TELKOMNIKA, Vol.11, No.1, January 2013, pp. 436~442
ISSN: 2302-4046

Dynamical Characteristics of the Linear Rolling Guide with Numerical Simulation and Experiment

Xiaopeng Li*, Hao Guo, Jingnian Liu, Yali Liu
School of Mechanical Engineering & Automation, Northeastern University, Shenyang, China
*Corresponding author, e-mail: xpli@me.neu.edu.com

Abstract

Research results will be different when the boundary condition is changed. In this work, the finite element model of the linear rolling guide of the NC machine tool is established. Then the natural frequencies and the corresponding vibration modals of the linear rolling guide model are obtained with two different boundary conditions. One boundary condition is that the movable joint surface of the linear rolling guide is considered, and regardless of the influence of the bolt joint surface of the guide. And another boundary condition is that the movable joint surface of the linear rolling guide and the influence of bolt joint surface of the guide are all considered. By comparing the modal characters of the two states, it is proved that the movable joint and bolted interfaces of the guide have certain effects on the dynamic performance of the linear rolling guide. For the experiment, the linear rolling guide also has been tested in two ways, the slider excited and the sliding guide excited respectively. Comparing the results obtained from numerical simulation and experiment, the validity of finite element model and the influence of the boundary conditions on the interface of the linear rolling guide are verified. This will help the dynamic analysis on the linear rolling guide and other research objects.

***Keywords**: Linear rolling guide-Vibration-Dynamical Characteristic-Boundary condition-Modal experiment.*

1. Introduction

The joint surface of the linear rolling guide (LRG) has significant influence on the dynamic characteristics of machine tools. Particularly, the dynamic parameters of the joint surface have been the focus of research. Therefore, when conducting the study on the dynamic characteristics of the joint surface, two main factors should be considered: one is the establishment of an accurate dynamic model of the joint surface; the other is applying different boundary conditions. The reason is that when changing the restricted location and the restricted way, the inherent characteristics of the structure (such as natural frequency and vibration mode) will change [1, 2]. The establishment of the dynamic model on the joint surface is studied widely and deeply by many scholars all over the world. For example, a concept on an ideal joint surface was put forward by Prof Tong and Zhang. While researchers only concentrate on the inherent characteristics of the structure when referring to dynamics, the position and way the constraint is loaded is only often explained simply or even ignored [3], so it is necessary to identify and analyze the effects of boundary conditions on the joint surface of LRG.

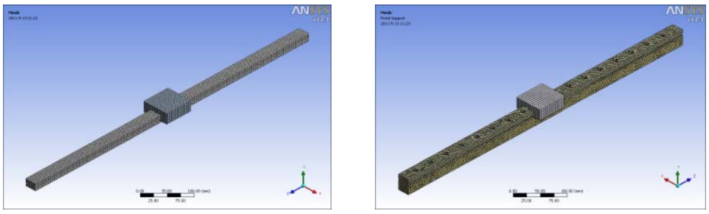
On the basis of previous studies, different natural frequencies and vibration modes are obtained by applying different boundary conditions. Then, by comparing the results, the effect of the joint surface is verified. Finally, the corresponding modal test is conducted to prove the validity of the FEM.

2. Modal Analysis of Linear Rolling Guide

The sliding guide is relatively complex. The internal shape of the slider is irregular, and there are many transitional curved surfaces. It is difficult to build the FEM if the model is analyzed according to the entity structure. Moreover, it may cause some problems. For example, the finite element mesh will be divided inappropriately; and the local mesh's density is distributed unevenly [4]. In this work, the dynamic characteristics of the joint surface is mainly considered, so that the model can be simplified in guaranteeing the equivalent of the quality and

Received August 14, 2012; Revised December 4, 2012; Accepted December 12, 2012

the stiffness. At the same time, the line is divided by the balls between the sliding guide and slider into a spring damping element to simulate the connection between the sliding guide and the slider [5, 6]. To facilitate the calculation, a total of 16 springs - damper units are used to simulate the joint surface [7]. The finite element model of the LRG is shown in Figure 1.



(a)Bolt joint not considered (b)Bolt joint considered

Figure 1. FEM of the guide with different situation

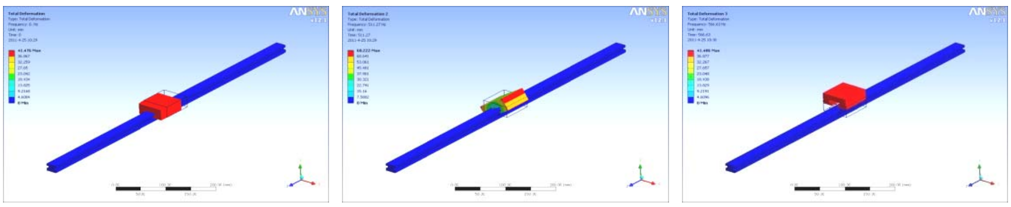
Then the natural frequencies and the corresponding vibration modes of the LRG are also obtained by the finite element analysis of the LRG in two different boundary conditions.

In boundary condition 1: the movable joint surface of the LRG is considered regardless of the guide bolt joint surface, and with the sliding guide is fully constrained on the ground. The finite element analysis results of LRG are shown in Table 1.

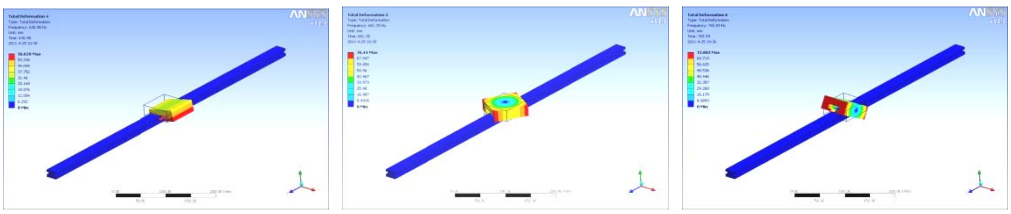
Corresponding to the different FEA frequencies, the first six order modes of LRG are shown in Figure 2.

Table 1. FEA results of the LRG on boundary condition 1

Order	Frequency/Hz	Vibration mode of slider
1	0	Translating along the Z axis
2	511	Turning around Z axis
3	566	Vibrating along the Y axis
4	631	Yawing along the X axis
5	681	Swing around the Y axis
6	765	Luffing along the Z axis



(a) First-order (b) Second-order (c) Third-order



(d) Fourth-order (e) Fifth-order (f) Sixth-order

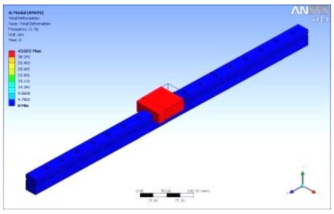
Figure 2. The first 6-order vibration modes on boundary condition 1

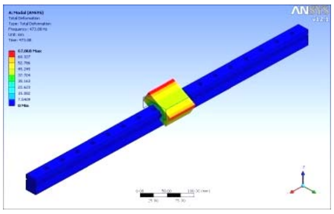
In the boundary conditions 2: the movable joint interfaces of the LRG and guide bolt joint surfaces are considered. Firstly, the prestressing analysis on the LRG is carried out, and then the method of the entity model is taken by the bolt to simulate its joint surface. The bolt is partly constrained with a 9.21N/m tightening torque applied while the guide is fully constrained. The modal analysis of the guide is taken under this condition. The FEA of frequency of the single slider is shown in Table 2.

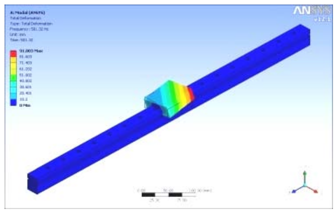
Corresponding to the different frequencies, the first six order modes of the LRG are shown in Figure 3. From Table 1 and Table 2, it can be found that the natural frequency and vibration mode by the finite element analysis are not the same in the boundary condition 1 and 2. Through this phenomenon the importance of the determining boundary condition will be realized when carrying out the analysis on LRG.

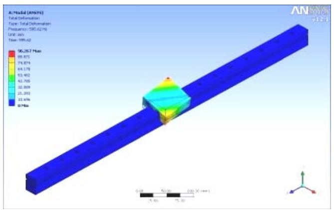
Table 2. FEA results of the LRG on boundary condition 2

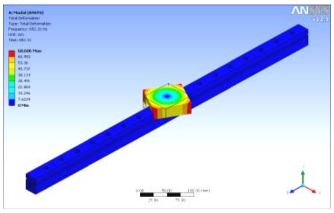
Order	Frequency/Hz	Vibration mode of slider
1	0	Translating along the Z axis
2	474	Turning around Z axis
3	501	Twisting around Z axis
4	596	Twisting around Z axis
5	618	Swing around the Y axis
6	703	Luffing along the Z axis


(a) First-order


(b) Second-order


(c) Third-order


(d) Fourth-order


(e) Fifth-order

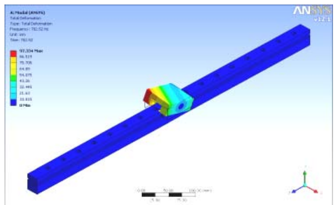

(f) Sixth-order

Figure 3. The first 6-order vibration modes on boundary condition 2

3. Experiment Analysis of Linear Rolling Guide

The experiment system is established to test the validity of the FEM. By comparing the tested results and the analyzed results [8, 9], it can be confirmed that the FEM established is correct.

The test system mainly consists of three parts: an excitation system, a signal pickup system and a data acquisition and data processing system. The principle of test is shown in Figure 4.

A multi-support excitation single-point response is chosen as the test method. During the experiment each measuring point is consecutively rapped 8 times with a hard hammer. The test needs a force sensor and an acceleration sensor. The force sensor, which measures the excitation signal, is mounted on the force hammer, while an acceleration sensor measuring the response signal is pasted with a permanent magnet. Each measuring point is equipped with three acceleration sensors for detecting response measurements in the direction of the x-axis, y-axis and z-axis. The force sensor and acceleration sensors are linked to the spectrum analyzer, and then the signal received is transmitted to the B&K data analyzer.

Reasonable selecting excitation point and vibration pickup point is very important. Meanwhile, it is necessary to arrange 36 measuring points on the slide and the slide surface symmetrically considering the structure of the LRG and the installation of sensors factors. The measuring points are shown in Figure 4.

In order to obtain the natural frequency of the LRG easily, this work chooses three portions of the straight guide to test: Firstly, the slider is excited. The normal and tangential dynamic flexibility amplitude-frequency curves are obtained by picking the results of the sliding guide. Secondly, the sliding guide is excited. The curves are obtained by picking the results of the slider. Lastly, the modal testing of the track is conducted, whose objective is to identify the natural frequency and damping of the LRG.

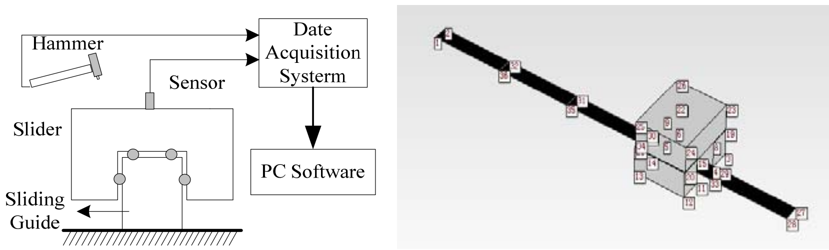
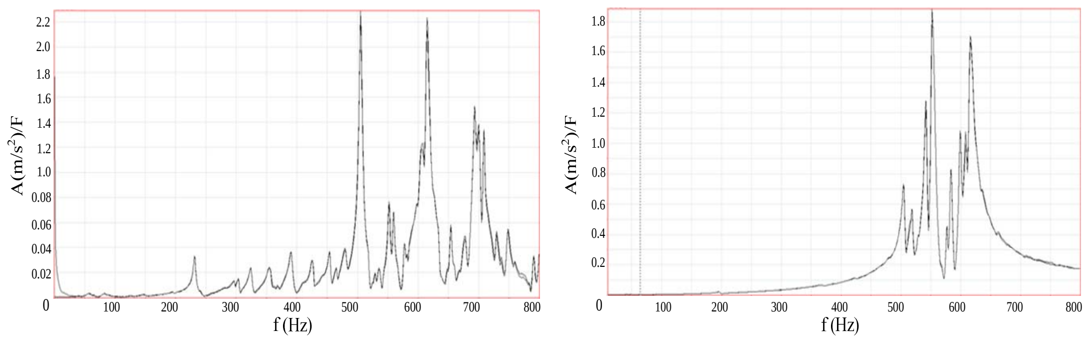


Figure 4. The schematic of experiment and measuring points



(a) Normal characteristic curve (b) Tangential characteristic curve

Figure 5. Amplitude-frequency characteristics curves exciting the slider

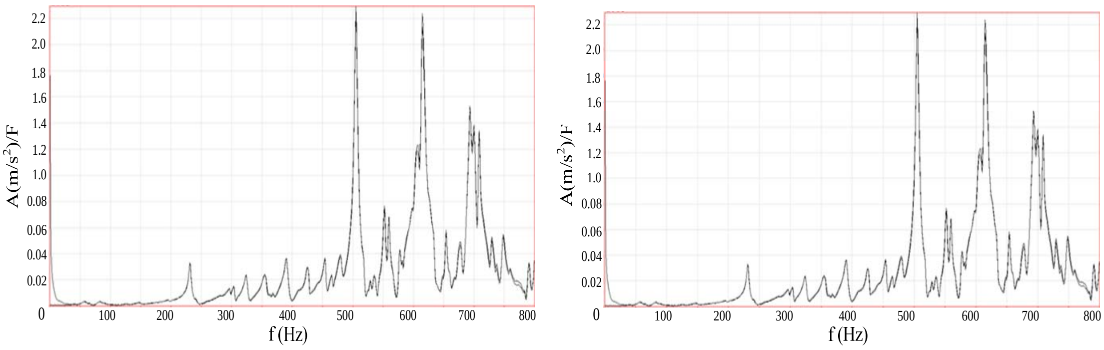
Firstly, the excitation is provided for the slider. The normal and tangential amplitude-frequency characteristics are obtained and shown in Figure 5.

From the curve of Figure 5, the natural frequencies and corresponding damping ratios of the LRG are identified as shown in Table 3.

Secondly, the excitation is provided for the sliding guide. The amplitude-frequency characteristics of the slide are obtained and shown in Figure 6. From the curve of Figure 6, the natural frequencies and corresponding damping ratios of the LRG are identified as shown in Table 4.

Table 3. Results of the LRG with the slider excited

Exciting Way	Order	Frequency/Hz	Damping Ratio /%
Normal	1	505	0.472
	2	614	0.506
	3	692	0.801
Tangential	1	504	0.495
	2	514	0.422
	3	544	0.623
	4	582	0.189
	5	504	0.495



(a) Normal characteristic curve (b) Tangential characteristic curve

Figure 6. Amplitude-frequency characteristics curves exciting the guide

By contrasting the test results of different excitation points, the natural frequencies of the slider –sliding guide are found. The main six orders are: 505Hz, 542Hz, 552Hz, 584Hz, 614Hz, and 692Hz. The damping ratios of the interfaces are shown in Table 5.

Table 4. Results of the LRG with the sliding guide excited

Exciting Way	Order	Frequency/Hz	Damping Ratio /%
Normal Excited	1	505	0.427
	2	691	1.12
	3	698	1.87
	4	708	0.934
Tangential Excited	1	504	0.495
	2	514	0.422
	3	544	0.623
	4	582	0.189

Table 5. Experimental Results of the LRG with slider and sliding guide excited respectively

Order	Natural Frequency/Hz	Damping Ratio /%
1	505	0.472
2	542	0.107
3	552	0.346
4	584	0.0677
5	614	0.506
6	692	0.801

Finally, the excitation is provided for the slider and sliding guide at the same time. Then by picking the results, the test results of the acceleration sensor from three directions are obtained and shown in Figure 7.

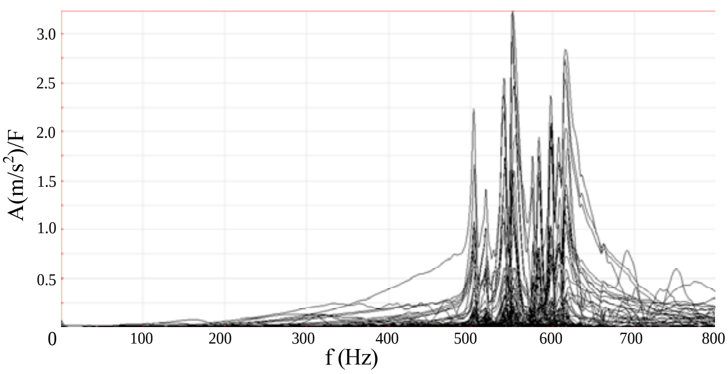


Figure 7. Response frequency curve of the guide

From the curve, the natural frequencies and the corresponding damping ratios of the LRG are identified as shown in Table 6.

Table 6. Experimental Results of the LRG with slider and sliding guide excited at the same time

Exciting Way	Order	Frequency/Hz	Damping Ratio /%
Normal Excited	1	505	0.427
	2	691	1.12
	3	698	1.87
	4	708	0.934
Tangential Excited	1	504	0.495
	2	514	0.422
	3	544	0.623
	4	582	0.189

The results of finite element analysis and the experimental results are compared as shown in Table 7. By comparing them it can be easily seen that the errors of all analytical results are very small, all analytical results are basically consistent. Besides this, through Table VII it can also be seen the first two natural frequencies of finite element analysis can match that of modal analysis when using boundary condition 1, while when using boundary condition 2, the last three natural frequencies can perfectly match the modal analysis frequencies.

Table 7. Results comparison between experiment and simulation

Order	1	2	3	4	5
Test Frequency (Hz)	503	541	551	584	614
FEA Frequency of Condition 1 (Hz)	511	566	631	681	765
Error (%)	1.6	4.6	14.5	16.6	24.6
FEA Frequency of Condition 2 (Hz)	474	501	595	652	703
Error (%)	5.8	7.4	8.2	11.6	14.5

4. Conclusion

The finite element model of the LRG is built with ANSYS software, then the natural frequencies and the corresponding vibration modes of LRG are also obtained by analyzing the FEM of the LRG in two different boundary conditions. In addition to this, each modal parameter is obtained by a dynamic test. Finally, the validity of the finite element model is verified by comparing the two methods.

When the bolt connection is used to simulate the joint surface, it can be seen that the FFM better matches the modal obtained with a modal experiment. The results of the finite element analysis indicate that the restricted position and restricted way have significant influence on the dynamic characteristics of the joint surface of the LRG. Hence, it is necessary for us to consider the joint surface when analyzing the LRG.

Acknowledgements

This paper is supported by National Natural Science Foundation of China (51275079), Program for New Century Excellent Talents in University (NCET-10-0301), Program for Changjiang Scholars and Innovative Research Team in University (IRT0816) and National Key Technology Research and Development Program (2009BAG12A01-F01-3), the Fundamental Research Funds for the Central Universities (N110403009).

References

[1] Vafaei S, Rahnejat H, Aini R. Vibration monitoring of high speed spindle using spectral analysis techniques. *Machine Tools & Manufacture*. 2002; 42: 1223-1234.
[2] Yang MY. Straight-line Rolling Guide Set and Its Application, *Machine Tool Technology*. 2004; 14(7): 276-277.
[3] Xi S, Andreas A, Polycarpou. Measurement and Modeling of Normal Contact Stiffness and Contact Damping at the Meso Scale. *Journal of Vibration and Acoustics*. 2005, 127: 52-60.

[4] Wu XJ. A Method for Establishing Dynamic Model for Fixed Joints. Mechanical Science and Technology. 2002; 21: 439-441.

[5] Kim SM, Ha JH, Jeong SH. Effect of joint conditions on the dynamic behavior of a grinding wheel spindle. *International Journal of Machine Tools and Manufacture*. 2001, 41(1): 1749-1761.

[6] Song Y, Hartwigsen CJ, McFarland DM and Vakakis AF. Simulation of Dynamics of Beam Structures with Bolts Joints Using Adijusted IWAN beam Elements. *Journal of Sound and Vibration*, 2004; 273: 249-276.

[7] Zhang YM, Liu CS, Xie ZK, Teng LB, Liu YX. Finite Element Analysis of NC Machine Tool Considering Linear Rolling Guide-way. *Manufacturing Technology & Machine Tool*. 2007; 7: 75-78.

[8] Czekanski A, Meguid SA. Analysis of Dynamic Frictional Contact Problems Using Variational Inequalities. *Finite Elements Analysis and Design*. 2001; 37(11): 861-879.

[9] Wang JH. Experimental Identification of Mechanical Joint Parameters. *ASME Journal of Vibration and Acoustics*. 1991; 113(1): 28-36.