Design of Testing Device for Anisotropic Friction Characteristics of Composite Materials

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Abstract. In order to meet the rapid and accurate measurement of anisotropic friction characteristics of composite materials, based on Coulomb's friction theorem, a new type of testing device for friction characteristics of composite materials is designed with the speed control of servo electric cylinder and the real-time data acquisition of tension pressure sensor as the core. The device can adapt to the test of five typical installation angles of 0 °, 45 °, 90 °, 135 ° and 180 ° between composite test plate and test moving direction. The load and speed can be set within a certain range, and the friction coefficient of composite material in typical direction can be calculated, displayed and replayed automatically according to the measurement results, so as to simulate the different laying direction, load and speed of composite material friction environment.

1. Introduction
Composite materials have been widely used in the field of aerospace because of their outstanding advantages such as high specific strength, high fatigue resistance, good shock absorption and strong designability. However, the manufacturing process of composite materials also determines its significant anisotropic characteristics in use [1]. In the cold launched missile weapon system, the launching cylinder is made of composite materials. When the missile is loaded into the launching cylinder and ejected from the cylinder, the anisotropic friction characteristics of the composite materials will cause the axial movement of the missile in the launching cylinder to deviate along the axial direction, thus affecting the accuracy of missile attitude control when the missile is loaded or launched [2]. In order to predict and control the axial deviation reliably, it is necessary to accurately measure the anisotropic friction characteristics of the composite used for the starting barrel, that is, the friction coefficient in each main direction separated from the direction of the composite plate.

In reference [1], a test-bed for composite friction coefficient is designed. The test-bed uses traction rod to pull the load-bearing test board for one-way movement without testing the return journey. To retest the friction coefficient of composite in different directions, it is necessary to take out the board, measure the installation angle manually and then complete the reinforcement. The operation process of the device is complex and the test time is long.

In order to overcome the above problems and improve the testing efficiency and accuracy, a new testing device for anisotropic friction characteristics of composite materials is designed in this paper.
2. Design requirements analysis and measurement principle

2.1. Design requirements
The overall design requirements of the device include two levels of function and performance. On the functional level, the device is required to be able to set the experimental state of different weight of push block, different speed of lead screw and different angle of placement of composite materials; it can accurately control the push block to do two-way uniform motion on the composite plate, and measure the thrust, so as to calculate the corresponding friction coefficient. The composite plate can be placed at 0 °, 45 °, 90 °, 135 ° and 180 ° respectively on the test bench with the composite material installed parallel to the test bench and its front end facing the electric cylinder. The push block is composed of a group of weights, which can be combined into 20kg, 25kg, 30kg, 35kg, 40kg and 50kg. On the performance level, it is required that the measurement error of tensile force is less than 1n and the maximum moving speed of push block is not less than 3m/min.

According to the above requirements, the design of the test device mainly includes the design of the mechanical body, the selection of the measurement and control equipment, the design of the electrical circuit and the development of the measurement and control software.

2.2. Measuring principle
According to Newton’s law of motion, when the push block moves at a constant speed on the horizontal experimental table, the thrust \( F \) is equal to the friction force \( f \), which can be expressed as \( F = f \); at the same time, the support force \( N \) is equal to the gravity \( G \) of the push block, which can be expressed as \( N = G = mg \); according to Coulomb’s friction theorem, the friction force \( f \) is equal to the friction coefficient \( \mu \) multiplied by the support force \( N \), which can be expressed as \( f = \mu N \). Comprehensive:

\[
F = \mu mg
\]  

(1)

In the formula, the thrust \( F \) is measured by the tension pressure sensor, and the unit is \( N \); \( m \) is the mass of thrust block, and the unit is \( kg \); \( \mu \) is the dimensionless friction coefficient. When the pull pressure sensor transmitter is calibrated as a unit \( kg \) of mass, \( F' \) indicates the measurement result of the pull pressure sensor transmitter. In this case, equation (1) can be expressed as:

\[
F = F' = \mu mg
\]  

(2)

Therefore, the friction coefficient \( \mu \) can be calculated by the following formula:

\[
\mu = F' / m
\]  

(3)

3. Design requirements analysis and measurement principle

3.1. Mechanical body design
The mechanical body of the test device is mainly composed of servo electric cylinder, horizontal experimental table and push block. At the bottom of the push block, polytetrafluoroethylene material is bonded. Composite material plate is placed on the experimental table, and the servo motor is directly connected with the lead screw to drive the push block to move at a constant speed on the horizontal experimental table.

The top view of the mechanical body of the test bench are shown in Fig. 1. It is mainly composed of stand, platen, electric servo cylinder, electric control box, pull pressure sensor transmitter, push block, linear guide rail, static slide rail and dynamic slide rail.

Among them, the platform is composed of four height adjustable pillars, four long side beams and four short side beams, and casters are installed on the lower long side beams. The bottom of the counterweight push block is bonded with polytetrafluoroethylene, and the composite plate is installed on the platform plate. The electric cylinder drives the push block to do reciprocating motion on the composite plate.
Figure 1. Top view of composite friction test device

The friction test bench plate is milled with ordinary structural steel plate, the composite plate placement position is a square groove with the same center and 45° intersection, which is designed to meet the placement of the composite plate during the test, and can be in accordance with the square of 45°, 90°, 135° and 180° Type to meet the requirements of friction test.

3.2. Design of measurement and control unit

The workflow of the measurement and control unit is shown in Figure 2.

Figure 2. Workflow relationship of measurement and control unit

The measurement and control unit controls the electric cylinder to push the block to run at a given speed at a constant speed, and simultaneously collects the real-time push and pull force of the pull pressure sensor. When the electric cylinder is running, the push rod cannot exceed the upper and lower mechanical limit.

The sensor and servo motor driver are connected to the computer through RS485 communication interface, and the upper and lower proximity switches and encoder are connected to the corresponding interface on the servo driver.
3.3. Main equipment selection

The electric cylinder and pull pressure sensor are the main equipment of this measuring device.

According to the requirements of push block weight, composite friction coefficient and measurement accuracy, the pull pressure sensor is MS-1, which is a digital output type pull pressure sensor of Xi’an Xinmin Electronics Co., Ltd. and the matched transmitter is BSQ-1-485 with RS485 interface. The measurement data is shown by IEEE 754 floating point standard and data transmission is carried out by Modbus RTU protocol. The range of the sensor is 0 ~ 30kg, and the overall accuracy is 0.9N.

The lead screw is directly connected with the motor, and the friction coefficient of the tested composite material is less than 0.1. According to the maximum load weight of the push block of 50kg, the torque required at the lead screw end can be calculated, and then the torque demand of the motor can be calculated inversely according to the mechanical efficiency. In addition, according to the maximum speed of pushing block, the maximum speed of motor can be converted. The maximum linear speed of pushing block is 3m/min, which is 50 mm/s. According to the load-bearing requirements, the ball screw pair with the specification of 20×5mm is preliminarily selected as the transmission mechanism of the electric cylinder, and the mechanical efficiency is taken as 0.8. Then the motor speed and torque requirements are calculated as follows [3]:

\[ n_{screw} = \frac{60 \cdot V}{P_{a}} = \frac{60 \times 50}{5} = 600 \text{rpm} \]  
(4)

\[ T_{screw} = \frac{F \cdot P_{a}}{2\pi} = \frac{(0.1 \times 50 \times 9.8) \times 0.005}{2 \times 3.14} = 0.039 \text{ N.m} \]  
(5)

\[ T_{motor} = \frac{T_{screw}}{\eta} = \frac{0.039}{0.8} = 0.049 \text{ N.m} \]  
(6)

Based on the above calculation results, Shanghai Jiwang SEA802-786 electric cylinder is selected. The effective stroke of the electric cylinder is 800mm, and the rated speed is 167mm / s. The supporting motor is delta ECMA-C10602SS, with rated speed of 3000 rpm and drive model of ASD-A2-0221-l.

4. Device software design

The software function of the test device includes the constant speed control of the electric cylinder and the real-time data acquisition of the pull pressure sensor. The constant speed control of the electric cylinder is directly completed by Asda soft V5 software of DELTA servo driver [3]. The real-time data acquisition of tension pressure sensor is developed by VB6 program. The program interface is shown in Figure 3.

![Data acquisition program interface of force sensor](image)

Figure 3. Data acquisition program interface of force sensor

The data acquisition program of the tension pressure sensor in operation is compiled with VB6.0 [5]. The core of data acquisition program is based on MSComm control serial data receiving and sending,
MODBUS protocol message analysis, IEEE754 floating-point conversion, file I/O operation, and real-time display and playback of acquisition data.

5. Conclusion
In this paper, a new measuring device of composite anisotropic friction coefficient is designed, which solves the problems of low efficiency, large measuring error, small measuring range and inconvenient use of the existing measuring system of composite friction coefficient. It provides a good experimental platform for the study of anisotropic properties of composite materials. The working state of the test device is shown in Figure 4.

It should be noted that in the process of use, occasionally, the computer cannot receive the response after sending the acquisition request to the pull pressure sensor. After repeated test and analysis, it is believed that when RS-485 bus is used to receive and receive data through serial port, it will be interfered by high frequency of servo driver, which will cause data error and packet loss. The solution is to limit the time-out of each data acquisition process, when the response is over time, the host will send data acquisition request again, so as to avoid the interruption of acquisition process.

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