Design of Integrated Cutter System for Machine Cutter Change of Tunnel Boring Machine

You-neng BAO*, Zhi-chao MENG and Jun-zhou HOU

School of Mechanical Engineering, Dalian University of Technology, Ganjingzi District, Dalian City, Liaoning Province, China

*Corresponding author

Keywords: Tunnel boring machine, Cutter change, Integrated cutter system.

Abstract. Tunnel boring machine is widely used in underground engineering construction. During the construction process, the cutter frequently detects and replaces the construction efficiency and harms the safety of the cutter changer. It is imperative to realize the cutter change "Machine replacement manual". Traditional cutter fasteners are numerous and discrete, and their shapes and sizes are different. To design an automatic cutter changer for this structure, the actuator design will be very difficult. Designing an integrated cutting system that is easy for machine operation is essential for “machine replacement manual”. In view of the above problems, this paper proposes an integrated cutter system scheme with three different structures according to the idea of integrating cutter, locking block and bolt. 7 performance indicators for integrated cutter evaluation for machine cutter change operation: static stiffness, static strength, weight, three-dimensional size, extraction size, disassembly action and pre-tightening force. Contrasting and analyzing the three integrated structural schemes and the various indicators of the traditional cuttering scheme, and obtaining an optimal cutting scheme for machine cutter change.

Introduction

The tunnel boring machine is a complex large-scale machine for tunneling excavation, drainage and lining functions. It is the key equipment for mechanization of tunnel construction work[1]. The cutter mounted on the cutter head is the main cutter for the full-face tunneling machine to break the rock. The existing cutter change relies on the manual operation mode. In the construction environment of large depth and high water pressure, the manual cutter change is undoubtedly a safety hazard[2]. It is imperative to realize an efficient and safe working mode of “machine replacement manual” for cutter change operations. Since the traditional cutter fasteners are numerous and discrete, if the automatic cutter change actuator is designed directly for this structure, the design of the cutter change action will be very cumbersome, and the design of actuator will be very difficult, so before designing the cutter change robot, design an integrated cutting system for machine operation is essential. There are few research results on the design of the integrated tool system. Only the French NFM company has launched relevant research abroad[3]. The Liyang Xie’s team of Northeastern University of China developed a rotary cutter system[4]. In general, there is little research on the development of integrated cutters. This research has important engineering significance.

Three New Integrated Knife Base Structures

Due to the multi-split structure of the conventional cutter, the cutter changing process is complicated, and the design of the cutter changer is complicated. The multi-split structure is improved into an integrated structure, which integrates bolts, wedge blocks and cutters of a conventional cutter system. Based on this idea, three different cutter system design schemes are proposed.
Performance Evaluation of New Cutter System

For the above three structural forms, the difference in performance needs to be analyzed using quantitative evaluation indicators to select the optimal solution. For the design requirements of automated cutter change, the following indicators must be considered:

**Static Strength / Stiffness**

In order to ensure the reliability of the cutter system, the cutter system needs to ensure a large rigidity in the load direction to resist deformation. Static strength is an important indicator of the performance of the cutter system. The finite element method is applied to obtain the static stiffness for applying the nominal load on the cutter. The nominal load is the limit value of the cutter load. Under nominal load, the normal load of all cutters is 315 KN, the lateral force is 47.25KN, and the rolling force is 31.5KN[5]. The direction is shown in Figure 4. In this paper, the advantages and disadvantages of several schemes are compared. It is necessary to ensure that other factors remain unchanged. In the finite element analysis and the comparison of subsequent indicators, all materials are selected from 45 steel, and the finite element mesh is selected as a hexahedral mesh. It is 10mm.
Cutter System Quality
The purpose of the cutter holder design is to take the robot to perform the cutter replacement. The quality of the cutter system directly affects the size and size of the robot. If the cutter holder is too large, the equipment that replaces the cutter requires a higher output power, so the quality of the cutter system is an important indicator of its performance.

Cutter Size
The position of the cutter in the plane of the cutter head is related to the size of the cutter holder. The more the number of cutters, the higher the efficiency of breaking the rock by the TBM/shield machine. When designing an integrated cutter, the impact on the efficiency of the cutterhead should be reduced. So cutter size is an important indicator of its performance.

The Size of the Cutter Extraction Direction
The size of the cutter extraction direction is very narrow in the TBM/shield machine. As shown in Figure 2.5, the cutter change space is the fan-shaped space inside the cutter head. The feature is that the size of the extraction cutter is small, and the size cannot be increased by modifying the structure of the shield machine. Therefore, the size of the cutter extraction direction is an important indicator to measure its performance.

The Disassembly Action
The purpose of the cutter holder design is to take the robot to perform automatic cutter replacement. The starting point of the design is to simplify the disassembly action and facilitate the automatic operation.

Available Preload
Available preload. The cutter is subjected to large impact forces and vibrations during operation[6]. In order to increase the reliability and tightness of the connection between the parts, it is necessary to apply a force in the structure in advance. Preloading can effectively improve the reliability and anti-loose ability of the structure[7]. Therefore, the preload force that the system can provide is another important indicator to measure its performance. When the four schemes are locked, the pre-tightening force of the locking block is provided by bolts. The bolts used in the engineering are all made of 10.9 fine bolts. The bolts are uniformly graded to 10.9 fine teeth. The bolts are according to their respective structures.

According to the above analysis, Table 1, all indicators of the four cutter systems are available.
Table 1. Four cutter evaluation indicators.

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Static strength /mm</th>
<th>Static stiffness /MPa</th>
<th>Cutter system quality/Kg</th>
<th>Cutter size /mm</th>
<th>The size of the cutter extraction direction/mm</th>
<th>The disassembly action</th>
<th>Available preload /KN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional hob</td>
<td>0.0181</td>
<td>95.369</td>
<td>197</td>
<td>606x530x650</td>
<td>650</td>
<td>9</td>
<td>916</td>
</tr>
<tr>
<td>Scheme 1</td>
<td>0.6524</td>
<td>626.05</td>
<td>293</td>
<td>580x450x610</td>
<td>610</td>
<td>4</td>
<td>428</td>
</tr>
<tr>
<td>Scheme 2</td>
<td>0.7399</td>
<td>95.556</td>
<td>319</td>
<td>472x600x620</td>
<td>490</td>
<td>2</td>
<td>916</td>
</tr>
<tr>
<td>Scheme 3</td>
<td>0.8055</td>
<td>233</td>
<td>269</td>
<td>580x450x680</td>
<td>610</td>
<td>2</td>
<td>916</td>
</tr>
</tbody>
</table>

According to the above comparison, we can know:

1. In terms of reliability, the static stiffness, static strength and pre-tightening force of the conventional cutter are optimal with respect to the integrated cutter, and the maximum stress is consistent with the level of the conventional cutter;

2. In terms of weight, the four new schemes are around 300Kg, which is not much different;

3. In terms of pre-tightening force, the pre-tightening force of scheme 1 is the smallest among the four new schemes, and the pre-tightening forces of other schemes are the same, which can reach 916KN;

4. In the automatic cutter change index, the three dimensions of the proposed three-dimensional scheme are smaller than the traditional scheme. The size of the scheme 2 is the smallest in both the three-dimensional size and the knife-cutting direction, which is most conducive to the design of the actuator, and the disassembly action is also reached two.

In summary, the scheme 2 is selected as the final cutter system.

Conclusion

This paper analyzes several traditional cutter structures on the market, and proposes an integrated cutter system scheme with three different structures according to the idea of integrating cutter, locking block and bolt. Seven performance indicators for integrated cutter evaluation are proposed: static stiffness, static strength, weight, three-dimensional size, extraction size, disassembly action and pre-tightening force. By comparing the three structural schemes and the various indicators of the traditional cutting scheme, the scheme 2 is obtained as the final program.

References


