Simulation Design and Analysis of the Three-dimensional Shape Testing Device for Functional Microfilaments

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Abstract. In order to study the micromechanical properties of functional microwires in three-dimensional space morphology, a performance testing device for functional microwires in three-dimensional morphology combined load mode was designed. First, the microwire material is introduced into the three-dimensional weaving process, and the cubic B-spline function curve is used to fit the shape of the three-dimensional microwire, and then the spatial configuration of the microwire is constructed. Secondly, based on the three-dimensional morphology of the microwire, the function and principle of the microwire in the compound loading mode are analyzed, and a three-dimensional testing device for the microwire is designed. Finally, the key components of the designed device were analyzed through simulation, and the key components of the test device were all within their yield limits, which verified the rationality of the test device.

1. Introduction

With the continuous emergence of new micro-nano materials, people pay more and more attention to the mechanical properties of functional micro-filament materials [1-3]. Microfilament material testing is the basis for evaluating the performance and quality of microfilaments [4], but because the microfilament material needs to maintain a quasi-static load in the actual service process [5,6], and the load it bears is not a single load. It is subjected to the combined action of a variety of loads. This complex stress state is the main reason for its deformation, damage and overall failure. In order to better evaluate the quality and reliable applicability of microfilament materials and their products, it is very important to design a microfilament performance test device suitable for multiple loads [7,8]. Most of the previous research has been devoted to the testing device of the mechanical properties of the alloy material in the two-dimensional form [9-12], and the testing device under the three-dimensional form of the functional microwire has not been involved. Based on the three-dimensional morphology analysis of microwires, this paper designs a functional microwire material composite loading test device, and analyzes the key components through finite element simulation to verify the reliability of the test device, and provide performance testing research for microwire materials. The basis of experimentation.

2. Three-dimensional Morphology Analysis of Microwires

In order to study the composite force morphology of microwires in three-dimensional space, we must first understand the three-dimensional space configuration of microwires. In the three-dimensional weaving process, the yarns interact in space to form a complete spatial network structure, as shown in Figure 1[13]. The microfilament structure can be introduced into the three-dimensional weaving process to construct a three-dimensional microfilament Spatial morphology, select the smallest repeatable representative volume unit in the mesostructure, namely the unit cell, as the research object. According
to elastic mechanics, the microwire between any two supporting points in the microwire unit cell structure can be regarded as an elastic thin rod, and the complex buckling model of the microwire can be simplified into a simply supported beam model. The differential equation of microwire deflection curve is [14]:

\[
\frac{d^2 \omega}{dx^2} = \frac{M(x)}{EI}
\]

(1)

\[
M(x) = Ax + B
\]

(2)

Among them, \( \omega \) is the deflection curve equation of the microwire, \( M(x) \) is the bending moment equation, \( E \) is the Young's modulus, and \( I \) is the cross-sectional moment of inertia. Substituting formula (1) into formula (2), the general form of the microwire deflection curve equation is:

\[
\omega(x) = \frac{A}{6EI} x^3 + \frac{B}{2EI} x^2 + Cx + D
\]

(3)

Among them, \( A, B, C, \) and \( D \) are unknown constants.

According to the formula (3), the deflection curve of the woven composite microwire is a cubic curve. Therefore, the cubic B-spline function curve can be used to fit the shape of the three-dimensional microwire, and the three-dimensional shape of the microwire can be drawn as shown in Figure 2. Can be used to design the microwire three-dimensional shape test device.

3. Design of Three-dimensional Testing Device for Microwires

3.1. Design and Analysis of the Overall Structure of the Test Device

In this paper, during the testing process of the composite load of the microwire in the three-dimensional form, the designed microwire 3D testing device should include a three-dimensional fixed mold, a three-dimensional solid unit, a low-speed transmission unit, a control system module, and a data acquisition module. The schematic diagram is shown in the figure. The function and use conditions of the target device require that the device should have the characteristics of small overall size, compact structure, high motion precision, high test accuracy, etc., and a low rate of force must be maintained during the test process to prevent the microwires from being broken and being affected. The shape can be maintained after the force, so as to obtain the mechanical parameters of the material under the compound load, and then obtain the micro-mechanical properties of the material. From a microscopic point of view, the failure mechanism of the material is revealed. The overall mechanism diagram is shown in Figure 4.
4. Analysis of Key Components

4.1. Statics Analysis of Worm Gear

In the quasi-static loading process, the device in this paper adopts two-stage worm gear transmission, and the ball screw can transform the rotation movement transmitted by the worm gear and worm, and finally realize the quasi-static loading of the test device. The conventional contact mechanics analysis of the worm gear is carried out to analyze whether its contact strength meets the transmission requirements, and the reliability of the test device is ensured. The parameters of worm gear are shown in Table 1[15].

Table 1. Worm gear parameters

| name      | material       | Young's modulus/GPa | Poisson's ratio | Yield limit/MPa |
|-----------|----------------|---------------------|-----------------|-----------------|
| Worm gear | ZCuAl8Mn3Fe3Ni2| 124.1               | 0.34            | 310~370         |
| Worm      | 40Cr           | 206                 | 0.28            | ≥785            |

The rated torque of the motor reducer is 4N·m. The torque input by the motor is transmitted to the motor reducer through the motor input shaft and then to the worm. The torque is output from the worm gear shaft through the contact of the gear teeth. Therefore, the set constraint method: A fixed constraint is applied to the center hole of the worm wheel, and a rotation angle constraint is applied to the end of the worm. The load method is applied: a torque of 4N·m is applied to the end of the worm shaft.
Figure 5. Worm Gear Stress Displacement Diagram

Figure 5 is the overall stress analysis diagram of the worm gear. The deformation amount is the largest at the position of the worm near the tooth tip, and its value is 0.0342mm. The stress is the largest at the position of the worm gear near the tooth tip, and its value is 140.3Mpa. Within its yield limit, the structure is reliable.

4.2. Dynamic Analysis of Fixed Fixture

The fixed fixture connected with the transmission unit in the test device is an important part of the load and is easy to cause resonance. In order to prevent the test device from affecting the experimental results due to resonance during the test process, a modal analysis of the test device is required.

Figure 6. The First Six order modal shapes of the fixed fixture
It can be seen from the figure 6 that the six natural frequencies of the designed fixed fixture before vibration are 171.41Hz, 175.20Hz, 593.45Hz, 1181.6Hz, 1374.0Hz, 1506.3Hz, and the motor speed of this device is 24r/min in actual work, corresponding to the lead screw. The rotation speed of the device is 0.027r/min, which is much lower than the first-order natural frequency of 171.41Hz of the designed device, so it can be considered that the designed device will not produce resonance phenomenon, and the structure is safe and reliable.

5. Conclusion
Firstly, this article analyzes the three-dimensional shape of functional microfilaments, secondly, designs a three-dimensional shape testing device based on its three-dimensional shape. Then, the key components of the test device are analyzed: Among the key components of the transmission link, the worm gear has the largest deformation at the worm tooth tip and the largest stress at the worm gear tooth tip, which is within its yield limit. Modal analysis was carried out to verify the reliability of the finite element model, which can show that the test device is reasonable and reliable, and provides a basis for the experimental research of functional microwire materials.

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