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Partial discharge activity sensing by inductive sensor and simultaneous acoustic emission sensing

Streszczenie. (Wykrywanie wyładowań niezupełnych czujnikiem indukcyjnym z równoczesną detekcją emisji akustycznej). *Artykuł opisuje badania polegające na równoczesnej detekcji wyładowań niezupełnych przy użyciu czujnika indukcyjnego i pomiaru ich emisji akustycznej. Zastosowane metody pomiaru wyładowań są porównywane dla określenia występujących pomiędzy nimi różnic.*

***Abstract**. This paper describes partial discharge activity sensing with inductive sensor along with discharge acoustic emission measuring. These methods of partial discharge measuring are compared and outlined its differences.*

Słowa kluczowe: wyładowania niezupełne, emisja akustyczna, czujnik indukcyjny.
Keywords: partial discharge, acoustic emission, inductive sensor.

Partial discharge activity monitoring in high voltage devices by inductive method

From the point of view of partial discharges that occur in unknown place of winding (placed in metal cover of transformer or in asynchronous machine) we face difficulties in easy accessibility of the faulty part under normal operation time. Besides these reasons the manufacturer of high voltage device does not allow to place the inductive sensor into the device. We searched for the possibility to sense the discharge activity outside of the body of high voltage device without high signal damping or deformation.

Outgoing from the theory of pulse events [1] we can suppose the discharge occurs in insulation between winding and magnetic core eventually between winding and vessel of the transformer or rotary machine.

The occurrence of inter-coil capacitance discharge is less probable but we can not exclude this case.

As the signal has a character of pulse we can write (based on Heller and Veverka [7]) basic differential equation [1]:

$$\frac{\partial^2 U}{\partial x^2} - L\left(C + C_M\right)\frac{\partial^2 U}{\partial t^2} + LK\frac{\partial^4 U}{\partial x^2 \partial t^2} = 0\,, \qquad (1)$$

where U is the amplitude of the propagated pulse.

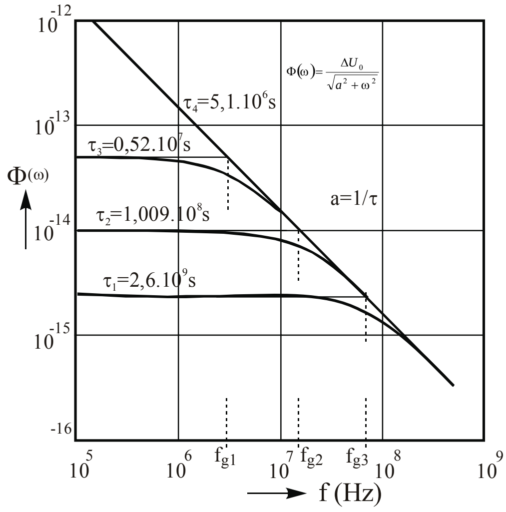

Fig. 1. The dependence of *Φ(u)* module on frequency.

As the pulse is a signal with certain frequency range it is possible to calculate the dependence of *Φ(u)* module frequency with time constant *τ* as parameter of partial discharge. Fig. 1 shows that with lower time constant values of the pulse the frequency range get more wider up to 109 Hz. This results in *u(t,x)* signal propagation following equation (1) which will be probably limited by differential inductances *Ldx* in circuit. This is caused by higher inductive reactance X_L at higher frequencies and consequently higher signal damping. More beneficial way of signal propagation seems to be in the direction of *K/dx* capacitances. The overall value of this capacitive reactance X_k was calculated with the help of following equation [45]:

$$X_k = \frac{1+\left(n-m_i\right)}{\omega K} = \frac{1}{f}\,\frac{1+\left(n-m_i\right)}{2\pi K} \qquad (2)$$

where n is the number of partial inter-coil capacitances and m_i is the number of capacitances rejected by partial.

Equation (2) says that for higher frequencies the value of X_k is non-linear lowered.

The partial capacitances of individual coils of winding against the vessel or body of the device *Cdx,* eventually differential capacitances against magnetic circuit *CMdx* participate equally on signal propagation. These elements are concentrated to working earth circuit which enables signal sensing that are dependent on current pulses.

Inductive sensor testing on high voltage devices

Toroidal types of inductive sensors were applied in voltage and current epoxide-finished device transformer measurements.

In order to compare the results of direct galvanic measurement method (i.e. direct connection of the device with the measuring device through measuring impedance) with the results of inductive measurement method we placed inductive toroidal shaped sensors in coaxial way into ferromagnetically shielded cover and located in earthning circuit of high voltage device.

We used standard setup in laboratory and in work, see Fig.2 (IEC 270).

Signal from the output of wide-range partial discharge measurement device was lead to digital oscilloscope connected to PC in order to statistically evaluate measured parameters in the dependence of phase angle.

It is sufficient to monitor some of the following parameters when we continually observe the quality or degradation of the insulation system of high voltage device by monitoring partial discharge activity:

- n – number of discharges in each angle step,
- q_{str} – mean value of apparent charge ,
- q_{max} – maximal value of apparent charge,
- q – point graph of measured apparent charge values,
- n – amplitude spectrum of measured apparent charge, partial discharge activity (φ-q-n), graph in Z-plane (φ-q-n).

Quantitative evaluation of these parameters ca be seen in the Figure 3 (inductive sensor - type PY) and in the Figure 4 (direct method)

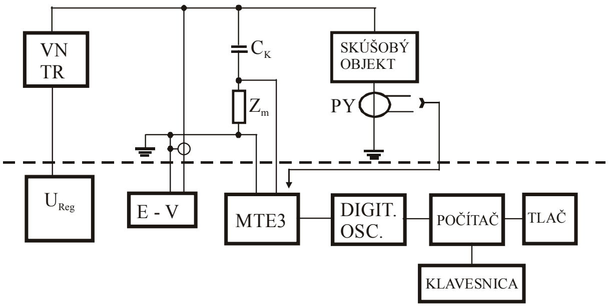

Fig. 2. Block diagram of measuring circuit

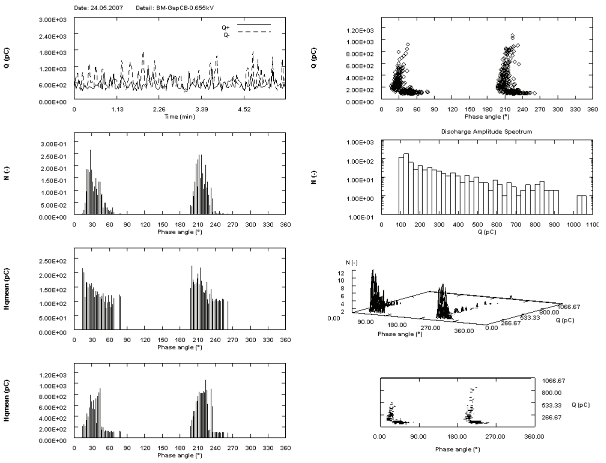

Fig. 3. Measurements results – inductive sensor - type PY

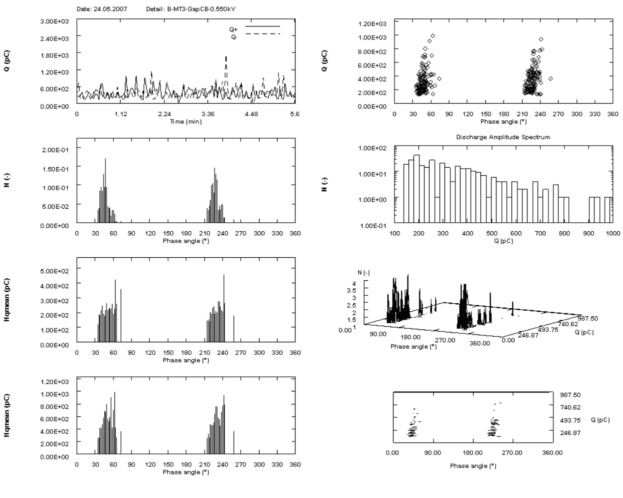

Fig. 4: Measurements results – direct method

Partial discharge measurement in oil transformer vessel by acoustic method and inductive sensing of partial discharge activity

Discharge activity measuring with inductive sensor and acoustic sensors seem to be very suitable for on-line diagnostics of high voltage transformers. In this case we get not only the quantitative evaluation of discharge activity but we can also locate the source of the partial discharges [3].

The detection of partial discharges by acoustic method in principally based on mechanic wave detection emitted by partial discharge sources. These mechanical waves propagate through the high voltage device [4]. Acoustic waves cross the surrounding oil and reach the walls of vessel where they can be sensed by acoustic sensors placed on the outer side of the wall. The shape of received signal depends on many factors such as the partial discharge source type, acoustic channel, acoustic sensor and measuring device. By measuring the relative arrival time of waves in acoustic sensors the place of the partial discharge source can be calculated.

That means acoustic method help to locate the faulty part of the insulation system and can decrease service time and costs.

Basic block diagram for combined inductive and acoustic measurement method is shown in the Figure 5.

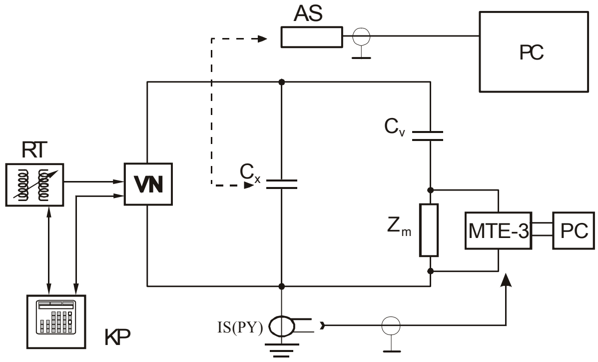

Fig. 5. Block diagram for combined inductive and acoustic measurement method (RT - regulation transformer, C_x - tested object, KP – control panel, C_v – coupling capacitor, VN – high voltage source, MTE-3 – partial discharge measurement device, IS (PY) – inductive sensor – type PY, PC – computer

Measuring the acoustic emission of partial discharges in high voltage electric power devices is based on the fact that partial discharges change a part of electric energy to mechanical energy. This energy is released in the form of short burst of mechanical vibration with characteristic frequencies falling into acoustic band of frequency spectrum.

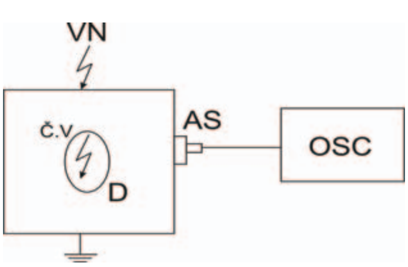

Fig. 6. Block diagram of measurement setup for acoustic method

Figure 6 shows a block diagram of the basic setup of partial discharge acoustic emission measurement. Electric power device is connected to high voltage VN. When there is a defect place in the insulation system of the device, e.g. a gas filled cavity D in transformer oil in high voltage transformers, this defective place becomes a generator of partial discharges ČV under some circumstances. Besides of electric or other methods of partial discharge characteristics measuring, acoustic method senses the acoustic emission of partial discharges by piezo-electric sensors which transform mechanical vibration to electric signal. Electric signal of acoustic emission is then led to display device e.g. oscilloscope or a device that stores the waveforms to evaluate them later.

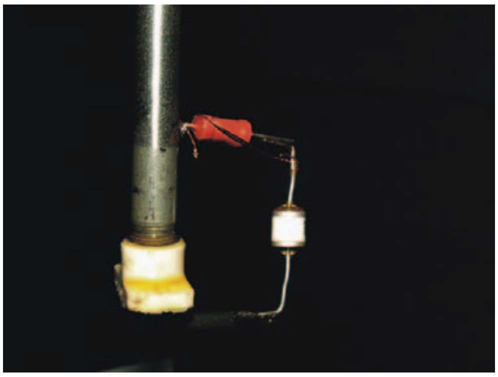

Fig. 7. Partial discharge acoustic emission simulation by spark gap

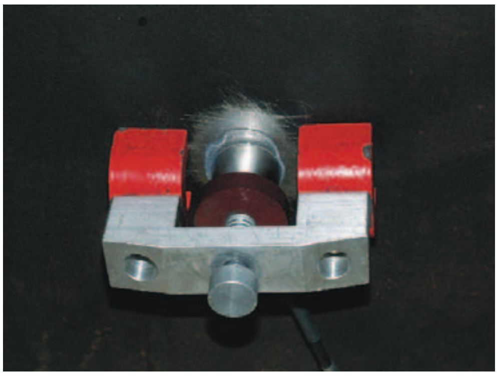

Fig. 8. Acoustic sensor with magnetic holder

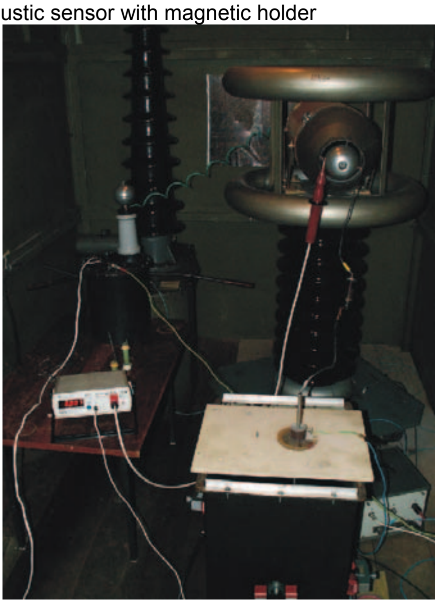

Fig. 9. Laboratory workstation

In order to verify the possibilities of signal parameter exploitation and if acoustic emission could be used for partial discharge type detection we made some introduction measurements in laboratory. Partial discharges were simulated by low voltage gas-filled spark gap immersed into metal vessel filled with transform oil. We placed acoustic sensors with the help of magnetic holders on various positions on the walls of vessel. The tested spark gap had two electrodes with constant distance between them encapsulated in gas environment. These properties ensure stable simulated discharges at constant voltage on electrodes. We made measurements with various conditions: various sample positioning with regard to vessel walls, with and without additional cylinder shaped barrier between sample and vessel walls. We measured also calibration pen acoustic emission signal as the measurement system required such calibration to enable automatic localization. We compared also these signal of acoustic emission with acoustic emission of artificially generated noise.

In the Figures 7-9 our laboratory workstation, tested sample and acoustic sensor with magnetic holder are shown.

Acoustic channel parts

Before the mechanical vibrations are transformed to electric signal, they pass the whole distance between acoustic emission source and the sensor. This path can be divided into three parts each of them influencing the final waveform in its way.

Comparing the dimensions of the defect in insulation and the wavelength of acoustic emission signal the source can be considered as vibrant sphere – 0th order's spherical transmitter with omni-directional transmitting and mechanical radiation impedance:

$$Z_{mv} = \frac{F}{v_S} = \rho_0 c_0 4\pi R^2 \frac{jkR}{1 + jkR} \tag{3}$$

This can significantly influence the waveform and frequency response.

The insulation system or dielectric can have high complexity. Therefore the influence on the waveform and frequency response of the stored signal can be very strong. This part of acoustic channel influence can be characterized by dielectric material characteristics such as:

- phase velocity of wave propagation c_f,
- group or envelope velocity c_g,
- damping factor α,
- material viscosity,
- material density.

In the case of more complex and non-homogenous dielectric another parameters have to be considered e.g. transition factor for the interface of two different dielectric materials.

Piezoelectric sensors exploiting piezoelectric effect and used to transform the acoustic to electric signal. Each sensor has its own and different frequency response that again influences the shape of final signal waveform.

Acoustic emission signal characteristics

After acoustic emission signal acquisition it is necessary to find the characteristic parameters of measured signals that would help us differentiate between various types of partial discharges. Obviously we have to take into account all those above mentioned factors of acoustic channel that could distort the shape of the waveform of partial discharge acoustic emission.

Signal examination and characteristic parameter search can be performed in time domain (main parameters are the shape of the waveform, rise or fall time of the pulse, peak count etc.) or in frequency domain.

For frequency domain examination two transform appear to be very useful. First there is the Fourier transform which helps to determine the frequency components of the partial discharge pulse. Main disadvantage of this transform is that the time relation between frequency components is lost.

Because the partial discharge signal can be classified as non-stationary, time relation between signal frequency components can have high importance in the process of partial discharge type recognition. Wavelet transform provides this additional information, so we can detect the position in time of every frequency component of partial discharge pulse.

Conclusion

Measurements in laboratory show that combination of various partial discharge measurement methods increase their ability to quantify the relevance of insulation system defect.

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