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Noise Characteristics of a Dry-Type Distribution Transformer Tested In a Semi-Anechoic Room

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Abstract. Noise characteristic is an important factor need to be considered in the noise control process of power transformers. A transformer noise test platform is constructed in a semi-anechoic room. With this platform, the noise characteristics of an 800kVA/10kV dry-type distribution transformer in different operation voltages and load conditions are tested. Discrepancies of the noise signals in time- and frequency-domains are compared. The A-weight sound pressure levels are also calculated. An interesting result shows that as the increase of load current the noise level decreases gradually. Transformer noise shows some discrepancies in unbalanced load conditions. The noise level of phase-B unbalanced transformer is much lower than that of phase-A and phase-C unbalanced. Harmonic load is found to have obvious impact on transformer noise. The noise level, waveform complexity and the amplitude of odd harmonics of 50Hz increase greatly. The results can be referenced in the noise and vibration control process of power transformers.

1. Introduction
Noise of power transformer is a critical issue need to be considered in the construction process of power transmission projects. As the development of the social economy and the increase of power demand, many dry-type power transformers are placed in the basements of residential buildings. The resulting noise issue is becoming the attention focus of the residents [1, 2]. In order to control the noise of power transformer in the neighborhood, the noise characteristics of dry-type power transformers need to be investigated.

Hitherto, many efforts have been made to transformer noise tests and characteristic analysis [3-7]. In these contributions, factory and on-site noise tests are conducted to high-voltage power transformers over 110 kV. The time- and frequency-domain characteristics of transformer noise are analyzed. However, few studies are observed about noise characteristics of dry-type distribution power transformer, which is commonly positioned in the residential buildings. Moreover, the noise characteristics of distribution power transformers are closely relative with the load conditions [8]. As the irregular load arrangement and the wide application of power electronics in household appliances, dry-type distribution power transformers are usually operating in unbalanced-load and high-harmonic conditions, which is in high discrepancy with the conditions of factory tests. Attribute to the
complicated operation condition, on-site and factory tests are precluded from detailed noise characteristics and relevant factors investigation of distribution power transformers.

In this paper, a prototype transformer noise test platform is designed and placed in the semi-anechoic room. With this platform, noise tests of a 10 kV/800 kVA dry-type distribution power transformer in various load conditions are conducted. The test results can provide technical support for noise control of distribution power transformers in residential buildings.

2. Noise Test Platform
The transformer noise test platform is mainly composed of voltage regulator, test transformer and load cabinets. The rated capacity of the voltage regulator is 800 kVA and the supplied voltage can be continuously adjusted from 0 to 11 kV. The test transformer is a three-phase dry-type distribution transformer with 800 kVA rated capacity. In order to avoid the influence of the ambient noise, the test transformer is placed in a semi-anechoic room with 6 dB (A) background noise, as shown in Fig. 1. The load cabinets are used to apply resistive, inductive and harmonic loads.

![Figure 1. Noise test transformer in a semi-anechoic room.](image1)

Four measurement points are used for the noise test of the transformer, as shown in Fig. 2. These measurement points are 2 m away from the transformer and located at 1/2 transformer height. The test transformer is located in the center of the semi-anechoic room which is 5885 mm×5650 mm×6100 mm in geometry. The B&K 4189 free-field microphone is used to measure the noise signal and the 12-channel B&K 3053 data acquisition module is used for synchronous signal test. The sampling frequency is set to be 65536 Hz.

![Figure 2. Noise measurement points of the transformer.](image2)
3. Test Result and Analysis

3.1. The Influence of Applied Voltage
Under no-load condition, the transformer winding current is small, and the influence of the winding vibration on the transformer noise can be neglected. In this condition, it is deemed that the transformer noise is caused only by core vibration. Adjusting the transformer voltage to be 50%, 60%, 70%, 90% and 100% of the rated value $U_N$, respectively, the A-weighted sound pressure level (SPL) of the transformer is shown in Table 1. With the increase of no-load voltage, the transformer SPL increases nonlinearly. In the condition of rated voltage, the maximum SPL of the four points is 61.5 dB (A). Although the position of the four measurement points and the transformer structure are symmetrical, the SPLs are not always in the same level. The applied voltage has a large influence to transformer noise.

| Applied Voltage (%$U_N$) | Point 1 | Point 2 | Point 3 | Point 4 |
|---------------------------|---------|---------|---------|---------|
| 50                        | 36.3    | 36.9    | 37.6    | 36.8    |
| 60                        | 39.8    | 41.1    | 41.1    | 40.0    |
| 70                        | 41.4    | 44.9    | 42.8    | 40.5    |
| 90                        | 53.6    | 45.9    | 53.1    | 48.4    |
| 100                       | 61.1    | 48.5    | 61.5    | 56.6    |

3.2. SPL of the Winding
In order to measure the SPL of the windings, the low voltage windings of the transformer are short-circuited. The load current is set to be 50%, 60%, 90%, and 100% of the rated value $I_N$, respectively. The A-weight SPL of the transformer is shown in Table 2.

| Supplied Current (%$I_N$) | Point 1 | Point 2 | Point 3 | Point 4 |
|---------------------------|---------|---------|---------|---------|
| 50                        | 44.2    | 38.3    | 43.9    | 41.8    |
| 60                        | 45.9    | 41.8    | 45.4    | 43.2    |
| 90                        | 50.3    | 48.2    | 50.2    | 47.3    |
| 100                       | 53.0    | 49.6    | 53.0    | 48.5    |

It is observed that transformer winding noise increases with the supplied load current. The maximum SPL of the winding is 8.5 dB (A) lower than that of the core noise.

3.3. The Influence of Applied Load
When the transformer operates in normal condition, the load current is set to be 18%, 29%, 43%, 50%, 60% and 75% of the rated value $I_N$, respectively. Take the measurement point 1 as an example, the transformer sound pressure variation versus time under different load conditions is shown in Fig. 3. With increasing load current, the time-domain waveform of the transformer noise signal keeps unchanged. Little change is found in signal amplitude. The sound pressures are within the range of 0.1 Pa. This is attributed to the reason that the transformer winding noise level is relatively low compared with that of the core. Thus, load change in the rated range is insufficient to cause obvious influence to the transformer noise level.
Figure 3. Time-domain noise signal of the measurement point N-1 of the loaded transformer.

Figure 4. Noise spectral of measurement point 1 of the loaded transformer.

Under different load conditions, the spectral distribution of the noise signal at the measurement point 1 of the transformer is shown in Fig. 4. It can be seen that the dominant frequency of the transformer noise signal is 200 Hz, which is accompanied with a few harmonics of 300 Hz, 400 Hz, 500 Hz and 700 Hz. Spectral distribution characteristics change little with the increase of load capacity. However, signal amplitude at 200 Hz declines slowly, which may be caused by the reason that the transformer noise is produced by overlapped windings and core vibration signals, as the existence of phase difference of the core and winding vibration signals, the phases of some frequency components are in the opposite direction. Thus, the winding vibration has a restrictive effect to that of the core.

Table 3 shows the A-weight SPL under different load conditions. An interesting result is found that at some measurement points transformer noise decreases gradually with increasing load current. When the load current increases from 18% to 75% of the rated value, the transformer noise of measurement point 1 and point 3 decreases 1.9 dB(A) and 2.8 dB(A), respectively.
Table 3. A-weighted SPL of the loaded transformer.

| Load Current (%IN) | Point 1 | Point 2 | Point 3 | Point 4 |
|--------------------|---------|---------|---------|---------|
| 18                 | 58.4    | 46.4    | 58.6    | 53.6    |
| 29                 | 57.9    | 46.0    | 57.9    | 53.0    |
| 43                 | 57.3    | 46.0    | 57.1    | 52.5    |
| 50                 | 57.0    | 46.0    | 56.6    | 52.1    |
| 60                 | 56.6    | 46.6    | 55.9    | 51.9    |
| 75                 | 56.5    | 47.6    | 55.8    | 52.7    |

3.4. Unbalanced Load

With the noise test platform, the transformer load of each phase can be adjusted. The following tests are carried out:

(a) Phase A and phase C are 75% loaded, phase-B is 0%, 18% and 43% loaded, respectively.
(b) Phase A and phase B are 75% loaded, phase-C is 0%, 18% and 43% loaded, respectively.

The spectral distribution of transformer noise at the measurement point 1 is shown in Fig. 5. It can be seen that when the applied load is unbalanced the dominant frequency is 200 Hz. The unbalance degree of load has no influence on the distribution of the frequency components. However, the amplitude of 100 Hz frequency component increases obviously with increasing degree of load unbalance. In addition, higher signal amplitudes of 100 Hz and 200 Hz are found when the C-phase load is unbalanced. The possible reason causing this phenomenon is that the B-phase winding is located between A- and C-phases. Although the B-phase is lowly loaded, the loads of other two windings are identical, so the vibration system can still be considered as a symmetrical one. However, when the load of C-phase is lower than that of A- and B-phases, the vibration system is no longer symmetrical. The vibration in this condition is more intense than that of the symmetrical state. Therefore, the noise signal amplitude is relatively higher.

Transformer sound pressure level measurement results under unbalanced load are shown in Table 4. It can be seen that compared with B-phase load unbalance, when transformer total load power is the same, transformer noise level with C-phase unbalance is higher, and the difference between the two is up to 1.2 dB(A). Compared with Table 1, it can be seen that the noise level is generally lower than load balance under the condition of unbalanced three-phase load, since the total load power is always above 50% rated power.
Table 4. A-weighted SPL of the transformer with unbalanced load.

| Unbalanced Load (%IN) | A-weight SPL (dB(A)) |
|-----------------------|----------------------|
|                       | Point 1 | Point 2 | Point 3 | Point 4 |
| B-phase               |         |         |         |         |
| 0                     | 55.7    | 47.0    | 55.7    | 54.7    |
| 18                    | 55.5    | 46.9    | 55.7    | 53.9    |
| 43                    | 55.7    | 46.8    | 55.8    | 53.5    |
|                       |         |         |         |         |
| C-phase               |         |         |         |         |
| 0                     | 57.0    | 44.4    | 56.7    | 52.4    |
| 18                    | 56.5    | 44.5    | 56.3    | 52.1    |
| 43                    | 56.2    | 45.1    | 55.8    | 51.4    |

3.5. Harmonic Load

In addition to unbalanced load, harmonic load is also a common state occurred in distribution transformers, which will cause obvious noise increase. In order to analyze the noise characteristics of transformer in harmonic load condition, the following transformer noise tests are conducted in sequence:

(a) 43%, 50% and 75% of the rated load including both 35 kVA 3rd and 5th harmonic loads.
(b) 43%, 50% and 75% of the rated load including 35 kVA 3rd harmonic loads.
(c) 43%, 50% and 75% of the rated load including 35 kVA 5th harmonic loads.

The transformer noise signal test results of measurement point 1 are shown in Fig. 6. The transformer noise amplitude increases with increasing harmonic content. Compared with the normal load condition, the maximum sound pressure amplitude in harmonic load condition is about 0.04 Pa higher. Many new frequency components present in the spectra, such as the odd harmonics of 50 Hz. In these frequency components, the amplitude of 150 Hz changes most significantly, which has overcome the 100 Hz fundamental frequency. The high-order harmonic frequency components over 1 kHz increase in a large degree. Under the effect of 3rd and 5th harmonics, the signal amplitude increases most obvious. The single 3rd harmonic load has less influence on the transformer noise than 5th harmonic, because the high voltage transformer windings are connected in triangular, which restrains the 3rd harmonic to some degree.

The SPLs of the transformer noise with harmonic load are shown in Table 5. The noise level is relative with the harmonic load. With the increase of harmonic content, transformer noise level increases accordingly. Compared with the normal SPL as shown in Table 1, in the condition of the same load, noise levels of transformer containing harmonic loads are much higher. As only 3rd and
5th harmonics are considered in the test process, the harmonic component is less complex than that of the on-site transformer. The influence of harmonics on transformer noise will be more serious. It is deemed certain that in the noise and vibration control process of the distribution transformer, load harmonic control should be used as an advisable measure, which will be helpful to improve the effect of transformer noise and vibration control.

| Harmonic Load (%IN) | A-weight SPL (dB(A)) |
|---------------------|----------------------|
|                     | Point 1 | Point 2 | Point 3 | Point 4 |
| 3rd and 5th harmonics |        |        |        |        |
| 43                  | 58.6    | 53.3    | 58.8    | 53.0    |
| 50                  | 58.3    | 53.1    | 58.4    | 53.2    |
| 75                  | 58.4    | 54.7    | 58.1    | 54.0    |
| 3rd harmonics       |        |        |        |        |
| 43                  | 56.5    | 45.6    | 56.4    | 52.2    |
| 50                  | 56.5    | 45.5    | 56.6    | 52.2    |
| 75                  | 56.2    | 47.2    | 55.5    | 53.3    |
| 43                  | 58.2    | 52.9    | 58.3    | 52.5    |
| 5th harmonics       |        |        |        |        |
| 50                  | 57.7    | 51.3    | 57.8    | 52.9    |
| 75                  | 57.4    | 53.2    | 57.1    | 53.8    |

4. Conclusion

In this paper, noise characteristics of a dry-type distribution transformer under the influence of applied voltage, load capacity, unbalanced load and harmonic load are studied through prototype tests conducted in a semi-anechoic room. The following conclusions can be drawn:

1) The applied voltage has a large influence to transformer noise level. In the noise control process of distribution transformer, the applied voltage should be controlled in the allowed range.

2) Transformer winding noise increases with the supplied load current, but its value is far below the core noise.

3) The noise level of transformer is relative with load capacity, but it does not always increases with increasing load capacity. The waveform of noise signal does not change with load capacity.

4) Unbalanced load will lead to spectral variation of transformer noise. Transformer noise with A- and C-phase unbalanced is higher than that of B-phase unbalanced.

5) Load harmonics has large influence on the waveform and frequency components of the transformer noise. Transformer noise level increases with increasing harmonic content. In the transformer noise and vibration control process, reducing the load harmonics is one of the effective measures could be considered.

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