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Effect of Wear in Linear Rolling Guide Rails on Motion Accuracy of CNC Machine Tool Feed Systems

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Introduction

Linear rolling guide rails are essential components in CNC machine tool feed systems due to their high stiffness, low friction, and precise motion capability. During long-term operation, repeated contact between rolling elements and raceways causes surface wear, which gradually degrades motion accuracy and positioning performance.

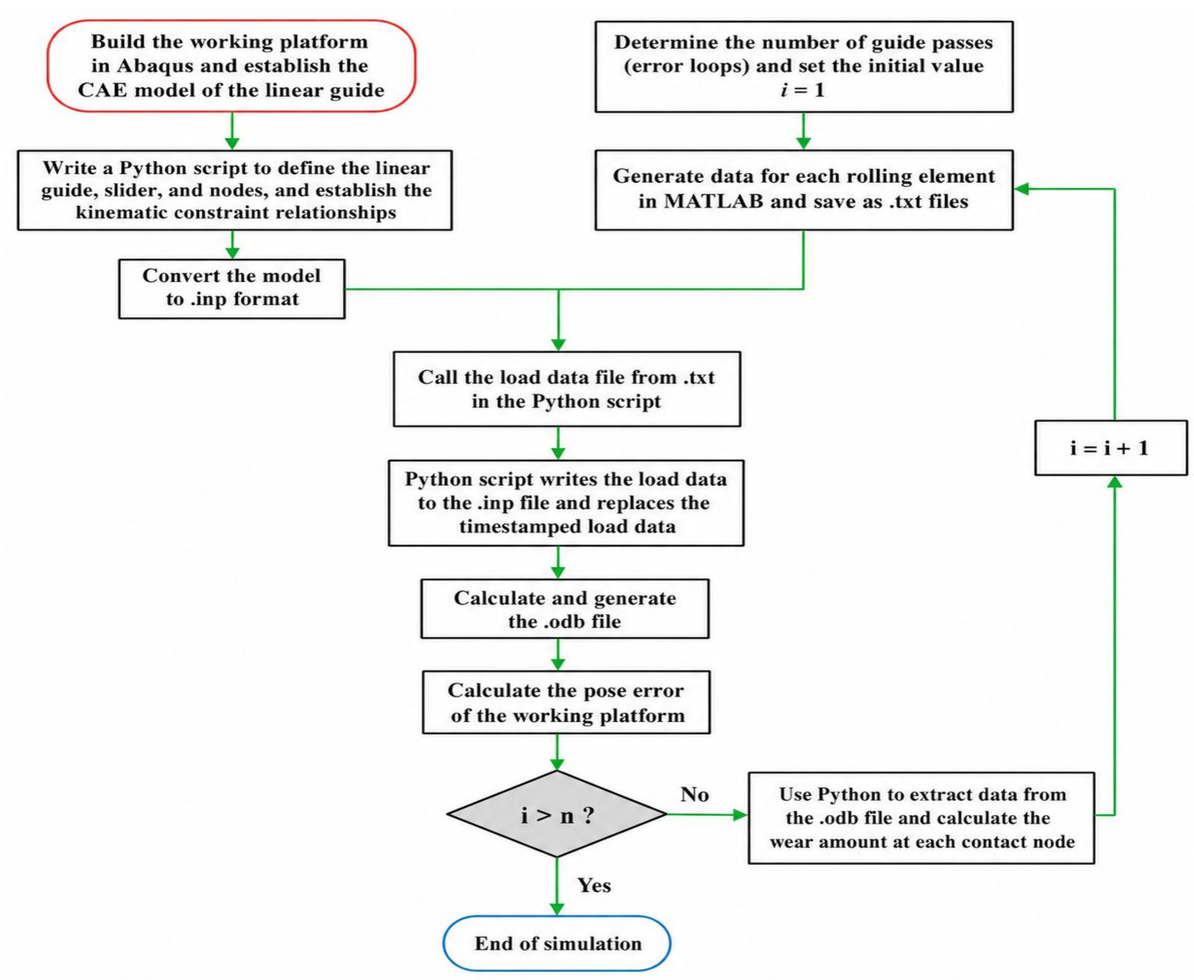
Wear changes the contact geometry and load distribution inside the guide system, resulting in stiffness reduction and motion instability. These effects become more significant in high-precision machining applications where micron-level positioning accuracy is required. Therefore, understanding the relationship between wear behavior and motion accuracy is important for improving machine reliability and maintenance strategies.

This study investigates the effect of wear in linear rolling guide rails on the motion accuracy of CNC feed systems through numerical analysis. The influence of wear depth and wear distribution on positioning error and motion stability is evaluated under different loading conditions.

Methods

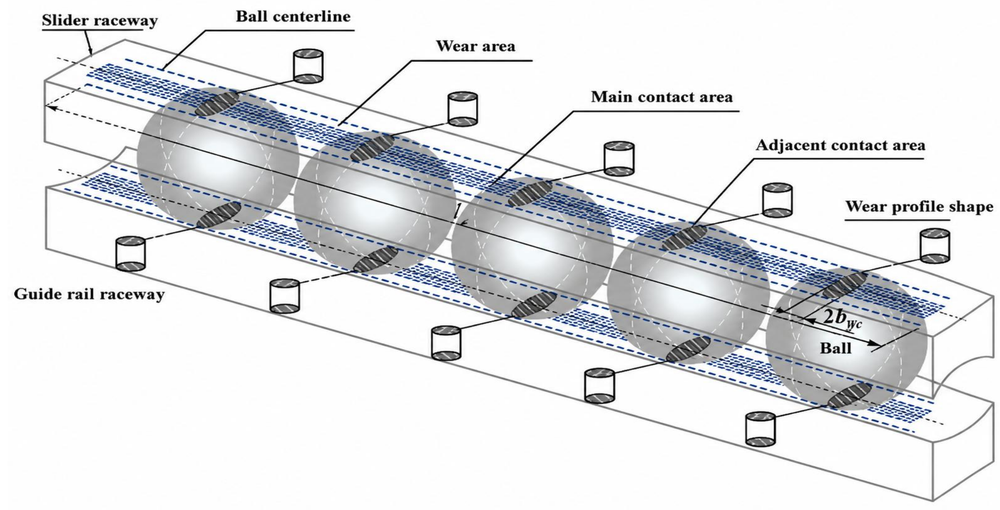
A numerical model of a linear rolling guide rail system was developed to analyze the influence of wear on feed system accuracy. The model includes the guide rail, carriage, rolling balls, and contact raceways.

Wear was introduced by modifying the raceway surface geometry according to different wear depths and localized wear distributions. Contact stiffness degradation caused by wear was incorporated into the model to simulate the change in mechanical behavior during operation.

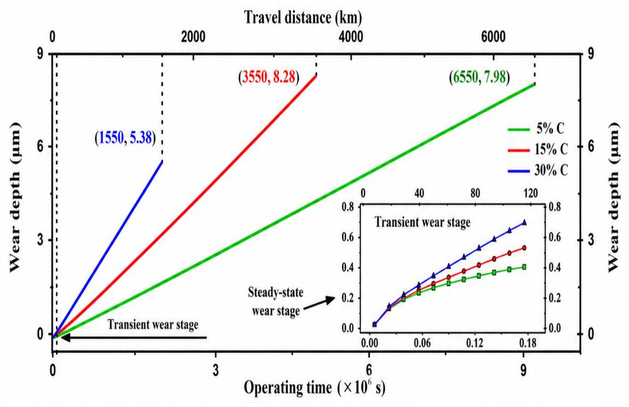


Simulation Analysis Flowchart

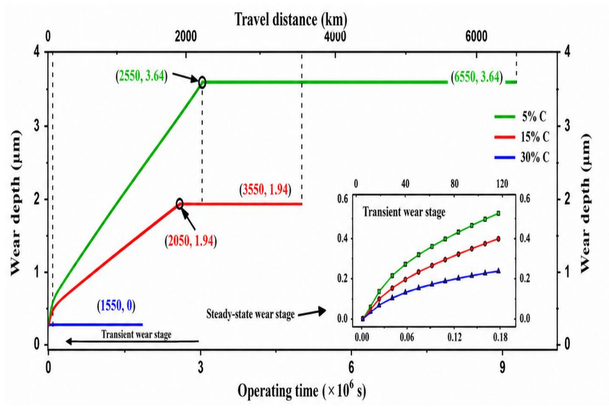
Graphics / Images



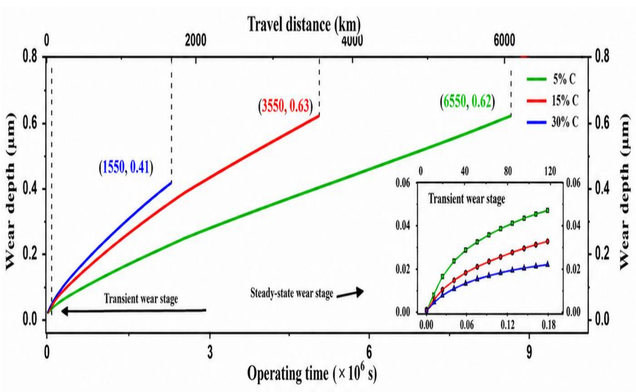
Schematic diagram of contact and wear between balls and raceways



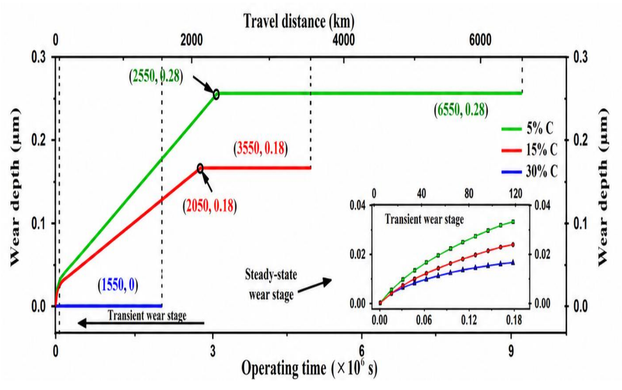
Wear depth variation of the upper raceway (i = 1 or 2) of the slider



Wear depth variation of the upper raceway (i = 3 or 4) of the slider



Wear depth variation of the upper raceway (i = 1 or 2) of the guide



Wear depth variation of the upper raceway (i = 3 or 4) of the guide

Conclusions

- Wear depth increases with operating time and becomes more severe under higher external loads due to larger contact stresses.
- The upper raceways carry higher loads and therefore show greater wear than the lower raceways, with the maximum slider wear depth reaching 8.28 μm under the 15% C load condition.
- The wear process includes a transient wear stage with rapid growth and a steady-state stage with nearly linear wear increase after the running-in process.
- As wear progresses, preload gradually decreases. When the external load exceeds the preload threshold, the lower raceways become unloaded and the wear rate drops to zero.
- The rail raceways exhibit similar wear trends as the slider raceways, but their wear depths are much smaller because the effective rolling distance on the rail is significantly larger.