High-current Testing Of Frequency Dependent Device

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Abstract— **It is shown experimentally that active resistance of frequence dependent device keep his high value till the currents of several kiloampere at the frequencies from 60 kHz up to 200 kHz. It points out on the working capacity of device not only at operating current but at lightning strokes.**

Keywords— Frequency dependent device, active resistance, reactive resistance, magnetic saturation.

I. Introduction

Nowadays a transport of electrical energy with the frequency dependent device (FDD) is proposed for safety of transformer from lightning strokes [1-5]. It is based on the skin effect in conductive devices with two layers. The inner layer is made of Al while the outer layer is made of special magnetic amorphous conductive material. The last layer has high resistivity and permeability but could decrease its value due to possible magnetic saturation at high currents.

The purpose of this paper is high-current testing of the active resistance, and the saturation currents recording in the model of FDD on different frequencies.

II. Experimental setup

The experiments were carried out on the model that was part of real FDD. Its length being three meters, it consists of two parts in radial direction: the inner part made of aluminum with diameter 15.8 mm and the outer part made of magnetic resistive amorphous material of 0.3 mm thickness. Besides, the outer part was covered by dielectric layer. The minimum resistivity of each dielectric tube was not less than 1014 Ohm·cm. The model has the form of a ring with diameter of approximately 1 m. To carry out the high-current testing of the sample, we used the scheme shown in Fig. 1 [6].

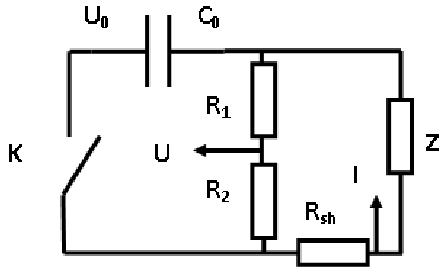

Fig. 1. Circuit diagram of a high-current testing

The capacitor C0 was charged by high-voltage 10 kV DC generator; after charging the key K was closed to generate damped oscillations. An untriggered spark gap was used as a key. The using of these components allowed us testing the model of frequency-dependent resistor at the currents of several kA. Charging voltage from the generator was measured by electrostatic voltmeter. Oscillations frequency was changed by the fitting of capacity C_0 from 0.1 μF up to 1μF. Shunt resistance was R_{sh}=0.3 Ohm. An oscilloscope RIGOL DS1022C was started up after the voltage divider R_2/R_1 signal.

III. Model

Active resistance of the model of the frequency-dependent device can be found from the oscillation circuit Q-factor. The measuring diagram of the oscillating circuit is given in Fig. 1. It is known that:

$$Q = \pi \frac{\tau}{T} \tag{1}$$

where $\tau = \frac{1}{\gamma}$ is the oscillation decay time or time lag when the oscillation amplitude decreases in e ≈ 2.7 times; $\gamma = \frac{R}{2L}$ is a damping coefficient; T is an oscillation period, L - inductance of the model .

Having determined the Q-factor, one can define the active resistance of the circuit from the expression:

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}} \tag{2}$$

where R is active resistance of the circuit; C is capacity C_0; inductance L is calculated by Thomson's formula:

$$L = \frac{T^2}{4\pi^2 C} \tag{3}$$

In this case, the active resistance of the circuit consists of the active resistance both of a shunt and a model.

IV. RESULTS AND DISCUSSION

The measurements were carried out with three capacitors C_0 of capacity 0.1; 0.5 and 1 μF. In such a case, the oscillation frequency was 240 kHz, 102 kHz and 66 kHz, respectively. In

Fig. 2, 3, some oscillograms of the oscillations (voltage and current) and diagrams of oscillation damping at the frequency of 102 kHz (C0 = 0.5 μF) are shown.

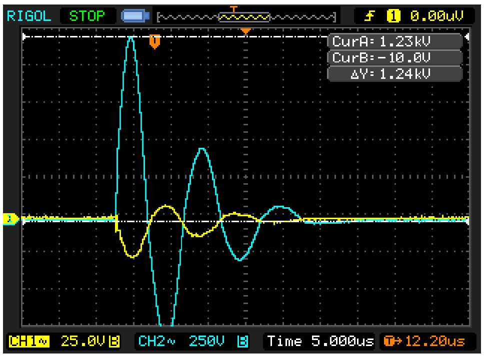

Fig. 2 Oscillograms of the oscillations (voltage and current).

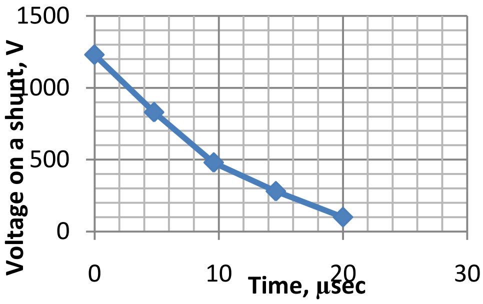

Fig.3. Current decrease during oscillation.

Table 1.The active resistance of FDD vs current at difference frequencies F=66, 102, 240 kHz

I (kA)	0.1	0.16	0.17	0.27	0.69	3.8	9.3
R(Ohm)	0.38	0.33	0.3	0.24	0.13	0.1	0.08

I (kA)	0.39	0.53	0.68	4.1
R(Ohm)	0,33	0,27	0,24	0,2

I (A)	33	35	56	92	300	3500
R(Ohm)	0.86	0.860	0.84	0.81	0.78	0.75

Having built the dependences of FDD resistance on electric current intensity through the FDD (Fig. 4-6), we make sure that the saturation mode occurs at any frequency. The saturation mode is characterized by the sharp decrease of the resistance. This allows us to define approximately the value of deep saturation current at different frequencies and to make conclusions regarding the working ability of the frequency-dependent device.

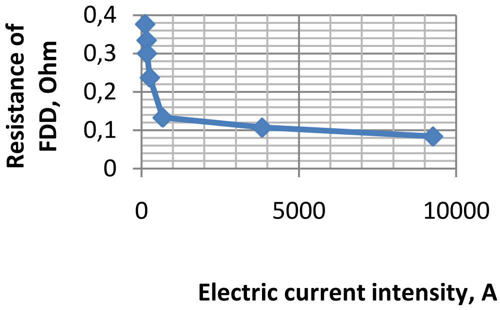

Fig. 4. Current dependence of FDD active resistance at f=of 66 kHz

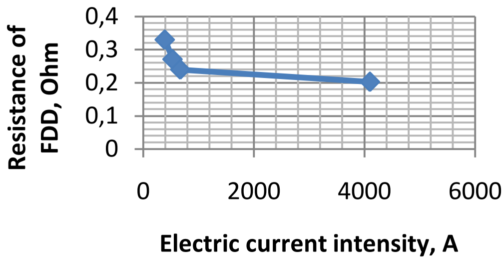

Fig. 5 - Current dependence of FDD active resistance at f=102 kHz

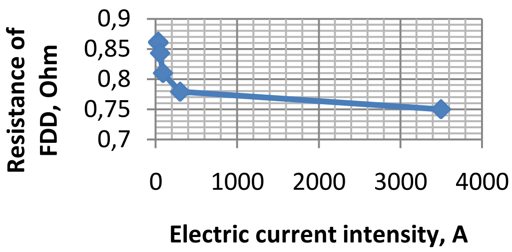

Fig. 6.Current dependence of FDD active resistance at f=240 kHz

Furthermore, the dependence of active resistance of the model, when the current of equal values at different frequencies passes through it, is presented in Fig. 4, 5 and 6 by the approximation. Thus, as an example, when the passing current is 300 A, the resistance will be 0.22 Ohm, 0.37 Ohm and 0.78 Ohm at the frequencies of 66, 102 and 240 kHz, respectively. The resistance will change according to the diagram given in Fig. 7.

The estimation of Q-factor of real FDD on the basis of current results gives the values from 10 up to 20. It depends on frequency -- the higher the frequency, the less the Q-factor.

The value of maximum current through the model can be defined by the peak of the first maximum of current oscillogram taken from the shunt resistance R_{sh} (a blue oscillogram in Fig. 2). As the shunt resistance is 0.3 Ohm, the value of the maximum current through the model is 4100 A.

A phase displacement and an oscillation period T were also measured in the manual mode. Then we built a diagram of the oscillation damping by the peak of current and defined the time lag when the amplitude of the oscillation decreased by 2.7 times (Fig. 3). The values of the Q-factor were calculated by the value τ and the oscillation period T. After that the circuit resistance R and a resistance per unit length of the model R_{length} were calculated by expression (2).

The calculated values of the active resistance per unit length R_{length} and the electric current intensity in FDD with the frequencies of input signal of 66, 102 and 240 kHz, are presented in Table 1, respectively. The dependence of the active resistance of FDD on electric current intensity is shown in Fig.3-5.

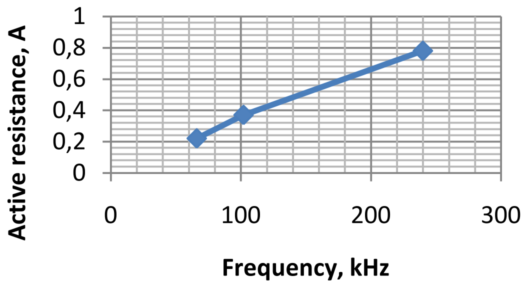

Fig. 7. Dependence of active resistance of the model on frequency when the current is 300 A

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V. Conclusions

Thus, high-current testing of the model of frequency-dependent device allows us to define the values of active resistance at different frequencies and to compare the given data with the measured data of FDD resistance by the method of voltmeter-ammeter by low voltage testing. Comparison of the results obtained at low and high currents permits us to state that the values of resistance at closely spaced frequencies are practically identical.

In addition, the high-current testing allows us to define the saturation values of electric current intensity at different frequencies.

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