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Application of Damping Vibration Reduction Technology in Machine Tool Transformation

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Abstract

The turning tool post is a key structural component of CNC vertical lathes, whose structural characteristics directly determine the machine tool's rigidity, machining accuracy, vibration resistance, cutting efficiency, and service life. Dynamic performance is even the core factor affecting the overall machine performance. Aiming at the cutting chatter problem during the machining of the SXT-032 CNC vertical lathe, this study modified the equipment for damping vibration reduction based on the principle of damping vibration energy dissipation. Measures included optimizing the ram structure of the vertical tool post, adopting a rolling-sliding composite guideway, and integrating a built-in damping system. Practical tests verified that: after modification, under the working conditions of ram extension of 500 mm, cutting depth of 5 mm, and feed rate of 0.5 mm/r, the cutting chatter of the equipment completely disappeared. Machining stability and surface quality were significantly improved, achieving the expected vibration reduction effect.

Keywords: *cutting chatter; CNC vertical machine tool; damping vibration reduction; ram modification*

1 Introduction

In recent years, machining vibration has been extensively studied as a common issue in manufacturing. Among various machining vibrations, self-excited vibration (i.e., cutting chatter)—the most intractable type—is the primary factor restricting high-speed machining stability. Cutting chatter refers to an unstable dynamic process between the machine tool, workpiece, and cutting tool during machining, which is an intense vibration excited by the mechanical system itself. In the machining industry, cutting chatter leads to poor workpiece surface quality, increased machining noise, shortened tool life, and damage to the machine tool system.

The vertical tool post is a critical component of CNC vertical lathes, whose accuracy and performance are closely related to the machine's overall accuracy, reliability, and durability. However, the vertical tool post is also the weakest part in terms of rigidity. Improving its performance—especially vibration resistance—is crucial for enhancing the overall performance of CNC vertical lathes.

2 Problem Analysis of the SXT-032 CNC Vertical Lathe

Figure 1 shows the SXT-032 CNC vertical lathe, with a maximum machining diameter of 6300 mm. The equipment adopts a fixed-beam gantry frame structure (the gantry frame is a purchased welded component), and the vertical tool post uses a T-shaped interface rolling guideway with a maximum vertical stroke of 1000 mm. During machining, the equipment exhibited cutting chatter: the ram and beam slide showed varying degrees of chatter, with the ram chatter being the most obvious. The machined workpiece surface roughness changed significantly, showing chatter textures. Specific phenomena are as follows:

(1) When the ram extension exceeded 300 mm, using a finish turning insert (R 0.4) with a cutting depth of 4 mm and feed rate of 0.5 mm/r, obvious jumping tool marks appeared with significant vibration Figure 2;

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(2) When the cutting depth was 1 mm and feed rate was 0.7 mm/r, the effect improved, but the turning trajectory remained obvious and vibration persisted Figure 3;

(3) When the cutting depth was 3 mm and feed rate was 0.3 mm/r, the tool feed was normal; however, when the ram extension reached 500 mm, the ram's cutting performance reached its limit.

Figure 1 SXT-032 CNC Vertical Lathe

Figure 2 Surface Roughness of the Turned Spigot

Figure 3 Cutting Texture of the Turned Workpiece Inner Hole

A test was conducted on the turning plane: when the ram extension reached 650 mm, cutting depth was 2 mm, feed rate was 0.3 mm/r, and worktable speed was 10 r/min, the ram chattered, and slight swing of the ram was visually observable Figure 4.

Figure 4 Turning Texture of the Plane

The authors identified design defects in the equipment as the root cause:

(1) The T-shaped ram of the vertical tool post had an excessively large spacing in the length direction and was an open-type welded structural steel ram. The window opening accounted for 50% of the cavity interface, resulting in severe stiffness loss;

(2) The ram guideway adopted a rolling guideway structure. Although rolling guideways have advantages such as high accuracy, good wear resistance, high sensitivity, and easy maintenance, their poor vibration resistance makes them unsuitable for large-scale turning equipment.

These defects inevitably lead to cutting chatter during machining.

3 Damping Vibration Reduction Modification Measures

3.1 Literature review on chatter suppression

Scholars at home and abroad have conducted extensive research on machining chatter and confirmed that reducing or eliminating tool vibration is key to ensuring machining quality. Relevant studies include:

(1) H Moradia et al. studied the influence of vibration absorber parameters in vibration-damping boring bars on their damping performance and derived corresponding variation laws;

(2) F Bakhtiari et al. designed a dynamic vibration-absorbing boring bar with a large length-diameter ratio and optimized its main parameters;

(3) Suyama et al. used cemented carbide and particle damping rods to improve boring bar rigidity;

(4) Liu Lijia et al. designed a variable stiffness-constrained damping boring bar (composed of a continuous body and a vibration unit) and added an intelligent drive unit at the bar end to realize on-line regulation;

(5) Shen Xingquan et al. developed an adaptive chatter suppression device based on the magnetorheological effect for lathe boring: three piston rod contact blocks (matching the boring bar diameter) were in light radial contact with the boring bar, and built-in magnetorheological fluid moved through the gap between the piston outer wall and cylinder inner wall under piston extrusion to suppress chatter.

3.2 Modification design

This equipment modification drew on the previous

"Research on Dynamic Characteristics of Damping Dynamic Vibration-Reduction Vertical Tool Posts" and took "damping dynamic vibration-reduction tools" as the reference. A "built-in vibration absorber for dynamic vibration-reduction boring bars" was designed for the vertical tool post to improve the chatter stability of the vertical tool post ram. This design is of great significance for enhancing tool post rigidity, solving chatter, improving machining quality and efficiency, and extending tool life.

3.2.1 Ram damping structure modification

The damped dynamic vibration-reduction ram consists of two parts: the tool post ram and the damping system. The damping system includes damping fluid, a vibration-damping block, and annular rubber rings. The damping fluid surrounds the gap between the vibration-damping block and annular rubber rings to provide resistance for the block's movement. The vibration-damping block acts as the "vibration core" in the ram—according to vibration absorber theory, a heavier mass block enhances damping effect, so the vibration core is made of high-density cemented carbide. The annular rubber rings (installed at both ends of the damping block) serve as supports to prevent contact or elastic collision between the damping block and ram. With a high elastic modulus, the annular rubber rings can provide a certain spring stiffness for the damping block through radial deformation (within the elastic range), showing a linear relationship with the applied load.

During machining, the ram generates cutting chatter under impact loads, and the internal vibration core produces forced vibration. The damping system then absorbs the kinetic energy of the ram vibration to achieve vibration reduction. Specific modifications included:

(1) Sealing the spaced cavities at the bottom of the ram;

(2) Adding 425 steel balls (diameter: 100 mm) and filling the cavities with methyl silicone oil;

(3) Filling the remaining cavities with steel fiber filaments and special micro-expansion grouting material Figure 5.

Figure 5 Structural Modification of the Damping Vibration-Reduction Ram

3.2.2 Guideway upgrade

The guideway was modified to a rolling-sliding composite structure: the original rolling guideway was retained, and a sliding guideway was added. The guideway was wrapped in the vertical tool post slide via side adjustment wedges and upper/lower pressure plates. The moving guideway pair used a 2A12 sliding guideway plate, and the contact surface of the tool post slide was inlaid with Turcite "B" SLYDWAY composite guideway soft belts (produced by SHAMBAN, USA). These soft belts solve long-standing problems of metal-to-metal guideway pairs, as follows:

(1) Anti-crawling performance: According to a report from Loughborough University (UK), the speed-friction coefficient curve of guideway pairs with SHAMBAN soft belts shows a "positive slope". Physicists Burdekin and Bell noted that sliding guideway pairs with a "positive slope" speed-friction coefficient relationship do not experience crawling;

(2) Stable friction coefficient: Tests by Engineer Cognigni (Italy) showed that the friction coefficient of the composite guideway soft belt is 0.05 under dry friction (no lubrication) and 0.03 with lubrication, with stable values;

(3) Excellent wear resistance and accuracy retention: For metal-to-metal guideway pairs, the softer surface

wears more severely (greater hardness difference leads to more wear). The composite guideway soft belt (lower hardness than metal) concentrates wear on itself. Tests showed that under 6 kg/cm^2 pressure, the soft belt's average wear thickness is less than 0.01 mm after 100 km of operation. Under the same working conditions, the accuracy retention of soft belt guideway pairs is 3-5 times that of traditional guideway pairs;

(4) Easy maintenance: When the old metal guideway pair wears, both the ram and vertical slide guideway surfaces need reprocessing. For the modified guideway pair, only the soft belt needs replacement-reducing workload, maintenance costs, and ensuring stable tool post operation and long accuracy retention Figure 6.

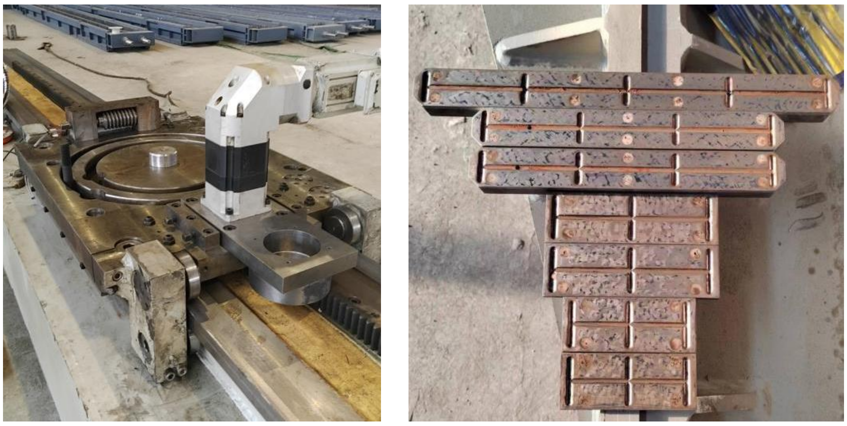

Figure 6 Equipment Modification Process

4 Test Results and Verification

The modification of the SXT-032 equipment was completed in cooperation with Qiqihar Tuoli Metrology Equipment Co., Ltd. Post-modification debugging and damping performance tests were conducted: with the vertical ram extending 500 mm, worktable speed of 12 r/min, intermittent cutting of a typical workpiece's inner hole (cutting depth: 5 mm, feed rate: 0.5 mm/r), the equipment showed stable machining performance, and cutting chatter completely disappeared Figure 7.

Figure 7 Modified Equipment

5 Conclusions

For the cutting chatter problem of the SXT-032 CNC vertical lathe, this study implemented targeted modifications: optimizing the ram's damping structure (integrating a built-in damping system with high-density cemented carbide vibration core, steel balls, and methyl silicone oil) and upgrading the guideway to a rolling-sliding composite structure with SHAMBAN Turcite "B" soft belts. Post-modification tests confirmed that the cutting chatter was eliminated under the specified working conditions, and machining stability and surface quality were significantly improved. The modification scheme provides a feasible reference for vibration reduction of large-scale CNC vertical lathes.

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