Rigid-Flexible Coupling Dynamics Simulation of Wedge Press

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Abstract. In this paper, according to the installation and replacement process of disc single edge hob, the automatic disassembly process of the press wedge of hob is selected as the main object for analysis and research, and a press wedge disassembly device is proposed based on the mechanical design theory, and its structure design and simulation analysis are carried out. First of all, through the understanding of the development and research status of tool change technology at home and abroad, the structure of tool box and the disassembly process of disc hob are analyzed. The disassembly process is divided into three steps, and the expected path curve is obtained by cubic spline interpolation. Secondly, a kind of wedge removal device is proposed and designed. The design scheme is divided into two parts: wedge clamping mechanism and path guiding mechanism. The functional requirements and mechanism realization methods are discussed respectively. The wedge clamping mechanism realizes the clamping power by transforming the traditional three claw chuck, and the path guiding mechanism adopts the two degree of freedom mechanical arm to realize the wedge pressing along the expected curve path. In order to verify its feasibility and rationality, the nx10.0 software is used to build the three-dimensional assembly model of the wedge removal device. Then, the trajectory planning simulation of the two degree of freedom manipulator is carried out, the manipulator model is established by using Matlab / Robotics toolbox, and the correctness of the kinematic equation is verified by comparative solution; the workspace of the manipulator is obtained by Monte Carlo simulation, and the correctness of the theoretical working area of the manipulator is verified by comparison; the method of quintic polynomial and cubic spline interpolation is adopted Methods the multi node trajectory planning of the manipulator joint was carried out, and the displacement, velocity and acceleration curves of the two joints of the manipulator were calculated based on the intermediate data points of the expected path, which verified the good motion stability of the manipulator. Finally, the virtual prototype model of the wedge removal device is established by the joint simulation method of Adams and ANSYS, and the rigid flexible coupling dynamic simulation analysis is carried out to simulate the movement track of the wedge in the removal process, which is basically consistent with the expected path curve, which verifies the feasibility of the removal device; the stress distribution of the connecting rod is evaluated and analyzed to verify that the connecting rod can meet the material requirements Material strength requirements.

Keywords: compression wedge disassembly device; structural design; trajectory planning; dynamic analysis.
1. Introduction
In recent years, with the rapid development of China's economy, the acceleration of urbanization, the explosive growth of urban population, and the continuous expansion of urban scale, in order to alleviate the huge pressure of urban traffic, China's road construction is moving from plane to three-dimensional direction, especially the underground tunnel construction has become the focus of road three-dimensional construction. According to the document of the 13th five year plan for the development of modern comprehensive transportation system, the total mileage of urban rail transit operation in China is expected to reach 6000 km [1] in 2020. By the end of 2017, 34 cities in China have opened and put into operation urban rail transit, with 165 urban rail transit lines and 5032.7 km of operation lines. Among them, the underground line is 3199.8km, accounting for 63.6% [2], which plays a leading role in the overall planning and layout of rail transit construction. In many construction machinery used in rail transit construction, shield machine is widely favored in the project for its advantages of adapting to various geological conditions, good anti-seepage and water leakage, good concealment and high construction quality. Driven by the growing demand, shield machine is developing rapidly. See Figure 1 for shield machine entity design scheme.

Shield machines began in the early 19th century, and became more and more mature in the 1990s. In 1818, inspired by borer drilling, Marc isambardbrunel developed shield construction technology [4], which has been developed rapidly in Germany, Britain, Japan and other developed countries for nearly 200 years. In China, the research on shield technology started late, starting in the 1960s and developing in the 1990s, which accounts for about 80% of the subway tunnel construction. In the past 30 years, the shield technology has made remarkable development, and the modern shield machine has developed into a kind of large-scale engineering machinery equipment with high intelligence, integrating machine, electricity, liquid, light and computer technology [4]. It has the following characteristics [5-9]:
(a) Diversified, there are many classifications of shield machines according to different structural forms;
(b) The construction stratum has wide adaptability, which can be applied to the excavation of various geological conditions and soil structures;
(c) The construction process has been preliminarily automated;
(d) The mud water balance shield and earth pressure balance shield are the main development directions.
2. Add driver function
After the device is disassembled to position and clamp the compression wedge, according to the expected operation path, move the compression wedge forward and push it out to the wedge end extending out of the tool box, then move the compression wedge along the curve path to make it run to the designated position in strict accordance with the fitting path, and finally move the compression wedge backward from the side space to take out the compression wedge. The operation time of the above three parts is set as 2S, 5S and 3S respectively, and the whole motion process is 10s in total. The driving functions of the three motion pairs involved in this series of motion are set, among which the driving functions of the moving pair of the x-axis linear module and the rotating pair of the swing hydraulic cylinder are composed of two-stage quintic polynomial functions and 47-stage cubic spline interpolation functions respectively, so it is necessary to set the driving functions in ADAMS. The software creates a cubic spline interpolation function based on the external planning data, takes time as an independent variable and joint variable as a dependent variable, imports the data of 48 intermediate path points into Adams, as shown in Figure 2, and then performs spline interpolation to obtain the spline function of joint variable and time, as shown in Figure 3, which is used to drive joint motion.
Adams / view allows three interpolation methods: cubic spline fitting, B-spline fitting and Akima fitting. Their corresponding functions are cubspl, curve and aki spl. Therefore, this paper uses cubspl function to define joint motion function and generate spline curve. The expression of cubspl function is
cubspl (1st - indep - VaR, 2nd - indep - VaR, spline - name, deriv - order), where 1st - indep - var represents the first independent variable, 2nd - indep - var represents the second independent variable, spline - name represents the name of spline data, and deriv - order represents the differential order of interpolation point. Combined with step function and if function, the driving function applied to the moving pair is as follows:

(a) The driving function of y-axis linear module is
STEP (time, 0, 0, 2, -100) +STEP (time, 7, 0, 10, 300)
(b) The driving function of x-axis linear module is
if(time-2:0,0,(if(time-2.3:(8.079533364274683e+03)*time-2)**4-(1.675745402129628e+03)*
time-2)**3-(1.057324872145059e+04)* (time-2)**5, -5.4939, (if(time-6.9:CUBSPL (time, 0,
SPLINE_1, 0), -0.3630, (if(time-7:(5.108290340830521*time)-(5.684341886080801e-14)*
time -69/10)**2 + (5.650257955017298e+02)* (time-69/10)**3 - (1.358367727335633e+04)*
time-69/10)**4+(6.455128977508586e+04)* (time - 69/10)**5-35.6510203351730597, 0,0))))
(c) The driving function of the rotating pair of the swing hydraulic cylinder is
if(time-2:0,0,(if(time-2.3:(33.249811851513428*(time-2)**4)-(9.324306370312348*(time-2)**3-
(35.418602468652345*(time-2)**5),-0.0685,(if(time-6.9:CUBSPL(time,0,SPLINE_2,0),-1.4940,
(time-7:((9.106186592356878e+03)*time-69/10)**4-4.440892098500626e-16)* (time-69/10)**2-
(5.869639944267701e+02)* (time-69/10)**3-0.301726675955370*time-(3.708219972133794e+04)*
time-69/10)**5+(5.87914064092053), -1.5708, -1.5708))))
The above three driving functions indicate that in the period of 0s-2s, the disassembly device holds the compression wedge and moves it forward by 100mm to make it out of the assembly state; in the period of 2s-7s, the curve guide mechanism drives the compression wedge to move along the track of 49 sections in turn, and moves it to the side gap through the assembly gap between the cutter box and the hob, and ensures the wedge is vertical. The time period of 2s-2.3s is set as the first one In the period of 2.3s-6.9s, a cubic spline trace function is set every second, and in the period of 6.9s-7s, it is set as the end segment quintic polynomial trace function; in the period of 7s-10s, move backward 300 mm to take out the compression wedge from the side gap and complete the disassembly process.

3. Verification of wedge removal track
Add the above driving functions to the corresponding joint drive respectively, set the simulation time to 10s, load step to 1000, carry out the rigid flexible coupling dynamic simulation analysis of the disassembly device, and get the motion curve of the wedge as shown in Figure 4.

![Fig. 4 Compression Wedge Simulated Motion Curve](image-url)
It can be seen from figure 4 that the simulation motion path is basically the same as the expected path. The simulation result track of wedge is imported into Matlab software, and compared with the expected path. The result is shown in Figure 5, which is more consistent as a whole. There is fluctuation at the coordinate value of X-axis 48mm, the displacement error of y-axis reaches 2mm, and the displacement error of y-axis sharply increases to 16mm at the end of the motion. Due to the large space of the motion termination position, the error will not cause collision interference, so it is considered that the wedge removal process can achieve the expected effect as a whole, and the expected removal work can be completed.

![Fig. 5 Difference Curve between Simulation Trajectory and Expected Path](image)

4. **Stress-strain analysis of flexible body**

The stress-strain distribution of the intermediate connecting rod in the compression wedge disassembly device changes constantly in actual operation. In order to determine the time and position of the occurrence of the maximum stress-strain, the node with the maximum stress-strain is extracted from the post-processing interface. The results are shown in table 1, which lists the five nodes with the maximum stress of the connecting rod during operation.

| Hot Spots | Stress (N/mm²) | Node | Time (sec) | Location Wrt LPRF(mm) |
|-----------|----------------|------|------------|-----------------------|
| 1         | 15.6025        | 316  | 2.9        | 18.6022 -38.0155 0    |
| 2         | 15.2726        | 292  | 3          | 18.6022 -38.0155 10   |
| 3         | 14.5618        | 303  | 2.8        | 18.5 -37.2391 0      |
| 4         | 14.521         | 291  | 2.8        | 18.5 -37.2391 10     |
| 5         | 14.231         | 188  | 2.1        | -18.6022 -38.0155 0  |

From table 5, it can be seen that the maximum stress on the connecting rod occurs for 2.9s, the node number is 316, and the position coordinate is, which corresponds to the edge part of the through hole on
the connecting rod. As shown in figure 6, it can be seen that this part is the weak area of the connecting rod, which is prone to fatigue damage. Therefore, further analysis of the law of stress change at the dangerous node is carried out, and the data is extracted and the danger is drawn in the post-processing interface of ADAMS software. The stress change curve of node 316 is shown in Figure 7.

![Fig. 6 Location of Maximum Stress](image)

**Fig. 6 Location of Maximum Stress**

![Fig. 7 Stress Change Curve of Connecting Rod 316 Joint](image)

**Fig. 7 Stress Change Curve of Connecting Rod 316 Joint**

It can be seen from figure 7 that the stress change at node 316 is relatively stable as a whole, with fluctuation around 7S. The maximum stress is 15.6025mpa. The connecting rod is made of 45 steel, with tensile strength limit of 600MPa and yield strength limit of 335mpa. The maximum stress value obtained by simulation is far less than the ultimate stress value of the material, so the connecting rod can be considered to meet the strength requirements.

5. Summary

(1) This paper analyzes the installation method and replacement process of the disc single edge hob, divides the disassembly path of the compression wedge into three steps, in which the plane curve movement path is the key and difficult point of the whole disassembly process. It focuses on analyzing
and planning the plane curve movement path to ensure that the disassembly process of the wedge is reasonable and feasible without collision interference. It uses the cubic spline interpolation method to construct in MATLAB software the disassembly path curve with continuous second derivative value is given, and 49 segment sub curves are generated by 50 data points, which can describe the disassembly path of compression wedge more accurately.

(2) The disassembly device of pressing wedge is divided into two parts: wedge clamping mechanism and path guide mechanism. Combined with the common clamping mechanism, the traditional three jaw chuck drive mode is transformed into direct drive of hydraulic motor to achieve the design purpose of stably and reliably clamping wedge shaft. According to the three steps of disassembly process of pressing wedge, the path guide mechanism is divided into linear reciprocating motion module and curve the former adopts ball screw linear module, the latter adopts the structure of two degree of freedom mechanical arm. Through the kinematic analysis of the mechanical arm, the feasibility of the path guidance mechanism is proved. Finally, nx10.0 software is used to establish the three-dimensional parametric model of all parts and complete the assembly, and then the solid assembly model of the compression wedge disassembly device is established.

(3) The manipulator model is built in the robotics toolbox of MATLAB software, and the correctness of kinematics equation is verified by comparison solution; the workspace of the manipulator is obtained by Monte Carlo simulation, and the correctness of the theoretical working area of the manipulator is verified by comparison; the multi node rail of the manipulator joint is carried out by the method of combining quintic and cubic spline interpolation Track planning, based on the middle data points of the expected path, calculates the displacement, velocity and acceleration curves of the two joints of the manipulator, and verifies the good movement stability of the manipulator.

(4) Through the joint simulation method of Adams and ANSYS, the rigid flexible coupling dynamic simulation analysis is carried out on the operation process of the compression wedge dismantling device, and the movement track of the compression wedge in the dismantling process is obtained. Compared with the expected path curve, the feasibility of the dismantling device is proved; the stress distribution of the connecting rod is evaluated and analyzed, and it is verified that the strength requirements of the material can be met, which is more true In order to reduce the test cost of physical prototype, the actual working condition is simulated on the spot.

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