METHOD OF ELECTRIC FIELD STRESS MEASUREMENT BASED ON ELECTRO – OPTIC KERR EFFCET

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Abstract: Electric field stress on high voltage insulation systems surface plays very important role. The stress determines electric field strength of the systems and inception voltage of partial discharges. It is a reason why the measurement of the stress is very important. The paper presents one of the methods, to measure the stress, based on electro – optic Kerr effect. The measurement of electric field stress, on high voltage insulation system surface, using the method based on the Kerr effect, was the objective of the paper. High voltage, long-rod, composite insulator 220 kV was the object of the investigations. Measured value of electric field stress was compared with the values, which were obtained using other methods, used by authors of the paper.

1 INTRODUCTION

Electric field stress is one of the key problems in design and operating of high voltage insulating systems. On one hand, large local electric field stress may lead to breakdowns or flashovers. On the other hand, obtainment of electric field stress, much lower than material strength, requires large dimension of insulating systems, which is totally, economically unsatisfactory.

Many methods for evaluation of electric field stress were elaborated. The methods are divided on computation methods and methods based on the measurement of electric potential.

Computational methods, like the most popular Finite Elements Method (FEM), are commonly used in design of insulating systems. The methods make the computation, with complicated shape and different materials, possible.

There are many methods of evaluation of electric field stress based on the measurement of electric potential, such as: sphere spark gap method, electrostatic kilo-volt-meter method, electrometer method, and compensatory method. Unfortunately, the methods have some disadvantages. They interfere in original electric field and change the value of electric field stress. They also measure the value of the stress, which is rounded value from bigger area of the surface.

Between many methods of electric field stress measurement, electro-optic methods are very promising [1-10]. The change of properties of light, passing through some material, which is caused by presence of external electric fields tress, is the basis of the methods.

Kerr effect method is one of the more popular electro – optic methods, which can be used to measure electric field stress. The electro-optic Kerr effect, known also as quadratic electro-optic effect, causes a change in polarisation of light, which is proportional to the square of electric field stress. Kerr law may be transformed to equation:

$$E = (\varphi / 2\pi l B)^{½} \qquad (1)$$

where: E = Electric field stress (V/m), φ = Angle of light phase displacement – the angle between polarization planes of in-coming and out-coming rays (radian), l = Length of Kerr cell (m), and B = Kerr constant of material of the Kerr cell (m/V^2). From this equation, the idea of measurement, as well as the measurement setup, were deduced.

2 OBJECT OF INVESTIGATION

High voltage, long-rod, composite 220 kV insulator was used (see Fig. 1). There were two versions of the insulator: with and without corona rings. In this way, two objects, with different electric field stress distribution on the surface, could be investigated.

Electric field stress, using the Kerr effect method, was measured just in one point – in triple junction of the insulator (insulator – high voltage electrode – air).

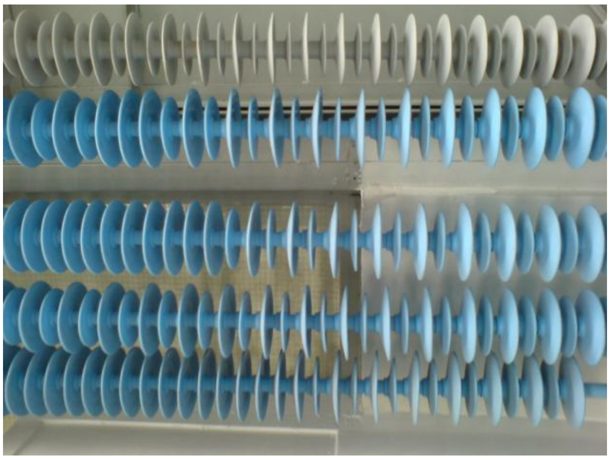

Figure 1: High voltage, long-rod, composite 220 kV insulator

3 MEASUREMENT SETUP

Measurement setup consists of five elements: the source of light (1), the polarisation system (2), the Kerr cell (3), the analysing system (4), and the detecting system (5), what is shown on Figure 2 and 3.

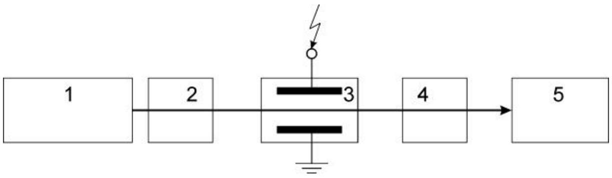

Figure 2: Measurement setup: 1 – the source of light, 2 – the polarisation system, 3 – the Kerr cell, 4 – the analysing system, 5 – the detecting system

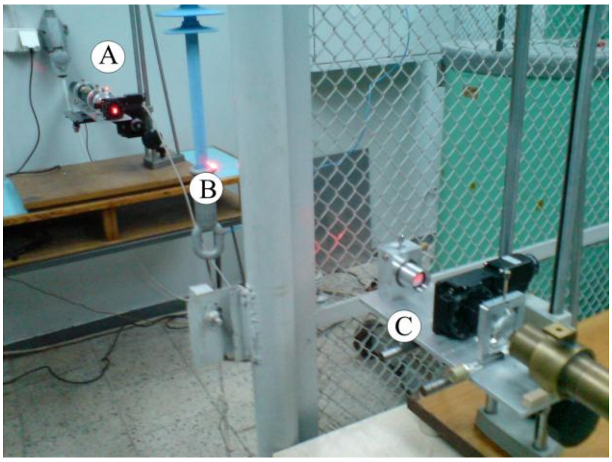

Figure 3: Measurement setup and high voltage insulator, A - the source of light (1) and polarisation system (2), B - the Kerr cell (3) in triple junction point, C - analysing (4) and detecting (5) systems

The source of light (1) is first element of the measurement setup, what is shown on Fig. 4. The main role of the element is to emit monochromatic light. That is a reason why a laser was used as monochromatic source of the light.

Figure 4: The source of the light – the laser He-Ne 25 LHP 151-230-5 mW (a) with the amplifier (b)

The polarisation system (2) is second element of the setup. Usually, a polarizer is used (see Fig. 5). The main function of the polarizer is to polarise the light. After that, the light has a linear polarisation.

Figure 5: The Glan-Thompson polarizer in the encapsulation (a) and turn-table (b)

The Kerr cell (3) is the more important element of measurement setup. The cell is made from glass pipe, filled in active electro-optic liquid. The length of the pipe was 50 mm. The pipe is sealed by a teflon cork (see on Fig. 6). If the liquid is placed in electric field stress E, the light inside the liquid changes its polarisation. The angle φ describes the level of the polarisation change, which is proportional to the stress E (see equation 1).

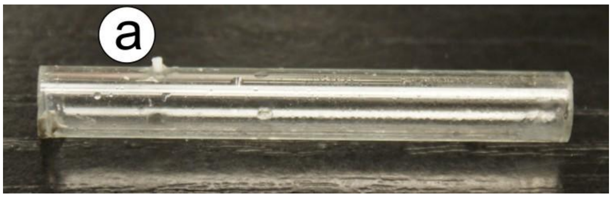

Figure 6: The Kerr cell – glass pipe (50 mm) filled with active electro-optic liquid, a teflon seal (a)

The analysing system (4) is next element of the setup, what is shown on Fig. 7. The measurement of angle φ is the main role of the system. The measurement of the angle is based on the measurement of light intensity i. The measurement of the intensity i is made in last, detecting system.

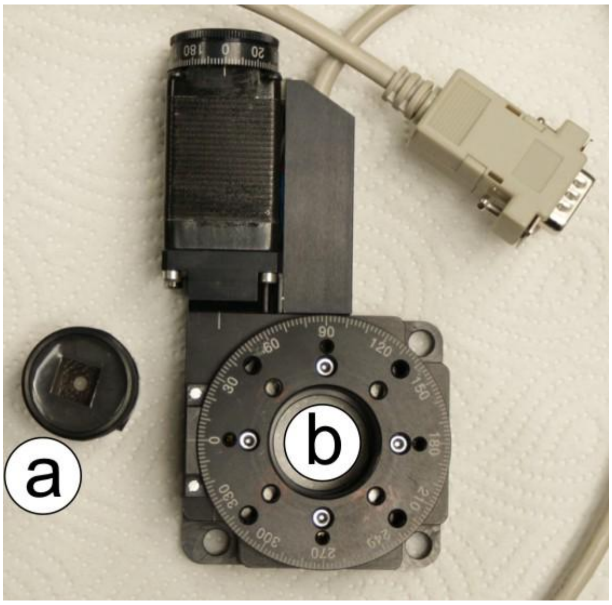

Figure 7: The Glan-Thompson analyzer in the encapsulation (a) and turn-table (b)

The detecting system (5) consists of the detector and the device which measures the signal from the detector. The detector (see Fig. 8) changes the light intensity *i* on voltage or current signal. Usually a photoelectric multipliers, photodiodes, or charge coupled device are used as the detector.

Figure 8: The detector – a photoelectric multiplier FEU-51 with the encapsulation

4 RESULTS OF MEASUREMENT

Test high voltage system was used for the measurement of electric field stress *E* in composite 220 kV insulator surface. The measurement of the stress was made in triple junction of the insulator. The test system consists of autotransformer (AT), high voltage test transformer (TP), and water resistor (RT) which was connected to investigation object – composite insulator (see Fig. 9).

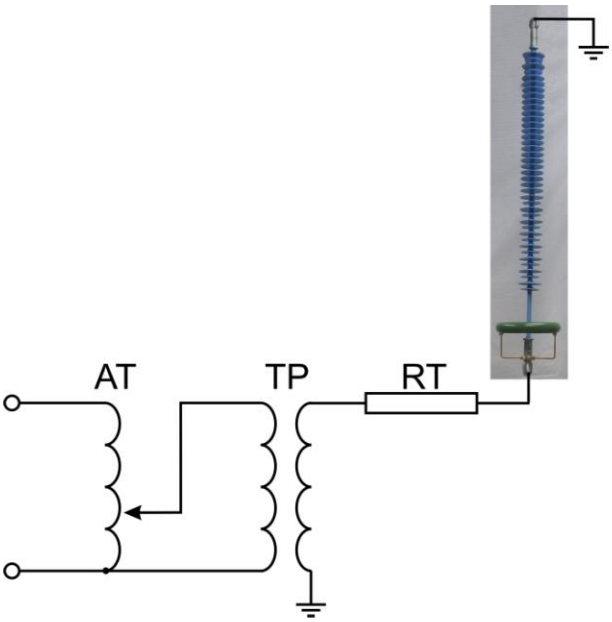

Figure 9: The test high voltage system, using for electric field stress measurement

The operating voltage of the insulator is 127 kV (phase voltage – 220/√3 kV ≈ 127 kV). But technical possibility of test system was just 100 kV. Because of this fact, and because of safety considerations, 64 kV was used to insulator to generate electric field stress *E*, which was measured by Kerr effect method. This value of voltage is 50% of operating voltage. It means that measured value of the stress *E* must be multiplied by two in order to receive real value of the stress.

Measurement of electric field stress *E*, using Kerr effect method, was based on application of equation (1):

$$E = (\varphi / 2\pi l B)^{½}.$$

Kerr constant of material *B*, and the length of Kerr cell *l* were known and equal respectively $30{\cdot}10^{-15}$ m/V^2 and 0.05 m. The angle φ was measured by electro – optic system.

In case of insulator without corona ring, measured value of the angle φ was 0.073°. It gives value of electric field stress *E* equal 0.368 kV/mm. After multiplication the value by two, the stress was 0.74 kV/mm. In case of insulator with corona ring, value of the angle was 0.024°. Using equation (1), value of electric field stress was calculated. The value, after multiplication by two, was equal 0.42 kV/mm. How we could expect, the presence of the ring caused the decrease of electric field stress *E* in area of the triple junction of the insulator. The value of the stress decreased from 0.74 to 0.42 kV/mm (about 43%).

Next stage of the investigations was comparison of electric field stress *E* value, obtained using different methods (Kerr effect method, computer simulation method, spark – gap method, and thermo – vision method), what is shown in table 1. How it is seen, electric field stress in insulator without corona rings is always bigger, than in case of insulator with the rings, almost not depending on the methods. All values have the same order of magnitude. It means that electro – optic method, based on Kerr effect, gives correct value of the stress.

Table 1: Electric field stress *E* in triple junction (insulator – high voltage electrode – air) of high voltage long – rod composite 220 kV insulator, obtained using various methods [10, 11]

Insulator	Electric field stress E [kV/mm] obtained using following methods			
	Kerr effect method	computer simulation method	spark-gap method	thermo-vision method
Without corona ring	**0.74**	1.32	0.55	0.55
With corona ring	**0.42**	0.32	0.13	0.20

5 CONCLUSIONS

Electro – optic Kerr effect was successfully used in order to measure the electric field stress *E* on surface of high voltage composite 220 kV insulator.

There were small differences in values of electric field stress, obtained using electro – optic Kerr effect and other methods. It means that method, based on electro – optic Kerr effect, gives correct value of the stress.

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