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Vibration Finite Element Analysis of SC10 Dry-type Transformer Core

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Abstract: As the popularization and application of dry-type power transformer, its work when the vibration noise problem widely concerned, on the basis of time-varying electromagnetic field and structural mechanics equation, this paper established a finite element analysis model of dry-type transformer, through the electromagnetic field – Structural mechanics field – sound field more than physical field coupling calculation analysis, obtained in no load and the vibration modes of the core under different load and frequency. According to the transformer vibration mechanism, compared with the experimental data, verified the accuracy of the calculation results, as the core of how to provide the theory foundation and to reduce the noise of the experiment. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Dry-type transformer, Multi-physical field finite element analysis, Vibration and noise, Modal analysis.

1. Introduction

1.1. The Research Background

As the growth of the national economy in our country, improve voltage level of power transmission and transformation equipment, power transformer in the practical application effect is more and more highlighted [11, 12]. Power transformer is one of the important electrical equipment in power system, it can transform a level of voltage into another level of use of it can unite the different voltage of power grid voltage, composed of complex power grid and power system. To ultra-high voltage in power system, power grid, capacity and automation direction at the same time improve the power system, one of the most important and most expensive it is particularly important to the operation reliability of the power transformer. Since the 1880s in China the introduction of dry-type transformer manufacturing technology, it obtained the swift and violent development in our country, such as the 2003 domestic production scale has reached 37 million KVA due to its free maintenance, safety, energy saving, fire-retardant explosion-proof, anti-short circuit ability, and many other advantages, is widely used in residential areas, hospitals, schools and other places [15, 16]. Dry-type transformer because of its simple structure, convenient maintenance and fire prevention, flame retardant, etc, since the late 1950 s that has started production in China, but nearly a decade before mass production. Dry-type transformer is a lot of more phyletic, basically have dipping insulation dry-type transformer and epoxy resin insulationdry-type transformer. But relatively dry-type transformer oil-immersed transformer noise slightly, which brought some let users and manufacturers are feeling confused noise problem.

In the operation of the power system, due to the electrical equipment failure cause local and even the whole area of a power outage, so that there are significant loss of national economy. Such as the famous 2003 blackout accident in the United States, from the subway, the airport, telecommunications and other facilities and public transportation basic paralyzed, directly lead to economic losses of $30 billion a day. Also often have power equipment failure in our country, such as on July 29, 2006, Jiangsu Shuyang mulberry market town, a private wood processing enterprises, 50 KVA transformer ignited the raging fire, the fire lasted more than an hour, the transformer and the wires, power distribution box burnt to the ground, metering device and other ancillary equipment. In this situation, to enhance the operation reliability of the electrical equipment is more and more important. With the development of national economy and people's material and cultural life level unceasing enhancement, our country traditional technology and management methods have been unable to adapt to the new situation, therefore, the modernization of power system become the inevitable trend of development of electric power industry in China. In order to accelerate the construction of modern power system, ensuring safe and reliable operation of the electrical equipment will be carried out on the data of transformer and induction the summary.

Vibrations of dry-type transformer noise pollution people living environment and health but also affect the normal operation and service life of equipment, the dry-type transformer noise and electrical performance and mechanical performance, has low energy consumption and explosion-proof performance is high and is the main technique index sign of the transformer. Dry-type transformer become manufacturer of transformer noise problems in some beneficial research and put forward the corresponding measures to reduce vibration to reduce the vibration noise of transformer to the impact of the people live and work. Early in the 20th century began, acoustic characteristics of transformer noise and vibration mechanism and noise reduction measures are studied in [1]. Related disciplines in the field of new technology are also attractive to research method, research scale expands unceasingly, and countries have formulated the corresponding technical and environmental standards [8]. In our country according to the national standards for acoustic environmental quality of GB3096-2008, according to the acoustic pressure calculation, the first kind of residential development, health care and other regions should be below 45 decibel noise at night, the second category of residents and commercial mixed area should be lower than 50 decibels at night, the third type of industrial area should be less than 55 decibels at night.

1.2. The Research Status

Some foreign large power transformer manufacturing companies such as Westinghouse, and general electric and related research institutions in the early 1920s began to transformer noise problem is studied. Mechanism involved in transformer noise and vibration, acoustic characteristics, noise reduction measures to the study of many aspects, such as [1], also includes countries successively formulated some technical and environmental standards [8]. Abroad since the 1970 s, the main transformer manufacturing countries invested a lot of manpower material resources to the transformer noise has carried out more extensive and deep research, the research scale expands unceasingly [17]. Research object often involves dozens of different specifications of the transformer, the related subject in the field of new technology has also been fetching in research methods: such as using the method of sound intensity, sound pressure method to determine transformer sound level and the far field radiation noise analysis (such as the Danish company environmental noise analyzer can easily when the transformer noise. Frequency domain real-time measurement and forecast) and gradually shifted from experimental study to construct the theoretical analysis of mathematical model (such as transformer source model), the new substation transformer noise estimates. At the same time also appeared a batch of simulation software, such as Flystry, SoundPLAN, Sysnoise for transformer vibration noise analysis and calculation.

Domestic study of transformer noise began in the 1980s, the main research units including large transformer manufacturing companies such as Xi'an transformer factory, Shanghai change especially in Xinjiang, etc. The local power supply department and Wuhan high voltage research institute and other research institutions. Domestic research involves the transformer, the mechanism of noise measurement, restrain measures, optimization design method, etc., and formulate the transformer noise standard (JB/T 10088-1999), the current domestic research mainly concentrated in the transformer vibration theory, experimental research and suppression measures has achieved a certain effect [10].

At present, the dry-type transformer core vibration research mainly focused on the mechanism of the transformer core vibration and control method. Mostly based on the qualitative analysis and summary of practical experience, put forward to reduce vibration of transformer core method. With the development of computer aided analysis and testing technology, researchers on the dry type transformer vibration test and analysis of frequency spectrum. Based on the finite element analysis software COMSOL vibration situation of main components of dry type transformer, come to the conclusion that has a lot to draw lessons from. But for the same parts of the same specifications of the dry-type transformer vibration, the vibration source also has difference, domestic haven't corresponding experimental simulation prove its correctness. The purpose of this paper is to verify the dry-type transformer core vibration of field test and finite element analysis and calculation results of consistency.

2. Field Measurement and Results

2.1. Test Apparatus and Measurement Schemes

On the surface of the dry-type transformer body vibration and pressure condition of transformer winding and iron core displacement and deformation state are closely related, therefore can by measuring the dry-type transformer body vibration to reflect the vibration of the winding and iron core.

This experiment uses the main measuring device of the piezoelectric acceleration sensor [6], the schematic diagram is shown in Fig. 1. When testing site measurements will need to support together with dry type transformer core part, bearing part is a circular powerful magnets. When transformer operation, the core and the bearing with the same acceleration motion, acceleration and the piezoelectric element received force of inertia of the mass in the opposite direction, at the top and bottom surface of crystal voltage, output voltage is proportional to the applied force, after amplification, signal amplification device GD-210 showed vibration frequency on the oscilloscope.

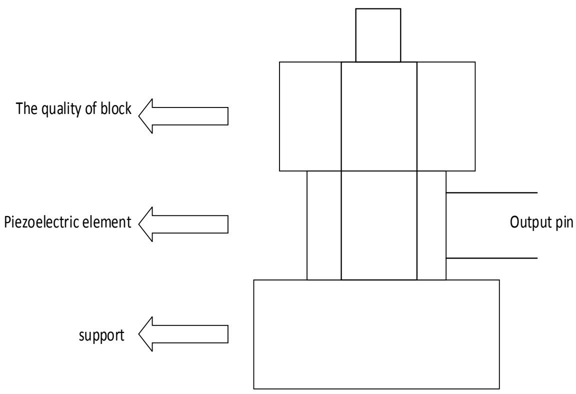

Fig. 1. The principle diagram of the piezoelectric acceleration sensor.

Table 1. The piezoelectric acceleration sensor specification parameter.

Model	YD-35D	**Install the resonance point (HZ)**	28K	**Range ms2 (±10%)**	200
Sensi-tivity (V/ms2)	0.02	**Frequency range (HZ) (±10 %)**	0.5~7000	**Resolution ratio (ms2)**	0.001
Weight (g)	70	**Physical dimension (mm)**	hexag-on 18*18*29	**output mode**	The top of the L5 output

Dry-type transformer no-load experiment was carried out first, and then through the load cases of load tests are carried out with different load. Vibration monitoring devices (YD-35D) piezoelectric acceleration sensor is the constant current source connected to an oscilloscope, GD-210 physical connection diagram as shown in Fig. 2. Piezoelectric acceleration sensor were placed in different position of the core points 1, 2, 3 three point placement [7, 14, 18], as shown in Fig. 3 below.

Fig. 2. Test equipment Physical connection diagram.

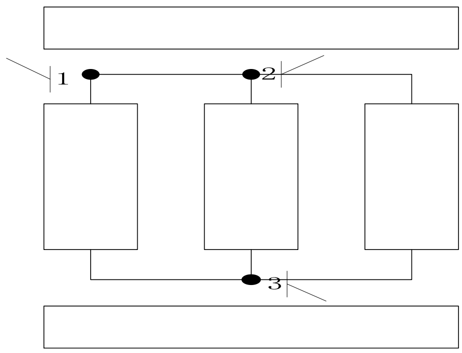

Fig. 3. Core vibration measuring device.

2.2. Vibration Signal of the Measured Results

In the process of debugging to accurately reflect the dry-type transformer core vibration as much as possible so set the sampling frequency is 200 M [13]. The vibration measurement unit for HZ, measurement results such as Table 2 and Table 3 below.

Table 2. Core vibration measurement data.

No-load Test				
Core Vibration	**Test point**	1	2	3
	Valid values(HZ)	109	121	125

Table 3. Core vibration measurement data.

Load Test					
Core Vibration	**Load(KW)**	**Test point**	1	2	3
	1	**Valid values (HZ)**	139	141	152
	2		185	179	160
	3		195	193	180

3. Finite Element Simulation

3.1. Modeling and Parameter Selection

Model building should reflect the entity structure characteristics, so as to ensure the corresponding calculation accuracy [19]. But with the improvement of geometric characteristics of complexity, it will give mesh, finite element analysis brings considerable burden, even can cause cell distortion cannot be thrown. So when modeling should be simplified, such as iron core equivalent. Due to the laminated structure of dry type transformer core lamination of the same core column, and is not a whole, but independent of each other. Core column and iron yoke between all kinds of joint structure. Therefore, in practice, how to simulate is worth first consider the problem. Through the paper [2, 3], the thought core lamination between the clamping force, can be regarded as a whole. Transformer core section, therefore, can be equivalent to a whole rectangle (iron core eccentricity, equivalent to ignore this factor).

At the beginning of the whole dry-type transformer model is set up, as a result of COMSOL modeling is more difficult, so the professional modeling software SOLIDWORKS for dry-type transformer model of the whole first, then by SOLIDWORKS connected to COMSOL, will build the complete model of imported into COMSOL, realize the whole process of modeling.

In the process of modeling and the vibration modal calculation is the most important two parameters of the elastic modulus and density. Steel alloy content on the influence of elastic modulus is not big, according to the paper [3], and selects elastic modulus parameters 2.1*10 Pa for after many experiments. In addition, in the paper [9] density of silicon steel 7650 kg/m^3. The considerations to the silicon steel sheet assembling simulation for the influence of density, after repeated attempts, pile multiplied by the coefficient of 0.97 the density is 7420 kg/m^3. Using COMSOLMultiphysics simulation model is set up as shown in Fig. 4 below, to split the core as shown in Fig. 5 below.

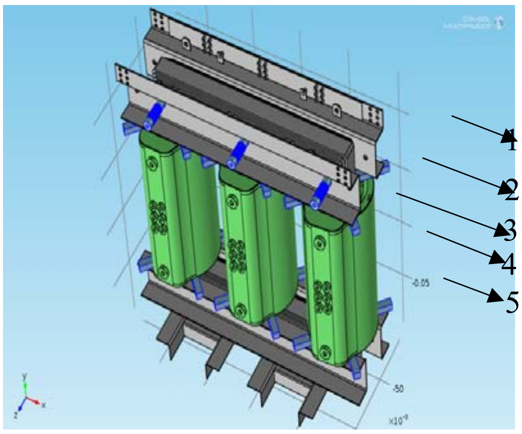

Fig. 4. Dry-type transformer simulation model.

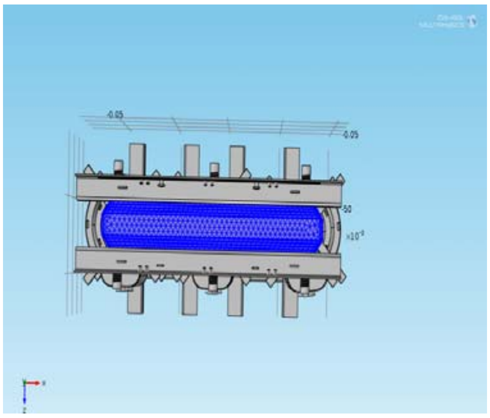

Fig. 5. Core subdivision graph.

As shown in Fig. 4, dry-type transformer whole model can be roughly divided into five parts, part 1 is iron yoke, intensify the role of the core; Part 2 is the iron core, part 3 is the insulation terminal, part 4 is the gaskets, it fixed the high and low pressure sleeve; part 5 is high and low pressure sleeve. Fig. 5 is the iron core part of the graph of subdivision.

3.2. The Simulation Results

Using COMSOLMultiphysics on dry-type transformer electromagnetic field – structural mechanics field – three coupled sound field calculation. Simulation results under no-load test as shown in Fig. 6, [20] the simulation results of the test under different load diagram as shown in Fig. 7 ~ Fig. 9 below.

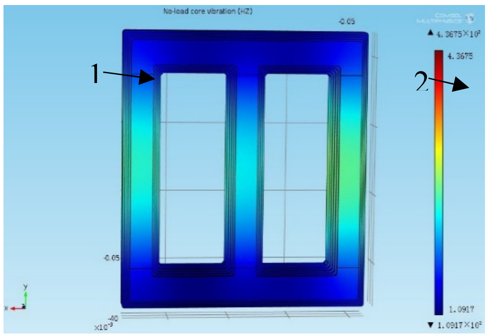

Fig. 6. Core vibration under no-load running simulation.

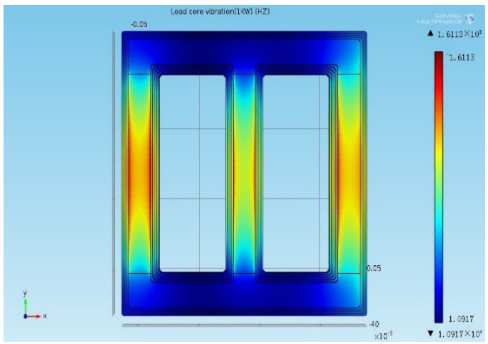

Fig. 7. 1 KW load vibration simulation runtime core.

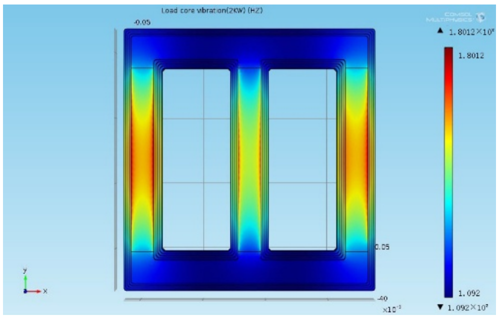

Fig. 8. 2 KW load vibration simulation runtime core.

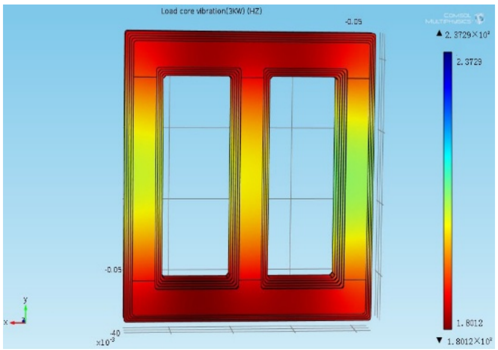

Fig. 9. 3 KW load vibration simulation runtime core.

As shown in Fig. 6 ~ Fig. 8, as shown in part 1 of the core simulation computing results, part 2 to vibration intensity zone, part 1, the deeper the color shows that the more vibration; part 2, down the frequency from big to small. In order to increase the contrast, in Fig. 9 3 KW load vibration simulation runtime core graph in the use of color to the contrary. Part 2, down the frequency from small to large, part 1, the deeper the color shows that the vibration is not strong.

4. The Calculation Results and Analysis

Dry-type transformer model is set up in the COMSOL. Carried out in accordance with the finite element method to calculate the load and solving, dry-type transformer core of different frequencies. Core structure finite element dynamics equations for [3, 21, 22].

$$M\ddot{x}+C\dot{x}+kx=f(t)\,, \tag{1}$$

where $\ddot{x}$ and $\dot{x}$ are the nodes acceleration vector and velocity vector. M, C, K and f(t) is the quality of the system matrix, damping matrix and node stiffness matrix. By separate unit matrix and vector integration. The equation form of transformation to the frequency domain, the transfer function of system is:

$$H_{tj}(w)=\sum_{r=1}^{N}\frac{\phi_n\phi_\eta}{m_r\left[\left(\omega_r^2-\omega^2+j2\varepsilon_{r\omega_2\omega}\right)\right]}, \tag{2}$$

where $\omega_r^2=\frac{k_r}{m_r}$, $\varepsilon_r=\frac{c_r}{2m_r\omega_r}$, m_r, k_r, r known as the first order r modal mass and modal stiffness (or generalized mass and generalized stiffness) ω_r, ε_r, ϕ_r respectively referred to as the first order r modal frequencies, modal damping ratio and modal vibration mode. It's not hard to find, N degrees of freedom system frequency response, equal to N linear superposition of single degree of freedom system frequency response. In order to determine all the modal parameters ω_r, ε_r, ϕ_r (r=1,2,3,…,N). In fact only measurement of frequency response matrix column corresponding excitation and each point measured $H(\omega)$ or a line corresponding to each point in turn vibration, point measurement $H(\omega)^T$ is enough. Finite element modal parameter identification task is within a certain frequency band by the measured frequency response function data, determine the modal frequency parameters of the system is ω_r, modal vibration modal damping ratio ε_r and type ω_r, ε_r, $\phi_r=(\phi_1,\phi_2,\ldots,\phi_m)$, r=1,2,…,N (N for the system in the modal test frequency).

After consulting relevant paper [4] this article introduce the experience formula

$$f_c=1.08k_c\frac{B_c+B_e}{(H_c+B_e)^2}10^5+\Delta f\,, \tag{3}$$

Verify the result of finite element calculation. Among the Eq. 3 H_c window for core high, B_e for the iron yoke the large wide, B_c for core column is the widest width, M for core window width, k_c is coefficient. Δf for load parameters. Under the no-load of 0 HZ, every increase 1 KW load, Δf value increases 20 HZ.

When the three phase:

$$k_c=0.080+1.105\left(\frac{H_c+B_e}{M+B_c}-1\right), \tag{4}$$

When single phase:

$$k_c=0.876+1.105\left(\frac{B_e+H_c}{M_c+B_c}-1\right), \tag{5}$$

Sc10 dry-type transformer produced by Tianjin special transformer field, with technical personnel after verifying that the transformer core specifications in Table 4. In order to prevent resonance, inherent frequency should avoid the following frequency band: 75 ~ 125 Hz; 175 ~ 225 Hz; 275 ~ 325 Hz; 375 ~ 425 Hz.

Using the above empirical formula Eq. 3 for calculation, the dry-type transformer core can get natural frequency value $f_c^{'}$, and extracted from finite element modal frequency f_c, the relative error was calculated by the $\left(f_c^{'} - f_c\right) f_c$. Due to the light differ with each test point measuring data under different load is small, in order to facilitate the contrast of three test points average. Compared with finite element calculation and the formula to calculate the results such as Table 5 below.

Table 4. Core data.

Model	Window of high (mm)	Largest iron wide (mm)	Mini-mum plate width (mm)	Window width (mm)	Total thickness (mm)
SCI10	800	210	90	310	204

Table 5. Results of calculation.

Results				
	No-Load	Load (1Kw)	Load (2KW)	Load (3KW)
The finite element calculation $f_c^{'}$ (HZ)	118.3	144.0	174.6	189.3
Empirical formula calculation f_c (HZ)	129.1	149.1	169.1	189.1
Error (%)	3.71	3.42	3.25	0.01

By the calculation results, Table 4 can be concluded that under the condition of no-load finite element calculation and empirical formula calculation error is less than 4 %, in the finite element calculation and experience formula under no-load alignment is very high. Then 1 KW, 2 KW, 3 KW load, the finite element calculation data and empirical formula calculation data are basic but 4 % refer to [5], using the empirical formula to the structure parameters and its internal action characteristics of core, also puts forward a structure of all kinds of hard core all applicable accurate calculation formula, so the finite element calculation results and the basic core test result from on macroscopic reflect core vibration condition.

5. Conclusion

This paper aiming at the vibration problem of dry-type transformer. In the finite element software COMSOLMultiphysics of dry-type transformer model is established, modal vibration mode and calculation analysis of the core modal frequency. By contrast, in the case of no-load and load both calculation error is less than 4 %, both highly consistent, preliminary judgment, the finite element calculation results and practical test results of the core vibration. The calculation in order to further explore the dry-type transformer vibration source provides technical and data support, also provides reference for the further improved the structure of the transformer.

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