Ironless Moving-Permanent magnet synchronous linear motors (IMPMSLM) are widely used in precision machinery manufacturing, aerospace, microelectronics and other high positioning accuracy requirements of the occasion. Wherein, the thrust fluctuation is an important factor affecting the positioning accuracy of the workpiece table. Many scholars have studied the thrust fluctuation reduction methods to improve the motor performance. Some articles optimized structure size [1], or the analytical method ignoring the end effect [2], or using look-up tables [3]. Another scholars have adopted active control strategy to compensate for the thrust fluctuations [4]. For IMPMSLM, the factors that cause the thrust fluctuation include motor size, end-effect of permanent magnet array, magnetic field distribution of permanent magnet array, the number of driving phases and the form of driving current, etc. This paper analyzes these factors respectively.

CAUSES OF TRUST FLUCTUATION
The thrust fluctuation is defined as:

\[ f_w = \frac{|F_{\text{max}} - F_{\text{min}}|}{F_{\text{avg}}} \]

respectively means that the mover thrust maximum and minimum value, \( F_{\text{avg}} \) means that the average thrust.

Factor of the motor structure size
According to the modified Fourier series, the paper establishes analytical model of the magnetic field and force, which considering the end-effect. Then, it analyzes the influence of the gas thickness, magnet height, magnet height to the thrust fluctuation.

Factor of the distribution of the magnetic field of the permanent magnet array
As the order of the Halbach permanent magnet array is changeable, the sinusoidal form of the magnetic field generated by the permanent magnet array is corresponding changed. In this paper, it mainly analyzes thrust fluctuation and magnetic field harmonics with different spread patterns.

Factor of the number of driving phases
In the case of the same permanent magnet array, the number of driving phases influences the thrust fluctuation. In this paper, it researches
the thrust fluctuation when the motors have different driving phases.

**Factor of the form of driving current**

For linear motors, the analytic formula of the force can be expressed through the back-EMF, as

\[ F_y = \sum_{i=1}^{k} E_{ai} I_i \]

\[ F_x = \sum_{i=1}^{k} E_{ai} I_i \]

There are high harmonics in back-EMFs, so through sinusoidal AC, there will be thrust fluctuation in motor. If the above expressions are as constraints, minimum power consumption that

\[ \min J = \min \sum_{i=1}^{k} I_i^2 \]

as the goal to resolve. In theory, it will get the resultant that the thrust fluctuation is 0, at the same time minimize the power consumption by the method of least squares.

![FIGURE 3. The obtained force when the form of current obtained by the back EMF](image)

**CONCLUSION**

The factors that cause the thrust fluctuation are analyzed in this paper, giving conclusions as follows:

①Considering the end-effect of permanent magnet array, the analytical model of the mover thrust force are established using the modified Fourier series. Then the effects of air gap thickness, the height of the permanent magnet, and permanent magnet width on thrust fluctuation are analyzed. With the change of these factors the thrust fluctuation is changed.

②The magnetic field of permanent magnet array has high harmonics, and the less the harmonic the small the thrust fluctuation.

③In the case of the same permanent magnet array, the more phases of the coils, the smaller the thrust fluctuation.

④Due to the high harmonics of the magnetic field, the thrust fluctuation is inevitably generated when the driving current is sinusoidal. In order to solve this problem, a method of current calculation is given on the basis of the given thrust, running speed of the mover and the back-EMF, so that the thrust fluctuation can be reduced to negligible.

The analysis above can be used in practice to reduce the thrust fluctuation, and to improve the accuracy of the linear motor.

**REFERENCES**


