Research on the influence of humidity on FG sensitive components

Abstract: In view of the abnormal phenomena during temperature rise of the optic fiber coil in the full temperature bias test, this paper starts from the thermal effect of ice melting, derives the disturbance of water vapor to the temperature conditions, explains the abnormal phenomena during temperature rise in the full temperature bias test based on the Shupe effect, and carries out experimental verification on this theoretical basis. The results show that the water vapor in the environment will disturb the temperature conditions during the full temperature bias measurement of the optic fiber coil, and make the bias curve show the abnormal phenomena during temperature rise. Controlling the ambient humidity can effectively suppress the abnormal phenomena during the full temperature bias test of the optic fiber coil.

Key words: Optical fiber coil, humidity, bias test, temperature rise

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Introduction

Optic fiber coil is the core sensitive component of fiber optic gyroscope (FOG), and the product quality of the optic fiber coil directly determines the the upper performance limit of the FOG. At present, the production of optic fiber coil is still in the stage of semi-automatic development, and human operation is still a key factor affecting quality. However, there is uncertainty in human operation, which leads to a certain quality fluctuation in the finished optic fiber coil. Moreover, the optic fiber coil plays a decisive role in the accuracy of the FOG, so the screening test of the optic fiber coil becomes an indispensable step before the assembly of the high-precision FOG.

As the core component of FOG, the optic fiber coil is very sensitive. In the bare coil state, the optic fiber coil is susceptible to interference from many environmental factors, resulting in various unintended phenomena. The optic fiber coil will be encapsulated and protected in the assembly process of the FOG, thus excluding some of the interference from environmental factors. To ensure the validity of the optic fiber coil screening test, it is also necessary to accurately identify and eliminate these unintended interfering factors during the screening test.

In this paper, it is found that the ambient humidity can affect the full temperature bias test of the optic fiber coil, causing the bias curve of the optic fiber coil to produce an abnormal phenomenon like "tick".

1 Operating Principle of Optic Fiber Coil

Optic fiber coils consist of optical fibers and glue, where the refractive index of the optical fibers is susceptible to change due to temperature. When the refractive index changes at the non-midpoint of the optic fiber coil due to temperature change, since the propagation of light takes time, two beams of light propagating in opposite directions will pass through the point at different moments, and due to the difference of refractive index between the two moments, different phases are superimposed between the two beams, thus introducing a non-reciprocal phase difference. This phase error introduced by the temperature change is the shupe error, which is expressed as:

$$\Delta\phi_E(t) = \frac{2\pi}{\lambda}\frac{\partial n}{\partial T}\int_0^L \frac{\partial T(z,t)}{\partial t}\frac{L-2z}{v}dz \quad (2.1)$$

Where: $\Delta\phi_E(t)$ is the phase difference caused by temperature change at moment t; λ is the wavelength of light in vacuum, v is the propagation speed of light in the optical fiber.

The output of the FOG will convert the phase difference into the form of angular velocity for output, so substitute (2.1) into (1.1) with $\phi_S = \Delta\phi_E(t)$. It can be obtained that the angular velocity drift caused by the shupe effect is:

$$\Omega_E(t) = \frac{n}{2LR}\frac{\partial n}{\partial T}\int_0^L \frac{\partial T(z,t)}{\partial t}(L-2z)dz \quad (2.2)$$

Where $\frac{\partial T(z,t)}{\partial t}$ is caused by the temperature change rate, so the magnitude of the shupe error is positively correlated with the temperature change rate of the optic fiber coil.

2 Full Temperature bias Test

The full temperature bias test refers to a test method to check the temperature performance of the optic fiber coil by applying a temperature change stress to the optic fiber coil alone, keeping the other parts of the FOG at room temperature, and recording the gyroscope output. The test optical path is shown in Figure 3-1.

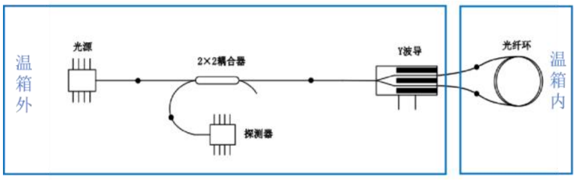

Fig. 3-1 Optical Path Diagram of Full Temperature bias Test

In the above test method, only the optic fiber coil is used as a variable in the temperature chamber for variable temperature test, so it can be assumed that the output curve of the FOG reflects the output state of the optic fiber coil.

The temperature range of the full temperature bias test set in this paper is -45℃~+80℃, the temperature change rate is 1℃/min, and the temperature curve is shown in Figure 3-2 after holding at both +80℃ and -45℃ for 2 hours.

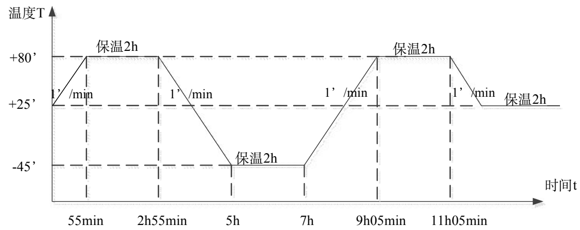

Fig. 3-2 Temperature Curve of Full Temperature bias Test

Because the shupe effect of the optic fiber coil is sensitive to the temperature change rate, the maximum temperature change rate of the body of the optic fiber coil heating and cooling must be strictly controlled within 1±0.1℃/min. In the ideal case, the bias is linearly correlated with the temperature change rate; assuming that the coil temperature varies strictly according to the set curve, the full temperature bias curve of the response is shown in Figure 3-3.

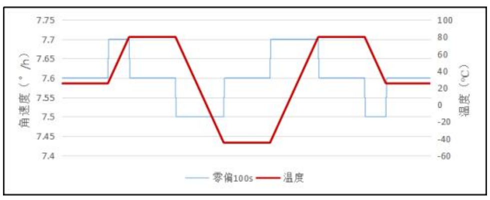

Fig. 3-3 Full Temperature Bias Curve in Ideal Case

However, due to the influence of the heat conduction process of tooling on the smoothing of the coil temperature curve, the noise of the FOG and other non-ideal factors, the output curve of the FOG and the temperature curve in the tooling under normal conditions are shown in Figure 3-4, and it can be observed that there are obvious peaks and valleys that fluctuate with the temperature change rate in the full temperature bias curve. Generally, these peaks and valleys are called "shupe peaks". The value of the shupe peak directly reflects the sensitivity of the optic fiber coil to the temperature change rate, and also directly affects the peak-to-peak value of the full temperature bias curve, which is the most core index for evaluating the temperature performance of the optic fiber coil.

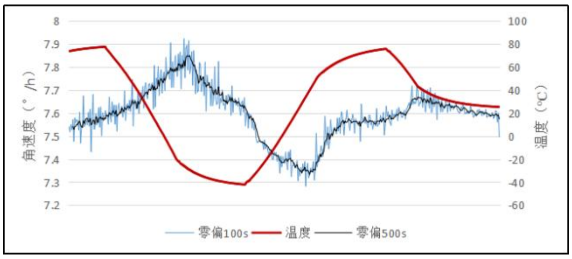

Fig. 3-4 Full Temperature Bias Curve under Normal Conditions

3 Influence of Humidity

Neither the coil winding glue nor the optical fiber coating reacts with water after curing, so the influence of humidity the chemical properties of optic fiber coil can be ignored. In this paper, the temperature range for the full temperature bias test of the optic fiber coil is -45~80°C, covering the melting point of ice (0°C), so the possible influences on the temperature caused by the change of state of water vapor in the test environment need to be considered.

During the cooling process, when the temperature in the temperature chamber is lowered to below 0℃, water vapor in the air condenses and adheres to the surface of the tooling and coil body, because most of the condensation of water vapor takes place in the air, so the influence on the temperature of the optic fiber coil is relatively small.

Throughout the cooling and low temperature insulation process, the moisture in the air completes condensation to form an ice film that adheres to the surface of the optic fiber coil and tooling.

In the process of heating up, when the temperature in the temperature chamber rises to 0℃ or above, the ice film adhered to the optic fiber coil and the surface of the tooling starts to melt and change from ice film to water for adhesion. Because the melting process absorbs heat, it affects the heating process of the optic fiber coil. In addition, because ice is crystalline, the temperature of the ice-water mixture remains almost constant throughout the melting process, blocking the heat conduction process of the air environment to the optic fiber coil and hindering the heating of the coil body. At the same time, in the process of melting from ice to water, as the air in the temperature chamber is in a dry state, accelerating the evaporation process of water, and the heat absorption of water evaporation also hinders the heating process of the coil body. Under the above three influencing factors, although the air inside the temperature chamber is kept heating under the control of the temperature chamber, the temperature difference between the coil body and the air is increased. When the water is completely evaporated, the coil body under the influence of a large temperature difference, the heat conduction of the coil body is enhanced, and the coil body heats up faster, even exceeding the originally set heating rate. The whole heating process of the coil body is shown in Figure 4-1.

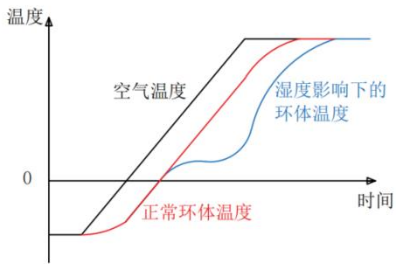

Fig. 4-1 Schematic Diagram of the Temperature during the Heating Process

Since the shupe effect is positively correlated with the temperature change rate, it can be expected that when the test environment humidity is relatively high, the optic fiber coil full temperature bias test curve will start to show an abnormal fallback in the reverse direction of the shupe peak after heating up to 0℃, and then turn back to rise after falling back to the lowest point until the end of the heating section. The phenomenon is called "tick" because the bias curve in the phenomenon resembles a hook.

4 Experiments and Results

In order to verify the theory, two high-precision optic fiber coils were taken for full temperature bias test under conventional low humidity conditions and enhanced dry conditions respectively, to observe the curve difference between them.

The temperature and humidity curves of the whole process measured by the temperature and humidity probe under conventional low humidity conditions are shown in Figure 5-1, and the full temperature bias test results are shown in Figure 5-2 and Figure 5-3, respectively. Because of the high accuracy of the coil, a certain dehumidification treatment is still adopted. It can be observed that there is a significant rebound peak of humidity during the heating process, with the maximum humidity reaching 29%, at which time both experimental coils showed the expected "tick" phenomenon during the heating process.

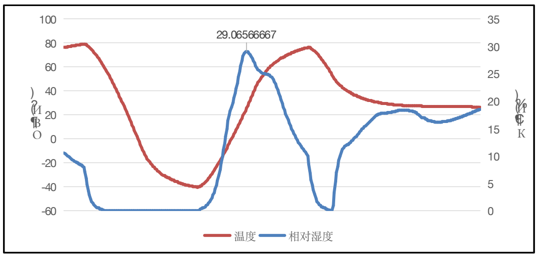

Fig. 5-1 Temperature and Humidity Detection Curve under Conventional Low Humidity Conditions

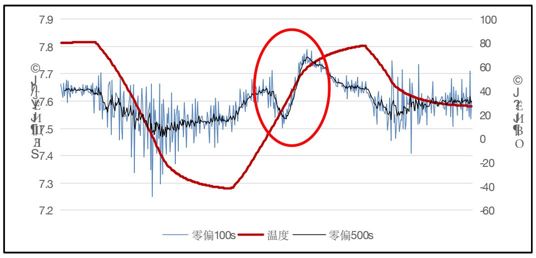

Fig. 5-2 Full Temperature Bias Curve of Experimental Coil 1 under Conventional Low Humidity Conditions

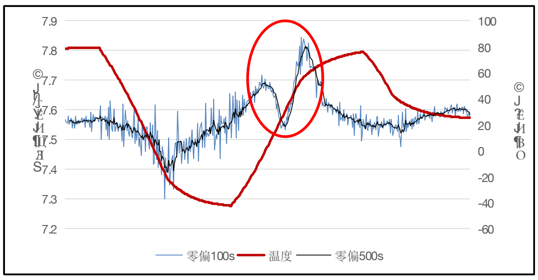

Fig. 5-3 Full Temperature Bias Curve of Experimental Coil 2 under Conventional Low Humidity Conditions

The temperature and humidity curves measured by the same temperature and humidity probe under enhanced dry conditions are shown in Figure 5-4, and the full temperature bias test curves under the corresponding conditions are shown in Figure 5-5 and Figure 5-6.

During the heating process after the enhanced drying, the humidity was suppressed to less than 1%, which basically excluded the interference of water to the test. It can be observed that there is no "tick" phenomenon in the full temperature bias test curve, and the full temperature bias test curve regresses to the standard state.

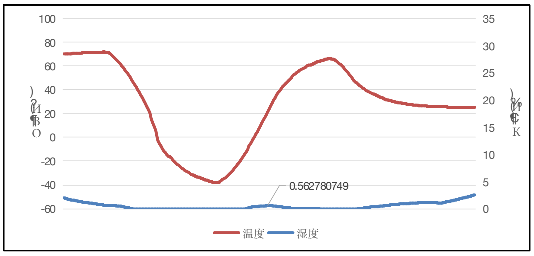

Fig. 5-4 Temperature and Humidity Detection Curve under Enhanced Dry Conditions

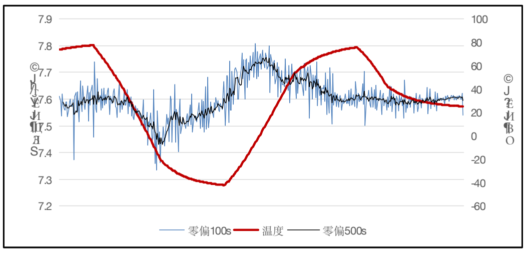

Fig. 5-5 Full Temperature Bias Curve of Experimental Coil 1 under Enhanced Dry Conditions

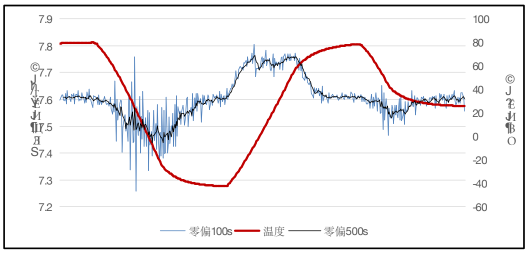

Fig. 5-6 Full Temperature Bias Curve of Experimental Coil 2 under Enhanced Dry Conditions

Based on the experimental results, it can be inferred that the humidity will affect the full temperature bias test of the optic fiber coil, causing the "tick" phenomenon of bias curve of the high-precision optic fiber coil during the heating period. This abnormal phenomenon can be effectively suppressed by controlling the humidity.

5 Brief Summary

In this paper, based on the thermal effect of ice melting and the shupe effect of optic fiber ring, the heating "tick" phenomenon in the full temperature bias test is explained and experimentally verified on the basis of this theory. It has been shown that water vapor in the environment will perturb the temperature conditions during full temperature bias test of optic fiber coils, which causes the bias curve to show a heating "tick" phenomenon; while controlling the ambient humidity can effectively suppress the heating "tick" phenomenon during full temperature bias test of optic fiber coils.