Simulation Research on Core Vibration Noise of Three-phase Three-post Transformer

Hongsheng Fan[1,*], Xinyang Yu[1,a]

[1]School of Electrical and Electronic Engineering, North China Electric Power University, Baoding 071003, China.

*794124342@qq.com, [a]1559668069@qq.com

*corresponding author

Abstract

In this paper, the finite element simulation software COMSOL Multiphysics 5.5 is used to model the internal core structure of the Three-phase Three-post transformer. Coupling electric field, magnetic field, solid mechanics, and sound field to study the internal magnetic flux, vibration and sound field distribution of the transformer core during operation. Have a clearer and more intuitive understanding of the noise and vibration of the transformer, so as to provide suggestions and measures for the improvement of the iron core structure and the prevention of noise.

Keywords

Transformer Noise; Iron Core; Multi-physics Coupling.

1. Introduction

As an important power equipment in the power system, power transformers are responsible for important tasks such as power distribution, voltage level changes, and electrical energy transmission. With the rapid development of China's social economy, the scale of the power grid has also continued to expand, and users' demand for electrical energy has also become higher and higher. This requires the power sector to adopt larger-capacity transformers, and due to the dispersion of users, it is impossible to centrally place power distribution equipment. The vibration and noise of the heavy load transformer cores scattered around the city cannot be ignored, which will interfere with the learning and living environment of residents to a certain extent, causing continuous sound pollution. How to reduce the noise pollution of the transformer while ensuring the power supply and quality is a problem that needs to be solved urgently.

The standard code issued by relevant national departments is: JB/T 10088-1999, which indicates that the value of noise is related to the equivalent capacity and voltage level of the transformer. For oil-immersed, self-cooled 2500kVA transformers with a voltage of 6kV-63kV, the standard stipulates that it does not exceed 60dB. The 110kV transformer is calibrated to not exceed 70dB. In special workplaces, there are more stringent standards, even requiring less than 50Db[1].

Carrying out research on the vibration and noise of power transformers is conducive to solving the problem of transformer noise from the internal structure and design of the transformer, and is of great significance to transformer design and manufacturers, and power environmental protection departments.

2. Organization of the Text

2.1 Analysis of Transformer Vibration Mechanism

Transformer noise usually has multiple sources, such as the vibration of the transformer core or auxiliary fans and pumps in the cooling system. In order to better reduce noise, each noise source needs to be processed separately in different ways. In research at home and abroad, it is believed that the core vibration of the transformer silicon steel sheet due to magnetostriction is the main cause of noise.

Magnetostriction refers to a ferromagnetic material whose size changes significantly when the current passing through the coil changes or the distance from the magnet changes when an object is magnetized in a magnetic field. Ferromagnetostrictive material. The silicon steel sheet used to make the iron core is a kind of magnetostrictive material. The magnetic flux in these directions will cause mechanical strain, and the rapid expansion and contraction of metal will cause vibration. When these vibrations are transmitted to the shell wall through the insulating oil and the clamping point used to fix the inner iron core, a buzzing sound that can be caught by human ears, that is, iron core noise, will be emitted[2], as shown in Figure 1.

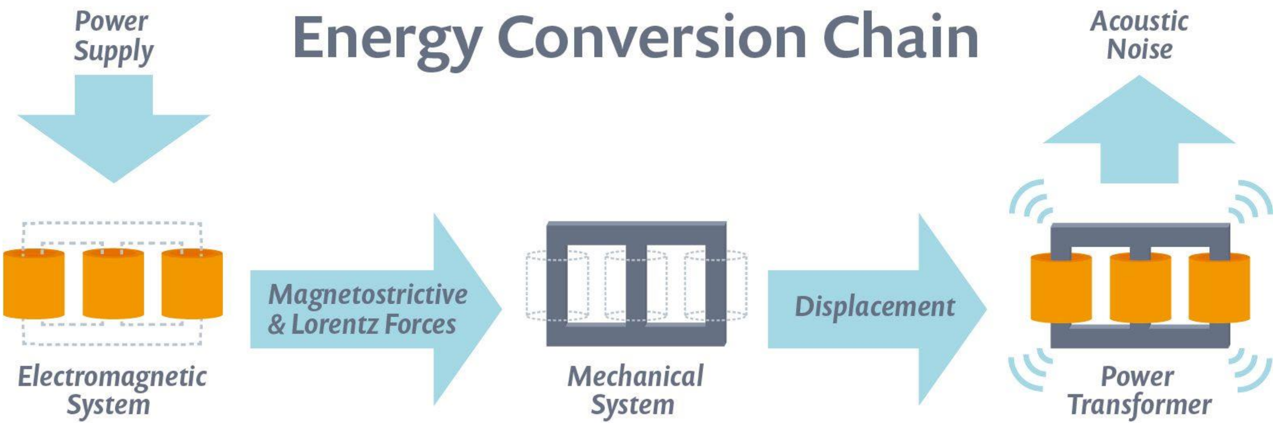


Fig. 1 Schematic diagram of transformer core noise[3]

2.2 Multi-physics coupling simulation analysis:

2.2.1 Principle of Finite Element Method (FEM):

People often use differential equations or partial differential equations to describe various physical phenomena (as shown in Figure 2). The definite solution conditions of differential equations consist of boundary conditions and initial values. The finite element method is a practical and efficient numerical solution method for differential equations. It discretizes the solution domain into interconnected micro-regions, assumes an approximate solution for each micro-region, and then improves the accuracy through iterative solution. When the solution converges, the problem is The solution is obtained.

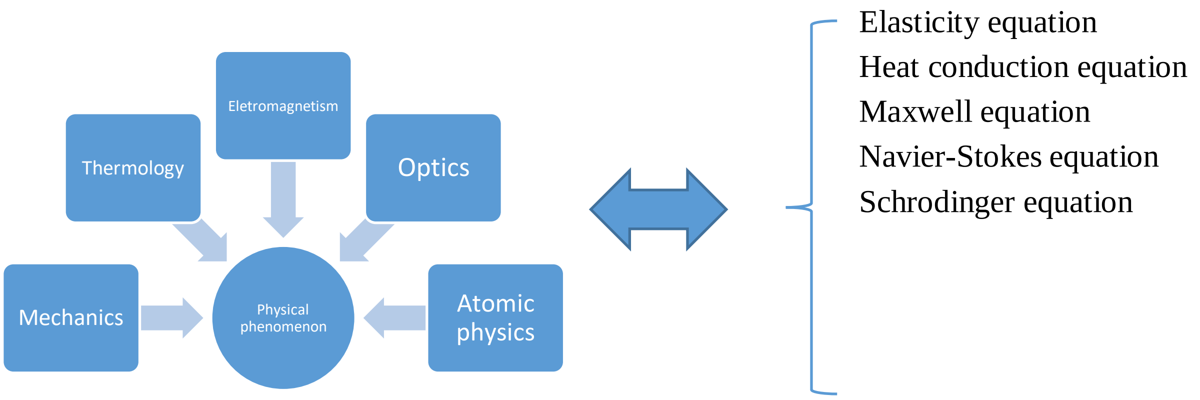


Fig. 2 Mathematical description of physical phenomena

2.2.2 COMSOL Multiphysics

COMSOL Multiphysic is a multi-physics coupling simulation numerical calculation software based on finite element theory. It takes partial differential equations as the basic research object, and realizes the numerical simulation of various physical fields through its multi-field coupling analysis function and efficient calculation performance. COMSOL Multiphysic has powerful multi-physics coupling capabilities, high-precision meshing capabilities, and plays an important role in the fields of engineering simulation and scientific research[4].

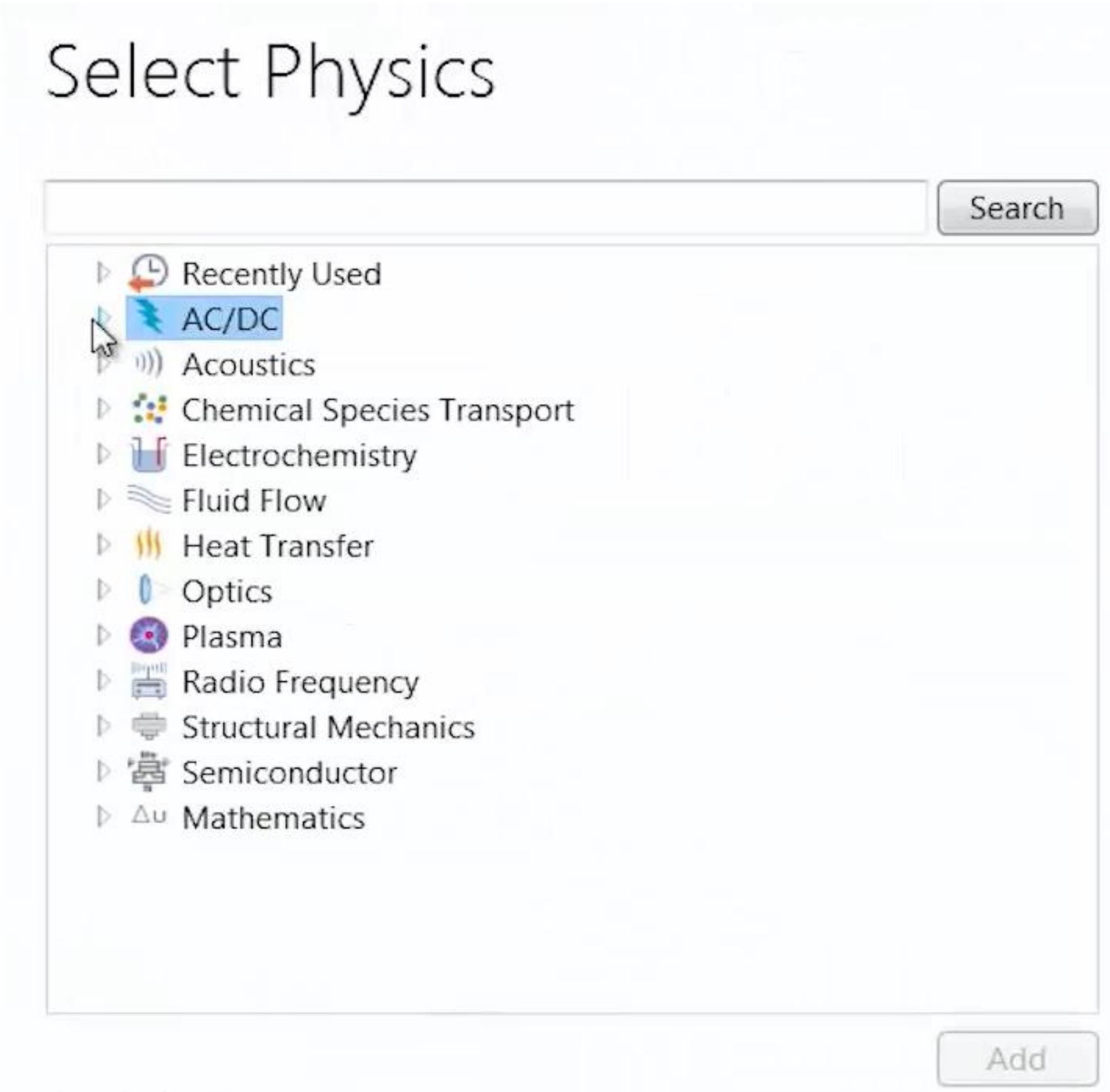


Fig. 3 COMSOL Multiphysic[5]

2.3 Simulation analysis

2.3.1 Model parameters and solution preset values

The simulation process is mainly composed of 4 steps (Figure 4)

We also constructed a two-dimensional model and a three-dimensional model for solution (Figure 5). We found that the results of the two-dimensional model and the three-dimensional model are basically the same under the condition that the grid distinguishing accuracy is high, and the two-dimensional model has the advantages of more intuitive results and significantly faster calculation speed than the three-dimensional model, so we will use it in the following The results of the two-dimensional model (pictured on the right) are analyzed.

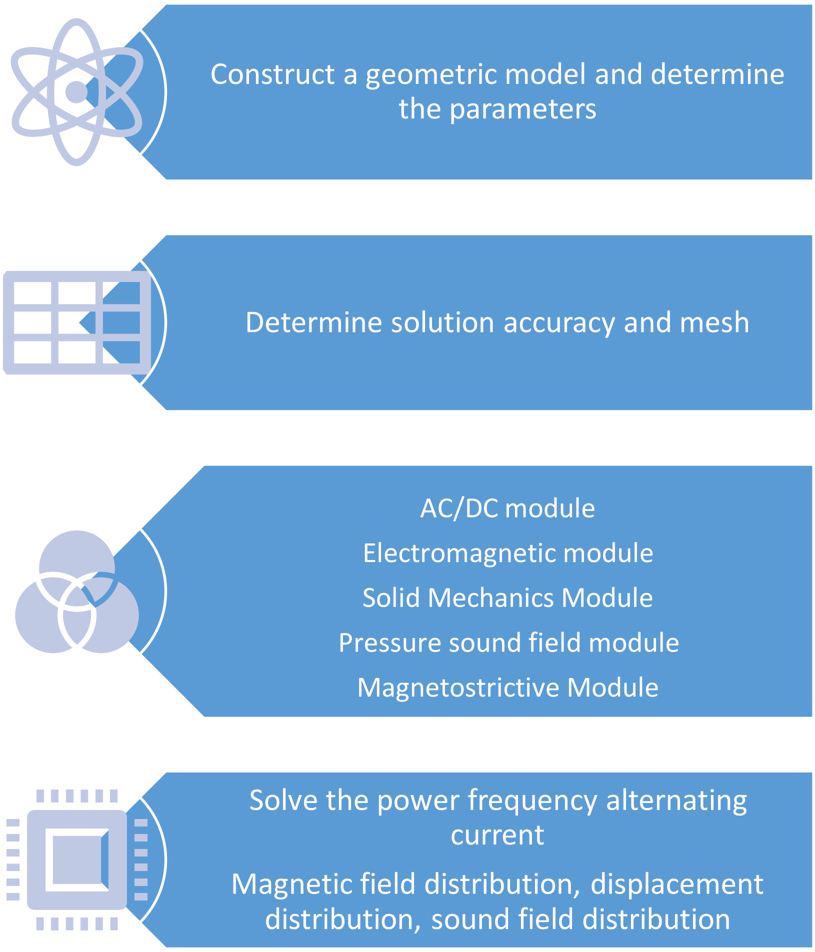
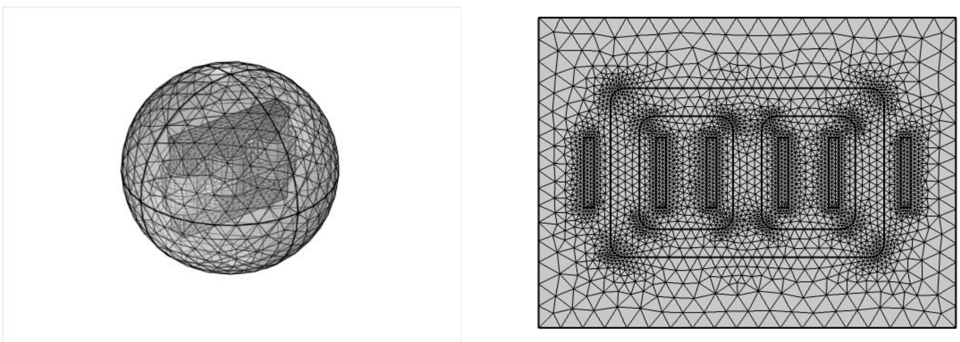


Fig. 4 Modeling and simulation process



3D model 2D model

Fig.5 The finite element mesh model of the iron core

In the electromagnetic field analysis of the iron core, the B-H (B is the magnetic induction intensity, H is the magnetic field intensity) magnetization characteristics of the silicon steel sheet material is a very important input parameter, which directly affects the accuracy of the electromagnetic field analysis results[6]. We used the B-H curve of a typical transformer core material as the simulation preset data. At the same time, we also specified the geometric size of the core according to the same principle (Figure 6), making the simulation results closer to the experimental results of the real transformer.

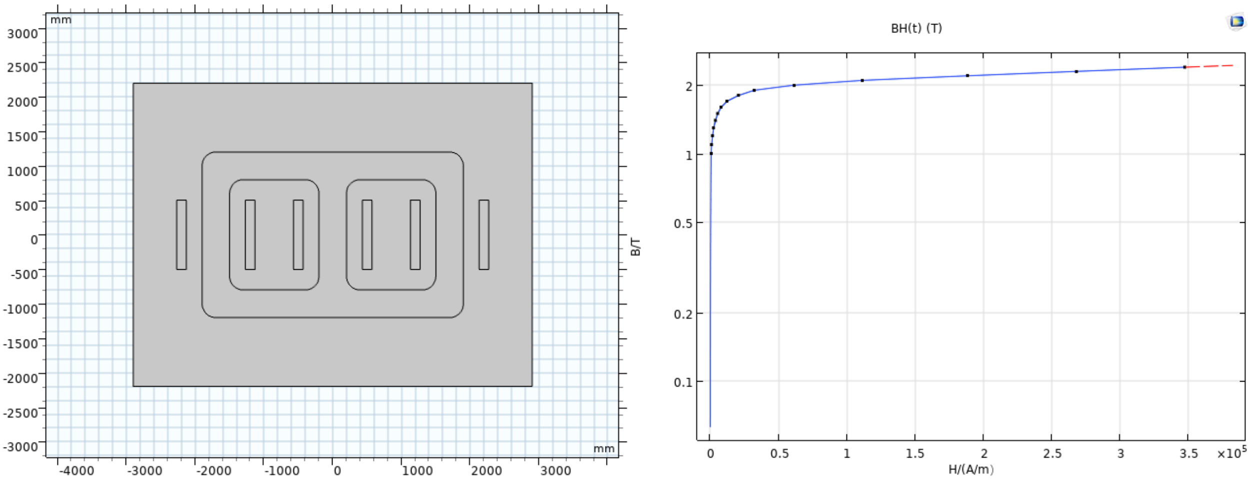


Fig. 6 A Core size(left), B-H curve(right)

In the AC/DC module, a three-phase excitation current is applied to the coil, and the magnetic field, sound field, and displacement distribution under the excitation of the current are calculated. The expression of the coil current is as follows:

$$\begin{cases} I_a = 300\sin(100\pi t) \quad A \\ I_b = 300\sin\left(100\pi t - \frac{2\pi}{3}\right) A \\ I_c = 300\sin\left(100\pi t + \frac{2\pi}{3}\right) A \end{cases} \tag{1}$$

In the structural force field simulation, the solid mechanics module is selected, and the structural force field solution domain equation is as follows:

$$m\frac{d^2u}{dt^2} + \tau\frac{du}{dt} + ku = f(t) \tag{2}$$

In the formula, m is the mass matrix; τ is the damping coefficient matrix; k is the stiffness matrix; u is the displacement vector[7]

The time solver step size is T=0.0005s, The model contains a total of 6628 domain units.

2.3.2 Simulation results

We first measured the magnetic field distribution around the iron core. Using 1/10 of the power frequency cycle as an interval, we intercepted 6 sets of magnetic field distribution clouds at different times, as shown in Figure 8.

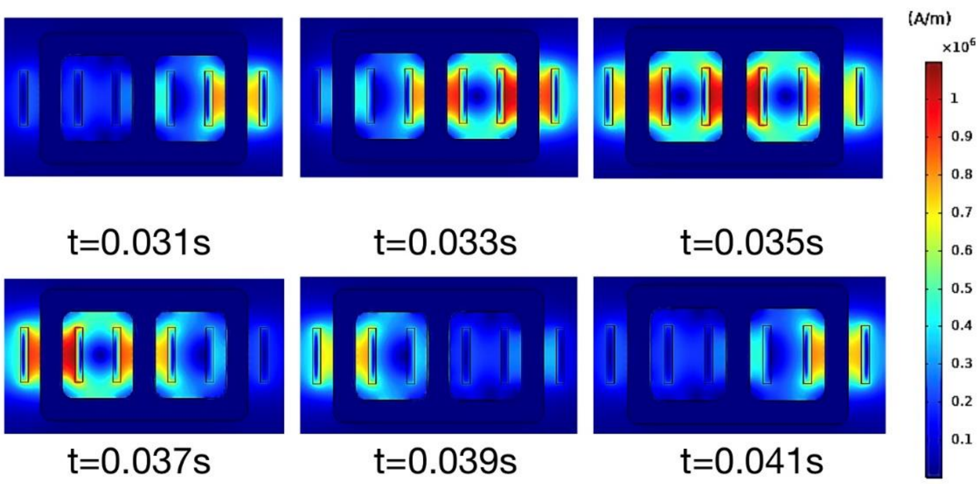


Fig. 8 Magnetic field distribution

It can be seen from the magnetic field distribution diagram that the magnetic field intensity changes continuously within half a power frequency cycle and shows a certain regularity. The magnetic field changes most obviously at the gap between the coil and the iron core and the maximum appears, while in other places For example, the strength of the yoke magnetic field on the iron core is very weak and the amplitude is close to zero. It may be that the leakage flux of the iron core produces an alternating magnetic field that is synchronized with the current change.

According to the distribution of the magnetic field, we can infer that the vibration of the iron core occurs in the part where the magnetic field strength changes rapidly and the amplitude is large.

With the same time step, we intercepted 6 sets of iron core acceleration distributions at different times. The red arrow on the surface of the iron core represents the direction and magnitude of the vector acceleration, as shown in Figure 9.

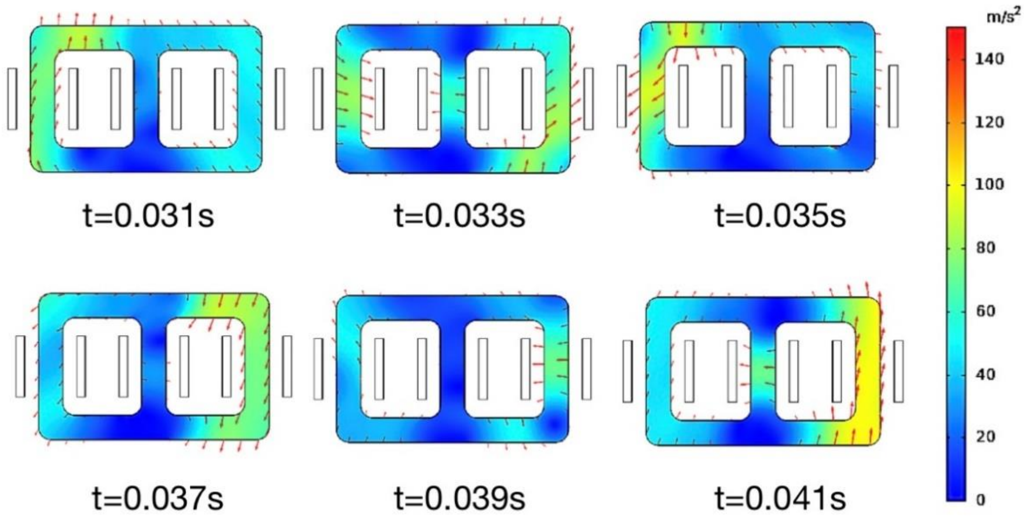


Fig. 9 Core acceleration (magnification 1)

Under the action of the alternating electromagnetic field, the iron core has undergone different degrees of deformation, but due to the small amount of deformation, it is basically impossible to observe with the naked eye on the original basis. Therefore, we enlarge the deformation variable in equal proportions. When the scale factor is 500, we can observe more obvious deformation, as shown in Figure 10.

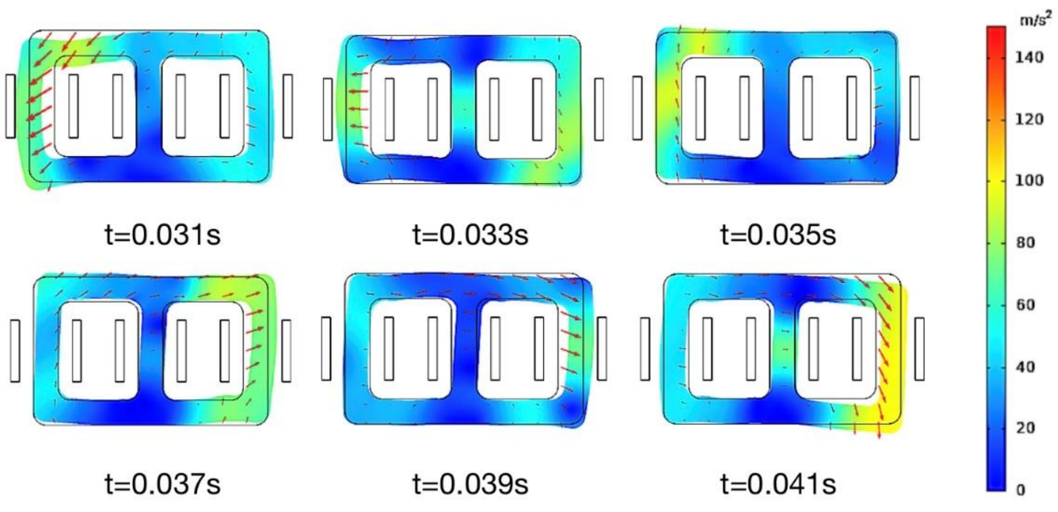


Fig. 10 Iron core acceleration (magnification 500)

It can be seen that the deformation of the two side columns of the iron core is obviously larger than that of the middle column, and the deformation shows a certain regularity. Since the bottom of the iron core is affected by gravity and bears the greatest pressure and weight, the deformation of the lower yoke of the iron core is smaller than that of the upper yoke. In many experiments, the acceleration direction of the iron core shows obvious irregularities, which may be caused by the randomness of the magnetic domain rotation position. However, the acceleration modulus of the side pillars shows the maximum value in many experiments.

The sound pressure distribution around the iron core is also our main research object. We have studied the pressure effect of the iron core on the outside air, as shown in Figure 11.

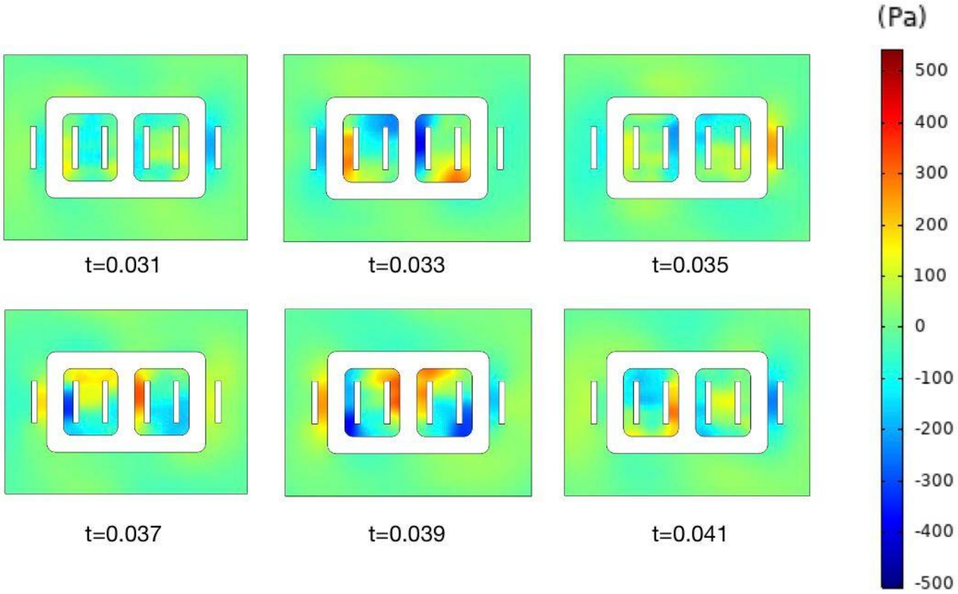


Fig. 11 Sound field distribution

The noise is mainly concentrated in the gap between the three iron core columns and the coil, among which the noise between the side column and the middle column is the most serious. This may be because the space between the pillars is relatively narrow, and the sound waves are reflected and superimposed back and forth between the pillars, which generates a lot of noise.

From Figure 9, Figure 10, Figure 11, it can be found that the displacement and sound pressure of the iron core have a certain non-uniform distribution. The difference between the upper and lower yokes and the stem of the iron core is particularly obvious, so we use the transformer core Choose different points (Figure 12) to observe the specific displacement (Figure 13) and sound pressure (Figure 14).

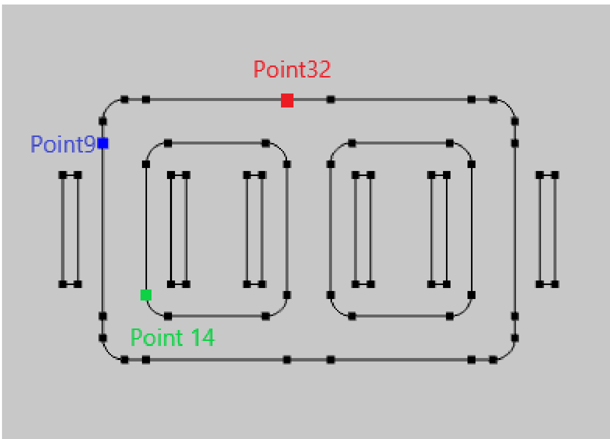


Fig. 12 Selection of measurement points

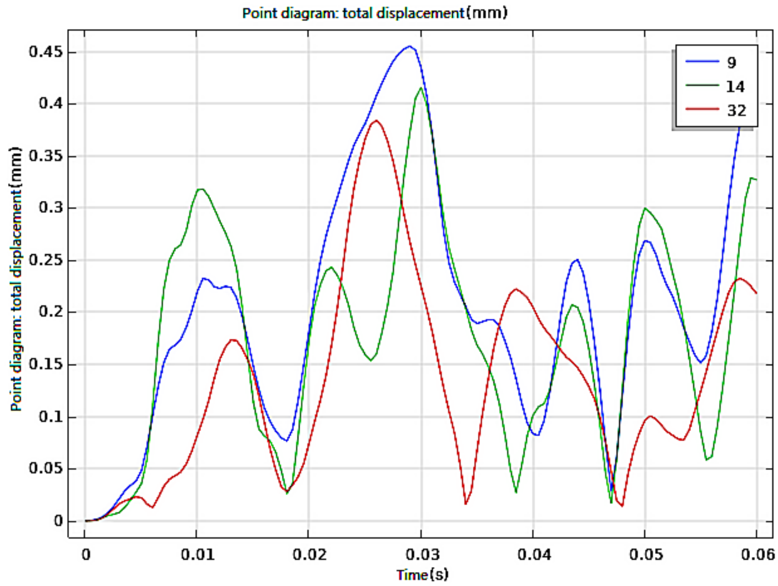


Fig. 13 Displacement at different points (left)

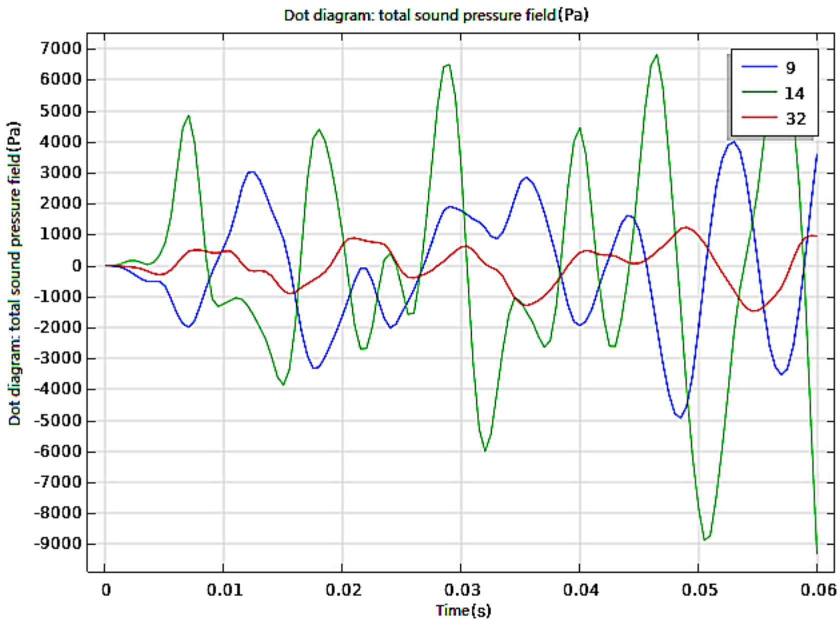


Fig. 14 Sound pressure at different points (right)

Comparing the displacement and sound pressure distribution of these three points, we can clearly find that point 9 on the side column has the largest displacement and strong fluctuation, and the displacement of point 32 on the upper yoke of the iron core is the smallest. The sound pressure amplitude at point 14 inside the iron core is the largest and has obvious fluctuations, while the sound pressure at point 32 on the upper yoke is relatively small and relatively stable. Based on this, we can clearly determine the location of the noise and vibration of the iron core during operation, so as to formulate reasonable measures to reduce the negative impact of noise and iron core vibration.

3. Conclusion

3.1 Summary of results

The finite element simulation of the transformer core was carried out. Through the coupling of electric field, magnetic field, solid mechanics field and sound field, the magnetic field, acceleration, displacement and sound field of the core under the excitation of power frequency three-phase current were observed, and the following conclusions were drawn:

(1) Solving the magnetic field distribution of the iron core, it is observed that the magnetic field strength in the gap between the coil and the iron core is relatively large and exhibits a certain regularity, which may be caused by the leakage flux of the iron core that is synchronized with the current change. Alternating magnetic field, and combined with the main position of core noise and deformation, it can be found that the greater the leakage of magnetic field, the more obvious the vibration and noise phenomenon.

(2) Solve the acceleration and displacement of the iron core, and set the magnification factor to the displacement of the iron core to achieve the magnified deformation so that the phenomenon of the iron core deformation can be directly observed. The deformation and acceleration of the two side columns of the iron core are obviously larger than that of the middle column, and the deformation shows a certain regularity, and the acceleration direction shows irregularities under the results of multiple simulations.

(3) The noise generated by the vibration of the iron core is mainly distributed at the junction of the coil and the three core pillars. In the cavity formed by the side pillars and the middle pillar, the sound pressure changes in this part due to the reflection and superposition of sound waves. And quickly, the noise is the most obvious.

3.2 Noise suppression measures

Based on the above simulation results, we put forward the following suggestions to suppress the vibration and noise of the three-phase three-leg transformer core due to magnetostriction:

(1) Improve the coil and core structure. For example, the coils are wound tighter to reduce the leakage flux and the electromagnetic force of the transformer iron wall, but attention should be paid to the insulation between the turns and the core column.

(2) Reinforce and fix the two side posts and upper and lower yokes of the iron core. For example, adding materials with higher magnetic permeability and strain resistance to the iron core of the side post can not only ensure the magnetic permeability of the material but also suppress the displacement and vibration of the side post.

(3) Use high-density transformer oil to slow down the sound pressure and suppress noise transmission.

(4) Place a buffer material between the iron core column and the column to absorb noise and avoid multiple reflections and propagation of sound waves between the columns.

References

[1] Sound level for 6kV-1000kV power transformers People's Republic of China Machinery Industry Standard, 2016.

[2] COMSOL_News_2019_ElectricPower_CN Large-scale transformer noise analysis-ABB continues to promote the development of the transformer industry by LEXI CARVER,2019.

[3] COMSOL_News_2019_ElectricPower_CN Large-scale transformer noise analysis-ABB continues to promote the development of the transformer industry by LEXI CARVER, 2019.

[4] Liu Hongliang. RESEARCH ON PROBLEMS OF VIBRATION AND NOISE IN TRANSFORMER CORE BASED ON COUPLING OF MULTI-PHYSICS [D] Shenyang University of Technology, 2014.

[5] Information on http://cn.comsol.com/comsol-multiphysics#optimize-models-accurate-results

[6] Wu Jian, Han Wen, Tian Haoyang, et al. Simulation of electromagnetic vibration of transformer core and its influencing factors[J]. Science Technology and Engineering,2021,21(2): 576-582.

[7] Li Kai.Research on Vibration and Noise of The Iron-core Reactor Based on Multi-physical Coupling Technique[D]. Harbin University of Science and Technology, 2016.