A strain measurement method for insulated cylinder based on OFDR fiber sensing system

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***Abstract*—In order to obtain the strain data of insulating cylinder surface, a strain measurement method for insulated cylinder based on OFDR fiber sensing system is proposed, which can detect the strain of insulating cylinder.**

Keywords—OFDR, nsulated cylinder, strain measurement

I. Introduction

The Gas Insulated Switchgear (GIS) is an important part of the UHV transmission network and its safe and reliable operation is very important to the stability of the power system, having high reliability, small footprint, strong scalability, easy maintenance and maintenance, etc. In GIS system, the safety of insulation equipment is very crucial, so the strain distribution characteristics and development trend of its surface are indispensable for the stable operation of the whole system[1].

With the research on sensing technology, distributed fiber optic sensing technology is becoming increasingly popular. Distributed optical fiber sensing technology is a new sensing technology that senses external signals with optical fiber as the medium and light wave as the carrier. Fiber sensors have been widely used in point sensing and quasi-distribution measurements, such as structural health monitoring, industry, and biomedical engineering. Among many detection methods, OFDR detection technology has a very prominent advantage. It can not only avoid the interference of strong electromagnetic field, but also become a very excellent detection means due to its high resolution and large dynamic range. It have been widely used in point sensing and quasi-distribution measurements, such as structural health monitoring, industry , and biomedical engineering[2].

II. Simulation

OFDR technology is an optical fiber sensing technology based on Rayleigh scattering. Figure 1 shows the structure of OFDR system, whose core parts are linear sweep laser source, interferometer structure and coherent heterodyne receiving module. Among them, the structure of the interferometer generally uses Mahzind interferometer structure or Michelson interferometer structure[3].

The laser sends out a laser signal, which is divided into two beams by a 1*2 fiber coupler. One beam enters the reference arm of the Mahzender interferometer as a reference signal, and the other beam enters the signal arm of the Mahzender interferometer as a probe signal. The detecting light generates echo signal due to Rayleigh scattering in the transmission fiber. The scattered light returns to the signal arm through the ring, the reference light and the detecting light are coupled by 2*1 coupler, and the coherent optical signal after coupling is sensed by the photodetector. After photoelectric conversion, the obtained electrical signal is sampled by the analog digital converter to obtain the digital signal. The digital signal is finally analyzed by fast Fourier transform[4].

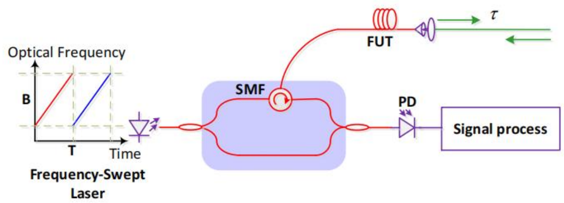

Fig. 1. OFDR system structure diagram

The Rayleigh spectrum of a finished fiber is stable and unique, and the Rayleigh spectrum is only affected by temperature or strain. The change of refractive index in the optical fiber to be measured will cause the generation of Rayleigh scattering. By analyzing its mechanism, it can be found that its drift property is similar to that of fiber Bragg grating, which can be considered as weak continuous Bragg grating with random period. By analogy with Bragg spectrum, it can be found that Rayleigh backscatter spectrum is also mainly affected by temperature and strain changes in the environment where the fiber is located[5].

After being stressed, the refractive index of optical fiber will change, which will have some influence on Rayleigh scattering. By using OFDR system to demodulate the backscattered light of fiber, the position and intensity of each disturbance on fiber can be accurately obtained. The relation between the disturbance position and the laser frequency can be expressed as[6]:

$$x_0 = \frac{c}{2n}\tau_0 \tag{1}$$

Where x_0 represents the distance from the starting point, and τ_0 represents the delay between the echo signal and the reference signal.

The power of the beat signal is proportional to the intensity of the reflected signal, and the frequency of the beat signal is proportional to the position of the point to be measured[7]. By Fourier transform of the beat signal, the state information of different positions on the optical fiber

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link can be obtained. After obtaining the data of beat signals corresponding to different positions, we need to analyze how the Rayleigh spectrum frequency shift is generated by temperature or stress.

For an optical fiber to be tested, the relationship between the variation of Rayleigh backscattering spectrum and the variation of external strain and temperature can be expressed as follows[8]:

$$\frac{\Delta\lambda_B}{\lambda_B} = (1 - P_e)\varepsilon_{fiber} + (\alpha + \xi)\Delta T \qquad (2)$$

where P_e is the effective photoelastic constant, ε_{fiber} is the strain on the fiber, α is the thermal expansion coefficient, ξ is the fiber thermo-optic coefficient, ΔT is the temperature variation and λ_B is the Bragg wavelength.

Before the specific experiment, the model can be simulated first, and the theoretical strain distribution can be compared with the experimental data later. First, we modeled a cylinder similar to an insulating cylinder using solidworks. The cylinder is identical in size and detail to the actual insulated cylinder. After that, finite element method was used to analyze the cylinder, the upper and lower circular surfaces were fixed, and the cylinder was heated in all directions. As shown in Figure 2. It can be seen that most of the strain values on the outer surface of the cylinder keep a small amplitude change, but some of the undulations are larger than the surrounding strain.

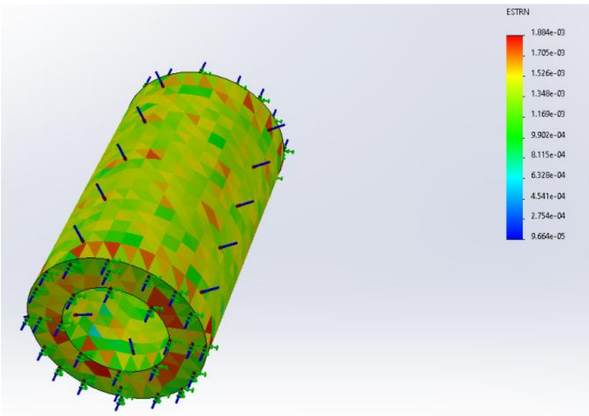

Fig. 2. Strain simulation diagram of cylinder after heating

III. Experiment

The shape of the insulation cylinder is similar to the simulated cylindrical shape, which is different from the plane. We must strictly consider the layout of optical fiber, so as to measure the strain caused by deformation more accurately. The sensing fiber is divided into two sections. The first section is the sensing fiber to be laid on the surface of the insulating cylinder for sensing detection, and the generated changes are transmitted to the upper computer. The other section is the ordinary optical fiber for data transmission, which is used to connect the sensing fiber to the upper computer. Since the shape of the insulating cylinder is a cylinder, two layout methods are assumed here. One is to lay along the direction of the bus, but it is difficult to turn when it meets two end faces. The other is the method adopted in this paper, which is the spiral layout, so that all sides can be completely detected, and there will be no large Angle bending. And the precision of measurement can be adjusted by changing the pitch. The sensing fiber is laid on the physical insulation tube, as shown in the following figure 3.

Fig. 3. Insulation cylinder physical picture

The next step is to adjust the environment of the insulation tube to cause the deformation of the insulation tube, so that the strain occurring on the surface will be evenly transmitted to the sensing fiber. In this paper, two methods are tried to deal with the insulation cylinder. The first is a common pressure squeeze, but because the fiber itself is too fragile, vertical side pressure is definitely not possible. Therefore, pressure can only be applied on two end faces, but the final result is very unsatisfactory. The shape variable of the side is very small, so that the strain value detected by the sensing fiber does not change. The second method is to change the application of pressure to a change in temperature. Due to the reason of thermal expansion and cold contraction, the insulation cylinder itself will expand to a certain extent when heated, which brings great convenience to the generation of strain. To heat the insulation cylinder, due to the site, only the heating gun can be used to heat the central part of the insulation cylinder, and then the temperature change of the whole insulation cylinder is caused by temperature transmission, and finally the strain is generated. Since the expansion coefficient and temperature of the insulation tube are linear, and the sensitivity of the optical fiber to temperature is also linear, it can be normalized that the measured strain value is linear in the deformation change of the insulation tube.

Every ten minutes of heating, we recorded the strain on the surface of the cylinder. After 40 minutes of heating, we stopped heating, let the insulation cylinder in a natural cooling state, and recorded the data ten minutes later. The resulting five sets of data are shown in Figure 4. The horizontal coordinate represents the length of the sensing fiber, that is, the position of the surface of the insulation cylinder. The ordinate represents the measured strain value. line 2-5 indicates the temperature rise of the insulation cylinder, and line 6 indicates the data ten minutes after heat dissipation is stopped. It can be found from all the five groups of data that the strain values on the surface of the insulated cylinder are not the same, that is, the insulated cylinder does not expand uniformly after being heated, but is in a form of small expansion and large expansion. It can also be found through data realization that the expansion changes periodically, and this period is the same as the length of each circle of the sensing fiber, that is to say, the maximum expansion of the insulation cylinder is basically flush with the bus bar.

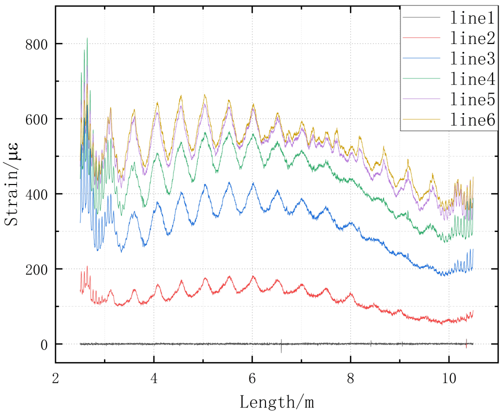

Fig. 4. Strain of the surface of the insulation cylinder

By comparing Figure 2 and Figure 4, it can be clearly seen that in the simulation figure of Figure 2, the outer surface does not expand uniformly due to temperature rise, but its strain shows a part of bulge, that is, at the same height, the strain has a certain fluctuation. This is very similar to the actual strain measurement results in Figure 4. By comparing the period of strain change in Figure 4 with the length of each circle of the sensing fiber on the surface of the insulation tube, it can be found that the two values are very similar, which can further determine the accuracy of the experiment.

IV. Conclusion

Therefore, the method of measuring insulation tube based on OFDR proposed in this paper is consistent with the actual measurement results.

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