Dynamic Strength Calculation of Power Transformer Windings under Multiple Impact Conditions

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Multiple short-circuit condition has brought new challenges to the power transformer winding mechanical strength design. In this paper, a method for calculating the cumulative deformation under multiple short circuit conditions is presented. The elastic-plastic model, which is suitable for multiple short circuit conditions, is introduced. The strength of power transformer windings is calculated using field-circuit-coupling method, compared with the experimental results. The results show that the calculation results are close to the experimental ones, and the calculation method presented in this paper can be used under the multiple short circuit conditions..

***Index Terms*—Power transformers, short-circuit currents, electromagnetic forces, couplings, dynamics**

I. Introduction

Power transformers should have sufficient mechanical strength to withstand multiple short-circuit forces. At present, the winding mechanical strength design has not considered the multiple short circuit condition. [1-2] In this paper, the nonlinear relationship between the short circuit electromagnetic force and the winding deformation is described by the elastoplastic material model. The strength of power transformer windings is calculated using field-circuit-coupling method.

II. PRINCIPLE

The power system short-circuit fault, the huge short-circuit current flows through transformer winding. Short-circuit current and the leakage flux produce the huge electromagnetic force, under the short circuit condition the outer winding of the transformer generates ring tensile stress, the within winding generates ring compressive stress, as shown in Figure 1.

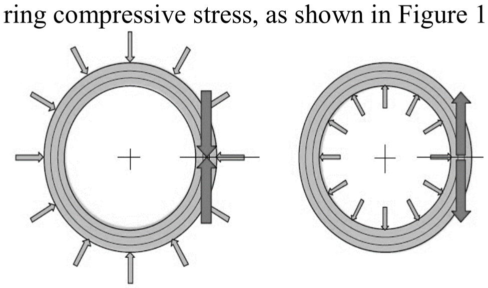

Figure 1: Stress in windings

The plastic deformation may be generated in the section of the winding conductor under multiple short circuit conditions, when the electromagnetic force peak reaches a certain level. Different from the elastic region where the winding is restored when the peak passed, the phenomenon of cumulative deformation may occur in parts of the windings. The value of the cumulative deformation and the peak value of multiple short circuit current, the material properties and the shape of the winding structure are all related.

III. MODEL

As mentioned, the calculation of the cumulative deformation needs to be loaded with multiple short circuit electromagnetic force load. Therefore, a finite element model is established in this paper. The multiple short circuit current and the cumulative deformation are calculated at the same time using field-circuit-coupling method. The short circuit mechanical strength of transformer winding under multiple short circuit conditions is investigated.

The short circuit current of transformer is calculated by Equation 1.

$$i(t) = \sqrt{2} I_d (\cos\alpha e^{-0.01t} - \cos(\omega t + \alpha)) \qquad (1)$$

The electromagnetic force of winding in power transformer is calculated by Equation 2.

$$\left\{ \nabla \times (\frac{1}{\mu} \nabla \times A) = \frac{i(t)}{s} \right. \qquad (2)$$

It is related to the elastic and properties of material with the multiple impact problem. The classical elastic plastic relationship is shown as Figure 2.

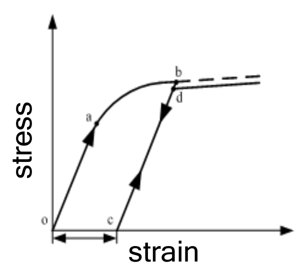

Figure 2: Classical elastic plastic relationship

During repeated impacts, due to the huge electromagnetic force loads, Plastic deformations appear repeatedly in the windings. Therefore, the elastic-plastic relationship model introduced must take the superposition effect into account. In this paper, a model with piecewise linear representation is introduced as shown in Figure 3.

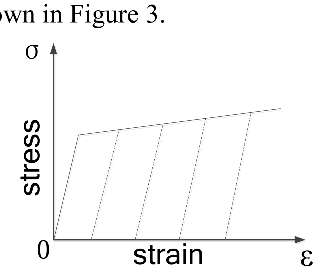

Figure 3: Piecewise elastic plastic material relationship

It can be seen that the position of plastic deformation can be simply pointed out by the piecewise linear curve. Based on the plastic mechanics theory, the deformation can be calculated by Equation (3).

$$dW = \left\{ \frac{\partial W}{\partial \sigma} \right\}^T \left[M \right] \left\{ d\sigma \right\} + \frac{\partial W}{\partial k} dk + \left\{ \frac{\partial W}{\partial \alpha} \right\}^T \left[M \right] \left\{ d\alpha \right\} = 0 \quad (3)$$

IV. EXAMPLE

A 250MVA/500kV single-phase transformer has been analysed under short circuit condition.

Calculated multiple short circuit electromagnetic forces are shown as Figure.4.

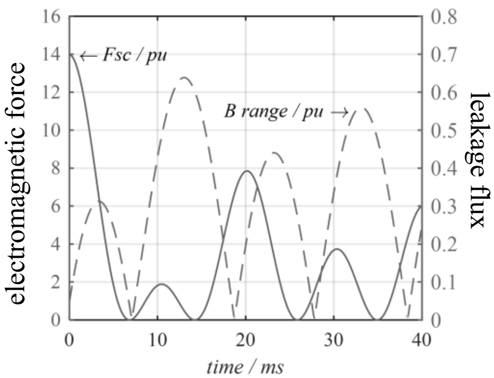

Figure 4: Calculated multiple short circuit electromagnetic forces.

Distribution of deformations are shown in Figure 5

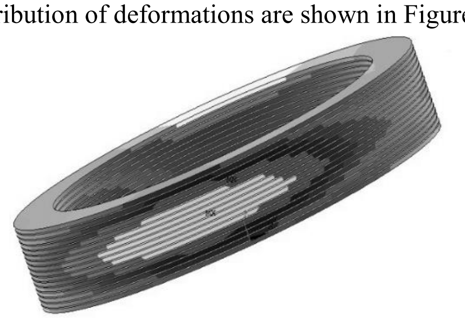
Figure 5: Distribution of deformations on the windings.

The electromagnetic force is calculated by the circuit and The deformation is calculated by the FEM, thus the cumulative deformation under multiple impact conditions can be determined using field-circuit-coupling method. Calculated deformations caused by multiple impacts are shown in Figure 6.

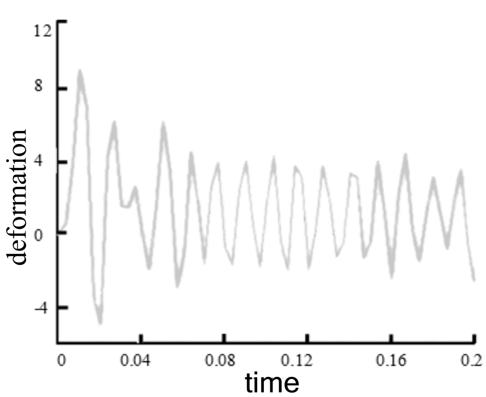

Figure 6: Measured deformations

Accordingly, the power transformer product has also a short circuit test and the displacement measurement has been made by laser ranging. Measured deformations are shown as Figure.7. The calculated values are in good agreement with the measured ones in terms of peak.

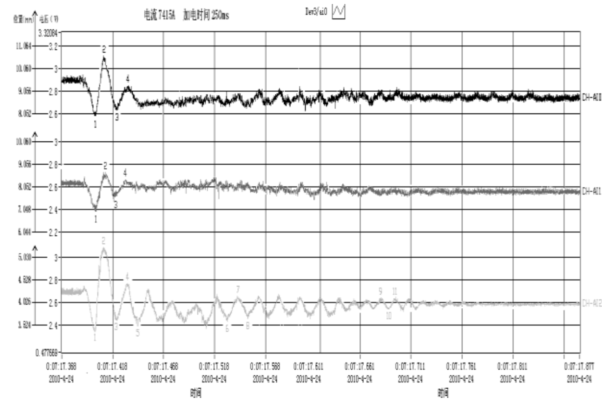
Figure 7: Measured deformations

V. CONCLUSION

In this paper, a method for calculating the cumulative deformation under multiple short circuit conditions is presented. A model with piecewise linear representation is introduced to simulate the elastic-plastic relationship. The deformations in power transformer windings under multiple impacts are calculated using field-circuit-coupling method. The result shows that the calculation results are close to the experimental ones. The calculation method provided in this paper may be useful for the study on strength of transformer winding under multiple short circuit conditions.

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