볼 스크류 이송장치 열 에러 보상 시스템의 시뮬레이션 및 계산 방법에 관한 연구

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Study on Simulation and Calculation Method of Thermal Error Compensation System for a Ball Screw Feed Drive

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Abstract

Due to the requirement of the development of the precision manufacturing industry, the accuracy of machine tools has become a key issue in this field. A critical factor that affects the accuracy of machine tools is the feed system, which is generally driven by a ball screw. Basically, to improve the performance of the feed drive system, which will be thermally extended lengthwise by continuous usage, a thermal error compensation system that is highly dependent on the feedback temperature or positioning data is employed in the machine tool system. Due to the overdependence on measuring technology, the cost of the compensation system and low productivity level are inevitable problems in the machine tool industry. This paper presents a novel feed drive thermal error compensation system method that could compensate for thermal error without positioning or temperature feedback. Regarding this thermal error compensation system, the heat generation of components, principal of compensation, thermal model, mathematic model, and calculation method are discussed. As a result, the test data confirm the correctness of the developed feed drive thermal error compensation system very well.

1. Introduction

According to requirement of development of

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precision manufacturing industries, accuracy of mach ine tools was became a key issue in this field. One of the critical factor that affect the accuracy of machine tool is the feed system which driven by a ball screw in general. Basically, in order to improve the performance of feed drive system which will thermally extended on length direction by continuous

usage, thermal error compensation system which is highly dependent on the feedback temperature or positioning data was employed in a machine tool system.[1-4] Due to the over dependence on measuring technology, cost of compensation system and low productivity level is an inevitable problem in machine tool industries. This paper presents a novel method in feed drive thermal error compensation system which could able to compensate thermal error without positioning or temperature feedback. In this thermal error compensation system, heat generation of components, principal of compensation, thermal model, mathematic model and calculation method were discussed respectively. And, in order to confirm the correctness of the developed thermal error compensation system, a series of tests were carried out in the same working condition of prediction. As the results, the test data can confirm the correctness of the developed feed drive thermal error compensation system very well.

2. Thermal model for compensation system

A demand of tight part tolerances and high productivity of product manufacturing which always represented priority of engineering field requires machine tools obtaining fast and accurate feed drive systems. A high speed feed drive generates more thermal error which results in greater positioning error directly. In a feed drive system, there are two main heat sources such as support bearings and ball screw nut. Friction between the balls and races of the bearings and screws are the predominant reason for temperature elevation in ball bearing and ball screw. Even the general models[5,6] of Finite Element Method or MLCM where are from the previous publications can well predict the thermal behaviour of feed drive system, but they exists some critical defects such as lack of generality and overmuch prerequisites. In order to establish a thermal model which can close to an actual ball screw feed drive system, a particular thermal analysis of ball screw feed drive system was needed.

In a ball screw drive system, there are some main heat sources as shown in Fig. 1. In this figure, heat generation by friction, heat dissipation by air convection and conductive heat dissipation through bearing bracket and nut supporting structure. A modified FE model which can overcoming the shortcoming of the traditional FE model for the feed drive was developed as shown in Fig. 2. This kind of FE model contains two constant themo-genesis loads at bearing parts, the other constant themo-genesis load at moving nut section and convective heat transfer boundary on the linear elements.
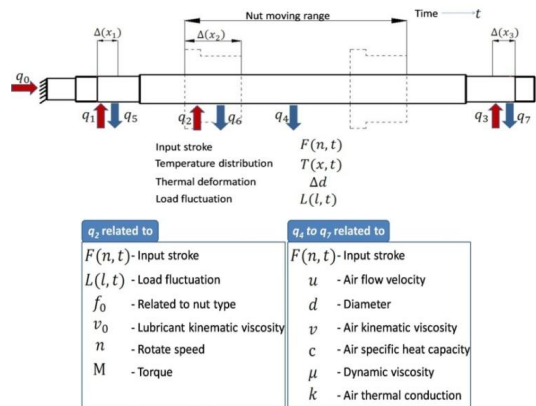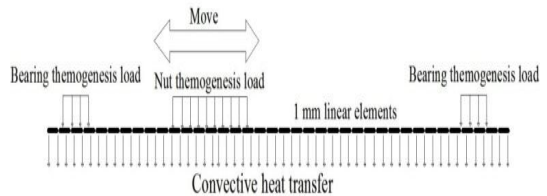

Fig. 1 Feed drive system thermal analysis

Fig. 2 Modified finite element model

3. Calculation method for compensation system

3.1 Calculating flow

Calculating flow of modified FE thermal model which contains motion equation input, loop in move, loop in stop and results output was shown in Fig. 3. In this calculating progress, the equation of action input to the meshed FE thermal model to gather the input thermal generation which causes loop in move and loop in stop. And through the loops, thermal deformation and temperature distribution of the feed drive can be calculated as shown in this figure.

3.2 Calculation method

In view of the axial symmetry of ball screw, in order to reduce the amount of calculation, 3 d model is substituted into 2 d model. Total length of Experiment device of screw is 1025 mm. According to the total length of screw, nut and screw pitch, total time of nut-moving can be figure out as 2530 seconds. First of all, according to the proportion, actual size of ball screw is assigned values to divided 1025 units.

Specific operation is Calculate the diameter, perimeter and volume of ball screw then assignment respectively. "Generate_mesh" function is created, used for return the assignment data of each unit finite element. Next to the nut movement trajectory calculation, divided into three kinds: big stroke case, small stroke case, multy stroke case. Because these three kinds of movement are different, that means nut move time, number of movements, pause time, pause frequency are not the same. So the three kinds of variable parameters are created, they are nut single move time, single pause time, moving rate(pitch). On this basis, define other public parameters, such as move range, specific heat capacity, air density, material density, the convection coefficient. In order

to calculate the temperature distribution, generated heat of finite element unit need to calculated step by step. In programming, input_heat, heat_trans, output_heat functions are created to calculate heat generation. And the main formulas of computational process of functions are shown in Fig. 5.
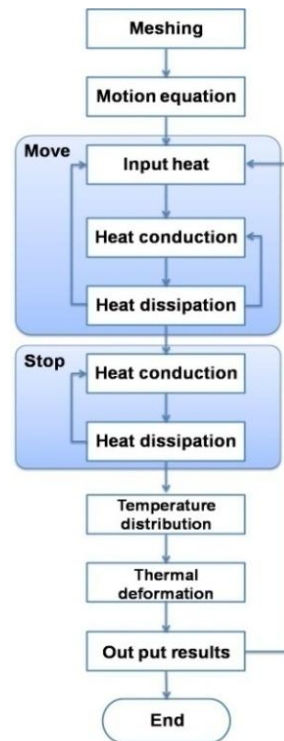

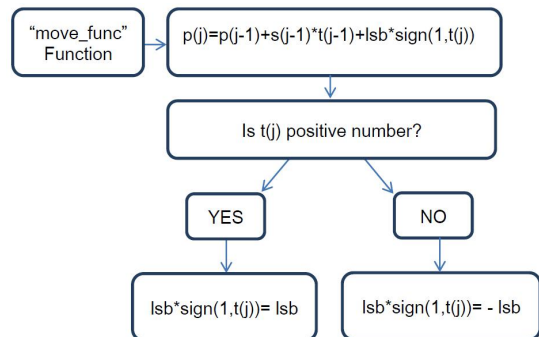Fig. 3 Calculating flow of FE thermal model
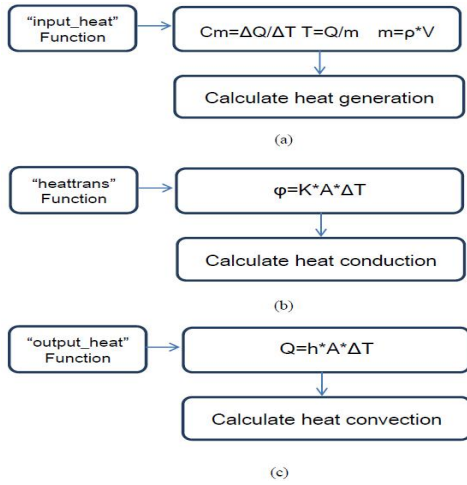

Fig. 4 Computational process of "move_func"

Fig. 5 Formula of computational process of Function

4. Constitute of compensation system

Basically, in order to improve the performance of feed drive system which will thermally extended on length direction by continuous usage, thermal error compensation system which is highly dependent on the feedback temperature or positioning data was employed in a machine tool system. Due to the overdependence on measuring technology, cost of compensation system and low productivity level is an inevitable problem in machine tool industries. In order to achieve the objective of eliminate errors caused by thermal behaviour in machine tool feed drive, the structure of machine tool frame is first of all modeled by using FEM or empirical method. Consequently, temperature or positioning on critical elements on the frame of machine tool which is a source of compensation dosage was measured.

A novel, closed circle feed drive thermal error compensation system was shown in Fig. 6 which can work without any temperature or positioning feed backs. From this figure a unique input can be figured out as working condition of feed drive. This input went through a process of calculation of thermal model and mathematical model.
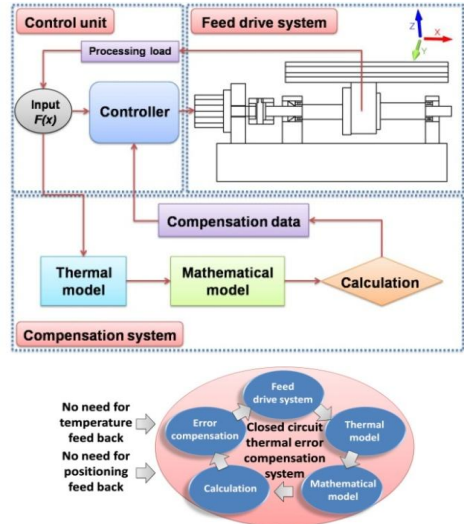

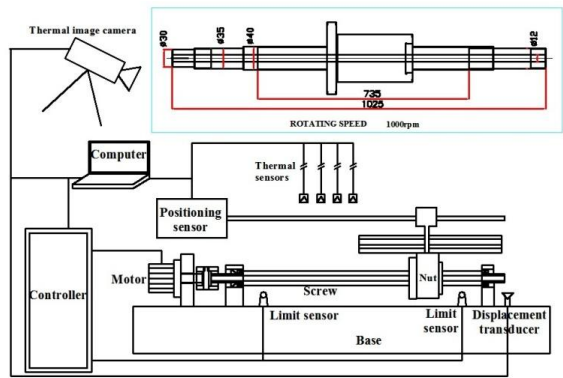Fig. 6 Improved ball screw feed drive thermal error compensation system
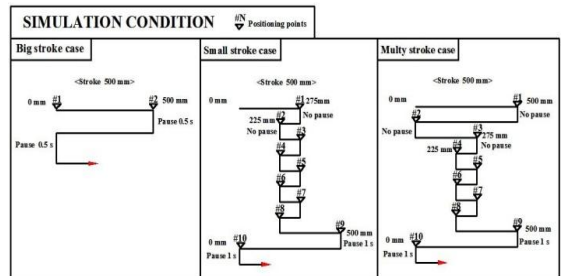

Fig. 7 Experimental set up

Fig. 8 Working conditions of a ball screw feed drive system

5. Experimental verification

5.1 Test piece and experimental method

A schematic diagram of setup of experimental equipments was shown in Fig. 7. Feed drive, motivating unit, measuring unit and control unit were contained in this setup. Fig. 8 shows the general feed drive work conditions which was used as simulation conditions.

5.2 Positioning

Fig. 9 to Fig. 11 show the results of comparison of simulated and experimental positioning error in variate working conditions as shown in Fig. 8. From these figures can be seen clearly that the position error change tendency is similar in ball conditions. Even very similar variation tendency can be find, but there is still about 13.07% - 13.46% of error in maximum presented in there figures. Similar patterns of error which is measured position data is smaller than simulated ones at one side and bigger in the other side which probably is from the sudden brake of the moving plate impact the screw that causes axial deformation of screw shaft itself.

5.3 Temperature distribution
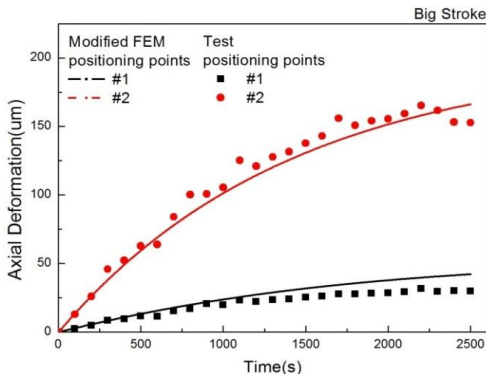
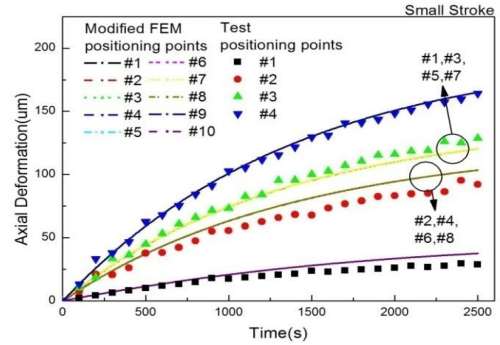Fig. 12 shows comparison of simulated results and
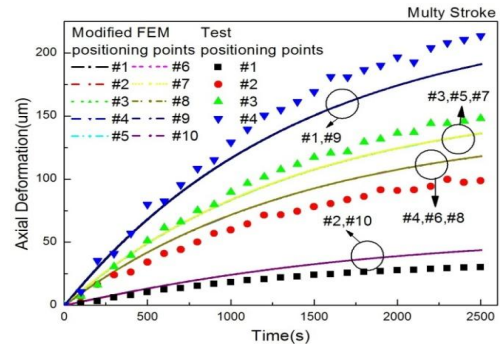

Fig. 10 Position error in small stroke case

Fig. 11 Position error in multy stroke case

experimental results of temperature distribution in big stroke case. Fig. 13 and Fig. 14 show the same comparison results simulated ones and experimental ones in small stroke and multy stroke cases. From these figures, can be found clearly that experimental results on of temperature distribution and variation can be well confirm the accuracy of simulated ones.
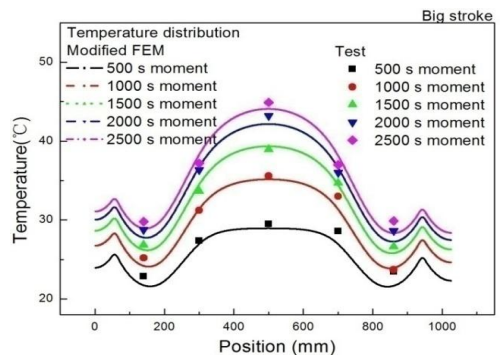

Fig. 9 Position error in big stroke case

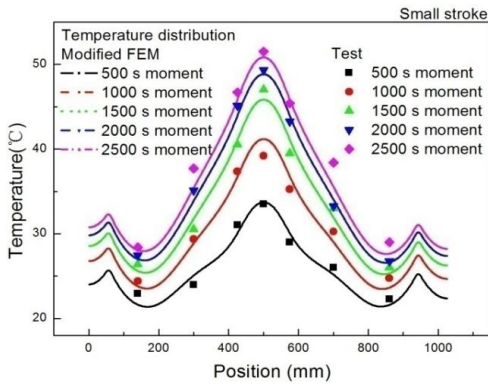**Fig. 12 Temperature distribution in big stroke case**

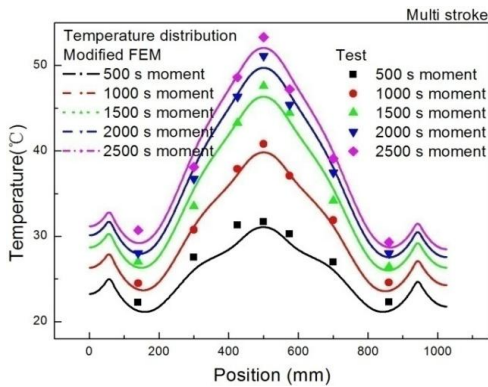Fig. 13 Temperature distribution in small stroke case

Fig. 14 Temperature distribution in multy stroke case

6. Conclusion

This paper presents a novel method in feed drive thermal error compensation system 삼which could able to compensate thermal error without positioning or temperature feedback. In this thermal error compensation system, heat generation of components, principal of compensation, thermal model, mathematic model and calculation method were discussed respectively. And, in order to confirm the correctness of the developed thermal error compensation system, a series of tests were carried out in the same working condition of prediction. As the results, the test data can confirm the correctness of the developed feed drive thermal error compensation system very well.

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