Experimental Study on Internal and External Noise Characteristics of a 10kV Oil-immersed Transformer

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Abstract. This paper investigates the internal and external noise characteristics of a 10kV oil-immersed transformer based on advanced acoustic measuring technology. A kind of fibre-optic hydrophone is installed inside the transformer and four acoustic sensors are placed outside in the air. The noise is measured under the condition of no-load and short circle, and the amplitude and frequency characteristics are obtained. The results show that the amplitude of internal noise is higher and contains more high order harmonics when compared with the external noise. It means the internal noise has a higher signal noise ratio, and contains more information. These results can be used for further research such as transformer noise generating mechanism, transmission regulation, transformer noise controlling.

1. Introduction
Transformer is one kind of the most important devices in power grid, which is used for transforming voltage and current. At runtime, transformer generates noise without intermission, and may cause noise pollution problem [1].

Scholars focused on the transformer noise characteristic for a long time. In the early 1920s, some transformer production companies and research institutions began the study of transformer's vibration and noise. In 1968, a report by the American Institute of Electrical Engineers indicated that there were 421 papers and 90 patents published from 1930 to 1966. The content included transformer noise generation mechanism, characteristics, reduction technologies, environmental standards and so on [2]. Hitherto, many efforts have been made by experimental and theoretical analysis. Mo Juan measured transformer noise in the short circuit and no-load condition, and analyzed the frequency spectrum and range [3]. Ji Sheng-chang theoretical analyzed the vibration of core and winding, and validated that the fundamental frequency magnitudes of core and winding vibrations are linear to square of no-load voltage and loading current respectively according to experiments [4]. Zhu Ye-ye constructed a transformer vibration monitoring system, which conducted to investigated the vibration characteristics under different working conditions [5]. Wu Xiao-wen studied the influence of operational condition on noise characteristics of power transformer in a semi-anechoic room [6]. Ming Jin experimentally studied the transmission of vibration in a 110kV power transformer with and without cooling oil [7]. Ma Yu-chao measured the vibration and noise of a 220kV oil-immersed transformer, and obtained the
vibration and noise characteristics inside and outside of the transformer firstly [8]. Generally speaking, the external noise characteristics of transformer have been studied in detail, while the internal noise have rare been studied.

In this paper, both of the internal and external noise of a 10kV oil-immersed transformer are investigated simultaneously. Two fiber-optic hydrophones are installed inside the transformer oil tank, four microphones are placed outside of the transformer. In section 2, the mechanism of transformer noise generation is analyzed briefly. In section 3, the experimental setups are introduced and the results are analyzed.

2. Transformer noise generation mechanism
The transformer noise is mainly generated by the vibration of transformer core and windings.

The core vibration is caused by the magnetostrictive effect of the silicon steel sheet, and the electromagnetic force which caused by magnetic flux leakage between the seams of the silicon steel sheets. The magnetostrictive effect is the primary cause of core vibration. The electromagnetic force's effect is not significant which benefited by the improvement of the silicon steel sheet stacking technology. Magnetostrictive cycle is half of the power source. As a result, the vibration fundamental frequency of the transformer core caused by magnetostriction is 100Hz. However, the silicon steel sheet is not always linear, and there are high orders harmonics vibrations occur.

The winding vibration caused by the electromagnetic force, including the force between the high voltage windings and low voltage windings, the force between coils, the force between wires. The magnitude of forces and vibration are proportional to the square of the current. So, the fundamental frequency of winding vibration and noise are twice of the frequency of current. While, the insulating materials like insulation paper and insulation block are not absolutely linear, so the winding vibration frequency contains high orders harmonic components too.

The vibration of transformer core and windings transfer though solid path, liquid path and air path, as shown in figure 1. The vibration of core and winding are interact with each other, and transfer through the transformer core bottom and the fasteners to the transformer tank. The vibration of transformer core and windings transfer through the insulating oil to the transformer tank simultaneously. Under the comprehensive effect, the tank begins forced vibrating and radiating sound via the air. It could be deduced that the characteristics of internal noise and external noise are different, however, previous studies mainly focused on the external noise.

![Figure 1. Vibration and noise transfer path of a 10kV oil-immersed transformer.](image-url)
3. Experimental investigation

3.1. Experimental setups

In order to investigate the internal and external noise characteristics, a 10kV three-phase oil-immersed transformer (S13-M-400/10) is used. The experiment is carried out in a transformer workshop, on the condition of no-load test and short circle test.

Ordinary electronic hydrophone or microphone could not be used in the transformer tank, because of high voltage and strong electromagnetic. So, a kind of special designed fiber-optic hydrophone is applied [9]. The fiber-optic hydrophone doesn't contain any metal parts, so it could be used in strong electromagnetic environment, and wouldn't affect the normal operation of the transformer. Two fiber-optic hydrophones are installed in the transformer, hanged by strings, as shown in figure 2.

![Figuer 2. The installing of fiber-optic hydrophones.](image)

Four condenser microphones are placed around the transformer at a distance of 30cm, half height of the transformer tank, as shown in figure 3.

![Figuer 3. The position of external microphones.](image)

3.2. Experimental results

3.2.1. No-load test

In the no-load test, the input voltage of transformer was 10 kV (which is 100% of the rated voltage) at the high-voltage terminal. The internal noise and external noise waveform are shown in figure 4 and figure 5.
Figure 4(a) and figure 5(a) shows the time domain waveform of internal and external noise, respectively. It could be found that, the maximum pressure at the position P1 and P2 (inside of the transform tank) is about 1.5Pa and 3.7Pa, and at the position N1, N2, N3, N4 (outside of the transform tank) is less than 0.1Pa. Obviously, the internal noise’s amplitude is much higher than that of the external noise. And, the curves in figure 5(a) seem to be un-periodic because the background noise is high, which confirmed in figure 5(b). So, the internal noise could contain much more information and the signal noise ratio is higher.

![Figure 4. Internal noise waveform in no-load test.](image)

![Figure 5. External noise waveform in no-load test.](image)

Figure 4 (b) and figure 5 (b) shows the frequency domain waveform of internal and external noise, respectively. According to the six curves, it could be found that the main frequency is 100Hz and its harmonics. The main frequency of the internal noise is distributed from 100Hz to 800Hz, and the amplitude is about 0.1Pa to 0.4Pa. While, that of the external noise is distributed from 100Hz to 300Hz, and the maximum amplitude is about 0.005Pa. At the fundamental frequency 100Hz, the amplitude of internal noise could be 100 times larger than that of external noise.
3.2.2. Short circle test
In the short circle test, the low-voltage terminals are connected with copper wire, and the current was 100% rated current. The noise results are shown in figure 6 and figure 7.

According to figure 6 (a) and figure 7 (a), the maximum pressure at the position P1 and P2 is about 1.2Pa and 1.9Pa, and at the position N1, N2, N3 and N4 is about 0.1Pa. Figure 6 (b) and figure 7 (b) show that 100Hz is the main frequency. The amplitude of the internal and external noise at 100Hz is about 0.2Pa and 0.004Pa, respectively. At the fundamental frequency (100Hz), the amplitude of internal noise could be 50 times larger than that of external noise.

In the short circle test, the voltage is low, so the core's vibration is small and the main vibration source is the windings. The results show the main frequency of noise is 100Hz, and the high order harmonics are small. It implies that the transformer windings have a good linear characteristic. In the no-load test, the current in windings is almost zero, so the vibration of windings is small and the main vibration source is the core. Compared with the results in short circle test, the noise in no-load test contains more high order harmonics, which means the core's vibration may respect strong nonlinear characteristics.

![Figure 6. Internal noise waveform in short circle test.](image1)

![Figure 7. External noise waveform in short circle test.](image2)
4. Conclusion
This paper reported an experimental study on the internal and external noise characteristics of a 10kv oil-immersed transformer by using a kind of fibre-optic hydrophone. No-load and short circle conditions were considered and the internal and external noise is obtained. According to the noise results, the internal noise is larger than the external noise, and contains more high order harmonics. At the fundamental frequency (100Hz), the amplitude of internal noise could be 100 and 50 times larger than that of external noise in no-load test and short circle test, respectively. Besides, the main frequency of internal noise distributes from 100Hz to 800Hz in no-load test, while that of the external noise distributes from 100Hz to 300Hz. The results imply the internal noise contains more information, and it may be more useful in transformer condition monitoring.

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