Micro-feed Mechanism with High-Resolution and Large-Stroke Based on Friction Drive

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ABSTRACT

Based on friction driving principle, design a long stroke length and high resolution walking micro-feeding device driven by piezoelectric ceramic elements and combined with the screw shaft and aerostatic guide way. The design was made to the adjustable preload device by flexible four-bar linkage. The static properties of flexible linkage device are analyzed with FEM. The transmission characteristics of micro-feeding device are exhaustively analyzed.

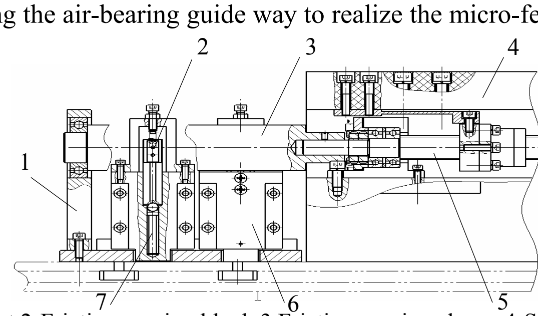
Keywords: Friction drive, Piezoelectric actuator, Flexure hinge,Finite element

1. INTRODUCTION

Aspheric optics has been widely used in industries such as aviation, aerospace, national defense and so on. However, the manufacture of large aspheric optics faces many problems such as great difficulty, low efficiency, high cost, increased requirement on process equipment etc [1, 2]. In order to arrive at high precision, the micro displacement resolution of ultra-precision machine must be further advanced, so as to compensating the processing error online. Therefore, the design of micro-feed mechanism has become one of the key technologies [3-7]. PZT is the new micro-feed mechanism developed in recent years. It has the advantages such as small volume, large power, high resolution, and high frequency response and so on and phenomena such as no heating, no backlash and mucosity, so it's widely used micro controller in micro-feed mechanism. Nowadays, friction gearing mechanism is gradually been acquired and used [8, 9].

2. STRUCTURE AND OPERATING PRINCIPLE OF MICRO-FEED MECHANISM

The micro-feed mechanism is made up of three parts: friction gearing, ball screw and static-pressure air-bearing guide way. Micro-feed mechanism uses the piezoelectricity ceramic friction gearing block, which twist up the sleeve and drive the ball screw, so as to bring along the air-bearing guide way to realize the micro-feed movement. The structure is shown as Figure 1.



1-Bearing bracket 2-Friction gearing block 3 Friction gearing sleeve 4-Static-pressure air-bearing guide way 5- Ball screw 6- Piezoelectricity ceramic base 7-Piezoelectricity ceramic used for feeding

Figure 1: (a) Structure of the feed mechanism

As shown in Figure 2, the operating principle of the feed mechanism is that, friction gearing sleeve connects with ball screw, four friction gearing blocks are placed symmetrically at both sides of the sleeve. Each block is droved by the corresponding piezoelectricity ceramic used for feeding and is gripped by the corresponding gripping mechanism, which is droved by the piezoelectricity ceramic used for gripping to produce clamp force. When feeding mechanism works, the

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3rd International Symp. on Advanced Optical Manufac. and Testing Tech.: Advanced Optical Manufacturing Technologies, edited by Li Yang, Yaolong Chen, Ernst-Bernhard Kley, Rongbin Li, Proc. of SPIE Vol. 6722, 67222E, (2007) · 0277-786X/07/$18 · doi: 10.1117/12.783140

piezoelectricity ceramic used for gripping on the same side drive both the friction gearing blocks to work in certain orderliness, so as that the friction gearing sleeve turn continuously.

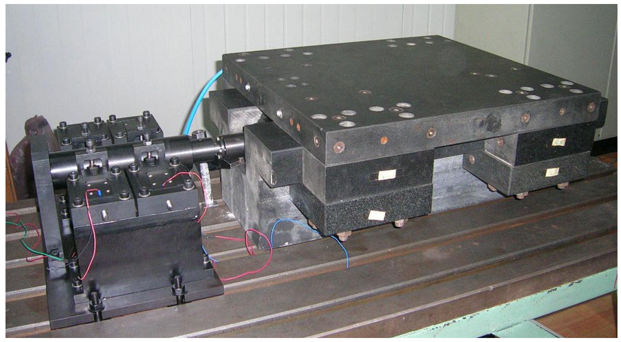


Figure 1: (b) Picture of the feed mechanism

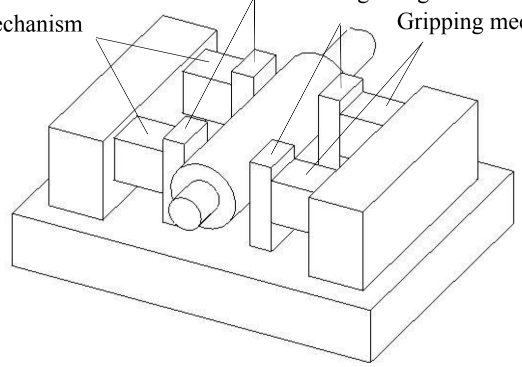


Figure 2: Operating principle of the feeding mechanism

3. DESIGN OF THE ADJUSTABLE PRETIGHTENING MECHANISM

An adjustable retightening mechanism is required in the friction gearing mechanism, which must has enough pretightening force. The typical pretightening methods are plate spring pretightening mechanism, helical pretightening mechanism, and air pressure pretightening mechanism and so on. The retightening mechanism designed in this paper is flexible parallel four bars mechanism. It's droved by piezoelectricity ceramic to supply pretightening force. The pretightening force can be changed by controlling the input voltage of piezoelectricity ceramic.

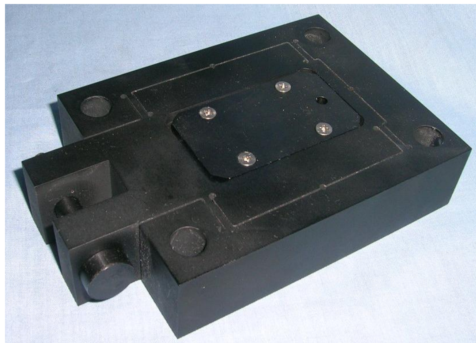
As shown in Figure 3, use the finite element software to analysis the static characteristic. When the drive force of piezoelectricity ceramic is 500N in maximum, the rigidity of flexible four bars mechanism, analyzed by finite element software, is $K=24.15N/\mu m$, and the maximum stress of flexible hinges is $\sigma=32.7Mpa$. If there is no distortion in flexible four bars mechanism (that is when the friction gearing blocks contact rigidly), the output force of piezoelectricity ceramic will completely translates to pretightening force through the flexible four bars mechanism.

4. DRIVE CHARACTERISTIC ANALYSIS OF THE MECHANISM

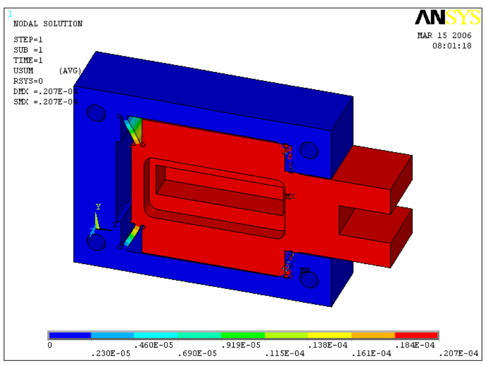
Studying and mastering the drive characteristic of mechanism redounds to adopting the proper measures to improve the whole performance and provides the design basis for designing the control system.

4.1 Drive torque

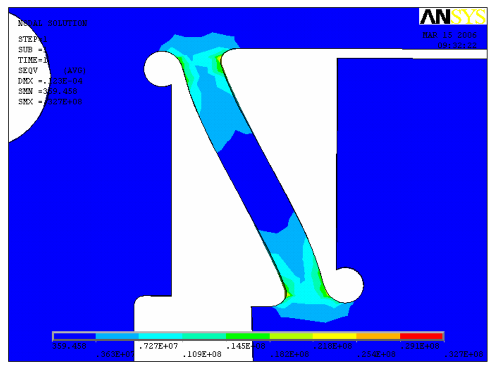
When system starts, there is a problem on initial inertia moment as a result of the existence of parts quality. To research the drive torque, choose the friction gearing sleeve as subject investigated. According to the theory that the kinetic energy of gearing train is same before and after conversion, the rotary inertia of each part is transformed to friction sleeve. Because of that, we can get the rotary inertia after conversion is



(a) Structure of the pretightening mechanism



(b) Node motion nephogram



(c) Von-mise stress envelope

Figure 3: The static characteristic assay plan of pretightening mechanism

$$J' = \frac{1}{2} m_{\mathrm{T}} r^2 + m_{\mathrm{S}} (\frac{p}{2\pi})^2 + m_{\mathrm{L}} (\frac{p}{2\pi})^2 + m_{\mathrm{D}} (\frac{p}{2\pi})^2 \tag{1}$$

Where p is pitch of lead screw, m;

r is radius of the friction sleeve, m;

m_{S} is quality of the ball screw, kg;

m_{T} is quality of the friction sleeve, kg.

Through the above analysis, we get the equivalent rotary inertia of friction sleeve. Now we choose the friction sleeve as subject investigated to discuss the drive torque (drive force) that is needed when device starts and it's influencing factors. The following equation works when device starts:

$$J' \cdot \alpha = M = F \cdot r \tag{2}$$

Where J' is equivalent rotary inertia, kg·m^2;

α is angular acceleration of friction sleeve, rad/s^2;

r is radius of the friction sleeve, m;

M is drive torque, N·m;

F is drive force（breakout friction between friction block and friction sleeve）, N.

When system starts, a condign drive deflecting couple should be applied on the friction sleeve, in order that the sleeve can have certain angular acceleration. The drive deflecting couple is generated by the output force of piezoelectricity ceramic. From equation 2 we can get that the equivalent rotary inertia of system, radius of the friction sleeve and drive force of the piezoelectricity ceramic (breakout friction between friction block and friction sleeve) are the influencing factor of mechanism start, so we should think over the influence of each factor to ensure the normal start of mechanism. Same questions exist when feed mechanism stop moving.

4.2 Driving rigidity

The driving rigidity is one of the important driving characteristics of feed mechanism. Now we will analyze the driving rigidity of feed mechanism in detail as following.

The rigidity of the feed mechanism is the cascade connection of the each segment rigidity of the feed mechanism, which has the calculated equation as follows:

$$\frac{1}{K}=\frac{1}{K_{\mathrm{Y}}}+\frac{1}{K_{\mathrm{F}}}+\frac{1}{K_{\mathrm{S}}}+\frac{1}{K_{\mathrm{S'}}}+\frac{1}{K_{\mathrm{N}}}+\frac{1}{K_{\mathrm{B}}}+\frac{1}{K_{\mathrm{H}}}+\frac{1}{K_{\mathrm{D}}} \tag{3}$$

Where K is the total rigidity of the feed mechanism;

K_{Y} is the rigidity of piezoelectricity ceramic;

K_{F} is the touching rigidity of surface in contact between friction block and friction sleeve;

K_{S} is the axial rigidity of lead screw;

$K_{\mathrm{S'}}$ is the axial rigidity changed from the torsional rigidity of lead screw;

K_{N} is the rigidity of nut;

K_{B} is the rigidity of axial bearing;

K_{H} is rigidity of nut bracket and bearing block;

K_{D} is the axial rigidity of nut link block;

Here is the analysis and calculation of part rigidity.

4.2.1 Rigidity of the piezoelectricity ceramic

The piezoelectricity ceramic in this paper is the ceramic micro positioner typed WTYD0808055 produced by China Electronics Technology Group Corporation No.26 Research Institute. It's rigidity measured through experiment is 15.15N/μm, as shown in Figure 4.

4.2.2 Touching rigidity of surface in contact between friction block and friction sleeve

Two objects contacting with each other will have certain tangential transition before relative slip in the action of tangential external force, which is called pre-displacement. The proportional relation between force and displacement reflects a rigidity characteristic in fact [10]. The corresponding rigidity now is:

$$K=\frac{F}{\delta}=kr^{1/3}N^{1/3} \tag{4}$$

Where k is const;

N is normal pressure;

r is the radius of idealized sphere on friction surface.

It's clear in the equation that, in special friction gearing system, k is got from experiment, r is const, the only influencing factor of touching rigidity is normal pressure N. It's evident that the larger N is, the larger the touching rigidity K is.

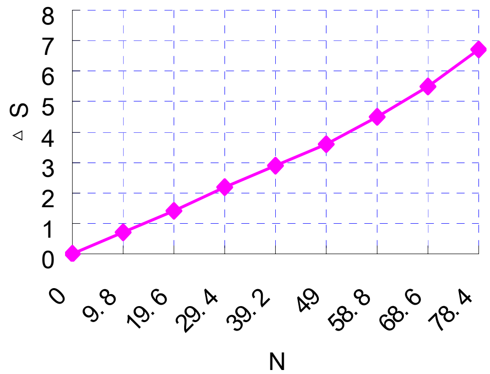


Figure 4: Rigidity curve of piezoelectricity ceramic

4.2.3 Axial rigidity changed from the torsional rigidity of lead screw

The dimension of driving chain needs to be transformed uniformly when calculating it's rigidity. Therefore, the torsional rigidity must be transformed into axial rigidity as the following equation:

$$K_{\mathrm{T}} = \frac{M}{\theta} = \frac{GJ_{\mathrm{P}}}{L} \tag{5}$$

$$K_{\mathrm{S'}} = \frac{4\pi}{pd\tan(\alpha+\varphi)} \cdot K_{\mathrm{T}} \tag{6}$$

Where α is the rising angle of lead screw, (°);

d is the diameter of lead screw, mm;

F is the axial force of lead screw, N;

M is the input moment of lead screw, N·mm;

φ is the friction angle between lead screw and nut, (°);

K_{T} is the torsional rigidity of lead screw, N·mm/rad;

θ is the torsional deformation of lead screw, rad;

p is the lead of lead screw, mm;

G is the shear modulus of elasticity of lead screw material, Mpa;

J_{P} is the inertia moment of cross section, mm^4, $J_{\mathrm{P}}=\pi d^4/32$;

L is the maximum distance from loading point to two thrust bearing, mm.

The axial rigidity of nut link block can be gained by the finite element analysis. The rigidity of nut bracket and bearing block is very large, which can be dismissed. The rigidity of other parts can be got by looking up table and calculating.

In a word, by deducing the equation of drive rigidity of feed mechanism, we have found the influencing factors of driving rigidity caused by each driving segment, which offers the basis for further study on the driving characteristic.

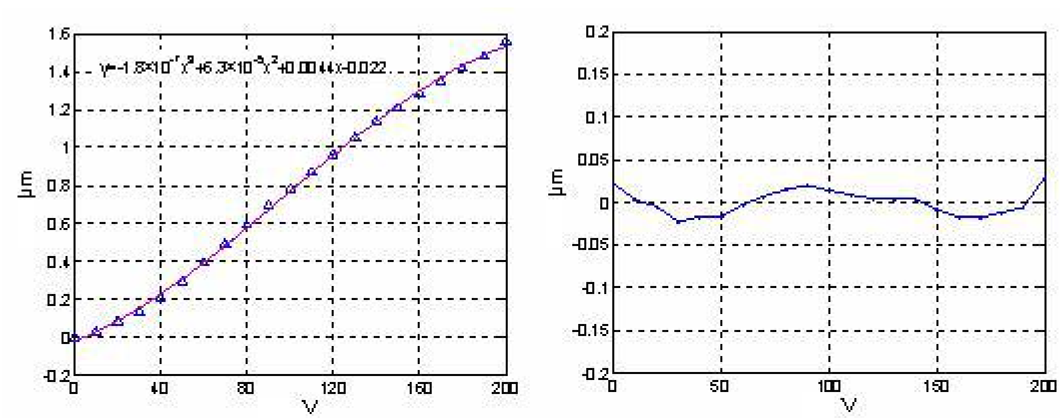
5. EXPERIMENTAL STUDY OF THE FEED MECHANISM

5.1 Foundation of the experiment system

As shown in Figure 5, the experiment system is made up of feed mechanism, computer, piezoelectricity ceramic driver and its power supply and the inductance amesdial.

Figure 5: Foundation of experiment system

This paper uses a control method based on average curve model to set up the open loop control model. Above all, measure the experimental curve of relation between piezoelectricity ceramic control voltage and slide carriage distance. Using the Matlab software to fit the line with cubic algebraic multinomial, and the fitted line and fitted error line are as shown in Figure 6, from which we get the corresponding relational expression of control voltage and distance and therefore control the distance of feed mechanism.



a) Fitted line　　　　b) Fitted error line

Figure 6: Fit with cubic algebraic multinomial

Relational expression of control voltage and distance is as shown in equation 7:

$$x = -1.8\times10^{-7}u^3 + 5.3\times10^{-5}u^2 + 0.0044u - 0.022 \quad (7)$$

Where x is the output distance, μm;

u is the control voltage, V.

5.2 Experimental study of system resolution

As shown in Figure 7, piezoelectricity ceramic has certain elongation. At this time, the distance of micro working table is 0.15μm. Then step elongating gradually on this base and keep 1.5s in each moment. The sampling time is 100ms. The resolution curve can be gained by measuring the practice distance of micro feed mechanism using the inductance amesdial.

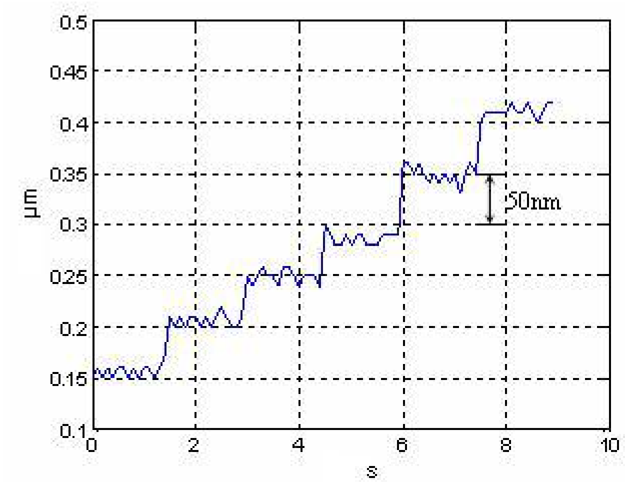


Figure 7: Distance resolution curve of feed mechanism

6. CONCLUSION

A step micro feed mechanism with long march and high resolution was designed in this paper, and the following conclusions were concluded:

1. Designed the pretightening mechanism based on the piezoelectricity ceramic flexible iron hinges and analyzed its static characteristic using the finite element software;

2. Analyzed the starting torque of micro feed mechanism and calculated the equivalent rotary inertia; analyzed the driving rigidity characteristic of micro feed mechanism and found its influencing factors;

3. The march of the micro feed mechanism can reach 300mm, and the resolution is less than 0.05µm.

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