Structure Design of Automatic Tool Change Mechanism for Hobbing Machine in Hard Rock Tunneling

Bin Wang, Xiaotong Tang

College of Physical Education and Health Science, Zhejiang Normal University, Jinhua, Zhejiang, China

Abstract: ***The purpose of the study is to solve the problem of severe wear and tear of the hobbing tools in the current TBM engineering practice, but the existing manual tool change method is not efficient due to the harsh service environment and the problem of "risky tool change", how to achieve safe and fast tool change has become an inevitable trend in the future development of the TBM. To this end, based on the realistic challenges of small working space and large loads, and considering the stiffness of each part of the body, we first used the 2D software CAD to sketch the dimensions, then used the 3D software solidworks to complete the solid modeling of each part of the 3D model, and constructed the assembly from the constructed parts by matching the conditions, and finally, used the simulation software Finally, the simulation software ansysworkbench is used to carry out finite element analysis on the designed automatic tool changing mechanism and its key components, and according to the deformation, stress and strain diagrams, the maximum stress on the mechanism is analyzed whether it exceeds the yield limit of the selected material to ensure that the new structure of the hob automatic tool changing is reasonable and reliable, and the tool changing operation can be completed normally for a long time under complicated conditions.***

Keywords: Hard rock tunneling machine; hobbing; 3D model; machine to man; automatic tool changing mechanism; simulation.

1. INTRODUCTION

At the present stage of TBM construction, due to the many traditional tool removal processes, the operator needs to replace worn tools, which not only threatens the safety of the operator's life, but also affects the progress of the project due to the narrow working space, resulting in a significant loss of efficiency. Therefore, it is necessary to study the new structure of automatic tool changing to adapt to the requirements of tool changing by machinery, improve the construction efficiency, and thus promote the shortening of construction cycle and guarantee the life safety of workers. How to clamping the hobbing tool in a stable and reliable way to ensure a reasonable and reliable structure when bearing large loads.

To this end, after understanding the working principle and design principle of hard rock tunneling machine, the design concept of TBM automatic tool changer and the need of TBM automatic tool changer in China, we chose the 2D software CAD to make a simple dimensional design of the overall mechanism and determine the overall structure of TBM automatic tool changer. The 3D model was then constructed using the 3D software solidworks, and the designed parts were imported and assembled into an assembly using the constraints, and a simple animation was created to identify problems and optimize the structure.

2. RESEARCH SUBJECTS AND METHODS

2.1 Research Subjects

2.1.1 Automatic tool change mechanism structure design

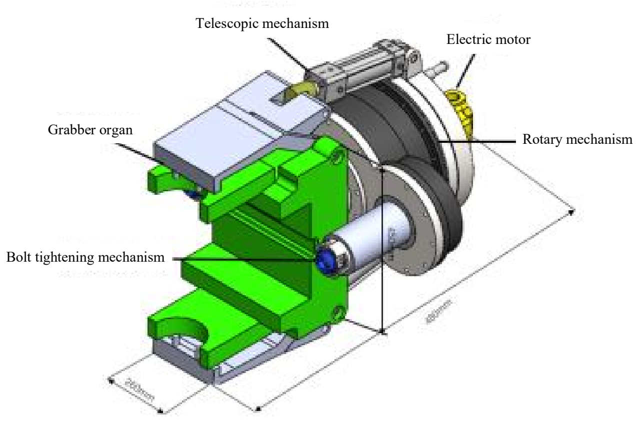


Figure 1: General mechanism of the automatic tool change mechanism of the hobbing machine for hard rock tunneling

Figure 1 illustrates the structure of the automatic tool changing mechanism of the hard rock boring machine hob in this paper.

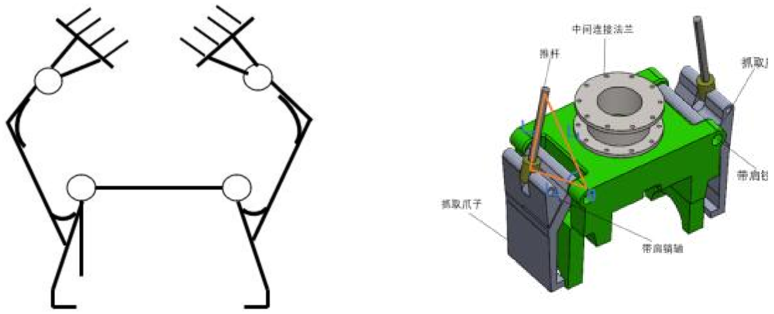
The design of the automatic tool changing mechanism needs to consider the limitation of the TBM working space size. The overall mechanism of the automatic tool changing mechanism is designed by taking the 19-inch TBM hob as the design object and making a full analysis of its space size and tool changing task. It consists of gripping mechanism, telescoping mechanism, bolt loosening mechanism, rotating mechanism, motor, etc. As shown in Figure 1. The grasping mechanism realizes the function of grasping the tool and changing the tool, the telescopic mechanism realizes the function of closing and opening the grasping jaws through the telescoping of the push rod, the bolt loosening mechanism realizes the function of tightening and loosening the bolt on the tool holder, the rotating mechanism realizes the function of tightening and loosening the grasping jaws.

The rotating mechanism realizes the function of turning the grasping jaws. The overall function of quick disassembly of the old tool and replacement of the new tool is realized. The overall size is l0×w0×h0=260mm×480mm×450mm.

2.1.2 Gripping mechanism

The one-piece hob is the gripping object of the automatic tool change mechanism. Based on the structure of one-piece hob, the gripping mechanism is designed, as shown in Figure 2. The hydraulic cylinders on both sides push the telescopic linkage to realize the gripping of the hob. The main function of the gripping seat is to stabilize the clamping of the hob.

The gripping mechanism consists of gripping jaws, gripping seat, intermediate connecting flange, shoulder hinge pin and shoulder pin. The whole device is connected to the rotating mechanism through the intermediate connecting flange, and the gripping mechanism realizes the function of gripping the hob when the automatic tool changing mechanism runs to a suitable position.



(a) Sketch of gripping mechanism (b) Gripping mechanism

Figure 2: Gripping mechanism

The relationship between the angle of motion and the hydraulic cylinder elongation equation:

$$\beta = \arccos\frac{L_1^2 + L_2^2 - (L_0 + \Delta L)^2}{2L_1L_2}$$

Table 1 shows the specific parts of the gripping mechanism

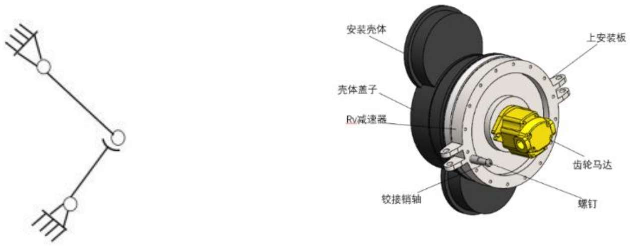
Table 1: A brief list of the main training methods for core strength

Name	Over size	Quantity
Gripping claws	310×162×100	2
Grabber Seat	406×250×310	1
Shouldered Hinge Pins	M20×220×10	2
Shouldered pins	M16×100×10	2
Intermediate connection flange	200×200×380	1

2.1.3 Rotating mechanism

In the automatic tool changing mechanism operation, because the bolt loosening mechanism needs to ensure the coaxiality when tightening and loosening the bolt, it is necessary to design the rotating mechanism and adjust the attitude of the end to realize the steering function. The design is shown in Figure 3, and the bolt tightening mechanism is driven to rotate by the hydraulic cylinder driving the push rod telescoping.

The rotating mechanism consists of RV reducer, mounting housing, upper mounting plate, screws, articulated pins, gear motors, etc. When the tool changing robot runs to the position where the cutter needs to replace the hob, the attitude is adjusted to realize the function of steering claw steering



(a) Sketch of rotating mechanism (b) Rotating mechanism

Figure 3: Rotating mechanism

Table 2 shows the specific parts of the rotating mechanism

Table 2: A brief list of the main

Name	Over size	Quantity
RV Reducer	325×162×131	2
Mounting Housing	572×325×132	1
Upper mounting plate	432×325×40	2
Housing cover	572×152×20	2
Gear motor	150×128×120	1
Intermediate connection flange	200×200×380	1

2.1.4 Telescoping mechanism

When the actuator works for tool change, the hob inside the tool holder needs to be taken out, so it is necessary to design a degree of freedom at the end that can be freely retracted, because the internal space is very limited, especially the direction of taking out the tool has dimensional constraints. The design of the telescoping mechanism is shown in Figure 4

The telescoping mechanism consists of a push rod, an outer earring, a push rod housing, a nut, etc. The mechanism controls the closing and opening of the jaws by telescoping the length of the push rod.

(a) Sketch of Telescoping mechanism (b) Telescoping mechanism

Figure 4: Telescoping mechanism

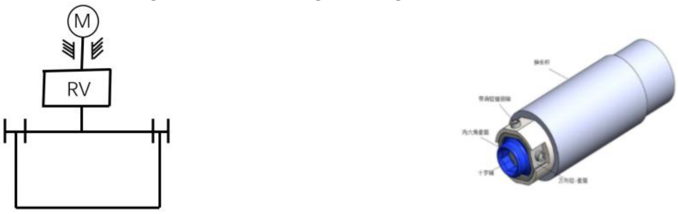
Table 3 shows the specific parts of the Telescoping mechanism

Table 3: A brief list of the main

Name	Over size	Quantity
Push Rod	220×9×9	2
External Earring	50×40×40	2
Actuator housing	266×58×58	2

2.1.5 Bolt tightening mechanism

Both sides of the screw need to turn simultaneously to loosen the tool holder, so to keep the same step of movement when the bolt tightening mechanism is tightened, use a single drive source to drive both universal hinge-sleeve simultaneously while aligning the sleeve and the screw head, the design of the bolt tightening mechanism is shown in Figure 5.



(a) Sketch of Bolt tightening mechanism (b) Bolt tightening mechanism

Figure 5: Bolt tightening mechanism

The bolt tightening mechanism consists of an extension rod, a cross shaft, a hexagonal socket, a universal hinge-sleeve, and a shoulder hinge pin to realize the function of loosening and tightening the bolt.

Table 4 shows the specific parts of the Bolt tightening mechanism

Table 4: A brief list of the main

Name	Over size	Quantity
Extension Rod	200×85×85	2
Cross Shaft	46×36×15	2
Hexagonal Sleeve	46×44×36	2
Universal hinge-sleeve	56×55×20	2
Shouldered hinge pin	M10×10	8

2.1.6 Automatic tool change mechanism structure optimization

Based on the actual size of the original hob, and considering the limited working space, an automatic tool changing mechanism was designed for changing the hob, thus realizing "machine tool changing".

Improvement idea: The original end-effector loosens the bolts on the tool holder through the bolt tightening mechanism, and then grabs the tool holder through the gripping mechanism, together with the tool. Normally, the wear of the hob is much more serious compared with the wear on the tool holder, so the frequency of replacement is much higher. If we can directly grasp the tool we need to replace, the efficiency of grasping can be improved.

Improvements:

1) The gripping mechanism is improved, the groove at the gripping seat is used to catch the tool, the two sides are stuck to the ends of the tool, and the claw hooks the tool screw hole to make the tool more stable when gripping.

2) The bolt loosening structure has added an extension rod, when the end-effector is close to the tool holder, the bolt on the tool holder can be tightened and loosened more safely to prevent the side plate of the tool holder from being touched because of too much extension.

2.2 Research Methodology

2.2.1 Finite element analysis

Finite element analysis is the use of mathematical approximations to simulate real physical systems. Using simple but interacting elements, it is possible to approximate a real system with a finite number of unknown quantities to an infinite number of unknown quantities.

Originally applied to structural strength calculations of aircraft, the finite element method is widely used in engineering problems because of its simplicity and efficiency. For example, for a force analysis of a product, for a shaft, if it needs to be calibrated, we can calculate it by hand or by software. FEA is a kind of hand calculation simulated by software for stress analysis, displacement analysis and other applications, as shown in Figure 6.

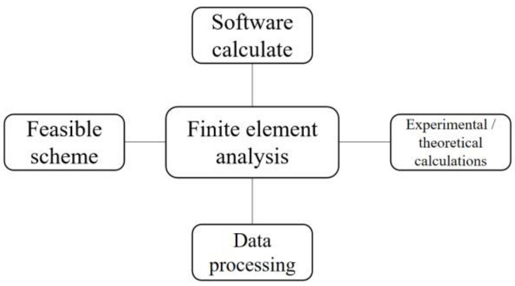


Figure 6: Application of finite element analysis

The modeling idea of finite element model: the establishment of finite element model is actually to construct a stiffness matrix, which mainly depends on the shape of the structure and the modulus of elasticity of the material. The modulus of elasticity of steel in general is very similar, and the density is also very similar, the main difference is the hardness and strength, and the hardness and strength parameters will not be introduced into the finite element model. Therefore the modeling is done by treating the parts of the component as the same material, this way the modeling can be simplified [23].

2.2.2 Selection of finite element simulation software

Ansys workbench is a professional general finite element analysis software, which integrates many software into one, can be used to solve the static mechanics, and has its own platform, its position in the industry is unshakable. It can meet the analysis in complex environmental situations, and the credibility of the calculation is relatively high, and it has a vast user base in the academic world. The general steps of finite element analysis are: analysis type selection, material selection and addition, model creation and import, meshing, boundary conditions, applied load, solution and post-processing

2.2.3 Establishment of finite element model for automatic tool change mechanism and its key components

Before starting the numerical simulation process, we need to first establish or import the pre-built 3D model. The 3D model of the automatic tool change mechanism is built in solidworks software, and the 3D model is imported into ansys software for analysis and solution.

We can use the default global coordinate system directly, or we can reconstruct a more suitable coordinate system, and after the coordinate system is constructed, we can directly change the global coordinate system to our own coordinate system and apply it later.

Since the designed automatic tool changing mechanism has a certain degree of complexity, the model can be processed first when doing the finite element simulation, and the parts that are not subject to force or are anisotropic should be deleted first. If any part of the structure is too complex then the local part of the complex part should be simplified appropriately:

1) The focus of this paper is the structural design of the automatic tool change mechanism and the static analysis of key components, so the hob can be ignored in the analysis, while the local mechanism of diamond-shaped holes, square holes, serrated holes and other shaped holes can be simplified.

2) Binding contact is selected between the parts, and the gap between the weld head and the joint can be neglected

3) Some parts of the mechanism that are not subject to force can be appropriately deleted or simplified

4) Some raised or depressed places in the mechanism are treated as slightly rounded and smooth. The structure of the end gripping claw of the automatic tool change mechanism is shown in Figure 7. When the finite element analysis is performed on the key parts of the gripping claw, it is appropriately simplified, and the simplified model is shown in Figure 8.

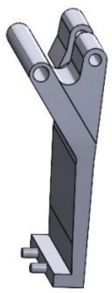


Figure 7: Grasping claw model

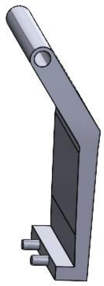


Figure 8: Simplified grasping claw model

Q345 steel was selected as the material for each part of the automatic tool change mechanism for the application. The performance parameters of the selected Q345 steel are shown in Table 5.

Table 5: performance parameters

No.	Performance index	Numerical value
1	Density kg/m³	7850
2	Modulus of elasticity Gpa	210
3	Poisson's ratio	0.3
4	Yield strength Mpa	345
5	Ultimate tensile strength Mpa	500
6	Fracture Toughness Mpa-mm½	201.12
7	Fracture threshold Mpa-mm½	6270.8
8	Thermal conductivity W/(m-K)	48

2.2.4 Delineation of finite element mesh

Finite element meshing is a crucial step in the static analysis, and its impact on the analysis results is great. The finer the mesh is divided, the more accurate the results of its calculation. In the simulation software, the simplified model of the automatic tool changer is imported, and the finite element mesh is divided by taking the hexahedral mesh method for the key parts, refining the key parts such as the grasping claws, and the mesh size is set to be adaptively adjusted according to the size. The automatic tool changer is meshed as shown in Figure 9.

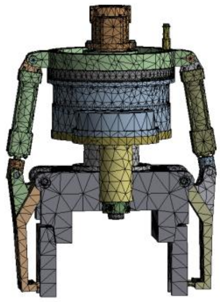


Figure 9: Automatic tool change mechanism grid diagram

After grasping the claw for meshing as shown in Figure 10.

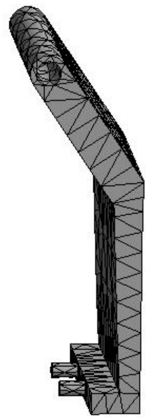


Figure 10: Grasping claw grid diagram

The The automatic tool change mechanism generated 220935 nodes as well as 118057 units.

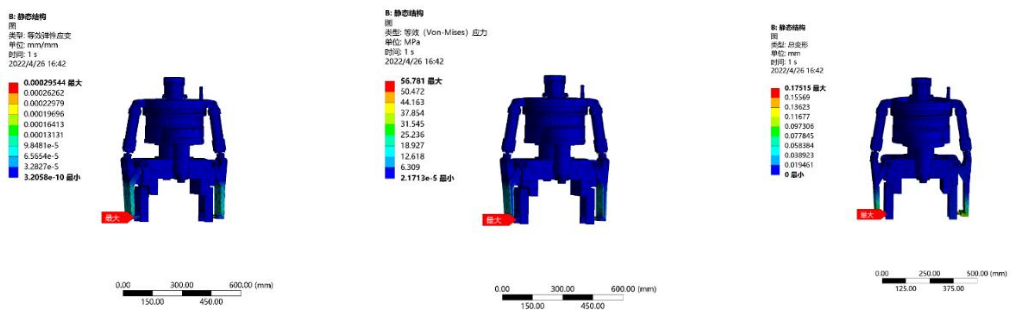
2.2.5 Setting of boundary conditions

The age change performance of strength quality is in children juvenile period, strength quality grows as the age, but the age After the mesh division is updated, we also need to set the boundary conditions, select fixed support, select the upper end face of the mechanism as the range of fixed support. Apply a load away from the four cylindrical surfaces of the grasping jaws, select the coordinate system constructed by ourselves in N, select the form of vector, and input a force of size 7750N for the vector Z-axis.

3. RESULTS AND ANALYSIS

3.1 Simulation results of automatic tool change mechanism

In the finite element analysis using ANSYS, the simulated load is the gravitational force of the TBM 19-inch hobbing tool with a vertical downward direction and a magnitude of 7,750 N. The simulated load's working condition.



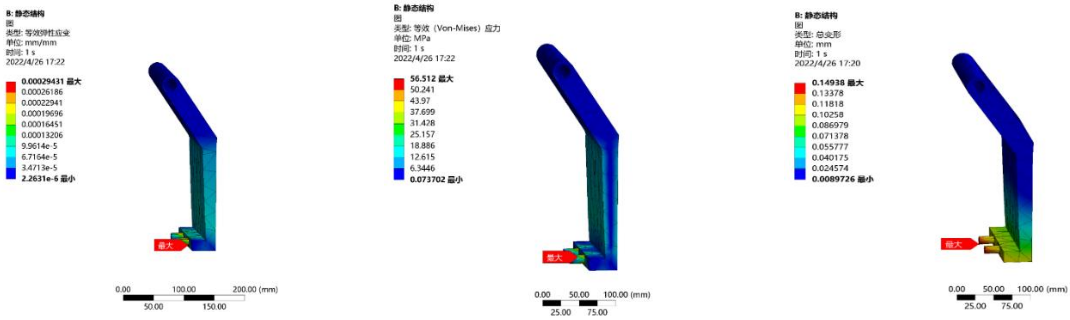
(a) Strain (b) Stress (c) Deformation

Figure 11: Simulation results of automatic tool change mechanism

Figure 11 shows the analysis results of the automatic tool changing mechanism in the finite element simulation software. The results of the simulation show the deformation and stress-strain distribution of the automatic tool changing mechanism. As can be seen from the figure, the pre-strain and pre-deformation of the automatic tool-changing mechanism are mainly concentrated in the lower end area of the side gripping jaw, which is because the gripping jaw is the part of the direct gripping jaw and is subject to the gravity of the hob, and the maximum stress value is 56.781 MPa, the maximum strain is 0.00029544 mm, and the maximum deformation is 0.17515 mm, under the simulated load of 7750 N force. All of them appeared in the area of the lower end of the gripping jaw. The maximum stress did not exceed the yield limit of 345Mpa for Q345 steel, so the automatic tool changing mechanism is structurally sound and safe under the corresponding working conditions.

3.2 Gripping claw simulation results

The gripping claw is the component that directly grips the roll to and is a key component, so we perform a separate static analysis of its simplified model.



(a) Strain (b) Stress (c) Deformation

Figure 12: Gripping claw simulation results

Figure 12 shows the analysis results of the gripping jaws in the gripping mechanism in the finite element simulation software. The results of the simulation show the deformation and stress-strain distribution of the automatic tool changing mechanism. As can be seen from the figure, the pre-strain and pre-deformation of the gripping jaws are mainly concentrated in the lower end and cylindrical region, which is because this region is directly subjected to the gravity of the hob.Under the simulated load of 7750N force, the maximum stress value is 56.512Mpa, the maximum strain is 0.00029431mm, and the maximum deformation is 0.14938mm, which all appear at the end of the cylinder. Since the material taken for the grasping jaws is Q345 steel, the maximum stress does not exceed the yield limit of 345Mpa of Q345 steel, so the structure of the grasping jaws is reasonable and the grasping mechanism is safe under the load.

3.3 Analysis of simulation results

The information of maximum stress, maximum strain, and maximum deformation obtained from the simulation analysis of the above automatic tool-changing mechanism and gripping jaws are integrated to obtain Table 6.

Table 6: Simulation results

Model	Maximum Strain	Maximum Stress	Maximum Deformation
Automatic tool change mechanism	56.781	0.00029544	0.17515
Gripping jaws	56.512	0.00029431	0.14938

Static analysis of the above model: the maximum stress of the automatic tool changer mechanism does not exceed the yield strength of the automatic tool changer mechanism material, but the lower part of the side claw has a higher stress in the key part, the maximum stress of the gripping claw does not exceed the yield strength of the gripping claw material, but the cylindrical area is subjected to great stress and is relatively weak.

When the automatic tool changer is gripping the hob tool, the gravitational load will cause a large stress and deformation to the mechanism, and the long time work will cause serious wear. In the finite element analysis software ansys, the static analysis of the designed automatic tool changer is carried out to check the overall structure of the automatic tool changer and the stress distribution and strain distribution of the key parts, and analyze To determine the maximum stress and strain on the mechanism and the maximum deformation, it was concluded that the maximum stress on the mechanism and the yield limit of the material would not be exceeded under the consideration of the safety factor, and the maximum deformation of the mechanism would be within a certain range.

4. CONCLUSION

Based on the defects of "manual tool changing", a new type of automatic tool changing mechanism for hobbing machine of hard rock tunneling machine is proposed, which consists of grasping mechanism, telescopic mechanism, rotating mechanism and bolt tightening mechanism. The automatic tool changer realizes the function of grasping the tool and replacing the tool through the grasping mechanism, the telescopic mechanism realizes the function of closing and opening the grasping claw through the telescopic push rod, the bolt loosening mechanism realizes the function of tightening and loosening the bolt on the tool holder, and the rotating mechanism realizes the function of turning the grasping claw. The overall function of quickly dismantling the old tool and replacing the new tool is realized.

Through the finite element analysis of the automatic tool changing mechanism and the key components of the grasping jaws, the deformation and stress-strain diagrams are obtained, and the simulation results show that the maximum stress on the mechanism can reach 56.781Mpa, which does not exceed the yield strength of the selected material Q345 steel, and can maintain good mechanical properties and service life during long time working.

The large deformation of the automatic tool changer mainly occurs in the lower area of the gripping jaw, the maximum deformation can reach 0.17515mm, which shows that the area is relatively weak, and the structure can be optimized by enhancing the thickness to make it have better deformation resistance.

Through the static analysis, the automatic tool changing mechanism has a reasonable structure, and the deformation and stress of the overall structure are in a safe and reasonable size range, so that the tool changing operation can be completed normally under complex working conditions.

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Author Profile

Bin Wang, professor, master tutor, school of physical education and health sciences, Zhejiang normal university. Research direction: humanities and sociology of sports. Email: 330977873@qq.com: wangbin@zjnu.cn.

Xiaotong Tang, postgraduate student of zhejiang normal university. Research direction: physical education. E-mail: 670687655@qq.com