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Optimization of Derusting Guide Rod and Static and Dynamic Analysis

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Abstract. In view of the problem of strong guide rod vibration and poor rust removal in the derusting process of the steel pipe inner wall rust-preventing guide rod of the coating production line , the structure of the guide rod was optimized and transformed. and the non-equal-section nesting structure was used to guide the static and dynamic analysis of the rod and the experimental verification show that after optimization, Finally it is concluded that the optimized guide rod deformation decreased by 38.3%, the concentration degree of the natural frequency increased by 41.38%, the working frequency is effectively avoided, and the quality of the rust removal after application is significantly improved.

1. Introduction

Inside and outside plastic-coated steel pipe is a new type of pipe developed in recent years in China. It is made of the steel tube as the base, and is coated with various materials of plastic in the steel tube. This kind of material makes it have the strength and rigidity of steel pipe, and also has the advantages of chemical resistance plastic pipe, such as no pollution, no mixed bacteria, smooth inner wall, no fouling, and low water resistance. Before the coating, it is necessary to pretreat the surface of the steel pipe. Good surface quality is conducive to enhancing the adhesion of the coating material. Therefore, it is necessary to optimize the derusting device to enhance the derusting effect. As shown in Figure 1.

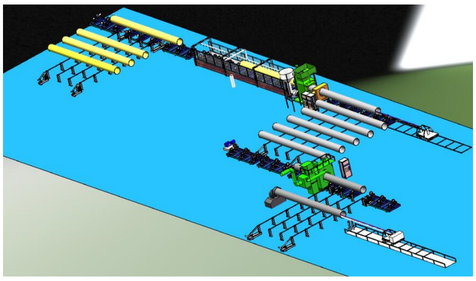

Fig.1 Coated production line

In the field of domestic modal analysis, according to the modal analysis of the beam of the machine tool, the literature [1]finds the weakest part of the beam, optimizes the structure, and finally designs the equipment that meets the quality requirements. the literature [2-4] modal analysis of the designed headstock was performed through the analysis software ANSYS, and then the structure was optimized to avoid the resonance phenomenon. The modal analysis is used in the literature [5] to obtain the strength distribution of the structure, so as to optimize the structure and ultimately improve the anti-vibration performance of the structure. In summary, in the process of modal analysis, the natural frequency and corresponding mode shape of the mechanical structure are mainly obtained, thereby optimizing the structure. the literature [6] through the analysis of the transverse forced vibration of the guide rod, a method for establishing the vibration model is proposed. After theoretical analysis and numerical calculation, the optimal solution is finally obtained.

2. Optimization of guide rod

2.1 Calculation of Guide Rod Natural Frequency and Bending Deformation

In the steel pipe wall rust removal system, the left side of the guide rod is fixed on the power trolley, the right side is supported by the universal wheel, and the guide rod is only affected by its own gravity when it is in a stationary state. Combined with mechanical dynamics and material mechanics, the guide rod is simplified to a schematic diagram of the vibrational mechanics of the guide rod as shown in Figure 2 .

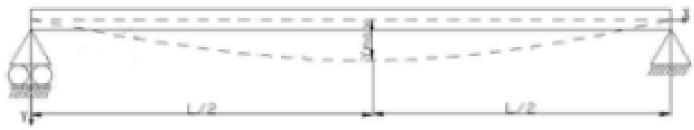

Fig.2 Guide bar vibration mechanics diagram

According to vibration mechanics, solve the natural frequency and mode shape of the transverse vibration of the guide bar

The differential equation of the transverse vibration of the rod is:

$$\rho A \frac{\partial^2 \dot{y}}{\partial t^2} + \frac{\partial^2}{\partial x^2}\left(EI \frac{\partial^2 y}{\partial x^2} \right) = F(x,t) \tag{1}$$

Using the method of separation of variables to solve the vibration function:

$$u(x,t) = \Phi(x) q(t) \quad F(x,t) = 0 \tag{2}$$

Substituting 2 to：

$$\frac{d^2 q(t)}{dt^2} + \omega^2 q(t) = 0 \tag{3}$$

Find the characteristic equation as：

$$\frac{d^4 \Phi(x)}{dx^4} = \beta^4 \Phi(x) \tag{4}$$

In the formula:

$$\beta^4 = \frac{\rho A \omega^2}{EI} \tag{5}$$

The left boundary condition is：

$$\Phi(0) = 0, \Phi'(0) = 0 \tag{6}$$

The right boundary condition is：

$$\Phi''(l) = 0 \quad Q = \frac{dM}{dx} = EIq \frac{d^3 \Phi}{dx^3} = qk\Phi(l) \tag{7}$$

Substituting boundary conditions into Equation 5 yields：

$$\Phi(x) = C_1 \sin \beta x + C_2 \cos \beta x + C_3 sh\beta x + C_4 ch\beta x \tag{8}$$

When k is infinite, the frequency equation is：

$$ch\beta l \sin \beta l - \cos \beta l sh\beta l = 0 \tag{9}$$

hat is, the natural frequency is：

$$\omega_i = \beta_i^2 \sqrt{\frac{EI}{\rho A}}, (i = 1, 2 \cdots) \tag{10}$$

Use software to draw two curves of tanβ and thβ. Determine the characteristic root of the frequency equation from its intersection as shown in Figure 3. It can determine the order of the guide rod natural frequency.

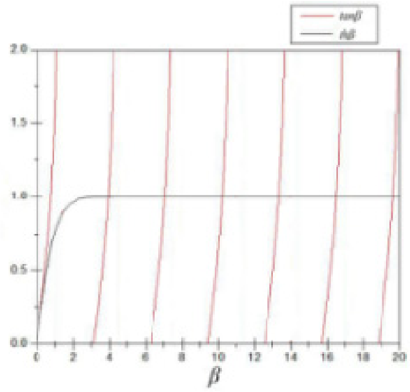

Fig.3 Characteristic root intersection curve

For a hollow rectangular section, the moment of inertia is：

$$I = \frac{BH^3 - bh^3}{12} \tag{11}$$

The data values in the formula are：Guide assembly qualityρA=2130.3kg；The elastic modulus of the guide rod material E=209GPa； The length of the guide L=12000mm; Section Width H=300mm,h=250mm, Section Height B=200mm,b=150mm。The guide rod is only affected by its own gravity, so the first six natural frequencies of the guide rod are calculated by taking the data, as shown in Table 1.

Tab.1 The first six natural frequencies

Modal Order	1	2	3	4	5	6
Frequency /Hz	1.2957	4.2362	8.9343	15.1308	23.1337	32.9545

Where yma is the midpoint deflection, according to the mechanics of the material:

$$y_{\max} = \frac{5\rho AgL^4}{384EI} \tag{12}$$

Bring the data into equation (12) to get ymax=17.33mm

From the above analysis we can see: the deformation and frequency of the guide rod are mainly affected by the guide rod's own weight and its own stiffness.，therefore, increasing the rigidity of the guide rod and reducing its quality and increasing its natural frequency can effectively enhance the overall performance of the guide rod.

2.2 The Optimal Design of the Guide

Because of the large span, the guide rod is bent due to its own gravity. Therefore, it is necessary to optimize the structure of the guide rod to increase the bending strength of the guide rod. The deformation of the guide rod is related to the support, load, material section and span. According to formula (12), it can be seen that increasing the elastic modulus E to increase the flexural rigidity of the guide bar is not significant. Therefore, increasing the moment of inertia I , which is a rational section shape used to rationally arrange the load , is the main measure to improve the flexural rigidity of the guide rod. Therefore, the guide rod is finally formed by two sections of non-equal cross-section nesting, connected by 8 fixing bolts, and the bending strength is improved by welding a plurality of ribs. Rectangular steel beam shown in Figure 4， its parameters are 200x300x8000mm, 100x200x6500mm，these two sections are assembled by site assembly.

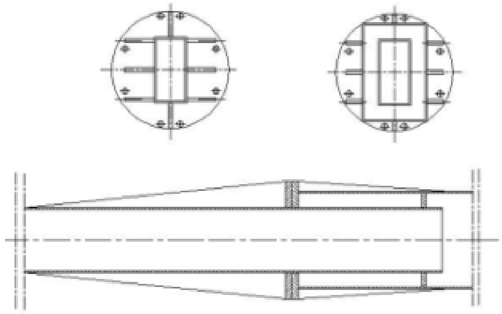

Fig.4 Non-uniform section guide bar

3. Static and dynamic analysis of guide rod

3.1 Force analysis of guide bars

When the guide rod is working in derusting, it is not only affected by its own gravity, but also the grinding force generated by the derusting power head and the steel pipe.As shown in Figure 5 rust power head shown， Among them, the fan and the vertical brush mainly play the role of cleaning off the rust, preventing the accumulation of iron, affecting the normal walking of the universal wheel. The circumferential distribution of the steel brushes is arranged at an angle, and a network structure is formed on the inner surface of the steel pipe by forward and reverse rotation to increase the adhesion of the coating material.

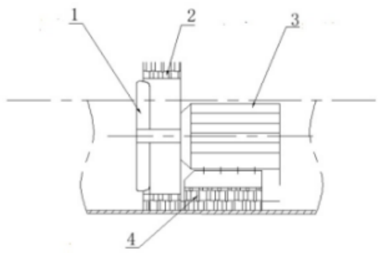

Fig.5 Derusting power unit

1.air fan 2. Steel brush 3. Frequency modulation motor 4. Article longitudinal brush

The formula for motor output force is:

$$F = \frac{9550 * P}{DN} \tag{16}$$

The rust removal power head motor is Y160L-4，Its power P=15KW. Motor speed is n=1460r/min, D=400mm. Bring data into the type, can calculate the grinding force of the brush head F = 245.291N.

3.2 Guide Bar Modeling and Meshing

The internal structure of the guide rod is relatively complex and it can be easily modeled by using UG software. In the process of modeling, in order to reduce the amount of calculations in the ANSYS workbench, other components that do not affect the analysis are omitted. In order to simplify the internal structure, it can be merged together by means of equivalent stiffness and equivalent mass. After completing the drawing of the model, it defines the material properties of the guide rod. The guide rod material is No.45 steel, the elastic modulus is 2.09×10^{11}, the Poisson's ratio is 0.269, and the density is 7890 $km \cdot m^3$.In order to reduce the amount of calculation while guaranteeing the calculation accuracy, the free mesh is selected. And after repeated verification, it is sufficient to satisfy the calculation requirements of the guide rod. The cell attributes set for meshing are tetrahedral Solid 187 cells with a mesh size of 10 mm, as shown in Figure 6.

Fig.6 Guide bar grid division

3.3 Static Characteristics Analysis

The deformation of the guide rod is elastic deformation. The load on the guide rod mainly comes from three aspects, the first one is the influence of the guide rod's own gravity, the second one is the force between the power head and the steel tube, ie the friction load, and the third is the force between the universal wheel and the steel tube. The grinding load can be divided into three components of the coordinate axis for application. According to the Machine Tool Manual, the axial force of the guide rod is negligible， According to experience, the normal force of grinding force is 1.5~3 times of the tangential force. Therefore, considering that the end face of the guide rod is subjected to F_x=200N, F_z=145.291N, a fixed constraint is applied to the tail of the guide rod, and a displacement constraint is applied at the other end, and the effect of the gravity on the guide rod is exerted by using the Standard Earth Gravity function in Inertial. Finally, it is calculated by the Solution analysis in the Static Structural module of ANSYS. Figure 7 shows the overall displacement deformation of the guide bar. The maximum deformation of the guide rod occurs at the two links of the guide rod, the maximum deformation is 10.687mm. The optimized guide rod deformation is reduced by 38.3%. The maximum stress of the guide rod is σ_{max}=72.398Mpa, which appears at the connection of the guide rod. The guide rod material is No. 45 steel, its minimum yield strength is σ = 355 MPa， The maximum stress on the guide rod is much lower than the allowable stress [σ] of the guide rod material, so the guide rod does not suffer from strength problems and meets the design requirements.

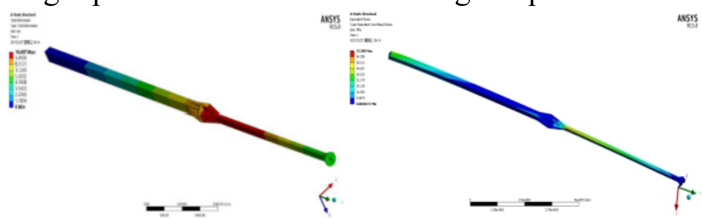

Fig.7 The displacement of the guide bar and the stress cloud diagram

3.4 Modal Analysis

Modal analysis is used to determine the vibration characteristics of the design structure or machine component, ie the natural frequency and mode shape of the structure. They are important parameters for the design of dynamic load structures. At the same time, it can also serve as a starting point for other dynamic analysis problems, such as transient dynamic analysis, harmonic response analysis, and spectral analysis. Modal analysis is also a pre-analysis process that is necessary for spectral analysis or modal superposition method harmonic response analysis or transient dynamic analysis.The modal analysis of the guide rods by the Modal module in the ANSYS software yields the first 6 modes, as shown in Figure 8.

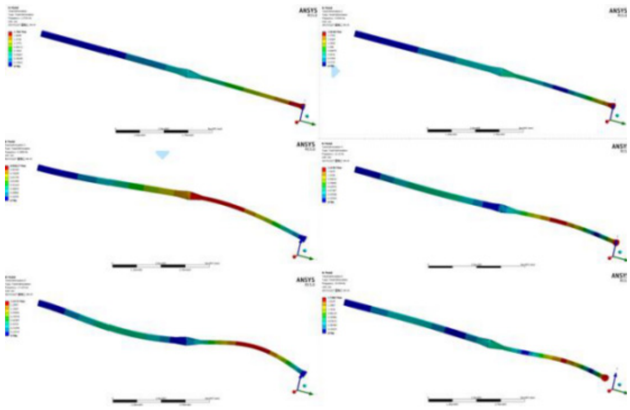

Fig.8 The modes of the restraint modes of the guide rod

In the first six modes, the natural frequency range is between 1 and 20 Hz. The natural frequency increases with the increase of the order, and the torsional deformation also becomes more intense. The natural frequencies before and after the optimization are compared as shown in the figure. From the figure, it can be seen that the first 6 natural frequencies are concentrated at 1.3716 Hz~19.934 Hz after optimization, which is 41.38% lower than the frequency range before optimization. In this way, vibrations due to the wider natural frequency band of the system can be avoided.

3.5 Harmonic Response Analysis

The harmonic response analysis is mainly used to analyze the dynamic response of the guide rod under the harmonic load of different frequencies. Its main purpose is to ensure that the guide rod can withstand different frequency load forces. Therefore, it is not enough to perform modal analysis only on the guide rods. It is necessary to perform response analysis on the guide rods to calculate the response curves and frequency curves of the guide rods at different frequencies. The main load related to the guide rod is the grinding load. Through the analysis of the guide rods, the guide rods are mainly based on transverse vibrations, that is, the X-axis direction. In harmonic response analysis, the Harmonic response analysis module in ANSYS workbench is used. Based on the modal analysis, it inherits the analysis results of modal analysis. So only need to set the frequency range (0~100Hz) and step length (1Hz) in Analysis Settings， select the X-axis in three directions and calculate Harmonic Response Spectrum by Clicking Solution， as shown in Figure 9.

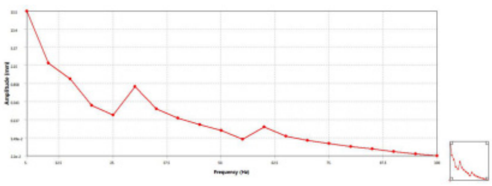

Fig.9 X-axis harmonic response spectrum

From the harmonic response spectrum, the maximum amplitude of the guide rod is the X-axis direction, ie, the lateral vibration. The maximum displacement displacement is 33.5mm, and the Y-axis and Z-axis deformations are small, which are 0.0502mm and 0.0962mm respectively. As the operating frequency gradually increases, the amount of deformation gradually decreases, the entire system tends to be stable, and the rated operating frequency of the motor is 24.3 Hz.， Therefore, the maximum response displacement of the designated guide rod at 24.3 Hz is 1.0399 mm, and the maximum response stress is 18.31Mp. As shown in Figure 10.

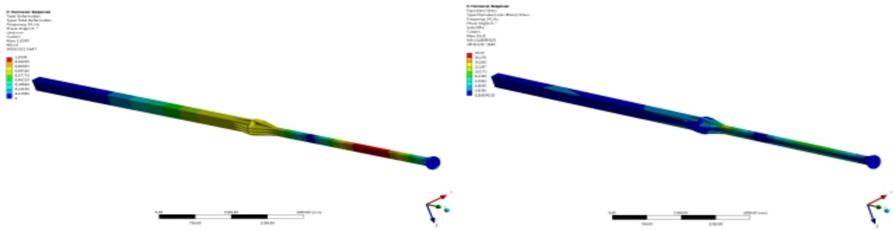

Fig.10 Stress response cloud

Combining modal analysis results shows that the amplitude of the first three steps of the guide rod is large, so that resonance phenomenon is unavoidable at the start of the motor, resulting in an increase in amplitude. Therefore, when the rust removal work is performed, the rust removal effect is best when the motor reaches the rated rotation speed (24.3 Hz).

4. Summary

In this paper, the first six natural frequencies are calculated by establishing a mathematical model of the guide rod, and the structure is optimized to analyze the stress of the guide rod. The static and dynamic analysis of the optimized guide rod was performed using the finite element analysis software, and the optimized guide rod was obtained, and the bending deformation was reduced by 38.3%. And the strength of the guide rod meets the design requirements, and the first six-order natural frequency concentration of the guide rod increases, which is 41.38% less than the frequency range before optimization. And this avoids vibration due to the wider natural frequency band of the system。According to the harmonic response analysis, the guide rod is mainly based on the lateral amplitude and the longitudinal amplitude is small, which does not affect the derusting work. Therefore, the overall derusting effect is improved after the guide rod is optimized.

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