Test and Research on Noise Distribution Characteristics of 220kV Oil-immersed Transformer

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Abstract—Large power transformer is the main noise source of substation. With the increase of voltage grade and rated capacity, the noise radiation value of power equipment continues to increase, which has a great influence on the noise standard of substation boundary. In this paper, two test conditions of no-load voltage and load current are considered. The transformer noise testing datum is constructed. The distribution law of factory noise SPL of 220kV oil-immersed transformer is obtained. The test results provide accurate test data for transformer factory noise evaluation.

1. Introduction
Large power transformers are the main noise source in substations. With the application of new technology, new material and new technology, the factory noise level of electric power equipment has been effectively controlled. But there is a certain gap in the noise level of different equipment manufacturers. At present, the evaluation of the factory noise level of power equipment is only the noise index under the no-load voltage state, which is different from the actual transformer operation condition. The factory noise test of transformer is implemented in GB/T 1094.10. Influenced by the actual transformer factory test environment and other factors, the factory noise of equipment of various manufacturers varies greatly. In actual operation, transformers have both rated voltage and load current at full load, and the radiated noise will change greatly, which bring uncontrollable factors to the noise standard of substation boundary. In order to accurately grasp the transformer noise distribution characteristics under the environment of the factory, this paper mainly aimed at no-load voltage and load current two kinds of test conditions, constructed the transformer noise test datum, the oil-immersed transformer factory noise sound pressure level distribution, finally also gives a test noise environment correction coefficient of the space, it provides accurate test data for transformer factory noise evaluation.

2. Acting Mechanisms of Transformer Noise
2.1. Transformer noise characteristics under no-load voltage condition
Transformer no-load test condition refers to the application of rated voltage, the current is only a very small excitation current, the excitation current will form magnetic flux in the core and make the core vibration, and because the current is very small so the transformer windings almost no force. Therefore, the electromagnetic vibration mechanism and characteristic analysis of transformer operating under no-load voltage is the magnetostrictive mechanism of iron core. Magnetostriction
refers to the magnetization of ferromagnetic materials when there is a magnetic field or flux in the material, that is, the magnetic domain inside the material is reversed and the domain wall moves. During this magnetization process, the size of ferromagnetic materials will change. Magnetostriction is one of the magnetic properties of ferromagnetic materials. Magnetostriction is divided into spontaneous magnetostriction and field magnetostriction. Spontaneous magnetostriction is related to the internal magnetic field of ferromagnetic material, while field magnetostriction is caused by the interaction between external magnetic field and material.

In order to illustrate the mechanism of material size change caused by magnetostriction, ferromagnetic materials can be considered to be composed of several disordered small regions (magnetic domains) with two magnetic poles like small magnetic needles, as shown in Fig.1(a). A magnetic domain is a phenomenon of spontaneous magnetization within a material. Under the action of an external magnetic field, the magnetic domain will rotate and deform in a specific direction, as shown in Fig.1(b). This rotation and deformation cause the material to grow in size in the magnetic field direction and decrease in size in the other direction, which is magnetostriction. When the external magnetic field continues to increase until all magnetic domain directions are completely distributed along the magnetic field direction, as shown in Fig.1(c), saturation magnetization occurs and the material deformation reaches its maximum.

2.2. Transformer noise characteristics under load current condition
Transformer load test is a conventional test before the transformer factory, it is to short-circuit the low-voltage winding, add a very low voltage in the high-voltage winding, generally only 10% of the rated voltage, at this time, the current of the original side winding has reached the rated current. The purpose of the test is to measure the short circuit reactance, which is characterized by high current, i.e., rated current, and low voltage. Therefore, in the short-circuit experiment, the effect of voltage excitation on the core vibration source can be ignored, and only the electromagnetic force effect of winding current is considered. Under the action of 50Hz current and magnetic leakage field, the direction of electromagnetic force received by the transformer winding is the same regardless of the positive and negative half cycle of current, that is, in one cycle, the winding is subjected to two inward tensions in the axial direction and two outward tensions in the auxiliary direction, which makes the vibration frequency of 100Hz. Due to the structural characteristics of the winding, the wire will not directly friction and collision with each other in the process of force deformation, so it will not produce vibration higher than 100Hz. Therefore, the vibration characteristics of the winding are concentrated at 100Hz, and the vibration of other frequency points is very small and can be ignored.

3. Noise Test Schemes
3.1. Test Conditions
According to GB/T 1094.10 test requirements, transformer factory noise test conditions are mainly no-load voltage and load current. Input rated voltage and rated current respectively to test the noise sound pressure level of equipment at the datum level.
3.2. Test Equipment

Sound pressure sensor and acquisition front end are usually used to test transformer factory noise sound pressure level. Multi-channel high-precision data acquisition front-end is selected for the acquisition instrument. Each front-end controller of data acquisition includes 16 data acquisition channels, which can carry out 24-bit A/D conversion. Standard ICP modulated input sensor and analog voltage input sensor can also be used, as shown in Fig.2. It can meet users’ requirements in data recording and management, mechanical failure testing and diagnosis. The function of the acquisition front end is to process the voltage signal collected and transfer it to the computer end to provide applicable test data. Sound pressure sensor adopts IEPE type sound pressure sensor, frequency response range is 10Hz~20KHz, dynamic range is not less than 130dB.

![Multi-channel high precision data acquisition front end](image)

3.3. Points arrangement

When sound level measurement is carried out under the condition of air-cooling equipment stopping operation, the measuring point should be 0.3$m$ away from the transformer reference emission surface. When sound level measurement is carried out under the condition of air-cooling equipment being put into operation, the measuring point should be 2$m$ away from the transformer reference emission surface. Measuring points shall be arranged around the transformer box at a distance of no more than 1m.  

![Arrangement of Noise Measuring Points outside Transformer](image)

For transformer with tank height less than 2.5$m$, the height of measuring point should be located on the horizontal plane of tank height 1/2. For transformers with tank height of 2.5$m$ and above, the height of measuring point should be selected from the horizontal plane at 1/3 and 2/3 of the tank height. The height $h$ of transformer tank in this project is 3.5$m$, so the test includes two horizontal planes, 1/3$h$ and 2/3$h$. The layout of noise SPL measuring points is shown in Fig.3.
4. Test Results and Discussions

4.1. No-load voltage condition

Fig.4 shows the time-history distribution characteristics of 1/3h horizontal measuring point noise under no-load voltage condition when the oil-immersed transformer air cooling equipment is out of operation. From the figure, we can see the noise distribution in four directions of transformer at measuring points 1, 9, 18 and 27. The highest sound pressure at measuring point 1 is 0.3Pa, that is, the noise at the short side of the transformer is the highest; the lowest sound pressure level at measuring point 27 is 0.16Pa, that is, the noise at the low-voltage side of the transformer is low.

![Fig.4 Time-history distribution of noise pressure at measuring points](image1)

Fig.5 shows the spectral characteristics of 1/3h horizontal measuring point noise under no-load voltage. It can be seen from the figure that the noise spectrum distribution in four directions of transformer at measuring points 1, 9, 18 and 27. The highest total sound pressure at measuring point 1 is 69.4dB(A), that is, the noise at the end of the transformer is the highest; the lowest total sound pressure level at measuring point 27 is 62.7dB(A), that is, the noise at the low-voltage side of the transformer is low. It can also be seen from Fig.5 that noise frequency is mainly concentrated in 100Hz, 200Hz and 300Hz frequency band under no-load voltage condition.
4.2. Load current condition

When the oil-immersed transformer air cooling equipment is in operation, the time-history distribution characteristics of 1/3h horizontal measuring point noise under load current condition are shown in Fig 6. From the figure, we can see the noise distribution in four directions of transformer at measuring points 1, 9, 18 and 27. The highest sound pressure at measuring point 9 is 0.5 Pa, that is, the highest noise at the high and low voltage sides of the transformer. The lowest sound pressure level at measuring point 1 is 0.2 Pa, that is, the noise at the end of the transformer is low.
Fig. 6 shows the noise spectrum characteristics of 1/3h horizontal measuring points under load current condition. It can be seen from the figure that the noise spectrum distribution in four directions of transformer at measuring points 1, 9, 18 and 27. The highest total sound pressure at measuring point 9 is 65.9dB(A), that is, the noise at the high and low voltage sides of the transformer is the highest; the lowest total sound pressure level at measuring point 1 is 61.5dB(A), that is, the noise at the end of the transformer is low. It can be concluded from the spectrum diagram that transformer noise is mainly in the frequency spectrum of 100Hz under load current condition.

Fig. 7 shows the noise spectrum characteristics of 1/3h horizontal measuring points under load current condition. It can be seen from the figure that the noise spectrum distribution in four directions of transformer at measuring points 1, 9, 18 and 27. The highest total sound pressure at measuring point 9 is 65.9dB(A), that is, the noise at the high and low voltage sides of the transformer is the highest; the lowest total sound pressure level at measuring point 1 is 61.5dB(A), that is, the noise at the end of the transformer is low. It can be concluded from the spectrum diagram that transformer noise is mainly in the frequency spectrum of 100Hz under load current condition.
5. Conclusion
Based on the large oil-immersed transformer as the research object, the mechanism of vibration and noise of oil-immersed transformer is analyzed. Two test conditions of no-load voltage and load current are considered. The transformer noise test datum is constructed in the project. The distribution law of factory noise SPL of 220kV oil-immersed transformer is obtained. In the no-load voltage condition, the noise radiation at the end of the transformer is high, and the noise spectrum is mainly concentrated in the frequency band of 100Hz, 200Hz and 300Hz. Under the load current condition, the noise radiation is the highest at the high and low voltage side of the transformer, and the noise spectrum is mainly 100Hz. The research results of the project provide accurate test data for transformer factory noise evaluation.

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