Karel ZÁLIŠ

Czech Technical University in Prague, Faculty of Electrical Engineering, Dept. of Electrical Power Engineering

Partial Discharge Measurement: Propagation of Partial Discharge Pulse in Winding and Calibration of Measuring Circuit

Streszczenie: ***(Pomiary wyładowań niezupełnych: propagacja impulsów wyładowań w uzwojeniu i kalibracja obwodu pomiarowego).*** *W Laboratorium Wysokich Napięć Czeskiego Uniwersytetu Technicznego w Pradze wykonano pomiary tłumienia impulsów wyładowań niezupełnych na modelu uzwojenia. Impulsy prądowe z kalibratora ładunku wstrzykiwano do różnych części uzwojenia, obserwując ich zniekształcenia oraz wyznaczając wartości ładunków na zaciskach uzwojenia. Stwierdzono, że ładunek pozorny jest parametrem diagnostycznym stosunkowo mało czułym w porównaniu do innych parametrów np. do kształtu i wielkości impulsu prądowego oraz ich zmian powstałych w czasie przejścia przez uzwojenie. Ładunek wyładowania po przejściu przez uzwojenie był wyznaczany poprzez całkownie impulsu prądowego na zaciskach za pomoca trzech różnych metod. Stwierdzono znaczne tłumienie impulsów, co potwierdziły wszystkie trzy metody. Wykonano ponadto pomiar tłumienia impulsu oraz zmian ładunku wyładowania w różnych typach uzwojeń. Stwierdzono, że tłumienie ładunków wyładowań zależy od parametrów uzwojenia. W badaniach ładunku kalibracyjnego od pojemności obiektu stwierdzono, że żaden z kalibratorów nie spełnia warunku niezależności wielkości ładunku pozornego kalibracji od wielkości pojemności obiektu. Dla pojemności ok. 500 pF odchylenia wielkości ładunku sięgały 20%, jednakże pojemności obiektów rzeczywistych jest często znacznie większa.*

Abstract. *In the High Voltage Laboratory of the Czech Technical University in Prague a lot of measurements of the attenuation of partial discharge pulses on the model of winding were realized. Current pulses from a charge calibrator were injected into different parts of winding, while their deformations were been observed, and the distortion of the charge at the end terminals was evaluated. It was found that the apparent charge of a partial discharge is a diagnostic parameter which is not relatively very sensitive, comparing to other diagnostic parameters, e.g. to the size the partial discharge pulse, to changes in shape and size of a partial discharge current pulse caused by passing through the winding.*
After passing through the winding the charge of the partial discharge was evaluated by integration of current pulse on terminals by means of three different methods. It was found that the attenuation of the partial discharge pulse is significant. It was also confirmed by all three evaluating methods with similar results. Furthermore, a measurement both of the attenuation of pulse and changes of partial discharge charge was realized on different types of winding. It resulted in finding that the attenuation of the partial discharge charge on different types of winding depends on the winding parameters.
In testing the dependence of the output calibration charge on the load capacity it was found that no tested calibrator fulfilled ideal conditions of the independence of the calibrator apparent charge size on the size of the object load capacity. For the load capacity of about 500pF all deviations from the given calibration charge size reach 20 per cent, the capacity of measured objects in operation is, however, often considerably higher.

Słowa kluczowe: wyładowania niezupełne, propagacja, kalibracja.
Keywords: partial discharges, propagation, calibration.

Introduction

At present the majority of diagnostic measurements of insulating systems of electric machines and high voltage machinery is made in off-line mode, i.e. on a detached machine during its check-up or repair, usually using the external adjustable source of a testing voltage. The main advantage of an on-line measurement, i.e. when the machine is working, is the possibility of finding the changes of insulation system immediately, which gives enough time for observing a defect progress and repair planning. When measuring off-line, the majority of insulation systems is under higher voltage than the operating voltage is (the winding is unearthed and the same testing voltage is through all the winding), while during the operation the voltage is evenly distributed along the winding from zero to the rated voltage. The method of measuring partial discharge seems to be a suitable diagnostic method for on-line type of measuring. For the operation use it is necessary to solve some of its problems, however.

Partial discharges often occur in places unapproachable for straight measurements, e.g. in the windings of electric machines. Current pulse, arisen from the partial discharge, is expanding from the place of its rise (usually from a vacuole in a winding insulation) and it is measurable only at the winding outlet - at machine terminals. When expanding through the winding the pulse distorts - its amplitude decreases, its shape changes and there is a possibility of a damped oscillation of the pulse.

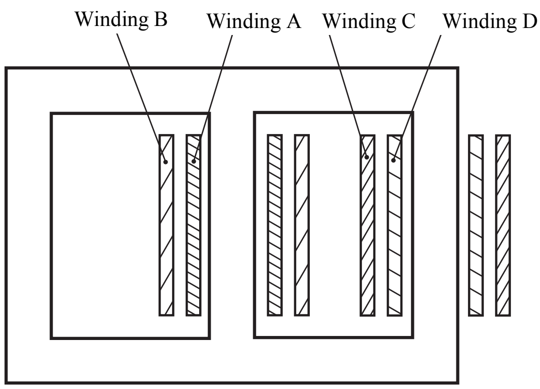

Fig.1. Model of transformer windings

Therefore, we do not measure a real charge of the partial discharge in an insulation vacuole, but the apparent charge, which can be different. The winding of the machine also has, besides distributed winding inductance L and winding resistance R, capacities between turns and coils and also between the winding and earthed construction. At operation frequency 50Hz, the capacity resistance 1/ωC, dependent on these capacities, is significantly high, and therefore we can ignore capacity currents, as they are imperceptible comparing to the currents passing through small inductive and ohmic types of winding resistance. On the other hand, high frequencies the situation is completely different, while passing through winding, the ratio of higher harmonics in an pulse decreases, which results in a change of the pulse shape.

In the Laboratory of High Voltage at Czech Technical University in Prague several measurements were realized to determine how much the value of basic diagnostic parameter, i.e. the apparent charge, changes while passing through the winding. Measurements were carried out on a model of a transformer winding which had three windings: coils A, B (a one-layer winding with different number of turns) with 11 taps, and coil C (a plate winding) with 22 taps, see Fig. 1.

For the simulation of partial discharges in the winding a calibrator TETTEX, type 9216 (pulse frequency 100 Hz, start-up time about 100 ns) was used. It imputed current pulses into the taps of the winding. Having passed the winding, the pulses were detected at the end of the winding (at the end terminals of the winding) and were evaluated by the digital oscilloscope LeRoy 9350 (bandwidth 500 MHz, sampling 2 GS/s for a single signal) with built-in mathematical functions, see Fig. 2.

The circuit diagram in Fig. 3 shows how the measurement was made. OSC stands for an oscilloscope, R_m is a load resistance; L is the total length of the winding, X represents the length of the winding, which the pulses of partial discharges pass through. It is determined by the position of the calibrator KG.

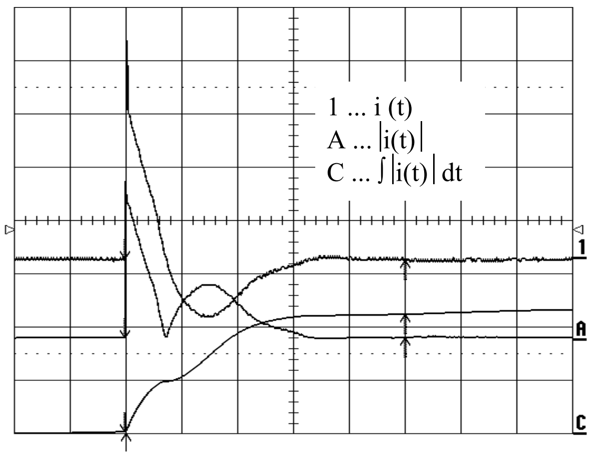

Fig.2. Measured and evaluated pulse of partial discharge

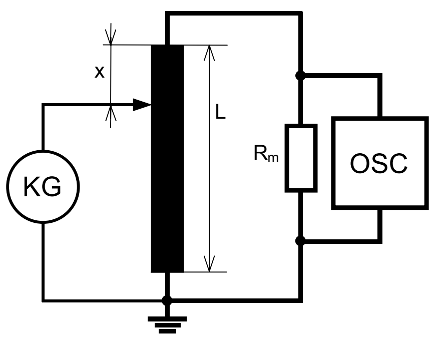

Fig.3. Diagram of the measuring circuit

Evaluation of the partial discharges

The shape of the partial discharge pulse is significantly influenced by passing through the winding. It can be distorted and then its apparent charge is very difficult to evaluate (i.e. in the pulse oscillation). Our aim was to find out which parts of the distorted current pulse of the partial discharge are the most suitable for the evaluation, so that the apparent charge of the pulse would show the smallest change. Therefore we used following three methods for evaluating the distorted current pulse of the partial discharge (see Fig. 4):

a) Only the first wave of pulse was evaluated, i.e. $q = q_1$.

b) Only waves of the same polarity were evaluated (in effect, only first two positive parts of the pulse), i.e. $q = q_p = q_1+q_3$.

c) All parts of the wave (regardless the polarity) were evaluated, i.e. $q = q_s = |q_1|+ |q_2|+ |q_3|+ |q_4|$.

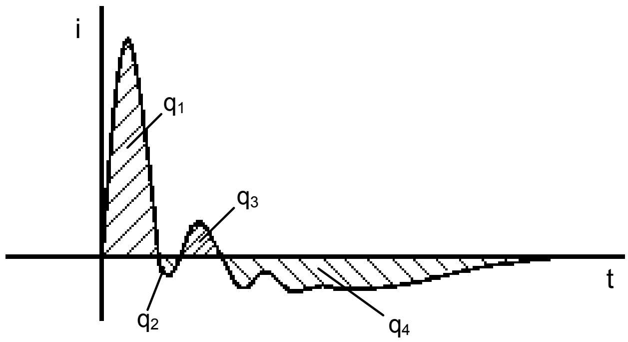

Fig.4. Distorted current pulse of partial discharge

Measurements were performed on winding A (load resistance R_m = 100 kΩ) and measured values were transformed to the chart, see Fig. 5.

We can see that the charge decreases while passing through the winding, when passing the 40 per cent of the winding it decreases to about 80 per cent of its original value, when passing 70 per cent of the winding to about 60 per cent of the value, when passing 90 per cent of the winding to about 25 per cent of its original value. This fact was confirmed with all the methods of evaluation.

The differences among the methods of evaluation of the apparent charge of the distorted partial discharge were not significant. Differences in values obtained in method a), i.e. q_1 (this method is used by the majority of commercial measurers) and in method b) i.e. q_p are max. 7 per cent, between q_1 and q_s (method c) is max. 5 per cent, which is quite acceptable for the operation measurements of the partial discharge deviation. As the evaluation of q_p is relatively difficult (it is necessary to use the per-partes method), for practical measurements and evaluations methods either the method q_1 (i.e. evaluation of the partial discharge from the integration of the first wave of the current pulse only) or the method q_s, where the partial discharge q is determined from relation:

$$q = \int |i(t)|\, dt = \frac{1}{R_m} \int |u_m(t)|\, dt$$

This method, i.e. method q_s, is more suitable in our case and that is why this method was used for an evaluation of the attenuation of partial discharges on different windings.

Attenuation of the apparent charge on different windings

To be able to find out the influence of the type of winding and winding parameters on the attenuation of the apparent charge we made measurements of the pulse attenuation and changes of the charge of partial discharges on different windings. Measured values of the apparent charge dependent on the partial discharge pulse passing through three different windings were plotted into the graph in Fig. 6.

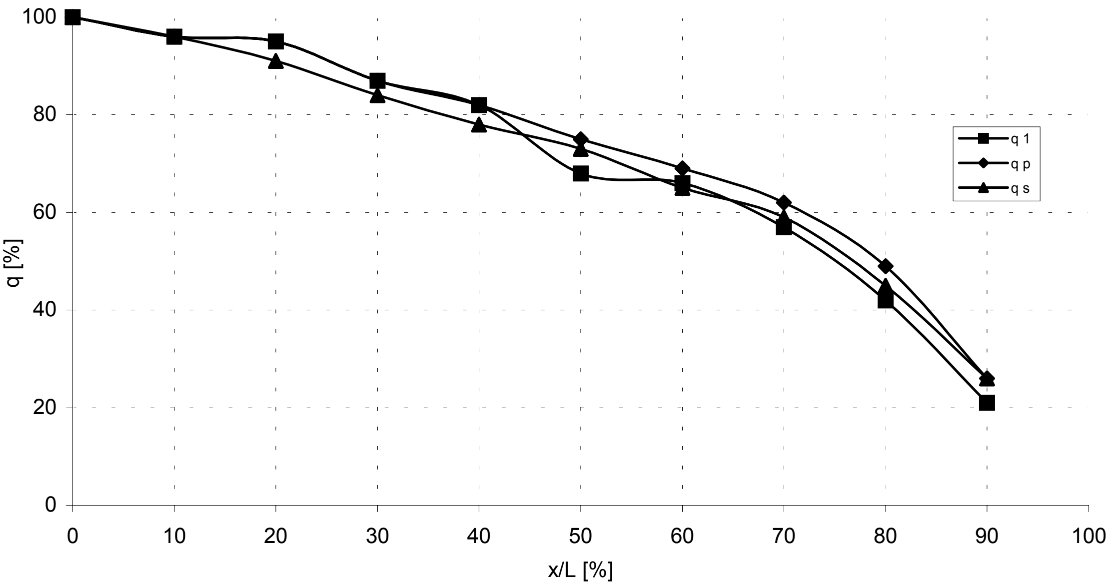

Fig.5. Evaluation of attenuation of partial discharge pulse by different methods

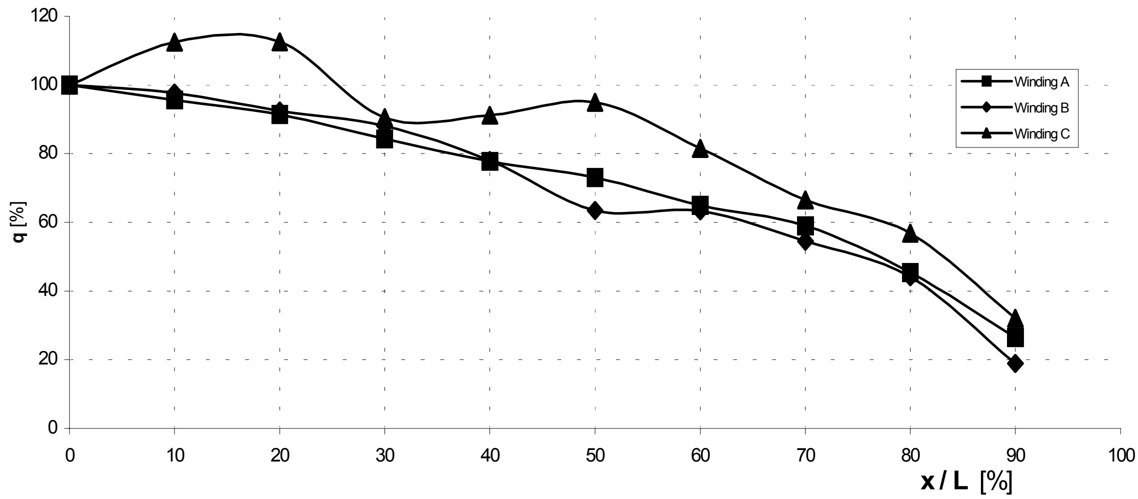

Fig.6. Attenuation of the apparent charge on different windings

We can see that the attenuation of the apparent charge of the partial discharge on different windings is similar and depends on winding parameters. This stands for all types of windings. In case of the plate winding (winding C) extra resonances and reflections occurred.

Calibration of the measuring circuit

Calibration of the measuring circuit is very often wrongfully ignored. It is important for a fact the measurement of partial discharges is a comparative method, i.e. the linear comparison of measured data and calibration values (these values are measured when the circuit is calibrated). Therefore we focused on detecting the accuracy and loading of available calibrators and we compared them each other and then to the calibrators made in Development Laboratories of the Czech Technical University in Prague detached in Poděbrady.

The stated rules should be followed, when calibrating the measuring circuit:

- The calibration charge from a calibrator should correspond to standards.
- The size of calibration charge should be similar to the presumed value of measured partial discharges.
- The size of calibration charge should be independent on the capacity of the measured object.

As we aimed to check up the calibrator resistibility, we made a test on the accuracy and the ampacity of both available commercial calibrators and calibrators made in Development Laboratories in Poděbrady.

We focused on two most important characteristics of charge calibrators:

- The accuracy of calibration charge when at no-load, or at rated load at maximum.
- The dependence of the decrease of the size of the calibration charge on the load capacity.

Following calibrators were tested:

- The calibrator „Master Calibrator“, made by BIDDLE, type 27 000, continuously tunable in the range 10 pC - 1000 pC, pulse frequency 100 Hz.
- The Calibrator TETTEX, type 9216, range 10 pC - 10 000pC, pulse frequency 100 Hz.
- The calibrator made in Development Laboratories of Czech Technical University, Faculty of Electrical

Engineering, in Poděbrady, type G6-6, year of manufacture 1993, range 5 pC - 10 000 pC, pulse frequency 100 Hz.

- The calibrator made in Development Laboratories of Czech Technical University, Faculty of Electrical Engineering, in Poděbrady, type G6-7, year of manufacture 1995, range 5 pC - 10 000 pC, pulse frequency 100 Hz or 1 kHz.
- The calibrator made in Development Laboratories of Czech Technical University, Faculty of Electrical Engineering, in Poděbrady, type G6-8, year of manufacture 1998, range 5 pC - 25 000 pC, pulse frequency switchable 50 Hz, 100 Hz, 1 kHz or 5 kHz.

All comparative measurements were related to the calibrator of BIDDLE company („Master Calibrator") considered as standard and which was used for calibrating the whole measured circuit before each measurement. Measured data of the calibration charge dependent on the load capacity were plotted into graphs, see Fig. 7.

As showed on the chart, when loaded with 300 to 500 pF all available calibrators work with the error about 20 per cent and this error rises with increasing capacity of the object. It means - if we try to calibrate the measuring circuit with a connected object (in accordance to regulations) whose capacity is bigger than about 500 pF, the total error is higher than 20 per cent, when the object capacity is about 5000 pF, the calibration charge is about one order lower.

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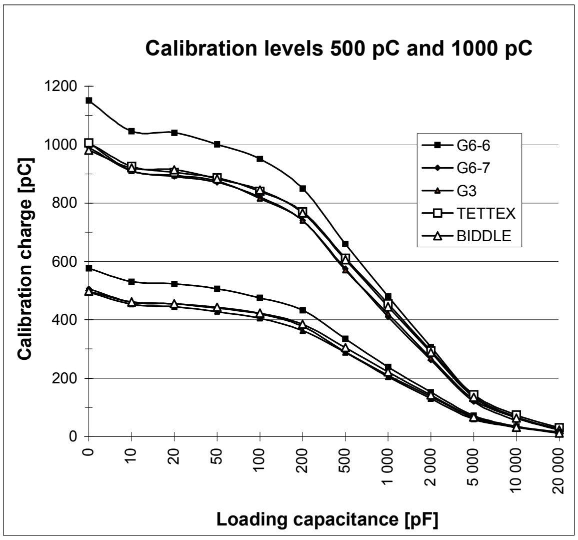

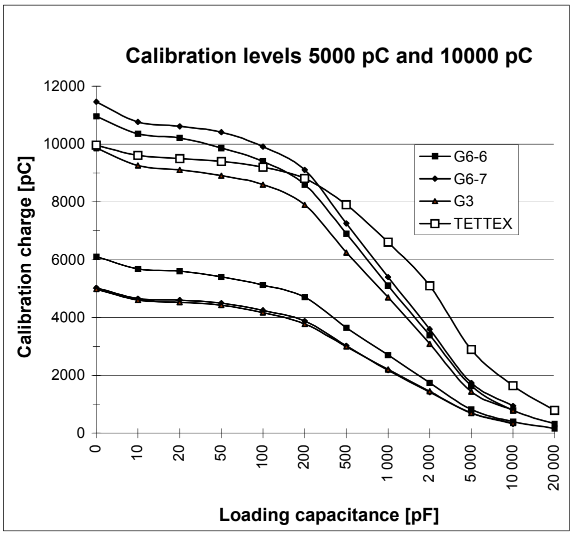

Fig.7. Dependence of calibration charge on loading capacitance

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Author: *Ass. Prof. Karel Záliš, Czech Technical University in Prague, Faculty of Electrical Engineering, Department. of Electrical Power Engineering, Technicka 2, Prague 6, Czech Republic. E-mail: zalis@fel.cvut.cz*