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The Analytic Algorithm Calculator Design of Air-Floating Guideway Loading Capacity Based on VB

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ABSTRACT. *Loading capacity is an important performance parameter of air-floating guideway. In engineering, when designing the air-floating guideway structure, analytic algorithm are often used to analyze the structural parameters around the loading capacity. In this paper, the algorithm for analyzing the loading capacity of air-floating guideway commonly used in current engineering is sorted out, and the corresponding loading capacity calculator is written in the VB language environment. After that, we verified the feasibility of the calculator through two engineering examples. The test results show that the calculator can quickly calculate the loading capacity and stiffness of the guideway with different guideway surface area, air supply pressure and gas film thickness. At the same time, the corresponding curve is draw, which can provides a convenient and intuitive theoretical reference to designers, and has high engineering application significance.*

KEYWORDS: *Air-floating guideway, Loading capacity, Mathematical model, Vb*

1. Introduction

The air-floating platform combined with air-floating guideway and linear motor drive technology has been widely used in lithography, precision measurement and integration as a precision positioning platform because it is connected by non-mechanical method to efficiently avoid the vibration disturbance from external environment and free from the friction, heat, wear, lubrication[1-2]. The static characteristics such as loading capacity and static stiffness of the air-floating guideway are important indicators for judging whether the air-floating platform can overcome the overturning moment and work smoothly. Therefore, it is necessary to check the structural parameters during engineering design to ensure that the work requirements are meet.

The design methods commonly used in engineering can be divided into two types: analytical algorithms and numerical algorithms. Although the physical quantities results of the numerical algorithm are detailed, but the pre-processing steps such as modeling, meshing, and boundary condition setting are also have high

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required, so it is more used for theoretical research and optimization of the program. The physical ite. Therefore, this paper intends to design a calculator for the air-floating guideway loading capacity analysis algorithm developed in the pre-engineering scheme through VB language, which can improve the calculation efficiency and provide theoretical basis for the subsequent design.

2. Analytical Algorithm for Loading Capacity of Air-Floating Guideway

The N-S equation is the basic equation for solving the gas lubrication problem. It consists of a motion equation, a continuous equation, and a state equation. After the boundary conditions are given, the simultaneous equations can be solved [3].

In engineering, the N-S equation is often simplified according to the characteristics of gas flow in air bearing. The main assumptions are as follows: (1) The gas is ideal laminar flow, the flow direction is parallel to the plane of the guideway. (2) There is no relative sliding between the gas and guideway. (3) The vertical plane where the restrictor is located is regarded as a continuous high-pressure area, and the gas only flows out along the width direction. At this time, the pressure distribution is shown in Fig. 1.

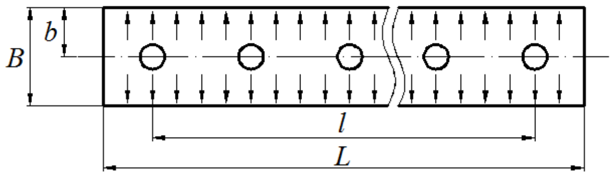

Fig.1 Pressure Distribution of Analytical Algorithm Model

Defined the total length of the guideway is L , the width is *B=2b* , the supply pressure is *Ps* , the outlet pressure of the restrictor is *Pd* , the atmospheric pressure is *Pa* , and the gas film thickness is *h* . Therefore, it can be assumed that the flow in the air film gap is shown in Fig. 2.

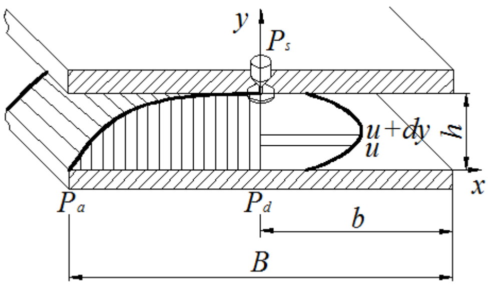

Fig.2 Model of Airflow Field

Based on the above assumptions, the N-S equation can be simplified to:

$$\frac{\partial P}{\partial x}=\eta\frac{\partial^2 u}{\partial y^2},\frac{\partial P}{\partial y}=0,\frac{\partial P}{\partial z}=0 \tag{1-3}$$

Where η is the gas viscosity, u is the component of the airflow in the x direction, after integration can get:

$$u=\frac{1}{\eta}\frac{dP}{dx}\frac{y^2}{2}+c_1y+c_2 \tag{4}$$

Where c_1 , c_2 is the integral constant.

Set the boundary conditions, when $y=0$, $y=h$, we get $u=0$, $c_2=0$, there are:

$$c_1=h\frac{1}{2\eta}\frac{dP}{dx},c_2=0$$

Then Eq. (4) can be sorted out:

$$u=\frac{1}{2\eta}\left(y^2-hy\right)\frac{dP}{dx} \tag{5}$$

Therefore, the gas quality on single side of the guideway is:

$$m_z=bl\rho\int_0^h udy \tag{6}$$

Assuming that the gas film is an isothermal flow process, substituting Eq. (5) and gas state equation $\frac{P}{\rho}=RT=\frac{P_a}{\rho_a}$, we can be obtained:

$$PdP=-\frac{12\eta m_z P_a}{lh^3\rho_a}dx \tag{7}$$

Where R is the gas constant, T is the absolute temperature, ρ_a is the atmospheric density, they are regarded as constant here. Therefore, after integration can get:

$$\int_{Pa}^{P_d}PdP=-\int_0^b\frac{12\eta m_z P_a}{lh^3\rho_a}dx \tag{8}$$

$$\int_{Pa}^{P_X}PdP=-\int_0^x\frac{12\eta m_z P_a}{lh^3\rho_a}dx \tag{9}$$

Simultaneous Eq. (8)(9):

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$$m_z = \frac{lh^3(P_d^2 - P_a^2)}{24\eta RTb} \quad (10)$$

$$P_x^2 = P_d^2 - \frac{x}{b}\left(P_d^2 - P_a^2\right) \quad (11)$$

At the same time, according to the law of conservation of mass, substituting the gas inflow quality m_{in} to make it equal to the overall quality of the gas film, then

$$m_{in} = nAP_d\phi\sqrt{\frac{2\rho_a}{P_a}}\psi = 2m_z \quad (12)$$

Therefore, the gas film loading capacity is:

$$W = 2L\int_0^b Pdx - 2LbP_a = \frac{4lb}{3}\frac{P_d^2}{P_d + P_a} - \frac{2}{3}LbP_a \quad (13)$$

When the platform is under vertical pressure, the ratio of the change in the loading capacity to the change in the gas film thickness is the stiffness of the guideway:

$$K_h = \frac{W(h - \Delta h) - W(h)}{\Delta h} \quad (14)$$

The above is the commonly used engineering algorithm derivation process [4].

3. Analytical Algorithm for Loading Capacity of Air

3.1 Loading Capacity Calculator Design

It can be known from Eq. (11) that the main parameters affecting the loading capacity of the air-floating guideway are the surface area ($L=n \times La$, B), the air supply pressure Ps, the gas film thickness h. And the parameters such as gas viscosity η, gas constant R, absolute temperature T, atmospheric density ρ_a are regarded as constant. Therefore, the calculator solving process is shown in Fig. 3:

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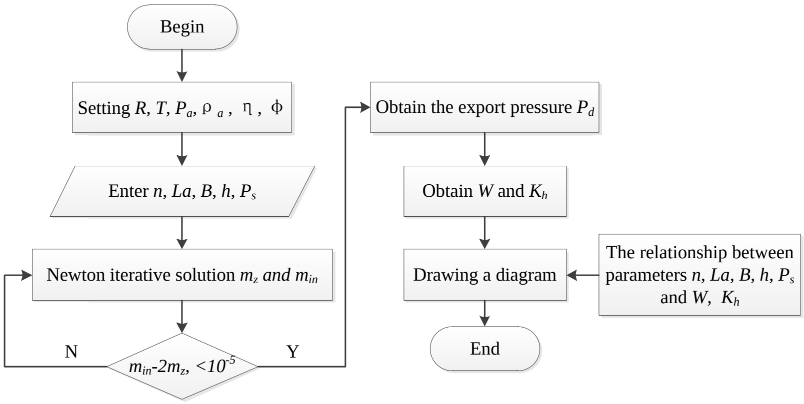

Fig.3 The Flow Chart of Calculator Solving Process

As depicted in Fig. 3, the gas constants of the solution is set in advance, and the structural parameters of the air-floating guideway and the air supply pressure are substituted into the formula as input variables for solution. There is a key assumption in the solution process: it is considered that the mass of gas flow into the guideway through the restrictor is equal to that flow out along the guideway width direction, that is, $m_{in} = 2m_z$. Therefore, the above formula forms a closed system of equations, and the m_z is repeatedly corrected by Newton iteration until it meets m_{in}-$2m_z$, < 10^{-5}, and the restrictor outlet pressure P_d can be obtained. Then the loading capacity W of the guideway and the stiffness K_h when the film thickness is h can be obtained, and the influence of the input variables n, La, B, h, Ps on W, K_h can be further obtained [5]. The calculator final interface is shown in Fig. 4.

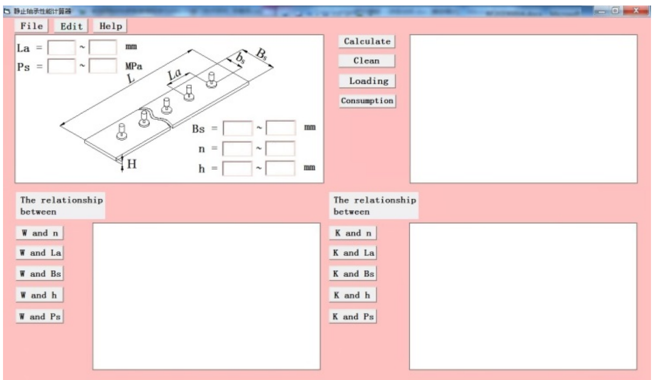

Fig.4 Calculator Interactive Interface

3.2 Calculator Application Examples

Now verify the feasibility of the calculator with two engineering examples as follow:

The total length of the air-floating guideway is L = 200 mm, the width of the guideway is B = 50 mm, the number of restrictor is n = 8, the restrictor spacing is La = 25 mm, and the restrictor chamber diameter is A_{rd} = 5 mm.

(1) Calculate the change trend of the loading capacity and stiffness of the guideway when the air supply pressure Ps = 0.20 MPa and gas film thickness h between (0.015 ~ 0.035) mm

(2) Calculate the change trend of the loading capacity and stiffness of the guideway when air supply pressure Ps between (0.20 ~ 0.80) MPa and gas film thickness h between (0.015 ~ 0.035) mm.

The solution results are as follows:

(1) Set the guideway structure parameters, click “Calculate”, and output the relationship between “W and n”, “W and h”. The result is shown in Fig. 5:

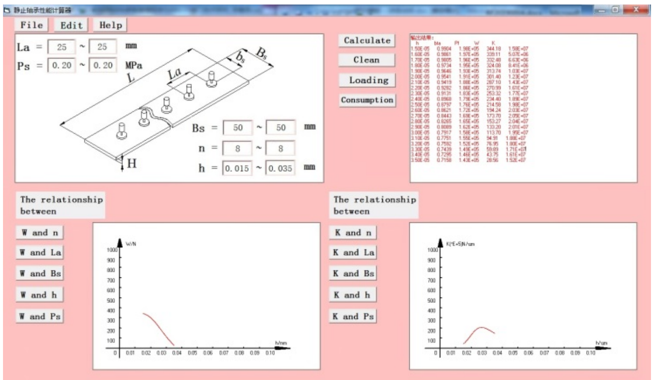

Fig.5 Loading Capacity Solution Result

It can be seen from the above figure that the loading capacity decreases rapidly with the increase of the gas film. When the gas film thickness h = 0.015 mm, the loading capacity is the largest, W = 344.18 N; when the gas film thickness h = 0.035 mm, the loading capacity is the smallest. W = 28.56 N. The reason is that as the gas film increases, the high pressure gas cannot form an effective high pressure gas film in the gap, and the gas film loading capacity is reduced. On the other hand, as the gas film increases, the stiffness of the guideway increases first and then decreases, and the film stiffness reaches the maximum value at h = 0.027 mm, K = 205×10^{5} N/um. In summary, in the example (1), the optimum film thickness value is 0.027 mm.

(2) The calculation example is solved by referring to the above method. When the film thickness is h = 0.015 mm, the relationship between the gas supply pressure and the loading capacity, stiffness is shown in Table. 1:

Table. 1 the Relationship between the Gas Supply Pressure and the Loading Capacity, Stiffness

Gas supply pressure(Ps)	Loading capacity(W)	Loading capacity variation(△ W)	Stiffness (K, N/um)	Stiffness variation(△ K)
0.20 MPa	344.18 N	-	5.07E+06	-
0.30 MPa	913.05 N	165%	2.20E+07	334%
0.40 MPa	1465.53 N	61%	5.04E+07	129%
0.50 MPa	1987.89 N	36%	8.74E+07	73%
0.60 MPa	2476.24 N	25%	1.30E+08	48%
0.70 MPa	2930.96 N	18%	1.75E+08	35%
0.80 MPa	3354.22 N	14%	2.21E+08	26%

It can be seen from the above table that when the air supply pressure is between 0.20 and 0.80 MPa, and the greater gas supply pressure, the greater the loading capacity and stiffness. As the gas supply pressure increases, the rate of increase slows down. When *Ps* = 0.80 MPa, the loading capacity is 3354.22 N, which is 9.7 times of *Ps* = 0.20 MPa, and the stiffness is also increased from 5.07E+06 N/um to 2.21E+08 N/um. The relationship between air supply pressure and loading capacity, stiffness is shown in Fig 6.

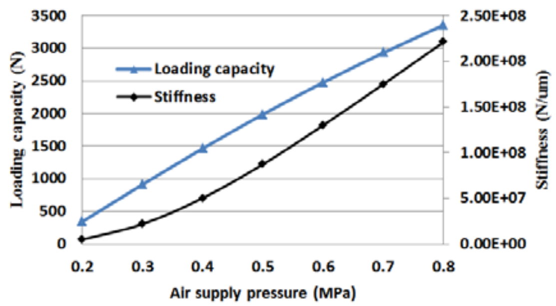

Fig.6 The Relationship between Air Supply Pressure and Loading Capacity, Stiffness

However, in engineering applications, increasing the supply pressure does not result in better air-floating guideway performance. Excessive supply pressure will

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bring a series of problems, such as increased air consumption, generating air hammer vibration, influence eccentricity and other so on.

Gas consumption is an important indicator of production cost, and excessive loading capacity will lead to unnecessary waste.

Excessive supply pressure will easily lead to excess energy in gas film, and the lag of force. As the energy is accumulated, continuous air hammer vibration is generated [6]. Generally, this vibration is unfavorable, it will cause instability of the air-floating guideway, and even damage the air-floating platform.

For T-type air-floating guideway, the top gas film surface is wider than the bottom gas film, because it needs to overcome the weight of the platform itself and the working load. Excessive gas supply pressure will increase the loading capacity of the top gas film rapidly, so that the top gas film thickness increase, the eccentricity will become larger, and the bottom gas film thickness reduced or even jammed, which will affect air-floating guideway performance [7].

Therefore, the supply pressure should be adjusted according to the actual working conditions.

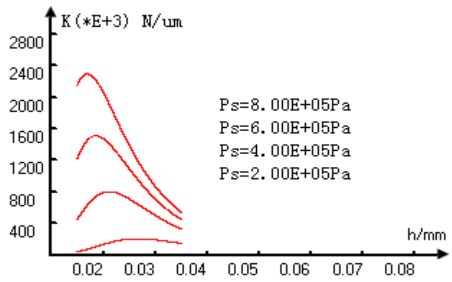

Fig.7 The Stiffness Variation with Different Film Thickness

The stiffness variation of guideway under different air supply pressure with different film thickness is shown in Fig. 7. When the film thickness *h* is between (0.015 ~ 0.035) mm, the stiffness under different supply pressure shows a parabolic trend of rising first and then falling. The greater the gas supply pressure, the higher the stiffness, which is consistent with the previous analysis. When the gas supply pressure increase, the gas film with the best stiffness is gradually decrease. In general, the optimum stiffness is easily obtained when h between (0.017 ~ 0.023) mm, Therefore, in this example, the average film thickness should be preferably selected within this range.

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4. Conclusions

This study sorted out the algorithm for analyzing the loading capacity of air-floating guideway commonly used in current engineering, and the corresponding loading capacity calculator is written in the VB language environment. Then the feasibility is verified by two examples, and the results show that the calculator can quickly calculate the loading capacity and stiffness of the guideway with different guideway surface area, air supply pressure and gas film thickness. At the same time, the corresponding curve is draw, which can provides a convenient and intuitive theoretical reference to designers, and has high engineering application significance.

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