Development of a Two-dimensional Micro Motion Platform System

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Keywords: Two-dimensional, Platform, Electromagnetic force, Cage-type structure.

Abstract. In order to simulate the fretting between the electrical contacts in the electric connectors, a two-dimensional micro motion platform system was designed and developed in this paper. The system drives a cage-type structure to realize a two dimensional micro-displacement by controlling the electromagnetic force. The stress and deformation of the cage-type structure was analyzed by the finite element method. The platform could achieve any trajectory of micro motion within 200 μm amplitude in the plane and the trajectory was verified by the simulation experiments of electrical contacts.

Introduction

Electrical connection is one of the most important parts in electrical and telecommunications equipment. It provides a guarantee for outputting energy and signal. Affected by the external vibration and the changes in ambient temperature, fretting within 200 μm will be formed in the contact interfaces. Fretting will make the plating metal be worn, so that the base material is corroded and the contact resistance degrades [1]. Therefore, it is very necessary to study the influence of fretting on the electrical contact reliability.

The simulation system used currently in the study of fretting is usually in one direction [2], but the actual micro-motion of the electrical contacts is mostly two-dimensional. The existed two-dimensional micro motion platform can be roughly divided into three categories. The first kind is guide rail worktable, which has a problem of crawling as the limit of precision machining and the friction of kinematic pair [3]. The second type is piezoelectric ceramic worktable, which can obtain different micro-displacement by changing the input voltage, but its micro driver has a low speed and low efficiency [4]. The third type uses electromagnetic drive and return bearing spring in the vertical direction [5]. However, this kind of platform is relatively complicated. Therefore, in order to reduce the friction between the platform and the driving mechanism and to simplify the whole structure, a set of system which can be used to study the fretting between connector contacts was designed and developed in this paper.

Functional Requirements and Overall Scheme

It requires that the platform can be implemented on any desired trajectory in plane and the amplitude is controllable within 200 μm [6]. In addition, the system should be fast responded, low friction and be able to work stably for a long time.
To achieve frictionless micro movement whose track is controllable, the scheme of the mechanical structure is shown in Fig.1. It includes a platform, multiple elastic steel columns, a base, 4 permanent magnets and a support frame. The scheme of the control part is shown in Fig. 2. By controlling the digital signals, current in the coils will be changed accordingly.

Figure 1. Scheme of mechanical structure.

Figure 2. Block diagram of control part.

Mechanical Structure of System

The mechanical structure of the system mainly includes two parts. The first part is the cage structure, which is used to support a platform in the longitudinal direction. The other one is the driving structure, in the horizontal direction, an electromagnetic force is adopted to drive platform to realize the micro displacement.

Design of the cage structure

The cage structure consists of a platform, a base and a number of elastic steel columns (Fig. 3). The elastic steel columns are fixed on the base to support the platform. The micro movement of the platform is depended on the distribution, quantity and structure of the elastic steel columns.

Distribution of the elastic steel columns. All of the elastic steel columns were designed to distribute as a circular which ensured the consistency of the system in all directions, shown in Fig. 4.

Figure 3. Cage structure.

Figure 4. Distribution of elastic steel columns.
**Structure and quantity of the elastic steel columns.** The less number and the longer length will lead the greater amplitude but a worse stability. In order to determine a reasonable structure and quantity, the finite element method was used to calculate and simulate the cage structure. The diameter of the elastic steel column was set up at 2mm, and the length was 64mm shown in Fig. 3. Platform and base’s materials were aluminum. The elastic steel columns’ material was 65Mn. Boundary conditions were that applying a fixed constraint to the base and a force of 10N to the platform. As was shown in Fig. 5, the maximum displacement of the platform was 103μm when the force was 10N. The stress contour of the cage structure was shown in Fig. 6, and the maximum stress was about 40.7MPa, which was far less than the allowable stress of 65Mn, 570MPa [7].

![Displacement contour](image1.png) ![Stress contour](image2.png)

Therefore, the cage structure with 16 elastic steel columns can reach the requirement of amplitude and has an enough strength and good stability.

**Design of the driving structure**

**Specific structure and driving principle.** The electromagnetic coils were used to drive the platform. As shown in Fig. 7. Two coils and permanent magnets were fixed on X and Y directions respectively. Fig. 8 shows the specific structure and driving principle. When the positive signal flowed into the coil, the coil would be energized to produce a magnetic field. The left coil would reject the left permanent magnet and push the platform to the right. At the same time, the magnetic field generated by the right coil attracted the other permanent magnet and pulled the platform to the right. On the contrary, when a negative signal flowed into the coil, the platform would move to the left.

![Symmetrical driving structure](image3.png) ![Profile sketch of the system](image4.png)
Calculation and design for coil. The analytical expression of the magnetic field is complex and it’s difficult to solve with the theoretical method [8]. The finite element method and the software of Maxwell were used to calculate the size and turns of the coil, which must generate a force of 10N on the platform. A three-dimensional model by using Maxwell3D [9] was shown in Fig. 9. The diameter and height of a cylindrical permanent magnet was set to 10mm and 30mm. The outer diameter, inside diameter and the height of coil with hollow cylinder was 28mm, 12mm and 22mm respectively. Then, the material of permanent magnet was NdFeB95 [10] and coils were made of copper wires. The boundary conditions were that applying current along the longitudinal section (Fig. 9) of coil and assigning permanent magnet a parameter of magnetic force.

Result is shown in Fig. 10. The horizontal axis is the product of current in single-turn multiply by the number of coil turns, the vertical axis is force suffered by permanent magnets, which can be approximately equivalent to the force suffered by platform. The result indicates that with the increase of the input current, the force suffered by platform is linearly increases, when the input excitation were 600 ampere-turns, it would generate a force about 6N. Considering the carrying capacity of copper wire, we made coil 2000 turns and the peak current was 0.3A. This also provides a basis for the subsequent design of control part.

![Figure 9. Coil-permanent magnet model.](image)

![Figure 10. Coil current-platform force.](image)

Control Part of the System

A two-way digital signal should be generated with computer software firstly according to the requirement. Then after DA conversion and power amplification, two signals are finally input to their respective coil and control the movement of the platform.

Hardware components

An external sound card was selected to complete the D/A conversion function. Power amplifier was TPA311-6D2, which has a wide voltage input with 8-26V and its amplification gain can be up to 36dB. Its rated output power is 40W and the maximum output current is 4A.

In view of the requirement of the power amplifier, we used an adjustable constant voltage source (0-24V) as the power supply unit. The output voltage could reach the peak value of 30V after amplification. The resistance of a pair of coils was 95Ω. So the maximum current of the coil could be 0.31A (30V/95Ω), which meet the requirement calculated above.
**Generation of control signals**

**Generating method.** As the plane trajectory can be decomposed into two independent movements, so the control of the planar motion can be simplified to control the motion of single dimension. For example:

The circular trajectory equation is:

\[(x-a)^2 + (y-b)^2 = r^2\]  \hspace{1cm} (1)

Transforming the trajectory equation into its parametric equation:

\[x = a + r \cdot \cos \theta, \quad y = b + r \cdot \sin \theta\]  \hspace{1cm} (2)

Point \((a, b)\) was the center coordinate of the circle; \(r\) was the radius of the circle, which was determined by the motion amplitude; \(\theta\) was variable parameter. Therefore, making the input signal were a cosine signal in X direction and a sinusoidal signal in Y direction, the circular could be achieved.

With the change of the signal’s strength, the current in coil changed periodically. Periodic variation of the electric field produced a magnetic field with periodic variation. Therefore, the permanent magnet would be subjected to different forces and platform would be formed of different displacement.

**Implementation method.** Two digital signals were generated by the MATLAB and the frequency of the signal was set according to the frequency of the fretting. Then we used the software of Cool Edit-Pro to synchronize the two signals into an audio file, the duration of the file was the cycle of the fretting experiment. As the audio file was played, the system began to work.

**Trajectory Verification**

The correctness of platform’s trajectory was verified by experiments. A copper flat sample was fixed on the platform [11] and a testing probe with a hemisphere head was fixed vertically on the sample surface at a certain pressure. The wear tracks could be observed by optical microscope.

Fig. 11 is the scratches shape of the circular trajectory. Fig. 12 is the corresponding micro scratches of ellipse trajectory. We can see that the platform could achieve the desired shape and reach the requirement of 200μm any direction in the plane. The results not only verified the correctness of the track but also confirmed the feasibility of the system.

![Figure 11. Fretting shape of circular.](image1) ![Figure 12. Fretting shape of ellipse.](image2)
The system which consists of a cage structure and electromagnetic driving has the advantages of low friction, fast response and brief structure. It can achieve the design objective and meet the functional requirements. This two-dimensional micro motion platform system runs smoothly and works reliably. It has provided a hardware support for the laboratory simulation and the theoretical study of the fretting.

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