutting head with different coal geological conditions and different cutting conditions, which will greatly improve the cutting head design level.

Key words: Cutting head; intelligent design; ANSYS/LS-DYNA; Visual C++

INTRODUCTION

The cutting head is an important part of roadheader, which directly acts on the coal and rock in the work process, and its performance affects the efficiency of the entire excavation. Cutting pick distributes in cutting head body according to certain spatial position and angle, and completes the crushing of coal and rock through the force of coal and rock mass in order to achieve tunneling work. In the excavation process, structure parameters, operating parameters and the characteristics of coal and rock of cutting head have an important influence on the machine performance; the driving efficiency can be greatly improved with reasonable structure design of cutting head, adaptive coal and rock conditions and cutting operating parameters selection. By using the finite element simulation analysis in the cutting process, the force bearing situations of cutting head and each cutting pick can be obtained, and the dynamic characteristics of cutting head can be accurately expressed. Based on the analysis, we can evaluate the parameters which affect the performance of the cutting head and provide guidance for the design and production of the cutting head, thus conduct the specific optimization and improvement.

In recent years, many domestic and foreign scholars carried out in-depth study on the design and analysis of the cutting head: Xiaohuo Li [1] proposed the method of cutting pick of spiral angle parametric arrangement, and on the basis conducted the optimization design of cutting head operating parameters; Xin Zhang et al. [2] conducted the simulation on the cutting load, and sequential quadratic programming method was adopted to optimization design to reduce the cutting head load fluctuations of cutting head; Yingfu Guo et al. [3] studied the influence of cutting head operating parameters on cutting pick movement through the computer simulation by using coordinate transformation; E. Mustafa Eyyuboglu [4] analyzed the effect of circular cutting pick spacing on the cutting head of roadheader performance by using experimental method; Bilgin [5] studied some geological and geotechnical factors affecting the performance of a roadheader in an inclined tunnel. According to the above access to relevant literatures, most researchers only focused on the study on theoretical analysis of cutting head or simply the simulation with the help of some software. Now there are no researchers study on ANSYS/LS-DYNA software platform combined with Visual C++ for cutting head of roadheader conducting fully parameterized design and modeling, parameterized dynamic simulation analysis, parametric results show, and the cutting head performance evaluation and optimization design.

1. PARAMETRIC MODELING FOR CUTTING HEAD OF ROADHEADER

Due to the complex shape and the larger difficulty of design of the cutting head, this paper presents a kind of parametric modeling method for cutting head of roadheader, which is based on Visual C++2010 foreground to call ANSYS system in order to achieve the design parameters input for front interface, using these design parameters and APDL parametric design language to conduct parametric modeling for cutting pick, pick holder and the head body, and build model library of cutting pick and pick holder; utilize cutting pick model of cutting model library, pick holder model of pick holder model library and head body model to establish cutting head design model, and output the cutting head design model; call excel to output position coordinates and the diameter, height, angle of circumference, angle of inclination and cutting angle of cutting pick, while the output of pick arrangement diagram is used to guide manufacture for the cutting head assembly. Specific design process is shown in Figure 1.

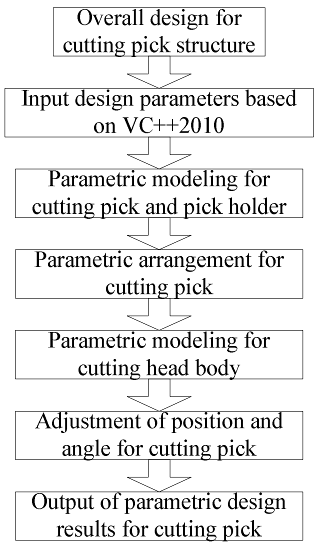

Fig.1 Flow chart of parametric design of cutting head

It includes the following design processes:
1) Overall design for cutting pick structure
According to the need for longitudinal cutting head of roadheader working conditions, analyze its cutting power, cutting hardness of rock and coal and working rotate speed, etc, determine the overall dimensions of the cutting head and type and size of cutting pick, pick holder.

2) Input design parameters based on VC++2010
Develop the longitudinal cutting head of roadheader parametric modeling interface based on Visual C++ language, to achieve front interface input, and the front desk to call ANSYS system. Achieve the relevant calculation parameters of the cutting head of roadheader input directly in the interface of the system, and anti-call input the related parameters of cutting head in the ANSYS system, easy to operate.

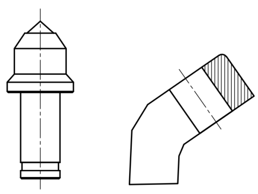

Fig.2 Schematic diagram of cutting pick and holder

3) Parametric modeling for cutting picks and pick holder
As shown in Figure 2, according to the size of the pick and pick holder, enter the relevant design parameters, including the industry standard values and custom parameters, and these parameters can also be given the recommended values. Based on ANSYS software, and using APDL parametric design language to build model library of cutting pick and pick holder, while provide the functions for models to add, modify, and delete.

4) Parametric arrangement for cutting pick
Cutting pick is located according to the cutter tip, distributed by space helix in space according to Eq. (1) and Eq. (2), arranged by using the intercept method in the height direction, and installed in the cutting angle and inclination angle. In general, cutting angle is 40°-50° and the inclination angle is about 8°.
Cylindro-conical helix:

$$\begin{cases} x = \dfrac{\lambda \omega t}{2\pi} \tan\dfrac{\varphi}{2} \cos \omega t \\ y = \dfrac{\lambda \omega t}{2\pi} \tan\dfrac{\varphi}{2} \sin \omega t \\ z = \dfrac{\lambda \omega t}{2\pi} \end{cases} \tag{1}$$

where λ is the helical pitch, ω is the rotation speed of generatrix, t is the time, and φ is the cone angle.
Spherical helix:

$$\begin{cases} x = r\cos(\lambda \omega t / 2\pi r)\cos \omega t \\ y = r\cos(\lambda \omega t / 2\pi r)\sin \omega t \\ z = r\sin(\lambda \omega t / 2\pi r) \end{cases} \tag{2}$$

Where r is the spherical radius, and the others are the same as Eq. (1).

5) Parametric modeling for cutting head body
As shown in Figure 3, the structure parameters of cutting head body mainly include total length, column diameter, half-cone angle, etc. Provide input function for the parameters in modeling interface system, read the relevant parameters in the ANSYS software, and complete parametric modeling for cutting head body.

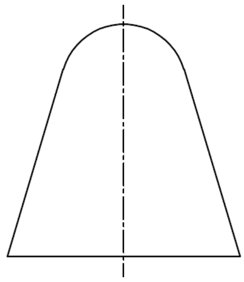

Fig.3 Schematic diagram of cutting head body

6) Adjustment of position and angle for cutting pick
Because of smaller space of the small end and transition section of cutting head, these areas often appear mutual interference between cutting pick and pick holder. Aimed at specific cutting pick, provide the position of the cutting pick and installation angle adjustment function.

7) Output of parametric design results for cutting pick (design model for cutting pick)
When parametric design for cutting head is completed, call excel output cutting pick location coordinates, including diameter, height, circumference angle, inclination angle, cutting angle and other parameters, at the same time output cutting pick arrangement diagram, which is used for cutting head tooling manufacturing process.

2. PARAMETRIC SIMULATION AND OPTIMIZATION FOR CUTTING HEAD OF ROADHEADER

Cutting head has greater impact loads in the work process and the forces of each cutting pick are different, so it will lead to weak pick failure when it reaches the maximum static strength; and load fluctuation can cause the machine vibration resulting in fatigue failure of some components, these factors will affect the service life of the whole machine. Different geological conditions of coal and rock have an important influence on load characteristics of the cutting head. The traditional cutting head design process is based on the given coal and rock parameters and cutting head working parameters, etc, relied on the designer's experience, with reference to the existing model to conduct analogy design, lack of sufficient theoretical support, which result in an overall lower level design, the cutting head designed is also very difficultly to adapt with the working conditions.

In order to solve the existing shortage in the design for cutting head of roadheader, this paper proposes a parametric computer-aided design method, which can aim at different geological conditions of coal and rock and different cutting conditions to carry out design parameters input, parametric modeling, finite element analysis and optimization adjustment, in order to obtain a reasonable design model, the specific process is as follows Figure 4.

According to the parametric design methods, before parametric modeling of cutting pick, designers firstly input parameters for preliminary design, select cutting pick and pick holder forms, determine the overall size of the cutting head and pick arrangement; on this basis, APDL parametric design languages are used to compiling parametric modeling command stream, parametric models of cutting pick, pick holder and head body are respectively established, and cutting pick will be arranged in cutting head according to the theory of pick arrangement.

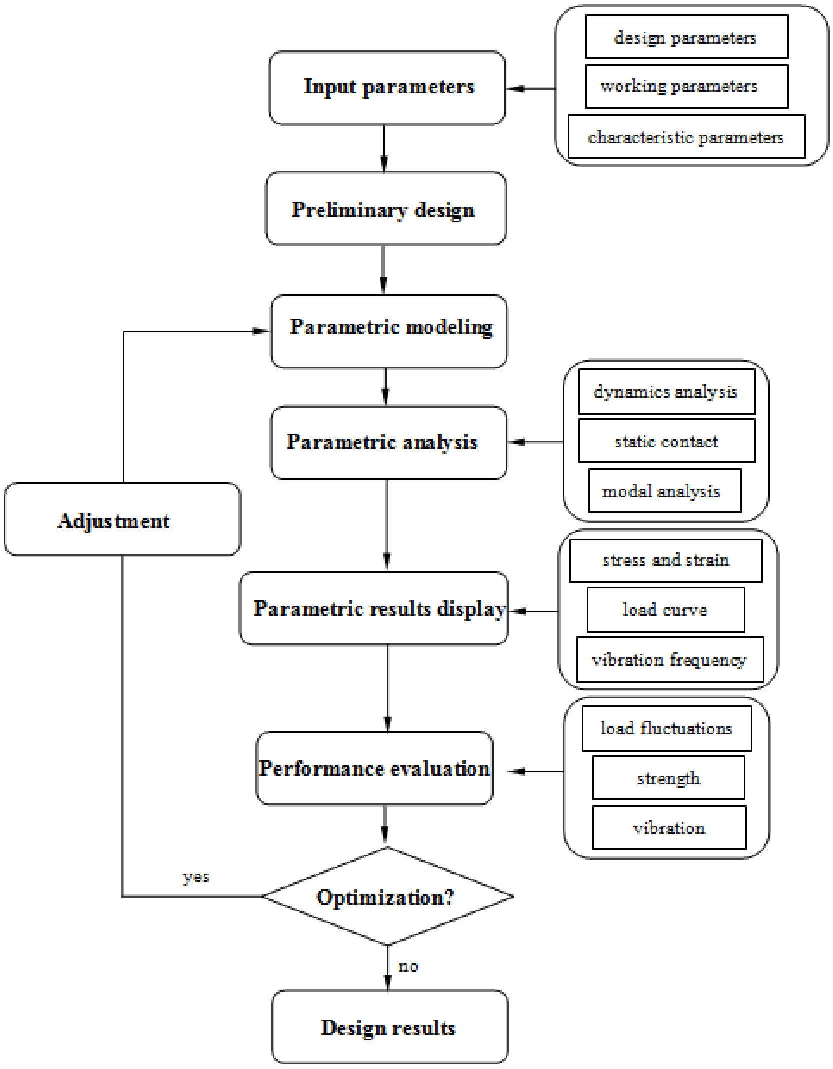

Fig.4 Flow chart of intelligent design of cutting head

When cutting head of roadheader conducts parametric analysis, the system first calls ANSYS/LS-DYNA dynamic analysis module, calls APDL analysis command stream to mesh the cutting head, define element type and material model, define contact, apply loads and constraints, set solving parameters, dynamic analysis can obtain dynamic process of cutting head cutting coal and rock, and arrive at the forces of cutting head and single picks in different moments, the cutting pick numbers with poor cutting performance can be determined according to dynamics analysis results; Based on the above dynamics analysis results, the system calls ANSYS Multiphysics static analysis module, to conduct static contact analysis on poor cutting performance of cutting picks, to obtain the stress and strain simulation results and check its strength, stiffness, fatigue life, etc; on the basis of the analysis, the system calls modal analysis module in ANSYS Workbench to analyze the vibration characteristics of the cutting head.

According to the results of finite element analysis, the performance of the cutting head is evaluated. If cutting performance can not meet the design requirements, then enter into the optimized adjustment module, designers adjust the corresponding design parameters and modify the design model according to the system optimization goal, finally output the cutting head design results.

The design and analysis system which is based on Visual C++2010 for secondary development for ANSYS, achieves the whole finite element analysis process of parametric modeling, parametric analysis and parametric results show, and conducts structure optimization and adjustment for cutting head according to the results of finite element analysis. The system includes the following modules (FIG 4):

1) Parameters input module, is used to input cutting head design parameters, working parameters and characteristic parameters of coal and rock for designers in accordance with the design requirements. Design parameters include the size of cutting pick, pick holder and cutting head body, and cutting pick arrangement parameters on the head body; working parameters include cutting speed and transverse cutting speed; characteristic parameters of coal and rock include density, Poisson's ratio, elastic modulus, friction angle, adhesion force, expansion coefficient and fractal dimension;

2) Parametric modeling module, used to call the cutting head design parameters by parameters input module input, combined with cutting pick arrangement theory, established the cutting head entity model initially; and the cutting head entity model is meshed to generate the cutting head finite element model for parametric analysis;

3) Parametric analysis module, used to call the cutting head finite element model and conduct finite element analysis, including the dynamics characteristic analysis of coal and rock, static contact analysis between cutting pick and coal and rock, modal analysis of the whole cutting head, get the results of the finite element analysis;

4) Parametric results display module, used to postprocess for cutting head finite element analysis results to obtain the stress and strain distribution of cutting head, the load curve of cutting head and pick, vibration frequency and vibration type of cutting head;

5) Performance evaluation module, load fluctuations, stiffness, strength and vibration characteristics of cutting head are evaluated based on the results of parametric module displays, and then get the cutting head design model;

6) Optimization and adjustment module, determine whether the module needs to be optimized according to evaluation results through performance evaluation module, if necessary, then designers adjust the corresponding design parameters to modify the design model on the basis of the optimization target. Design models can also be modified as the finite element model of cutting head, call repeatedly parametric analysis module, parametric results display module and performance evaluation module, so as to obtain better cutting head design model.

3. CASE STUDY

4.1 Design parameters

The main structure parameters of cutting head include: cutting head length, diameter, cone angle, number of thread of helical blades, the number of cutting pick, etc [6-7]. Structure parameters are given in Table 1, this paper will take the set of parameters as an example for parametric design of the cutting head.

Table 1. Structural parameters of cutting head

Length (mm)	Diameter (mm)	Cone angle (°)	Helical blade head number	Pick number
900	ϕ 950	32.6	3	48

Cutting pick is in spiral arrangement, the installation angles are shown by the cutting angle α and inclination angle β, take α =45° and β =8°。The parameters of coal and rock and material parameters of the cutting head are as shown in Table 2.

Table 2. Material parameters

	Mass density (g/mm^2)	Poisson's ratio	Elastic shear modulus (MPa)	Failure surface shape parameter	Angle of friction (rad)	Cohesion value (MPa)	Dilation angle
Coal-rock	1.5e-3	0.3	1400	1	0.45	0.766	0.6
Cutting head	7.8e-3	0.3	2.7e+5				

The working parameters of the cutting head is known as rotating speed for 36r/min, turning speed for 1.2m/min, transverse cutting speed for 1.8m/min.

4.2 Parametric modeling

According to the above design parameters, the corresponding values are input in parametric design system interface, the relevant parameters are read in ANSYS software, parametric modeling is completed by using APDL language [8]. Finite volume rectangular replaces the coal and rock model, infinite volume can be simulated by adding non-reflective boundary conditions on surfaces that cuboid is not cut, so it can achieve cutting simulation and save computing resources. During the analysis, coal and rock and cutting heads all select SOLID 164 unit, use No. 193 materials (MAT_DRUCKER_PRAGER) in LS-DYNA program material library to simulate the coal and rock, cutting head selects the rigid material model, the specific parameters is shown in the Table 2.

Because of the complex structure and many components of the cutting head, this paper uses intelligent free meshing method for meshing cutting head, coal and rock is used swept meshing way due to the simple shape model. After meshing, define cutting head and coal and rock as two "PART", set the contact type between them for the face to face contact erosion. The completed finite element model is shown in Figure 5.

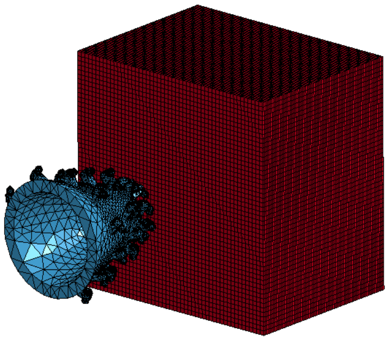

Fig.5 FE model of cutting head

4.3 Parametric analysis

Read into the working parameters of the cutting head, define the load curve of the cutting head, limit other degrees of freedom, and add the non-reflective boundary conditions for not cutting surface of coal and rock in the simulation system.

According to the cutting speed of cutting head and its own speed, set the solving time is 50 seconds. Select reasonable quality scaling factor, the time step factor is 0.9. Output model keywords K file, modify the material model in K file, set the damage parameter "MAT_ADD_EROSION" as shear strain value is 0.03, the unit will be failure when the shear strain is larger than the preset value among finite elements during cutting simulation process, the failure elements will be deleted from the calculation model. When a node all associated unit failure, the node will be deleted in the finite element calculation model. After the calculation, the program according to the requirements output result files for LS-PREPOST post processing, read the file, observe the simulation process, the process is shown in Figure 6.

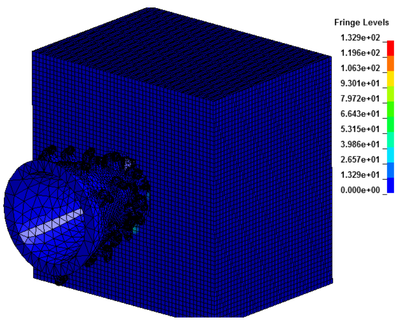

Fig.6 Cutting process of cutting head

4.4 Evaluation of analysis results

According to the results of dynamics analysis of the cutting head, you can get time-dependent force curve of entire cutting head, Figure 7 shows time history curves of traction resistance, cutting resistance and lateral force in the cutting process, a single pick can be evaluated considering the forces of each cutting pick, meanwhile the optimal design can be completed by taking into account the entire cutting head loading conditions to adjust the arrangement of the cutting pick.

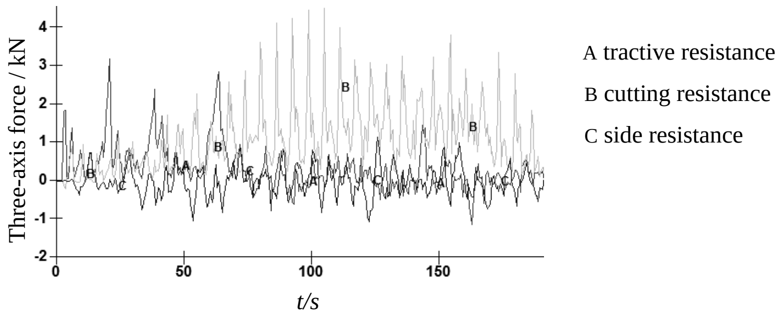

Fig.7 Time history curve of the three-axis force on cutting pick

CONCLUSION

Based on the Visual C++2010 for ANSYS secondary development, parametric design method for cutting head of roadheader was proposed, the whole finite element analysis process which include parametric modeling, parametric analysis and parametric result show was realized by using APDL parametric design language, the structure of the cutting head was optimized and adjusted according to the results of the finite element analysis. It has achieved cutting head structure design and optimization under different geologic conditions and different cutting conditions by using this design method, and greatly improved the cutting head design level.

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