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Analyze ball screw feeding system dynamics simulation Based on the ADAMS

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Abstract: *This paper studied the Nan Jing ' table with high precision manufacturing,use the software of Solidworks to draw the table,and then import to the ADAMS to establish model of ball screw feeding system virtual prototype.For this system,we research its kinematics and dynamic simulation,and then obtain the simulation curve of torque displacement speed and acceleration.In order to analysis this curve,the result of simulation indicate that the stiffness of ball screw have an important effect on the feeding system,increasing the stiffness of ball screw and adjusting the parameter of ball screw,are valid way to reduce the error of table and then raise the precision of table.*

Key words:*Adams;Feeding system;table;ball screw*

I. Introduction

With the ultra-precision machining technology continues to develop nanoscale precision, microelectronics manufacturing, surface topography measurement, a variety of ultra-precision machining field, micro-electro-mechanical control systems, semiconductor lithography technology has raised higher and higher the requirement for precision bench[1.].Although its emergence and development of experienced hundreds of years of history, as a high-precision ball screw drive components and efficient, it is only 40 years for us to study it in our country.From 40-50 years of the last century to the 1970s, it began agility from energy saving features to achieve precise positioning transmission function; From the 1980s to today, it experienced a large lead fast driving, high-speed precision driving stage. In these processes, product upgrading have made a qualitative change again and again.

A lot of theoretical research has been made about the kinematics and dynamics of ball screw over the sea, just like Japan, the United States, as well as Romania and other countries.These experts have made these investigation about the state of the ball screw ball, the efficiency of estimation of the ball screw and the stiffness of ball screw nut in detail.In China, Harbin Institute of Technology,Huazhong University of Science and Technology, Zhejiang University,Shandong University and other units also done a lot of research work on the ball screw,they made a dynamics analysis about the models of ball screw.Improve the static stiffness of the ball screw and increase the accuracy of the table feed system has made many contributions to the development of China[2.].

II. Feeding system

Generally,X-Y table feeding system consists of servo motors, couplings, linear rolling guide, ball screw, workstation and other mechanical components.It is the part that direct contacted with machining part of machine tool. The dynamic characteristics of mechanical transmission system not only affect the machining accuracy of parts,but also as a key factor impact the high-speed and high-precision. So it is very important to make the study about the dynamic performance of feeding system.

For example,this article chooses Nanjing Industrial CNC table as a case.We establish the ball screw feeding system dynamics model and then make an analysis about the precision of feeding system and the error of the table.At last it puts forward some corresponding measures for improving the precision.

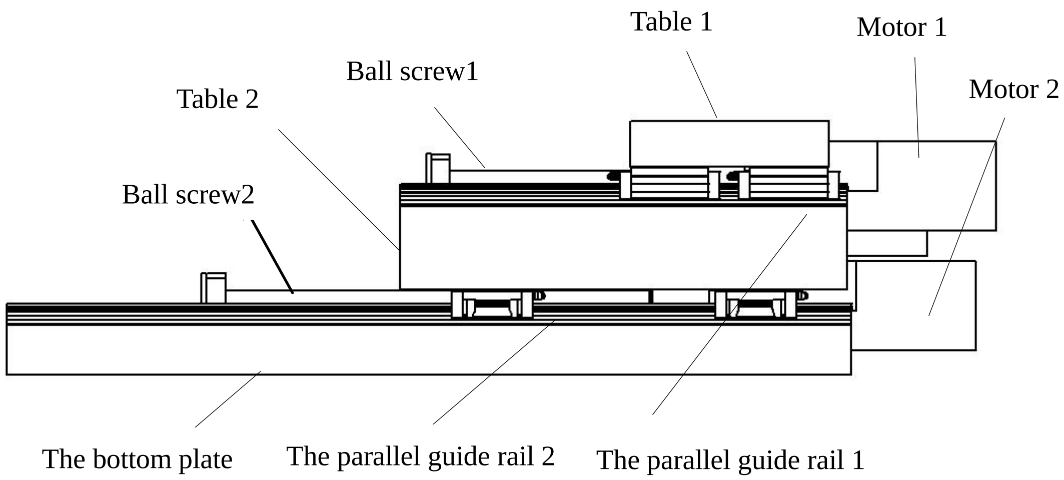

Fig. 1 X-Y axis feeding system structure diagram

III. A dynamic model of ball screw

In this paper, it draws the ball screw feeding system with the help of Solidworks which called three-dimensional solid modeling software.Then import the model to the ADAMS in a Parasolid format.At this time,we will obtain the model which have no quality,material and other physical parameters.All of the parts of the model have no content each other. We will define the physical parameters of the actual selected components,and then add constraints and load on it.Finally,we create the virtual prototype simulation model.

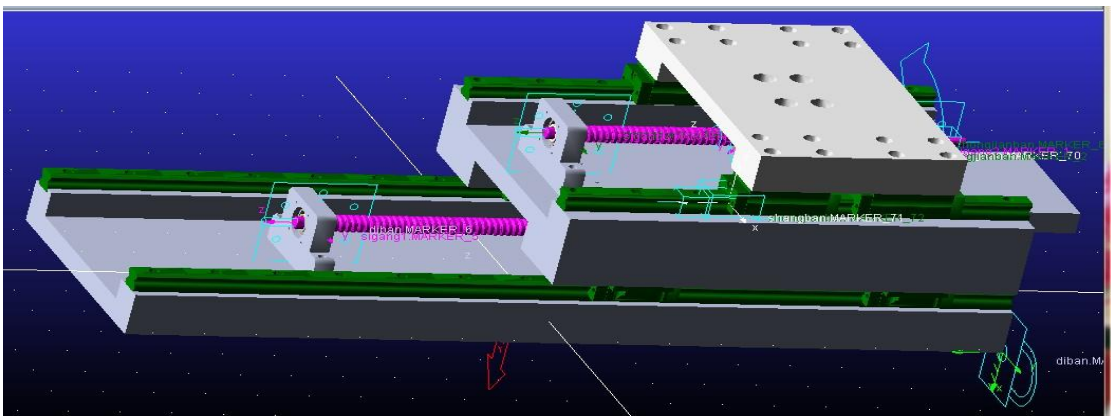

Fig.2 The ADAMS simulation model

According to empirical analysis, because of the lubrication between table and rail, it produce viscous resistance coefficient.In the dynamic model,the friction between table and rail can be simplified with a damper and the ball screw can be turned into a torsional stiffness of the spring,so the table movement will be transformed into a model kinetic model equivalently.

Generally speaking,the feeding drive system of precision table have an higher demand for the friction,transmission stiffness,rapid positioning performance,inertia of the moving parts and transmission clearance and so on.Typically,under the ideal conditions,we often see ball screw as rigid body and consider the deformation displacement error is zero in the transition process acceleration.But in the actual conditions,the stiffness of each component is no longer infinity,which will make the ball screw, the workstation and other components deformed in the process of acceleration and deceleration.As a result,the transient process curve about the acceleration and deceleration exists the displacement deviation.It effect the transient tracking accuracy under the high-speed positioning.Eventually,it lead to positioning errors[3.].According to the analysis above,under the ideal state,we know that the input of the driving system is:

$$\theta_m(t) = \frac{2\pi}{P_h} X(t) \quad (1)$$

The first and order derivatives of the formula one are formula two and formula three

$$\theta_{\mathrm{m}}'(t) = \frac{2\pi}{P_h} X'(t) \quad (2)$$

$$\theta_{\mathrm{m}}''(t) = \frac{2\pi}{P_h} X''(t) \quad (3)$$

Among them: $\theta_{\mathrm{m}}(\mathrm{t})$、$\theta_{\mathrm{m}}'(\mathrm{t})$、$\theta_{\mathrm{m}}''(\mathrm{t})$ are angular displacement of the input, the angular velocity and angular acceleration respectively; $X(\mathrm{t})$、$X'(\mathrm{t})$、$X''(\mathrm{t})$ are linear displacement table, velocity and acceleration; P_{h} refer to lead screw feeding system.In the process of simulation,the setting simulation time is 10s,and the simulation step number is 500,the form of simulation is Dynamic.The curve about the screw1and 2 can be obtained under the ideal case as shown below.

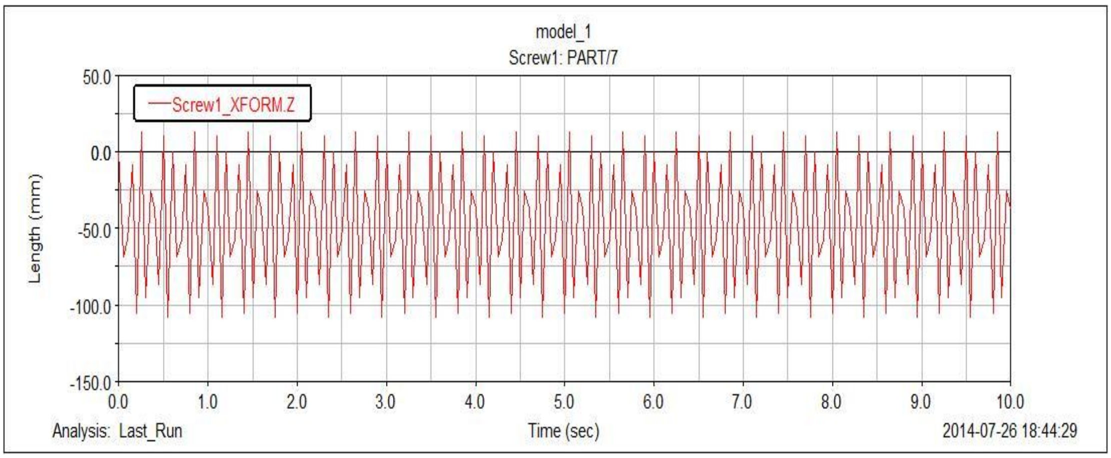

Fig. 3 The motion curve of ball screw1 along the X axis

We make an analysis about the motion of screw1,set the feeding rate 3cm/s.According to the curve of ball screw,we can conclude that,in the ideal case,the movement of the ball crew is stable on the plane. The change of speed in direction is equal in the same plane.We also find that the table will fluctuate as we change the ball screw feeding speed.This is caused by the stiffness of leading ball screw.When we reduced the stiffness,the greater the speed,the less stability of table.

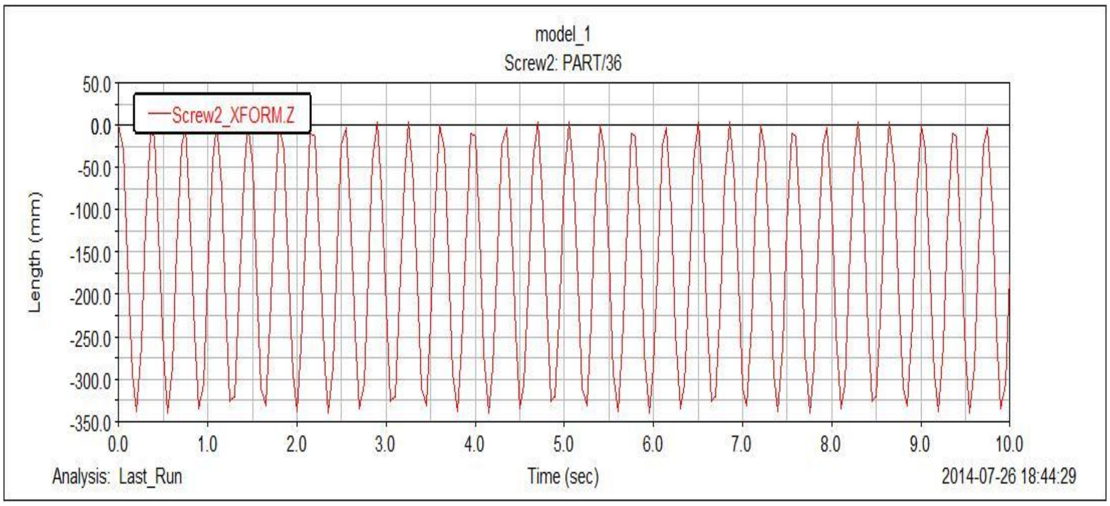

Fig.4 The motion curve of ball screw 2 along the X axis

The motion analysis of the ball screw two,the feeding rate is 1cm / s. Because the given speed is less than screw one, so on the image, there is a certain gap between the two velocity curve. The stability of the screw two is superior to the screw one.

IV. The dynamic equation of feeding system

The rate of angular motion of ball screw is ω, table seen as centralized mass m moving along the screw. When the table start to work, the feeding system is bound to produce axial deformation and torsional deformation,because of the cutting force and the frictional forces , resulting in the output of the hysteresis and affect the accuracy of table[4.] .

The relationship between ball screw and feeding system dynamics is:

$$T_M = J_R \frac{d}{d_t}\omega + B_R\omega + T_p \quad (4)$$

Among them: T_M is torque of electric motors; B_R is viscosity damping coefficient of rotary component; J_R is the rotational inertia of rotary component; ω is the motor speed; T_p is torque produced by resistance of feeding table;

According to the law of conservation of energy , in order to meet the needs of the table movement, the motor speed to provide to meet the moving speed of the table, the relationship between the two is as follows:

$$V_t = \frac{L_s}{2\pi}\omega \quad (5)$$

Among them: V_t is the speed of bench; ω is the motor speed; L_s is the lead of ball screw.The screw as an elastic body, the transmission torsional deformation and elastic deformation existed obviously[5.].So that there is always a dynamic error between the real and the ideal displacement of the screw.

When we consider the displacement of table $X_0(t)$,it include the axial displacement of the rotating ball screw $\gamma_{\theta 0}$,the axial displacement of quality block due to the torsional deformation of ball screw $\gamma_{1\phi(\gamma\theta_0,t)}$,the axial displacement of quality block due to the the axial deformation of ball screw $S_{1\phi(\gamma\theta_0,t)}$, local vibration displacement between quality block and the ball screw assembly attaches λ ,

$$X_0(t)=\gamma\theta_0+\gamma_1\phi(\gamma\theta_0,t)+S(\gamma\theta_0,t)+ \qquad (6)$$

Among them:t is time, γ is load gain which we often called the conversion coefficient between cutting force and torque, $\gamma = h/2\pi\eta$, h is the lead of ball screw, η is the total transmission efficiency of feeding system, θ_0 is the ball screw rotate angle, $\theta_0=\omega t$, γ_1 is the shift conversion coefficient between angle and displacement[6.].

The total axial displacement of the quality block caused by the torsional deformation of screw causes is

$$\gamma_1\phi(\gamma\theta_0,t)=(\theta-\theta_0)\gamma_1=\frac{T\gamma_1}{K_N}=\frac{F\gamma\gamma_1}{K_N}=\frac{Fh\gamma_1}{2\pi\eta K_N} \qquad (7)$$

Among them： θ is the input angular displacement of the servo motor,T is the load torque, K_N is the torsional rigidity of feeding system，F is the sum of forces acting at the feeding system.

The axial displacement of quality block due to the the axial deformation of ball screw is $S(\gamma\theta_0,t)$:

$$S(\gamma\theta_0,t)=x-x_0=\frac{F}{K_Z} \qquad (8)$$

Among them: θ_0 is the ball screw rotate angle, x is the corresponding axial displacement, K_Z is the axial stiffness of feeding system.

If the friction of feeding system meet the coulomb viscous friction model,then the F:

$$F=F_x+M\ddot{x}_0+u_c\left(\pm\operatorname{sgn}\dot{x}_0\right)+u_v\dot{x}_0 \qquad (9)$$

Among them: F_x is the cutting force,M is the totally quality of the feeding system, u_c is the factor of coulomb friction,sgn is the symbolic function, u_v is the factor of viscous friction[7.].

After the Laplace transformation:

$$F_{(s)}=F_x(s)+Ms^2x_0+u_c(\pm\operatorname{sgn}x_0)sx+u_v \qquad (10)$$

Substitute the above formula into the original formula:

$$x_{0(t)} = \gamma\omega t + \left[F_x + M\ddot{x}_0 + u_c\left(\pm \operatorname{sgn} \dot{x}_0\right) + u_v \dot{x}_0 \right]\left(\frac{\gamma\gamma_1}{K_N} + \frac{1}{K_Z}\right) + \lambda \quad (11)$$

According to Lagrange equations, we use the above formula to get feeding system dynamics equations.

$$[M]\{\ddot{q}\} + [C]\{\dot{q}\} + [K]\{q\} = \{F(t)\} \quad (12)$$

$[M]$ 、 $[C]$ 、 $[K]$ are mass matrix system, damping matrix and stiffness matrix of a system respectively.

$$\{q\} = \left[x_0(t), s(x,t), \phi(x,t)\right]^T \quad (13)$$

$\{F(t)\}$ is force vector.

In the feeding system, the screw is equivalent to a rigid body[8.], calculate feeding axial stiffness and torsional rigidity of the system are

$$\frac{1}{K_Z} = \frac{1}{K_S} + \frac{1}{K_{BL}} + \frac{1}{K_{LM}} + \frac{1}{K_{LMZ}} \quad (14)$$

$$K_N = \frac{1}{K_\phi} + \frac{1}{K_{\phi s}} + \frac{1}{K_{\phi 1}} + \frac{1}{K_{\phi 2}} \quad (15)$$

Through the above calculation and analysis: when we increase the rigidity of the ball screw, the error of screw can be reduced during the movement, thus increasing the rigidity of the ball screw can reduce the error of feeding system, but the limitation about the ball will affect the stiffness characteristics of the overall system.In the actual machining process, the tool table and the drive can not be completely rigid, especially in the case of high speed and high load, the deformation of its yield are can not be ignored.

V. Conclusion

Through the above simulation analysis,we found that in the high-speed high-precision of ball screw feeding system, due to the elastic deformation of the feeding system,it will produce mechanical parts transient positioning errors, and ultimately it will affect the positioning accuracy. To reduce the transient positioning errors, improve its dynamic characteristics, we can use high coupling stiffness and ball screw. But the change that parameters to improve overall system response is not obvious,the quality of table is the most sensitive factor about the dynamic characteristics.Finally the weakest link in the system is the table, so make a optimize design is the most effective way to improve the dynamic characteristics. In its stiffness without reducing the premise of reducing its quality, which can effectively improve the dynamic characteristics of the system.

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