

Research on Transformer Core Loosening Faults Considering Hysteresis Effect

Shun Yu, Xiongbo Wang, Zhanyang Yu, Yan Li, Jingmeng Li

School of Electrical Engineering Shenyang University of Technology, Shenyang 110870, China

Abstract—At present, the simulation of the magnetic characteristics of transformer cores generally adopts the constitutive model of the basic magnetization curve. However, the hysteresis effect of silicon steel sheets can not be reflected by this constitutive model. As a result, there will be relatively large errors in the excitation current and the internal magnetic field of the core, which will lead to inaccurate calculation of magnetostrictive force. In this paper, the hysteresis model is used to reasonably represent the hysteresis effect of silicon steel sheets, and the finite element hysteresis constitutive model is constructed by applying the measured hysteresis loops. Taking an 800 kVA power transformer model prototype as the research object, the electromagnetic simulation calculation is carried out first. Subsequently, based on the electromagnetic structural coupling method, the vibration caused by the magnetostrictive effect of the core is solved. For the vibration conditions of the core under different degrees of looseness, the internal relationship and variation law between the core looseness fault and the vibration characteristics are analyzed. Finally, the simulation results are verified by means of the vibration test of the model prototype to ensure the accuracy of the simulation calculation.

Keywords: Power transformer, Hysteresis effect, Core vibration, Magnetostriction, Electromagnetic structure coupling

I. INTRODUCTION

ACCIDENTS caused by transformer core faults rank third among all transformer accidents. Therefore, it is of great engineering significance to study the mechanism of core vibration faults and then propose preventive measures. The magnetostrictive effect of silicon steel sheets is an important source of vibration in power transformers [1]. When a power transformer operates under no-load conditions, the vibration of its body mainly comes from the core [2]. How to accurately simulate the magnetic characteristics of the core is the key to solving the core vibration problem. In this paper, the accurate simulation of the magnetic characteristics of the core is achieved by setting up a hysteresis model. Then, the core looseness fault model is simulated and analyzed through the electromagnetic structural coupling calculation. Finally, the simulation method is verified by means of vibration tests.¹

II. SIMULATION MODEL AND KEY PARAMETERS

TABLE I presents the key technical parameters of the 800kVA power transformer. Three-dimensional model is shown in Fig. 1.

TABLE I
KEY PARAMETERS OF TRANSFORMER

TransformerParameters	Value
Rated Capacity(kVA)	800
Voltage Combination(kV)	6/0.315
Turns Ratio	462/14

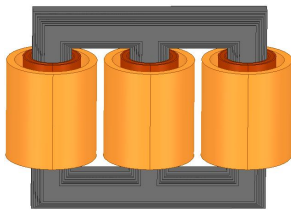


Fig. 1. Transformer simulation model.

III. ELECTROMAGNETIC CALCULATION UNDER NO-LOAD CONDITIONS

The no-load condition is set by applying the rated voltage on the low-voltage side while keeping the high-voltage side open-circuited. To simulate magnetic characteristics of core, its constitutive relation is usually set as the basic B - H magnetization curve. However, in practice, silicon steel sheets have hysteresis phenomenon, and there will be errors when using the basic magnetization curve to replace the hysteresis loop. Therefore, the construction of the finite element nonlinear hysteresis model can be completed by measuring the hysteresis loop through experiments. The measurement of the hysteresis loop is shown in Fig. 2 (a). The finite element model of the hysteresis loop is shown in Fig. 2 (b).

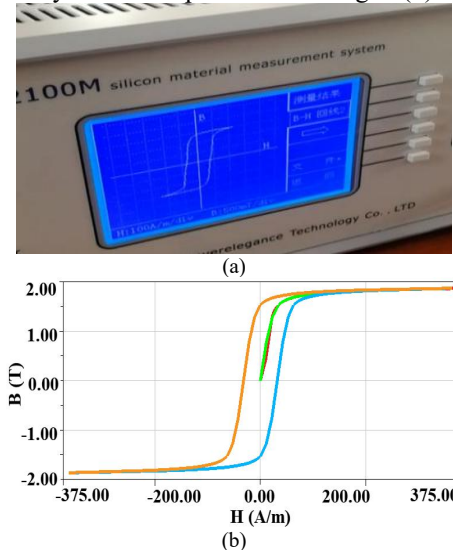


Fig. 2. Measurement and setting of the hysteresis loop. (a) Experimental measurement. (b) Hysteresis model setting.

The no-load current obtained by solving the B - H constitutive model and hysteresis mode is shown in Fig. 3 (a) and (b).

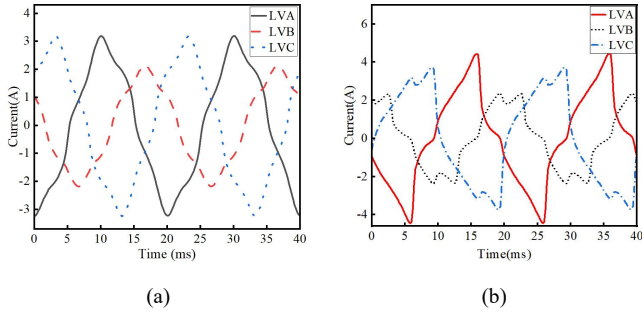


Fig. 3. No-load current waveform. (a) B-H constitutive model. (b) Hysteresis constitutive model.

Because the middle magnetic circuit of the core-type core is shorter, its current value is smaller than that of the other two phases. Compared with the basic magnetization curve model, the current waveform obtained by the hysteresis model has a greater degree of distortion and a higher harmonic content, which is caused by the non-coincidence of the ascending and descending segments of the magnetization curve.

Fig. 4 shows the cloud diagram of the core magnetic flux density at the moment of 10 ms. Since the current amplitude of phase A is the largest at this time, the magnetic flux density value of the core limb of phase A is much larger than that of the other two phases, and its magnetic flux density is approximately 1.57 T.

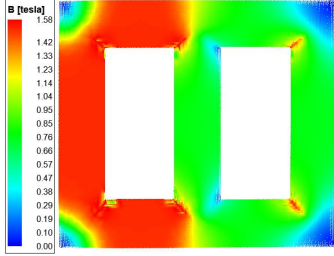


Fig. 4. Cloud diagram of magnetic flux density at 10ms.

IV. ANALYSIS OF CORE VIBRATION IN DIFFERENT LOOSE STATES

In order to calculate the magnetostrictive force of the core, it is necessary to input the curve of magnetostrictive strain λ and magnetic field strength H , as shown in Fig. 5. There is a corresponding coupling calculation relationship between the magnetic field and the structural field, as in:

$$S = C^{-1}T + \frac{\partial \lambda}{\partial H} |_{T} H \quad (1)$$

Where, S is the strain tensor. C is the stiffness matrix. T is the stress matrix. H is the magnetic field intensity.

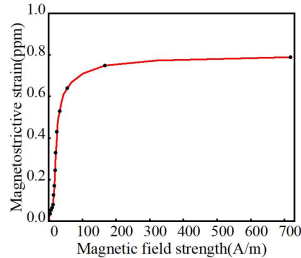


Fig. 5 Magnetostrictive single-valued curve.

By applying clamping forces of 100%, 80%, and 60% to the core to simulate different degrees of loosening states, the

simulation results of the vibration displacement of the core are shown in Fig. 6.

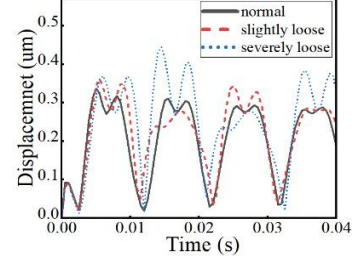


Fig. 6 Magnetostrictive single-valued curve.

The period of vibration displacement of core is 10ms, which is due to the frequency of magnetostriction is 100Hz. With the reduction of core clamping force, the degree of core looseness increases, and the amplitude difference of vibration displacement waveform in adjacent periods becomes larger, which increases the degree of vibration distortion and the content of odd harmonics. In the long run, the core will be worn, and in severe cases, the fault will occur.

V. MODEL PROTOTYPE VERIFICATION

To verify the accuracy of the above simulation calculations, a no-load test was carried out on the model prototype. The test site is shown in Fig. 7.

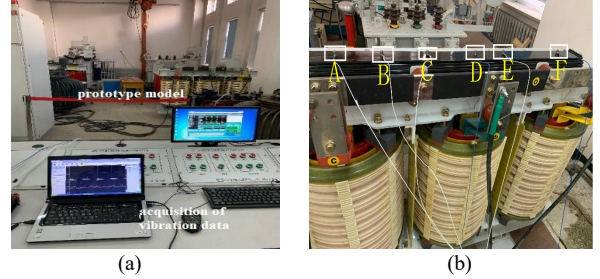


Fig. 7 No-load test site. (a) Vibration testing equipment. (b) Test prototype.

The vibration test results of measuring point A is compared with the simulation results, as shown in Fig. 8. Since the simulation model does not take into account the assembly relationship between the core and other components, the simulation results are slightly larger than the test data. But within the allowable error range, it can prove the accuracy of the simulation calculation.

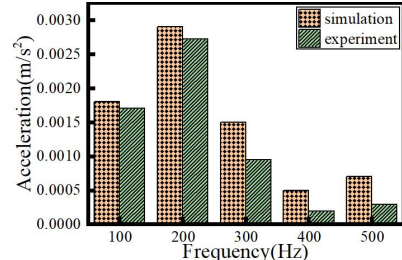


Fig. 8 Comparison between simulation and experimental results

REFERENCES

- [1] T. Tanzer et al., "Magnetostriction of Electrical Steel and Its Relation to the No-Load Noise of Power Transformers," *IEEE Trans. Ind. Appl.*, vol. 54, no. 5, pp. 4306-4314, 2018.
- [2] K. N. Romaric, D. Liu and B. Du, "Investigation on Vibration Characteristics of Amorphous Metal Alloy Core Dry-type Distribution Transformer," *CES Trans. Electr. Mach. Syst.*, vol. 6, no. 3, pp. 324-331, 2022.