Structure Design of Needling Machine Producing Small Diameter Felt Jacket and Simulation Analysis of Its Bed

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Abstract. This Paper discusses a kind of needling machine producing felt jacket with small diameter. The structural design and optimization of assembly and disassembly components and supporting bed will lead to quality improvement of felt jacket produced through reducing the bed's bending deformation. As the critical part, the supporting bed was studied through experimental modal analysis and finite element analysis, indicating that the needling process does not cause resonance of the machine since its operating frequency is much lower than that of the first two natural frequencies of the bed under certain circumstances. The supporting bed is well-designed to meet the needs of enterprises due to its small maximum deflection, and its rigidity and stability are qualified. The study helps realize producing the felt jacket with small diameter.

Introduction

The small diameter thermal contraction felt jacket is an indispensable workpiece for the coating process of the equipment for coating the Insulating paint between silicon steel sheets in the metallurgical and electromechanical manufacturing industries, and the cord sizing in the line making industry. The diameter of small diameter felt jacket used in this kind of occasion is generally less than 180 mm. The product size and performance requirements are special, so new requirements are put forward for the design and manufacture of needling machine, which is the main production equipment. The key is to solve the problem of the bending strength and stability of the supporting bed surrounded by the small diameter felt jacket, which also greatly limits the application of industrial small diameter felt jacket with diameters ranging from 50 mm to 180 mm.

General Structure Composition of Small Diameter Felt Jacket Needling Machine

Basic Principle of Needle Punching

The production of nonwovens by needle punching is completely through a mechanical action. That is to use the puncture of the needle to reinforce the fluffy fiber web into cloth [1]. This process does not use yarn at all, and it relies on the mutual cohesion of fibers and fibers to obtained strength. The commonly used needling machine is composed of the frame, the needle mechanism, the transmission mechanism, etc. The needle mechanism is the main mechanism, which is composed of the main drive shaft, the eccentric wheel, the connecting rod, the needle beam and felting needle, the main drive shaft rotates through the connecting rod to drive the needle beam (felting needle) to reciprocate up and down to complete the needling action.

General Composition Scheme of Small Diameter Felt Jacket Needling Machine

In order to meet the production requirements of small diameter felt jacket, we studied and designed a specialized needling machine for mall diameter felt jacket. The new kind of machine is mainly composed of the assembly and disassembly mechanism, the supporting platform mechanism, the supporting bed mechanism, the needle mechanism, the frame and so on. The structure diagram is illustrated in Fig. 1.

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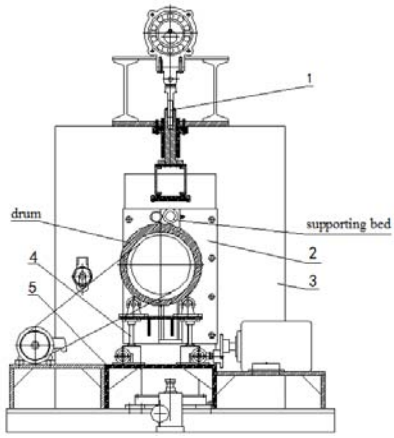
The assembly and disassembly mechanism is used to complete the assembly and disassembly of the small diameter felt jacket products, and the needle mechanism completes the needle-punching movement. The supporting platform mechanism is mainly used to support the worm screw elevator and other components, and to realize the supporting platform movement. The supporting bed mechanism is located below the bed to complete the supporting function. The basic working principle of the machine is as follows: opening the assembly and disassembly mechanism, installing the blanket cloth on the supporting bed (roller) and resetting it back; adjusting the drum, the bed and the mechanism system to the appropriate height position through the supporting bed mechanism; driving the needle mechanism by the motor, so as to solve the limitation of ordinary needling machine in the production of small-sized felt jackets. At the same time, the needling is repeated up and down to complete the production of small diameter felt jackets that meet the requirements.



1 Needle mechanism; 2 Assembly and disassembly mechanism; 3 Frame;
4 Supporting bed mechanism; 5. Supporting platform mechanism

Figure 1. Structure diagram of small diameter felt jacket needling machine

Rigidity and Stability Analysis of the Supporting Bed

When the needling machine is working, in the process of needling, the needle will exert a great downward periodic needling force on the bed supporting the felt jacket, which will make the bed bend and vibrate. In severe cases, the bending and vibration of the bed will affect the quality of nonwovens. Therefore, it is necessary to control the bending deflection and stability in the structural analysis, so as to ensure the strength and the operation safety of the supporting bed. So that the downward bending deflection of the middle point of the bed can be controlled within 0.5 mm and the natural frequency of the bed can be avoided from the working frequency of the needling machine. In this paper, we carry out the finite element simulation analysis and experimental modal analysis on the bed of needling machine to study and solve the issues of the rigidity and stability.

Finite Element Simulation Analysis of the Supporting Bed

The needling machine bed has a circular structure with total length of 2440 mm, a cross-section diameter of 76 mm, a wall thickness of 13 mm, a material of Q235A, an elastic modulus of 206 GPa and a Poisson's ratio of 0.3. According to the structural size of the bed, the three-dimensional geometric model was first built by using Solidworks software, and then the model is imported into the numerical calculation model by the finite element analysis software, and the finite element mesh is generated. When choosing tetrahedron eight-node solid element for mesh generation, we should ensure that the mesh is very uniform and the number of elements is sufficient [2]. The Z-direction and X-direction displacement constraints are applied to both ends of the bed, and then finite element simulation analysis is carried out. The morphological parameters of the supporting bed are extracted by the lanzos algorithm [3]. The finite element simulation model is shown in Fig. 2.

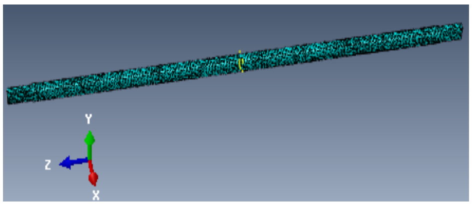


Figure 2. Finite element simulation model

According to the finite element simulation analysis, the first two natural frequencies of the Y-direction of the supporting bed are 23.43 Hz and 100.75 Hz.

Experimental Modal Analysis of the Supporting Bed

Basic Principles of Experimental Modal Analysis

Experimental modal analysis (EMA) includes excitation, data acquisition and parameter identification. The time history of excitation and response is measured by experiment, and the frequency response function of the structure system is obtained by using the technology of digital signal process [4], and then the parameter identification method is used to identify the frequency response function. Modal parameter identification refers to the process of acquiring the modal parameters (system pole, natural frequency, damping factor, residue and vibration mode) from modal experiments of the structure [5], providing theoretical basis for the design and modification of the structure.

In structural modal analysis, the specific mechanical structure can be seen as a multi-degree-of-freedom vibration system [6]. The differential equation of motion for a linear structure system with N-degree-of-freedom is as follows Eq. 1 [7]:

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=\{f(t)\} \tag{1}$$

Where $[M]$ is the mass matrix; $[K]$ is the stiffness matrix; and $[C]$ is the damping matrix of the system respectively. In the modal coordinate system, $[\Phi]$ is used as the modal mode matrix, so Eq. 1 can be written as follow Eq. 2:

$$\{x\}=[\Phi]\{q\} \tag{2}$$

Where $\{q\}$ is the modal coordinate vector; the first equation is left multiplied by $[\Phi]^T$ to obtain Eq. 3:

$$[\Phi]^T[M][\Phi]\{\ddot{q}\}+[\Phi]^T[C][\Phi]\{\dot{q}\}+[\Phi]^T[K][\Phi]\{q\}=[\Phi]^T\{f\} \tag{3}$$

Due to the orthogonality of the mode matrix, the mass matrix, stiffness matrix, and damping matrix are diagonalized , then substituting the diagonalized matrixes into the Eq. 3 to obtain the Eq. 4.

$$\begin{bmatrix} \ddots & & \\ & m_i & \\ & & \ddots \end{bmatrix}\{\ddot{q}\}+\begin{bmatrix} \ddots & & \\ & c_i & \\ & & \ddots \end{bmatrix}\{\dot{q}\}+\begin{bmatrix} \ddots & & \\ & k_i & \\ & & \ddots \end{bmatrix}\{q\}=[\Phi]^T\{f\} \tag{4}$$

Let $\{f\}=\{F\}e^{jwt}$, $\{q\}=\{Q\}e^{jw}$, $\{x\}=\{X\}e^{jwt}$, Eq. 5 can be obtained by substituting them into the Eq. 4:

$$\{X\}=\sum_{r=1}^{N}\frac{\{\varphi_r\}\{\varphi_r\}^T\{F\}}{k_r[1-(\frac{w}{\Omega_r})^2+j2\xi_r(\frac{w}{\Omega_r})]} \tag{5}$$

Where Ω_r is the rth order natural frequency of the system; ξ_r is the rth order damping ratio of the system. If the exciting force F_j is only at the point j on the system, the excitation force array is:

$$\{F\} = \{0\ 0\ 0 \cdots F_j \cdots 0\ 0\} \tag{6}$$

Substituting the Eq. 6 into the Eq. 5, the response of the system at point p is defined as:

$$X_p = \sum_{r=1}^{N} \frac{\varphi_{pr}\varphi_{jr}F_j}{k_r[1-(\frac{w}{\Omega_r})^2 + j2\xi_r(\frac{w}{\Omega_r})]} \tag{7}$$

The frequency response function between point j and point p on the system is given as

$$H_{pj}(w) = \frac{X_p}{F_j} = \sum_{r=1}^{N} \frac{\varphi_{pr}\varphi_{jr}}{k_r[1-(\frac{w}{\Omega_r})^2 + j2\xi_r(\frac{w}{\Omega_r})]} \tag{8}$$

The single mode identification method is used to identify the modal parameters of the frequency response function obtained from the experiment, and the natural frequencies, damping ratios and residues of the system are obtained.

Experiment Modal Analysis of the Supporting Bed

Frequency domain signals $F(w)$ and $X(w)$ are obtained by FFT(Fast Fourier Transformation) of the acquired time domain signal $f(t)$ of exciting force and $x(t)$ of response, then the frequency response function of the structure is defined as Eq. 9:

$$H(w) = \frac{X(w)}{F(w)} \tag{9}$$

Experimental modal analysis is performed on the bed. In the experiment, a force-hammer is used to excite the structure. According to the experimental conditions in the field, the method of SIMO (Single Input; Multiple Output) is adopted. The proposed method utilizes five acceleration sensors to collect the Y-direction acceleration signals at selected locations on the supporting bed. In the modal experiment, the excitation and response points on the bed are arranged as illustrated in Fig. 3. The excitation point is arranged at reference location 2, and the five response points are arranged at reference location1, 2, 3, 4 and 5 respectively.

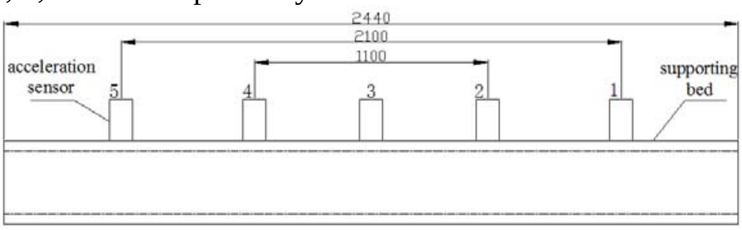


Figure 3. Location map of excitation point and response points

Fig. 4 depicts the frequency domain curve of the supporting bed. Though observing the frequency domain curve, we find that there are plenty of low frequency vibration signals, and all frequencies are the frequency multiplications of the fundamental frequency of 2.8125Hz. According to the speed ratio of the driving motor and the retarder of the needling machine in the field, the speed of needling is 170 times/min, that is 2.83Hz, which is basically the same as the fundamental frequency obtained by the test. Based on the analysis, the frequency multiplications mainly come from the felting needles, because each felting needle has three sets of barbs, and the whole row of needles can not penetrate the felt at the same time. So different frequencies are generated, but they are the frequency multiplications of the speed of the needling.

According to the frequency domain curve, the working frequency of the device is mainly in the low frequency band, so the modal analysis is mainly dominated by the first two modes. The first two natural frequencies are 26.94 Hz and 106.04 Hz by modal test, as illustrated in Fig. 5 and Fig. 6. Based on the analysis of frequency domain curve, the vibration frequency of 26.94 Hz is not found, and the working frequency is much lower than the first two natural frequencies of the supporting bed. The machine will not produce resonance during needling.

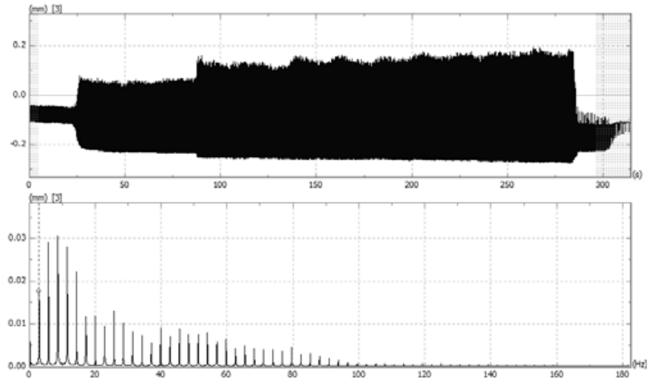
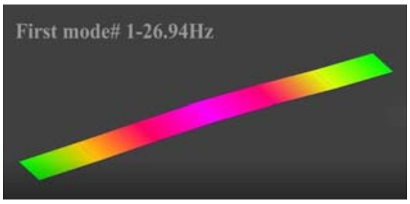


Figure 4. Frequency domain curve of the supporting bed



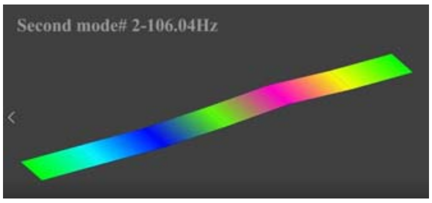


Figure 5. First mode graph

Figure 6. Second mode graph

Rigidity Analysis of the Supporting Bed

In the design of the new needling machine, we set up a supporting bed mechanism (see Fig. 1) to reduce the bending deformation. In order to measure the needling force and the bending deformation of the supporting bed during the operating process, two pressure sensors are installed at both ends of the bed and five displacement sensors are installed along the length of the bed. The sensor arrangement is shown in fig. 7.

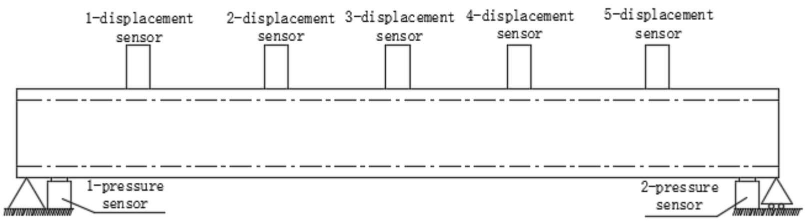


Figure 7. Sensor layout

Because of the influence of the supporting bed mechanism, the downward pressure measured by force sensors at both ends is greatly reduced, and the maximum downward pressure is 3.65 kN. The measured vibration signal is illustrated in Fig. 8. The deeper the felting needles penetrate into the felt jacket, the greater the deflection of the bed. According to the depth of needling into felt jacket, the working condition of needling machine has changed from shallow to deep. Based on the time domain chart of the deepest interval, it can be seen that the deflection of the bed tends to increase with the prolonging of needling time. This result is due to the densification of the felt jacket during needling. Therefore, for the convenience of analysis, we analyze the maximum deflection based on the data of the displacement sensor location 3 and 4. As shown in Fig.9.

It can be seen from the Fig. 8 and Fig. 9 that the supporting bed is not in the center position during the testing process. After calibrating the zero position, the maximum downward deflection is 0.15 mm and the maximum upward deflection is 0.30 mm. The upward deflection of the bed can be overcome by adjusting the position of the stripping plate in the needle mechanism, so it is not necessary to consider it. The needling speed is about 350 times/min or more when the enterprise carries out the following trial production , and the phenomenon of tight two sides and loose middle of small diameter felt jacket is not found. That is to say, there is no excessive deformation in the supporting bed, and the rigidity and stability meet the design requirements. So the needling machine can realize the production of small industrial felt jacket with diameter less than 180 mm.

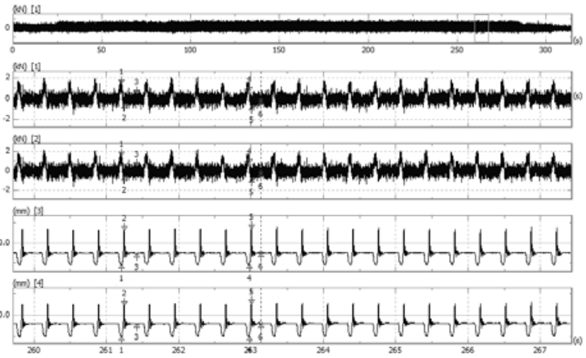


Figure 8. Vibration time domain amplification signal chart

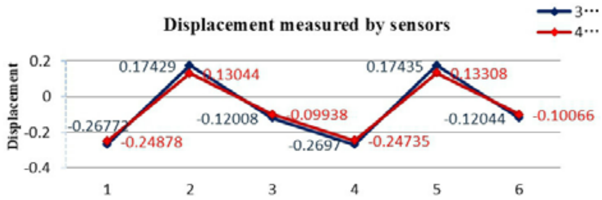


Figure 9. Displacement diagram measured by sensors

Conclusions

(1) The structure design of the small diameter felt jacket needling machine, especially the combination application of the assembly and disassembly mechanism and the supporting bed mechanism, effectively reduces the bending deformation of the bed, improves the quality of the felt products, and enables the needling machine to realize the function of producing small diameter felt jackets.

(2) Based on the basic principle of experimental modal analysis, the experimental modal analysis and finite element simulation analysis of the supporting bed of the needling machine are carried out, and the results are basically the same. The analysis results show that the working frequency of the needling machine is much lower than the first two natural frequencies. The machine will not produce resonance during needling, and the stability of the supporting bed is better.

(3) Under a certain working condition, the rigidity of the supporting bed is measured in the field. The results show that the maximum downward deflection is 0.15 mm, which meets the needs of enterprises less than 0.5 mm. Therefore, the rigidity of the supporting bed can reach the design requirements.

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