Experimental Study on the Vibration Characteristics of Oil Tank Model of Oil-Immersed Transformer

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Abstract. The problem of vibration and noise of transformers in urban substations is more and more concerning to society. With a 110kV transformer substation as the research object, the oil tank model of the oil-immersed transformer is designed according to the principle of similitude. Through the modal test of the oil tank model, the vibration characteristics of a 110kV oil-immersed transformer model are obtained, which will help avoid the resonance frequency in the structure design of transformer oil tanks and provide measured data for the vibration and noise control design of transformers. Finally, the finite element model of transformer oil tanks is established, and the vibration characteristics of the oil tank are simulated, and consistent analysis results are obtained.

1. Introduction
Oil immersed transformers are the main noise source of transformer substations. In recent years, many urban transformer substations have gradually been built in densely populated areas, and the impact of substation vibration and noise on residents has widely concerned society. A large number of field tests and experimental studies show that the vibration and noise of transformers are mainly concentrated on 50Hz and its frequency multiplication components in the range of 1000Hz. Therefore, it is very important to study the vibration characteristics of oil-immersed transformers. With a reasonable design of oil tank structure, avoiding the main frequency of transformer vibration and noise, the resonance effect of equipment can be effectively reduced. In this paper, the transformer of a 110kV substation is selected as the research object, and the oil tank model of the oil-immersed transformer is designed according to the principle of similitude. Through the modal test of the oil tank model, the vibration characteristic test of the oil tank model of the oil-immersed transformer is carried out. The test and analysis conclusions can provide a reference for the design of the structural vibration and noise control of the transformer oil tanks in substations.

2. Vibration mode test method of transformer oil tank model
Experimental modal analysis (EMA) is one of the effective methods to solve dynamic problems in a complex vibration system. With the continuous development of signal processing technology, the modal analysis method has been gradually used in engineering structure problems such as vibration characteristics, fault diagnosis and vibration noise. In this paper, the experimental modal testing technology is used to study the vibration characteristics of a transformer oil tank model. The experimental modal analysis is divided into force-hammer excitation EMA technology and exciter
excitation EMA technology. In consideration of equipment and other factors, this test adopts force-hammer excitation technology.

Single reference points are set in the test, and the force-hammer is fixed at the reference point for hammering. All response sensors are used to measure the response of the structure once, and then the hammer is moved to the next reference point to repeat the test. Three reference points are set up in the test, and all the response sensors are divided into three lots to measure the vibration response of the structure. See Fig. 1 for the flow chart of modal test.

3. The modal test of transformer oil tank model

3.1. The design of the oil tank model
In this paper, the scale model of the oil tank structure of typical oil-immersed transformers is selected to conduct a vibration mode test. In view of the production cost, test site and other factors, 110kv 50MVA oil-immersed transformer oil tanks are selected as the prototype structure. According to the principle of similitude, the design scale proportion of the oil tank model is 1:3, that is, the model size is one third of the prototype structure. The model of transformer oil tank is shown in Fig. 2 and Fig. 3.

![Fig. 2 The size of transformer oil tank model (Unit: mm)](image)

![Fig. 3 The material object of transformer oil tank model](image)
3.2. The modal test
The test plan of the transformer oil tank model is shown in Fig. 4-7. In the whole test plan, the sensors are arranged uniformly. A total of 25 sensors and a force-hammer are used. Five sensors are respectively arranged on the four side walls and the top surface of the transformer oil tank and on the plane of five model oil tanks. After each hammering, move the five sensors in the plane to the next column, as shown in the figure, the black points are the acquisition points of acceleration sensors. Through repeated striking of the force-hammer, the acceleration sensors were moved four times, 25 measuring points appear on each surface, a total of 125 measuring points, to complete the data collection of all measuring points. The red dot in the figure is the striking position of the force-hammer. Fig. 7 shows the site of vibration mode test.

Fig. 4 The sensor arrangement on the front of oil tank model(Unit: mm)
Fig. 5 The sensor arrangement on the side of oil tank model

Fig. 6 The sensor arrangement on the top of oil tank model

Fig. 7 The site of modal test

3.3. Analysis of modal test results
In the modal analysis software, the vibration data of the model transformer oil tank, which were obtained, from the field measurement are analyzed. The structural model of the model transformer oil tank is established in the software as shown in Fig. 8. Then, the measured modal data of 125 measuring points of the model transformer oil tank were inputted into the structural model, and the PolyLSCF fitting method is used for modal analysis. The fitted stability diagram of model transformer oil tank is shown in Fig. 10. At the same time, the finite element software is used to establish a numerical model of the model transformer oil tank, as shown in Fig. 9. See Table 1 and Table 2 for the final measured results and simulation results of the vibration mode of model oil tank.
Fig. 8 The modal analysis model of model transformer oil tank
Fig. 9 The finite element numerical model of model transformer oil tank

Fig. 10 The stability diagram of PolyLSCF fitting method

Table 1 The frequency of top 10 orders of model transformer oil tank (Unit: Hz)

| Order  | Measured | Simulated |
|--------|----------|-----------|
|        | Frequency| Frequency |
| 1      | 193.06   | 187.36    |
| 2      | 239.43   | 242.45    |
| 3      | 265.18   | 261.91    |
| 4      | 322.16   | 315.44    |
| 5      | 358.92   | 334.50    |
| 6      | 466.22   | 461.55    |
| 7      | 508.52   | 501.76    |
| 8      | 556.35   | 553.19    |
| 9      | 698.47   | 681.92    |
| 10     | 750.52   | 730.86    |

Table 2 The vibration modes of the first three orders of model transformer oil tank (unit: Hz)

| Order | Measured Frequency | Simulated Frequency | Measured vibration modes | Simulated vibration mode |
|-------|--------------------|---------------------|--------------------------|--------------------------|
| 1     | 193.06             | 187.36              |                          |                          |
| 2     | 239.43             | 242.45              |                          |                          |
| 3     | 265.18             | 261.91              |                          |                          |
From the test results and simulation results, it can be concluded that the vibration mode characteristics of the transformer oil tank model are similar. The first-order, second-order and third-order modes feature the front and rear vibration of the oil tank as a whole; the maximum vibration of the long side with a peak value and the maximum vibration of the long side with two peaks, respectively. The results of finite element simulation are basically consistent with the measured vibration modes, the simulation frequency is more accurate, and the effect is better. The main modes of the oil tank model do not coincide with the main frequency of transformer noise.

4. Conclusion
In this paper, a 110kV transformer substation is taken as the research object. According to the principle of similitude, the oil tank models of the oil-immersed transformers were designed. The modal test of the oil tank model was conducted. The vibration characteristics of oil-immersed transformer models are obtained. The main modes of the oil tank models do not coincide with the main frequency of the transformer noise, thus avoiding resonance frequency. A peak value existed in the middle of the side vibration mode of the transformer oil tank model. It is necessary to increase the plane rigidity of the oil tank wall and decrease the vibration amplitude in the design of the oil tank to reduce noise radiation of the transformer. The simulation results are in good agreement with the test results. The numerical method can be used to further study the optimization of the structural parameters of the transformer oil tank and provide a reference for the design of transformer vibration and noise control.

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