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Application of Acoustic Sensor in Partial Discharge of Transformer

Zhe Hou*, Zhiwei Dai, Jie Zhou

Wuxi Division of No.703 Research Institute of CSSC, Wuxi, Jiangsu, China.

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***Corresponding author:** Zhe Hou, Wuxi Division of No.703 Research Institute of CSSC, Wuxi, Jiangsu, China.

Abstract

The insulation problem of power equipment is one of the main reasons for power equipment failure. The insulation condition of power equipment can be judged in advance by monitoring partial discharge. It is of great significance to realize on-line monitoring of partial discharge defects in time and effectively, and to monitor the real-time status of transformers and conduct fault analysis based on them. Acoustic detection methods are widely used due to their good non-destructive properties. When a discharge fault occurs inside a transformer, it generates rich acoustic signals during the specific process from severe defects to faults. By monitoring the acoustic signals, it provides auxiliary basis for power grid dispatchers to make decisions. In this paper, the application status of audible acoustic sensor and optical fiber acoustic sensor in transformer partial discharge is summarized. Transformer partial discharge monitoring technology based on acoustic sensor is a relatively new transformer fault diagnosis method, which has great research significance. This study provides a good theoretical basis and practical guidance for partial discharge online monitoring.

Keywords

Audible sensor, optical fiber acoustic sensor, transformer, partial discharge

1. Introduction

Partial discharge is an important sign and manifestation of insulation failure. By detecting the partial discharge of power equipment, the defects existing in the equipment can be found timely and effectively, so as to realize fault early warning. Therefore, partial discharge detection technology is of great significance for ensuring equipment safety and power supply reliability. At present, the partial discharge detection methods of power equipment can be roughly divided into two categories, namely electrical detection method and non-electrical detection method [1]. Among them, electrical detection method (current method, UHF method) is the most commonly used partial discharge detection method at present, while non-electrical detection methods such as acoustic wave method, decomposition product detection method and optical detection method have also been proved effective and developed for a long time, and have accumulated a rich knowledge system. However, from the perspective of field application at this stage, only UHF method and acoustic method are more practical methods.

Acoustic wave method is an important online nondestructive partial discharge detection method for power equipment. Compared with the electrical detection method, it has a strong ability to resist electromagnetic interference. In addition, because the propagation speed of acoustic wave is far less than that of electromagnetic wave, the use of ultrasonic signal can accurately locate partial discharge [2]. Therefore, the acoustic method is very suitable

for partial discharge detection of on-site power equipment. In recent years, with the cross-development of various disciplines, the optical fiber acoustic sensor technology has attracted the attention of researchers. Compared with PZT sensor, optical fiber acoustic sensor has the advantages of good insulation performance, excellent anti-electromagnetic interference performance and good multiplexing performance, and can gradually replace the traditional PZT sensor for sensing acoustic signals.

2. Audible sensor

The acoustic wave generated by the internal discharge of the transformer is a complex propagation process, which can only be transmitted to the transformer box after passing through a multi-layer complex dielectric structure. This process will inevitably lead to the attenuation of acoustic energy, and the mechanism of acoustic wave attenuation is quite complex. The results show that the structure and type of transmission medium, the propagation conditions of sound waves and the shape of sound waves all affect the attenuation process of sound waves. The interior of the transformer is an overly complex environment. Generally, the attenuation degree of the sound wave is judged by the way of test and measurement [3].

Sound wave is a kind of mechanical wave, and its wavelength can be converted into frequency. Wavelength is an important characteristic index of sound wave and a measure of the nature of sound wave. The sound signal that can be heard by the human ear is 20 Hz~20 kHz. Taking frequency as the dividing line, sound waves can be divided into infrasound waves, audible sound waves, ultrasonic waves and microwave waves. The frequency band division is shown in Figure 1. Audible sound waves and ultrasonic waves are essentially the same, both belong to mechanical vibration and can only propagate in elastic media [4].

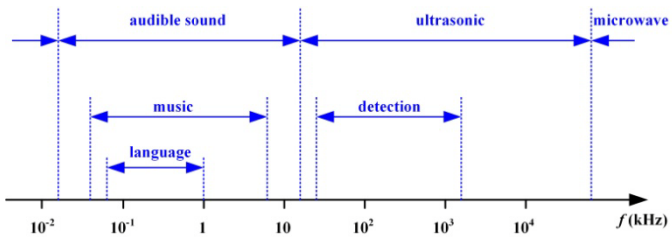


Figure 1. Boundary diagram of acoustic frequency band division.

By analyzing the characteristics of the material, the researchers obtained the expression of the attenuation coefficient of sound wave propagation as [5]:

$$a = \frac{2\pi^2 f^2}{c^3 \rho_0}\left[\frac{4}{3}\eta + \frac{(\gamma - 1)k}{Cp}\right] \tag{1}$$

Which, a is the absorption coefficient of sound wave, f is the frequency of sound wave, and η is the viscosity coefficient of sound wave transmission medium.

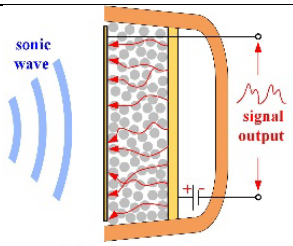
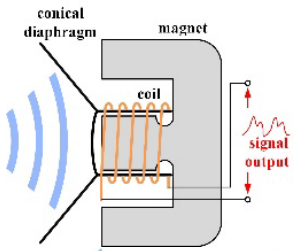
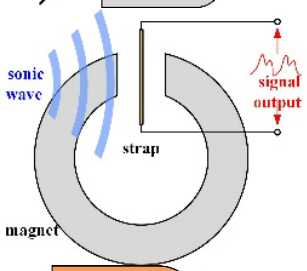
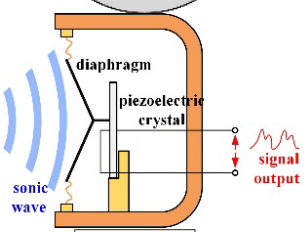
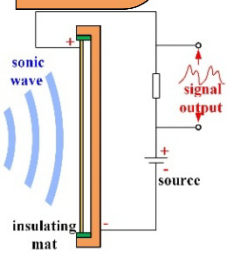
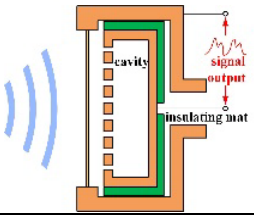
It can be seen from the above formula that the attenuation coefficient of sound wave is proportional to the square of sound wave frequency, so for low-frequency sound wave, its attenuation will be far less than that of ultrasonic wave. The sensor is placed inside the transformer to avoid the attenuation of acoustic energy caused by complex environment and reduce the energy loss of acoustic signal during transmission. The on-site test personnel can also hear the sound emitted by the transformer in operation through the human ear. Through the analysis and discussion of the audible sound inside the transformer and the acoustic signal in the ultrasonic low frequency band, the internal condition of the transformer can be judged qualitatively.

The transformer arc discharge monitoring technology based on audible sound is a relatively novel transformer fault diagnosis method at present. For the monitoring of sound signals, in recent years, many researchers have carried out some research on transformer fault diagnosis technology based on audible sound and obtained many theoretical results by using test methods, among which the research direction is mainly to extract the characteristics of the obtained sound signals [6-8].

Zhao Lihua of Sichuan University, et al. [9] selected the audible sensor by analyzing the characteristics of the

audible signal in the transformer and the corresponding monitoring requirements, and finally showed that the electret capacitive audible sensor was suitable for the acquisition of the audible signal in the transformer and was verified by tests. The traditional audible sensor is mainly microphone, and its schematic diagram is shown in table 1.

Table 1. Schematic diagram of various audible sensors

audible sensor	schematic diagram
carbon microphone	
dynamic microphone	
ribbon microphone	
crystal/piezoelectric microphone	
condenser microphone	
electret microphone	

Literature [10] has studied three types of spark discharge: needle-needle, needle-plate and suspension in oil. Spark discharge is the process of developing into arc discharge. The frequency range with the largest proportion of energy is defined as the characteristic frequency range of this type of spark discharge, and the characteristic frequency range of the three types of spark discharge is 5~6 kHz, 6~8 kHz, 1~3 kHz. Wu Guoxin et al. [11] proposed a transformer discharge diagnosis method based on audible sound by simulating different discharge types in a real transformer tank and using wavelet packet-BP neural network algorithm. Fu Jinsong [12] studied the acoustic diagnosis of internal spark discharge faults in transformers by comparing the acoustic methods such as ultrasonic detection, noise analysis and vibration detection. Feng Tingna [13] used the test to obtain the discharge audible signals under different discharge types and different voltage levels in the transformer, carried out time-frequency analysis on them, and drew the following conclusions: the discharge frequency of audible signals includes both odd and even frequency doubling of 50 Hz.

In the field of voiceprint of transformer winding fault, in terms of standard application, the electric power industry standard DLT573-2010 Guide for Power Transformer Maintenance [14] describes the abnormal acoustic signal of transformer by onomatopoeia, but it is easy to be affected by subjective conditions. Liu Yunpeng et al. [15] characterized the winding deformation of 110kV transformer by constructing two kinds of transient voiceprint characteristics of short circuit impact, namely, spectral entropy and spectral component Euclidean distance.

3. Optical fiber acoustic sensor

As one of the passive optical devices, fiber grating has developed rapidly in recent years. Its initial research began with the scientific research achievements of Hill et al. in 1978. They first discovered the photosensitivity characteristics of optical fiber when conducting experimental research on germanium-doped quartz fiber materials using 488 nm argon ion laser [16]. One of the most important preparation methods of fiber gratings is the phase mask method, which was first proposed by Hill et al. [17] in 1993 and finally confirmed. This mature technology has been used until now, which has greatly promoted the theoretical research of fiber grating and provided strong support for the in-depth research of fiber grating characteristics and its sensing field.

At this stage of rapid development of fiber grating sensing technology, its sensing theory has made a major breakthrough. With the continuous development of interdisciplinary science, its application in the field of electrical engineering has also been rapidly developed and been gradually mature due to its unique advantages. Webb et al. In 2000, Takahashi et al. [19] designed a new type of fiber optic hydrophone using fiber grating (FBG). The experimental results show that it can effectively monitor the sound waves in the frequency range of 1 kHz to 3 MHz. American scholars Fomitchov and Krishnaswamy first used FBG to detect acoustic signals in fluid and solid structures in 2003 [20], and built an ultrasonic detection system based on FBG using tunable laser sources and photo detectors to detect acoustic signals in fluid and solid structures. The results show that the fiber grating can effectively perceive the ultrasonic signal at least in the frequency range of 10 kHz - 5 MHz. In literature [21], Sarkar et al. applied fiber grating to the detection of partial discharge ultrasonic signals in transformers. Fiber grating sensors can measure ultrasonic signals in the range of 30~240 kHz. In 2005, Wang Qianchun et al. [22] built a set of fiber grating acoustic sensors using tunable laser sources by analyzing the mechanism and frequency range of ultrasonic signals and combining the change of the frequency response of the fiber grating reflection spectrum. 1 mm fiber grating is used to monitor the acoustic signal emitted by the transducer under water conditions. The experimental results show that the response ability of the sensor is closely related to the optical wavelength of the input sensing system. In addition, there is a linear relationship between its response ability and the sound pressure. In 2010, Wild et al. [23] studied the response characteristics of the fiber Bragg grating to the space ultrasonic signal by using the fiber Bragg grating and confirmed through experiments that the fiber Bragg grating sensor has a strong dependence on the perception of the acoustic signal from different directions.

4. Conclusion

Partial discharge is an important manifestation and symptom of transformer insulation deterioration. Therefore, it is of great significance to realize the on-line monitoring of partial discharge defects in time and effectively, and to monitor the real-time status of transformer and analyze the fault based on it. This paper focuses on the important value of acoustic signal perception by analyzing the existing research results of audible sensors and optical fiber sensors in transformer partial discharge.

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