Numerical Investigation of Ball Stress Distribution in Linear Rolling Guide Rails under Preload and External Loading

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Introduction

Linear rolling guide rails are widely used in precision machinery, CNC equipment, and automation systems because of their high stiffness and positioning accuracy. During operation, preload is commonly applied to improve rigidity and reduce vibration. However, preload combined with external loading can significantly affect the stress distribution of rolling balls, which may influence contact fatigue life and running performance.

This study focuses on the numerical investigation of ball stress distribution in a linear rolling guide under different preload and external loading conditions. A contact mechanics-based numerical model is developed to evaluate load sharing among rolling balls and identify the maximum contact stress. The results provide insight into the influence of preload on load distribution and structural reliability of linear guide systems.

Methods

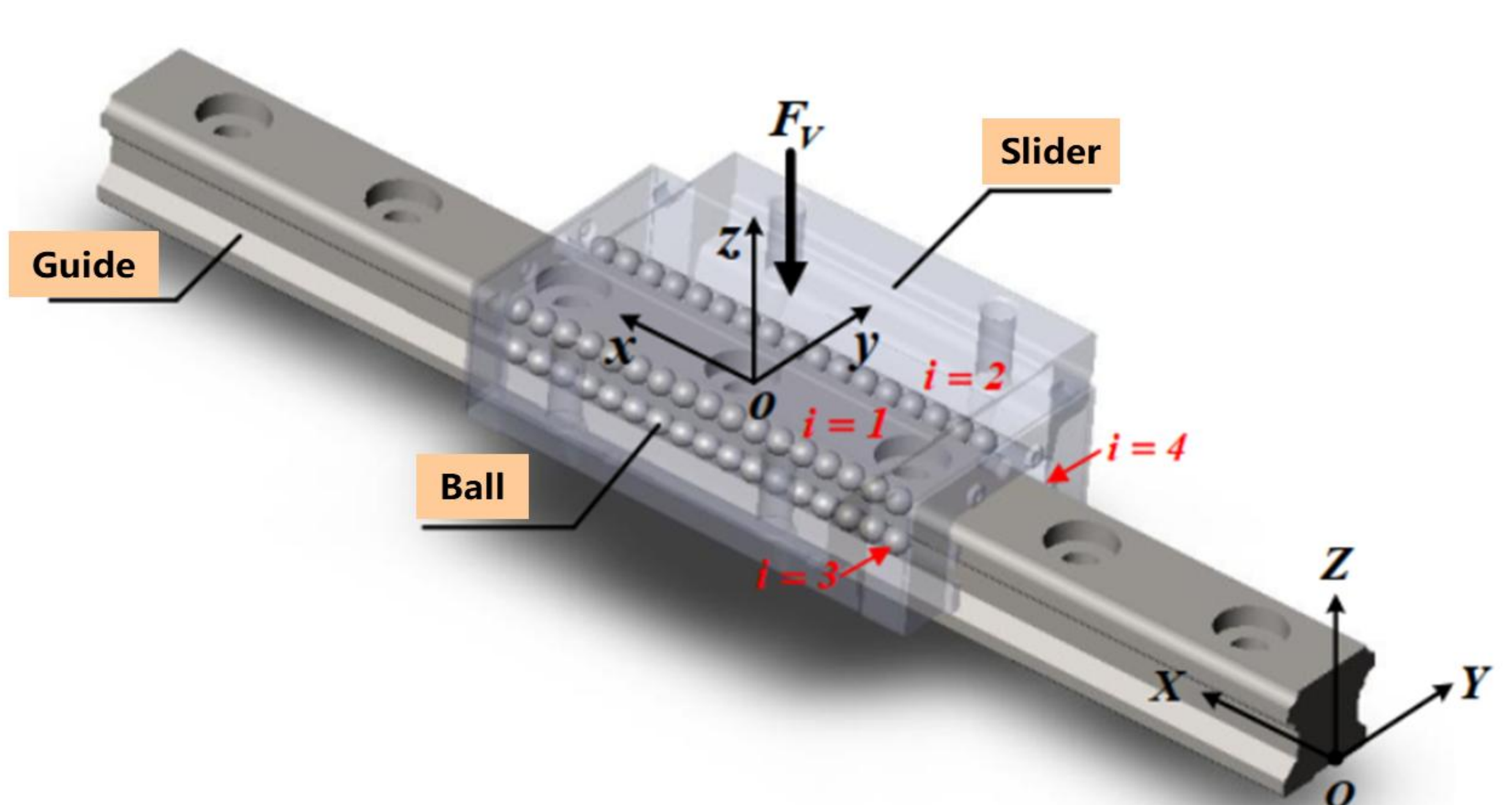
A three-dimensional numerical model of a linear rolling guide rail was established. The rolling balls, carriage, and rail raceways were modeled based on Hertzian contact theory. Preload was introduced by applying an initial displacement between the carriage and rail, while external loading was applied vertically to the carriage.

The analysis procedure includes:

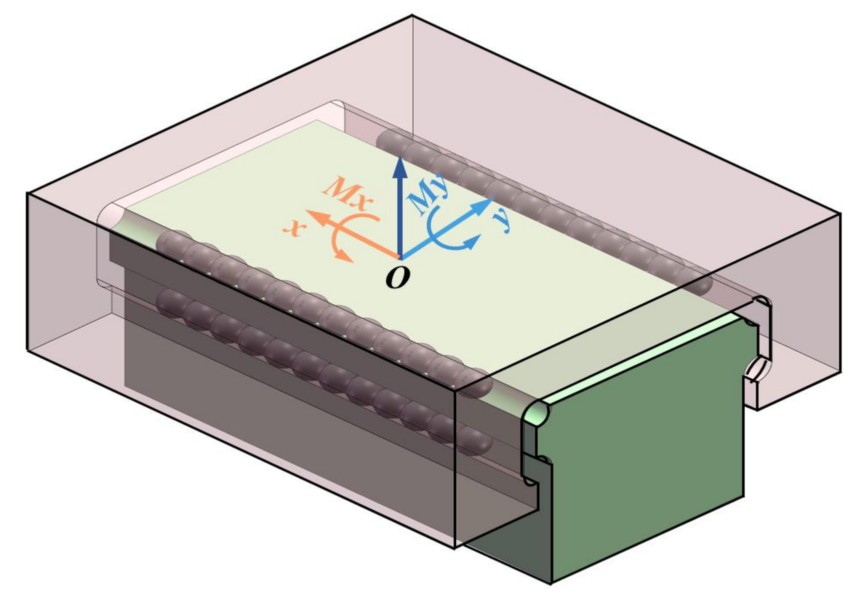
- Defining geometric and material parameters of the guide system.
- Applying preload conditions to generate initial contact forces.
- Applying external loads and calculating load distribution among rolling balls.
- Evaluating maximum contact stress and stress variation under different loading cases.

The numerical calculations were performed using finite element/contact analysis methods, and the stress distribution results were compared under multiple preload levels to investigate their influence on bearing performance.

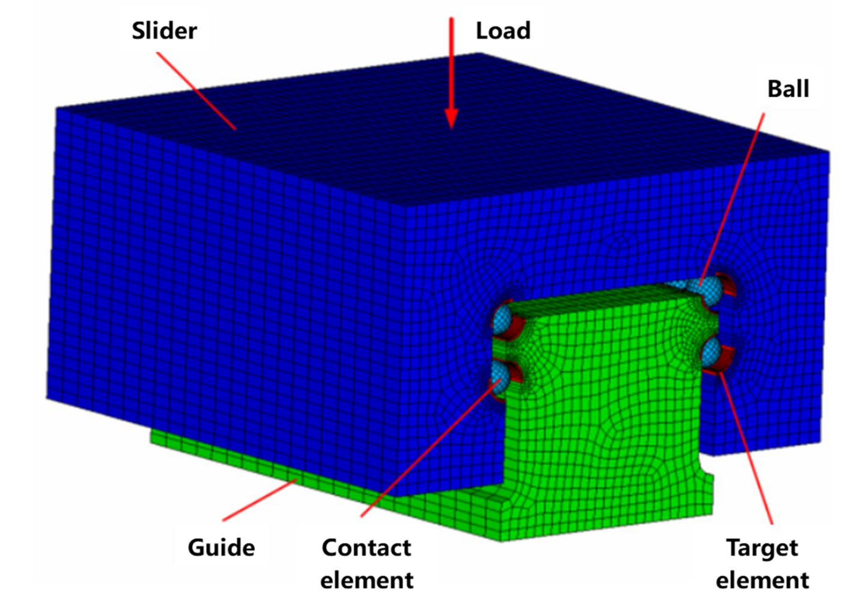
Graphics / Images



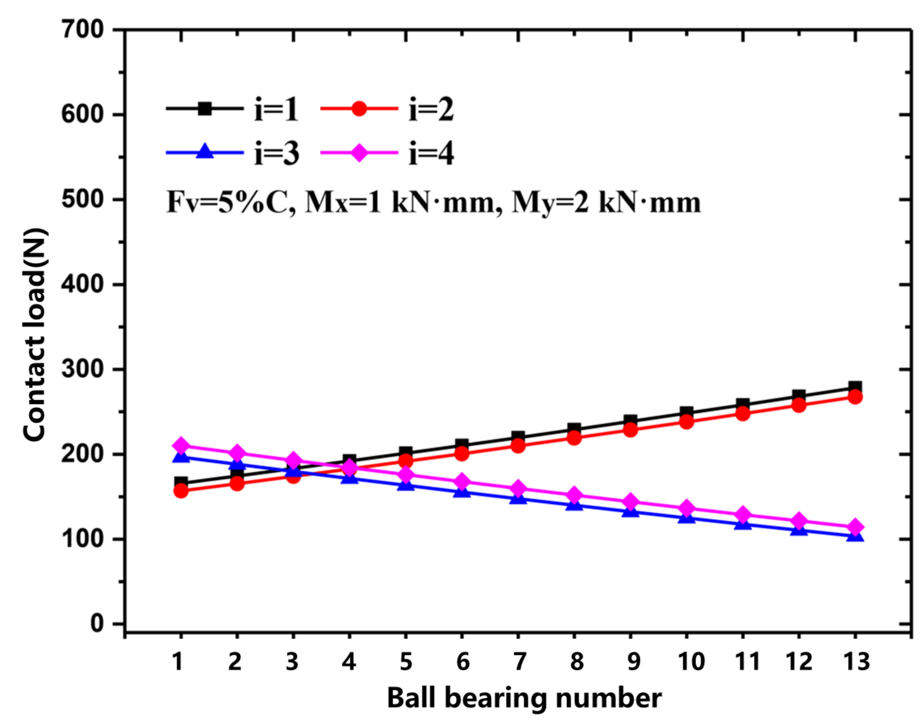
Linear rolling guide assembly diagram



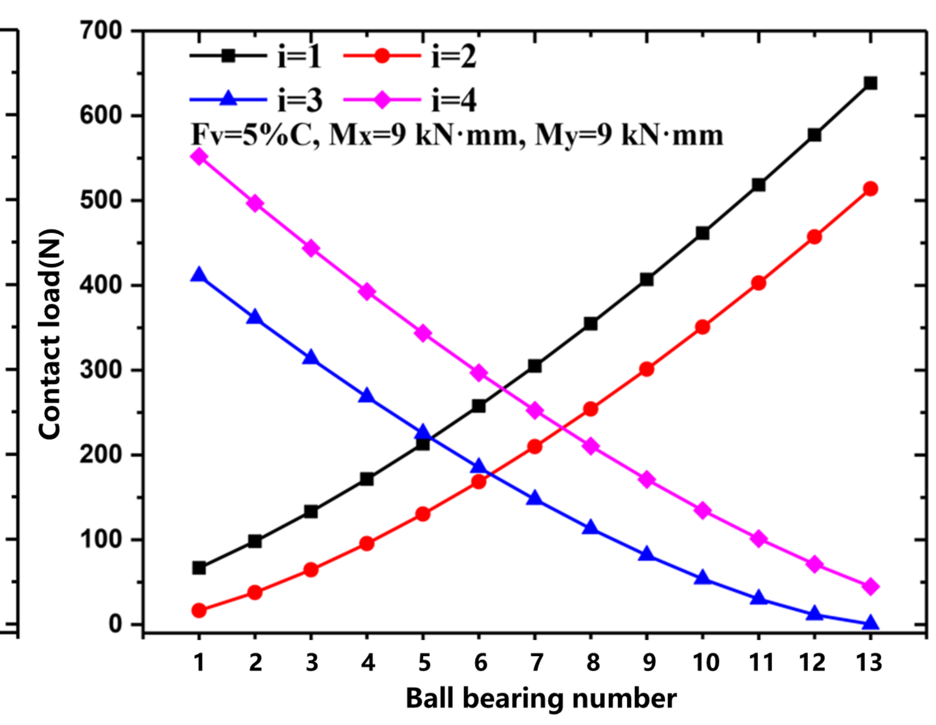
3D model of linear rolling guide



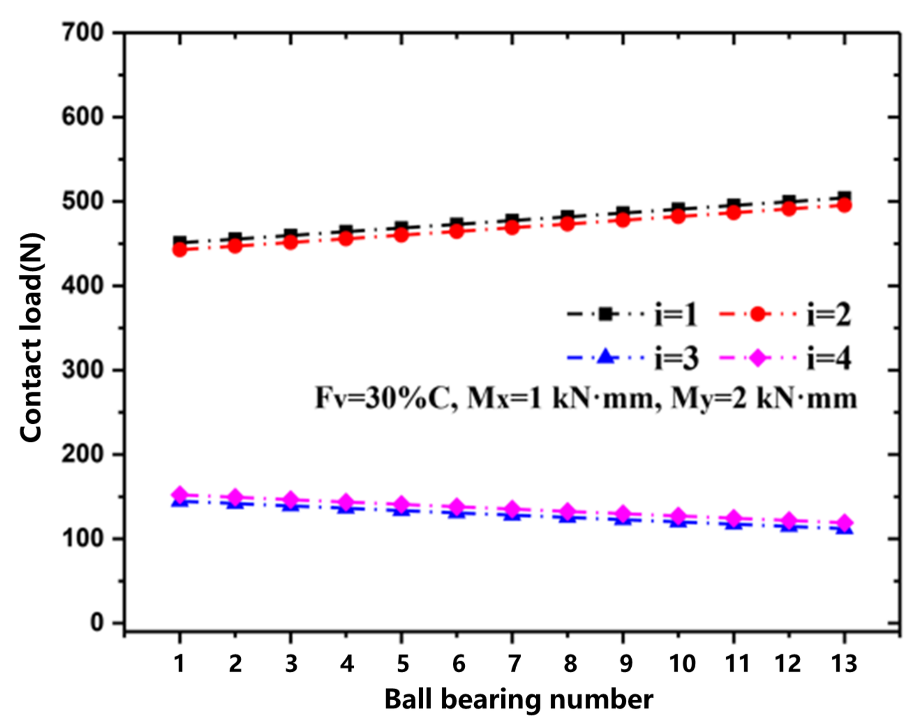
Mesh



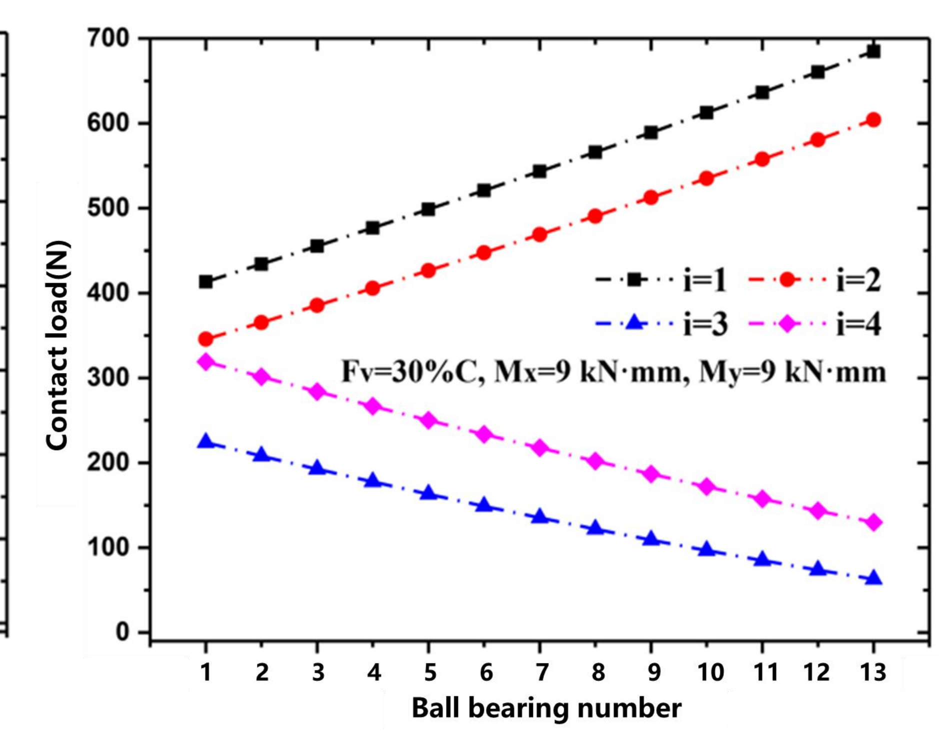
Case 1: Fv=5% C, Mx = 1kN · mm, My = 2kN · mm, C=20kN



Case 2: Fv=5% C, Mx = 9kN · mm, My = 9kN · mm, C=20kN



Case 3: Fv=30% C, Mx = 1kN · mm, My = 2kN · mm, C=20kN



Case 4: Fv=30% C, Mx = 9kN · mm, My = 9kN · mm, C=20kN

Conclusions

- Based on the aforementioned analysis and findings, the emergence of eccentric load torque leads to uneven loading of the balls in each column within the linear rolling guide pair, and this non-uniformity intensifies as the eccentric load torque increases.
- However, as the external load increases, a larger initial normal contact force can reduce the fitting clearance between the balls and the raceways, enhancing stiffness. Consequently, when subjected to eccentric load torque, deflection is minimized, and fluctuations in contact load distribution are reduced.
- In practical applications, balls with a diameter slightly larger than the distance between the slider and the guide raceways are commonly employed to eliminate radial clearance between the balls and the raceways, generating an initial normal contact load, known as preload.
- Therefore, in practical use, selecting an appropriate preload according to operating conditions can have a positive impact on the accuracy and service life of the linear rolling guide pair.