Dynamic Simulation and Analysis of the Synchronous Mechanism of High-Speed Machine Tool Protective Cover with Joint Clearance

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Abstract. The synchronous mechanism is the driving part of the machine tool guide rail protection device, which makes the relative speed of each cover sheet the same, which can well reduce the vibration and noise generated by the machine tool protection device. In high-speed operation, because the gap in the hinge pair of the synchronous mechanism has a great influence on its movement accuracy, this paper establishes a multi-body dynamics model of the synchronous mechanism of the high-speed machine tool guide rail guard based on the Hertz theory, and uses ADAMS to The dynamic simulation analysis of the synchronous mechanism of the clearance shows that the pin near the joint between the worktable and the cover has the greatest influence on the motion accuracy of the synchronous mechanism. At the same time, the speed of the pin is analysed under different clearances. The transformation law of acceleration, contact and collision force of the kinematic pair with clearance and its influence on the performance of high-speed machine tool guards.

1 Introduction

High-speed rail shield is an indispensable part of high-speed machine tools, which plays an important role in ensuring high precision, high speed and low noise of CNC machine tools [1]. As the main driving mechanism of high-speed rail shield, the motion precision of the co-moving mechanism is required to be higher and higher under the condition of high-speed motion.

Due to machining error, assembly error, wear and other reasons, it is inevitable that there will be gaps in the motion pair sufficient for the synchronous mechanism [2]. The existence of the gap significantly broke the ideal organization model, so that the movement characteristic of institutions appear error, because of the machine tool guideway protective device is a reciprocating motion, the workbench when start, run, and stop the effect of friction and impact load lead to clearance, will accompany the vibration and noise produced at the same time, and even cause the failure of kinematic pair and destruction.

This paper takes the co-acting mechanism of the DVG850 high speed vertical machining center protection device as the research object, establishes the dynamic model with kinematic pair clearance, Uses ADAMS to carry on the dynamic simulation of the co-acting mechanism with different clearance, and analyses its influence on the working performance.
2 The structural principle of synchronous mechanism

Figure 1 and 2 is the general schematic diagram of the guide rail protection device of DVG850 high speed vertical machining center, which is mainly composed of cover piece, slide block, scraper and synchronous mechanism. Protective device cover the first piece of fixed by screw and guide rail, a final cover with fixed worktable, cover each piece with pin shaft link mechanism in the middle of the row, and thus drive do isometric mobile cover each piece, because of the high speed rail shield under the working condition of high speed and high acceleration, therefore, in the middle row of kinematic pair clearance, will greatly affect the movement precision of mechanism, so that the cover piece movement does not reach the designated position, vibration and noise.

3 Dynamic model of synchronous mechanism with joint clearance

3.1 Vector model of movement pair clearance

Ideally, the center distance between each articulated movement secondary axis of the same moving mechanism and the connecting rod hole is 0, but in actual situations, due to the existence of the gap, the center distance between the two is not 0, so that the rotating pair produces impact and For collision, Figure 3 shows the rotating pair with clearance [3]. There are generally three motion states of a rotating pair with a gap:

Continuous contact (pin shaft and connecting rod hole always keep contact).
Free movement (the pin shaft and the connecting rod hole do not contact, the pin shaft is in free movement).
Collision (the pin shaft and the connecting rod hole have a contact collision, and a collision force is generated) [4].
3.2 The model of contact collision force of the kinematic pair clearance

When two rotating sub-parts with a gap are in contact, it will cause the transformation of constraint conditions and increase the force constraint. The dynamic equation of the same moving mechanism can be expressed [5] as:

\[ M \ddot{q} + k \dot{q} + \varphi_T \lambda = Q + F \]  

(1)

\[ \varphi(q, t) = 0 \]  

(2)

The contact force model based on the ADAMS simulation software platform is determined by the impact function, which uses a nonlinear spring damping model to calculate the contact force. When \( \delta \geq 0 \), the function is activated. The normal contact force is composed of rigid contact force and viscous damping force, and its specific expression [6] is:

\[ F_n = k \delta + \text{step}(\delta, 0, 0, d_{\text{max}}, C_{\text{max}}) \frac{d\delta}{dt} \]  

(3)

The tangential friction at the gap can be calculated using the Coulomb friction model, and its expression is [7]:

\[ F_t = -\mu_d F_n \text{sgn}(v) \]  

(4)

\[ v(q, q, t) \neq 0 \]  

(5)

4 The establishment of the simulation model of the synchronous mechanism with the movement pair clearance

4.1 The establishment of three-dimensional model of synchronous mechanism

The DVG850 high-speed vertical machining center protection device has a total of 6 cover pieces, all of which are connected to the middle row pin shaft of the synchronous mechanism. Use UG to establish a synchronous mechanism, which is composed of a long connecting rod, a short connecting rod and a pin shaft. The long connecting rod is 148mm in length, 20mm in width, 4mm in thickness, and 8mm in the connecting rod hole; the short connecting rod is 74mm in length, 20mm in width, and 4mm in thickness; the pin shaft is simplified as an 8mm cylinder. The completion of assembly establishment is shown in Figure 4. Since the driving pin of the synchronous mechanism always starts to move under the traction of the workbench in actual work, the pin near the joint between the workbench and the cover is most likely to wear out. The gap is more likely to affect the overall motion accuracy of the simultaneous mechanism. Therefore, the position of the motion pair with the gap is set as the rotation pair that moves with the worktable, and the gap is adjusted by model.

Figure 4. Three-dimensional model of synchronous mechanism.
4.2 The establishment of multi-body dynamic model of the same moving mechanism

Export the 3D model established by UG into the Parasolid file format, and then import it into ADAMS, and set up the material, constraint pair, drive and contact force in turn to construct its dynamic equation.

![Figure 5. Three-dimensional model of synchronous mechanism.](image)

Use Revolute to define the rotation pair without gap, and use Contact to define the contact force for the rotation pair with gap; set the pin at the right end and the ground as the moving pair, the direction is along the common tangent of the middle row pin axis, and the drive is set at the most Pin on the right end [8]. The final dynamic model of the simultaneous mechanism is shown in Figure 5.

5 Dynamic simulation structure and analysis of synchronous mechanism

5.1 Set simulation parameters

Due to the synchronous mechanism of the protective cover of high-speed machine tools requires a speed not less than 60m/min and an acceleration not less than 2g. Therefore, the rightmost drive function is defined as: IF (time-0.05: -20000*time, -1000, -100), the simulation time is 0.1s, and the number of steps is set to 1000 [9].

5.2 Simulation result extraction and analysis

Perform dynamic simulation calculation on the dynamic model of the same moving mechanism. After the simulation is completed, the speed and acceleration of each pin in the middle row and the collision force of the kinematic pair with clearance are extracted. Then, the working performance of the synchronous mechanism under different gaps is obtained by simulation by changing the gap amount. Figure 6 shows the comparison of the acceleration parameters of each pin when there is no gap and the gap is 0.1. The red solid line is the measurement value with gaps, and the dashed line is the measurement value without gaps.

![Figure 6. The acceleration of each pin when the clearance is 0.1.](image)
It can be seen from the acceleration graph of each pin that the acceleration at each pin fluctuates, and the maximum peak acceleration of pin 1 to pin 6 increases sequentially. The gap has the greatest impact on the acceleration at pin 6, so focus on the analysis of pin 6.

It can be seen from Figure 7, 8 and 9 that there is and no gap at the pin 6, the displacement curve is relatively stable, there is no obvious local fluctuations, and the gap has almost no effect on the displacement; in the speed curve, the speed fluctuates at the beginning of the acceleration stage, which is generally relatively consistent. The influence of speed is small; and in the acceleration curve, the gap and no gap are generally consistent, but there are large fluctuations in the local area, especially in the initial acceleration stage, the fluctuations are very severe.

Figure 10 and 11 are a comparison of the motion parameters of the pin with a gap of 0.4mm. It can be seen from the figure that at the beginning of the acceleration phase, the speed and acceleration fluctuations are more obvious than when the gap is 0.1mm, and the fluctuation amplitude increases.

Figure 12 and 13 show the comparison of the contact collision force at the pin 6 with a gap of 0.1mm and a gap of 0.4mm. It can be seen from the figure that the greater the gap, the lower the frequency of collision, but the greater the magnitude of the collision force.
6 Conclusion

In this paper, the high-speed machine tool protective cover co-moving mechanism with rotating pair clearance is the research object. ADAMS establishes the dynamic simulation model of the co-moving mechanism, and uses the contact pair Contact in ADAMS to define and calculate the contact collision force. The simulation analysis of the synchronous
mechanism with clearance shows that the speed and acceleration have the greatest influence on the pin 6 and the influence of different clearances on the speed and acceleration of the pin 6 and the contact and collision force of the kinematic pair. The simulation results show that the clearance of the kinematic pair basically has no effect on the displacement of the pin 6. However, there is a local fluctuation in the initial acceleration stage, but the overall influence is small, while the local obvious fluctuation in acceleration has the greatest influence. And when the gap increases, the fluctuations in velocity, acceleration, and contact collision force become more obvious. This is because when the gap increases, the collision interval between the connecting rod and the pin increases. The structure of the simulation is consistent with the situation of increased wear of the rotating pair of the high-speed machine tool guard in the engineering practice.

As the pin shaft is connected with the high-speed shield plate, assembly error and wear will lead to improper movement, vibration and noise of the shield plate. Therefore, the synchronous mechanism must meet the requirements of assembly accuracy. Consider lubricating and installing bushings for protection.

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References