RECOVERY VOLTAGE MEASUREMENT ON OIL-PAPER INSULATION WITH SIMPLE GEOMETRY AND CONTROLLED ENVIRONMENT

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Abstract: Using the recovery voltage of oil-paper insulation to diagnose its state of maintenance is very popular among electrical engineers. Many advantages of using recovery voltage includes non-intrusive, easy to operate, more resistant to noise compare to other non-intrusive diagnostic methods. However the lack of understanding on the physical process causes dispute over interpretation of measurement results. This also discourages further application of recovery voltage to non-standard insulation systems because there is no known standard reference to which comparison can be made. Experiments have been carried out to study recovery voltage of oil-paper as a response of insulation material. The variation of recovery voltage in response to sample geometry, temperature and moisture are studied. The results reveal that the traditional Debye polarisation model, implemented as parallel RC-circuit in recovery voltage software, is not a satisfactory description of the physical process. The interfacial charge movements play more dominant role in the formation of recovery voltage in oil-paper insulation systems and the use of exponential function to describe the interfacial charge movements is both uneconomical and unphysical.

INTRODUCTION

Commercially available instruments only register the polarisation spectrum of recovery voltage[1]. This resulted in many research publications on recovery voltage based on the polarisation spectrum[2][3][4]. Although its simplicity enables recovery voltage technique to be useful in the industry there is a major drawback in this approach. The polarisation losses most of the information contained in recovery voltage measurement (RVM) by summarising the information of the whole curve into three parameters: peak voltage, initial rate of voltage rise and time to reach peak voltage. No convincing physical model can be built based on these parameters alone because much of the information of recovery voltage has not been taken into account. However by studying the whole recovery voltage curve versus time, a model can be built based on the characteristics of recovery voltage curve in time domain. Some researches[5] have been studying the recovery voltage of transformers using the whole recovery voltage curve and assume that the insulation system has Debye response. The current experiment is to study the effect of environment parameters such as moisture content, temperature and geometry of insulation on the recovery voltage.

EXPERIMENTAL DETAILS

The purpose of the experiments is to understand the dielectrical properties of the oil-paper insulation. Therefore a vacuum tight vessel has been built to contain oil-paper insulation. The paper insulation is sandwiched between two electrodes and recovery voltage measurements can be performed on the paper. Fig. 1 shows the schematic diagram of the experiment, the interconnections between equipments and the arrangement of sample.

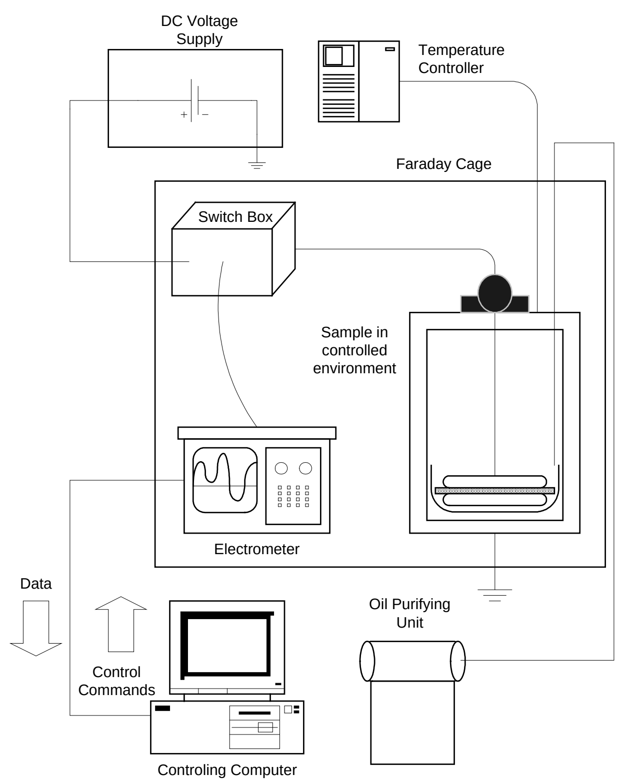

Fig. 1: The layout of experiment

The whole experimental procedure is automated and controlled by a personal computer. The high voltage is applied across the sample for a period of time t_c and then earthed for another period of time t_d, typically t_d= ½ t_c. The voltage across the sample after this period is called recovery voltage[1]. The result is sometimes presented in a very compact form called the recovery voltage spectrum where the peak voltage is plotted against t_c[1]. The recovery voltage recorded by electrometer will then be stored in the computer for analysis later.

Good quality oil-paper system is exposed to moisture in atmosphere for extended period of time before the experiments start. The moisture in the insulation is then removed by using the oil-purifying unit. The moisture in the oil is removed by passing the oil through coalescers in vacuum. As the dryer oil is pumped back into the vessel new equilibrium between the paper and oil will be achieved. The moisture level of the oil is determined using Cou-Lo Compact Coulometric Karl Fischer Titrator in line with standard set in [6]. This enables the recovery voltage at different temperatures and moisture levels to be measured.

Repeating the same procedures for samples with different ageing conditions or geometries will enable us to characterise the oil-paper insulation at these various conditions. The air in the vessel is pump out by vacuum pump and refill with dry nitrogen gas after the sample is placed into the vessel to make sure that the air moisture does not play any significant effect in affecting the overall moisture equilibrium.

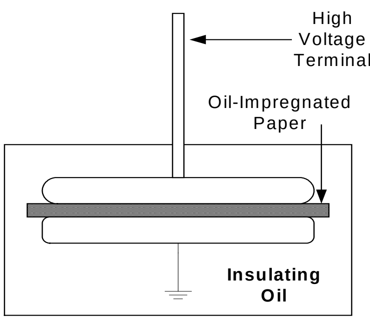

Fig. 2: Standard flat disk sample

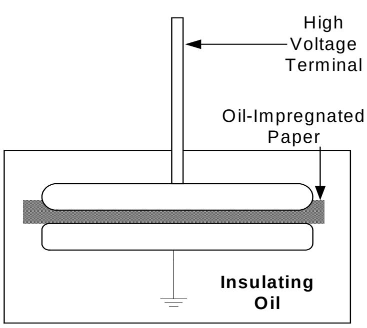

Fig. 3: Disk with rim around the high voltage electrode

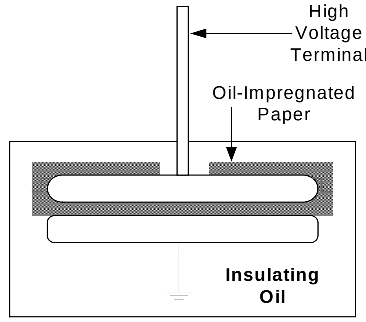

Fig. 4: Pressboard enclosing high voltage electrode

Pressboards with three types of geometries are used: flat disk (Sample A, Fig. 2), disk with rim (Sample B, Fig. 3) and sample enclosing electrode (Sample C, Fig. 4). All samples are cut from the same piece of pressboard without any ageing history. These samples are 15mm in diameter and 2mm thick between electrodes.

OBSERVATIONS

Sample A

The recovery voltage peaks of Sample A occur too fast to be recorded by electrometer under most conditions as shown in Fig. 5. These observations have been verified by using oscilloscope. The only exception is the sample with low temperature and very low moisture level when some peaks occurs several seconds after measurement is initiated. Fig. 6 shows the effect of different temperatures on the measured recovery voltage. Lower temperature produces higher recovery voltage.

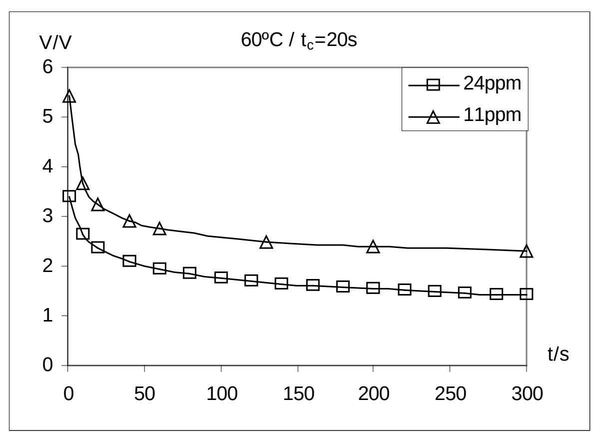

Fig. 5: Recovery voltage at various moisture levels (Sample A)

The tail of the recovery voltage stays above zero for a very long time relative to the charging time. Lower moisture level and lower temperature produce higher residue voltage. Similar phenomenon has been observed on recovery voltage of dry pressboard[7]. Comparing the results of dry paper in Fig. 7 with oil-paper, the presence of insulating oil significantly shortens the time to reach peak voltage and reduces the magnitude of peak voltage. It is also noticed that the current passing through the oil-paper system during polarisation increasing linearly with respect to applied voltage and exponentially with respect to temperature. However the current is unusually big for an insulator (0.1mA-0.5mA) which leads to suspicion that it is not polarisation current but leakage current. This is later confirmed by measurements on samples B and C as the magnitude of current on these samples are below the measurement device (μA).

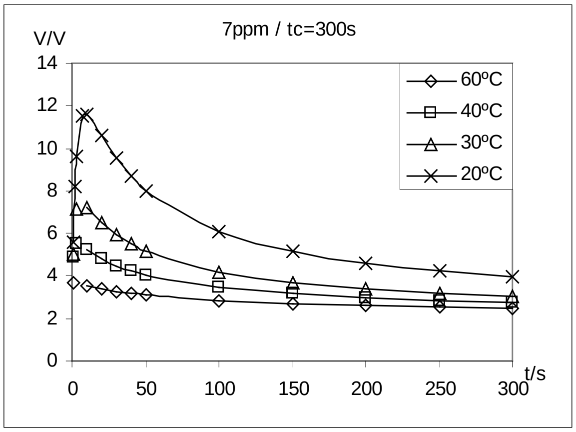

Fig. 6: Recovery voltage at various temperatures (Sample A)

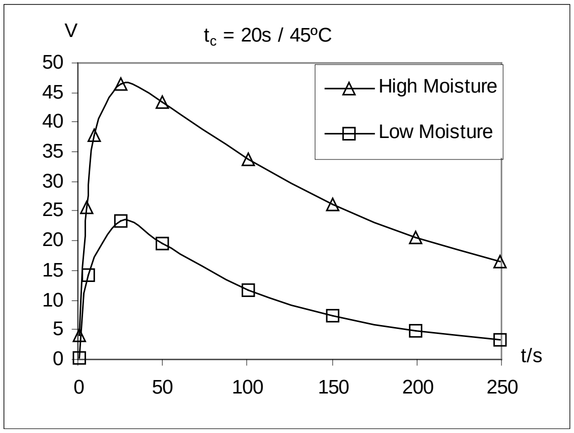

Fig. 7: Recovery voltage of dry pressboard with same geometry as Sample A

Sample B

The recovery voltage and polarisation current of flat disk sample lead us to suspect that the recovery voltage of oil-paper is actually dominated by charge transfer between electrode and the surface of paper. Therefore a sample with rim around the circumference of the disk is used. The rim around the edge disruptes the smooth path of electric field and electrical charge along the surface of paper. Therefore if charge transfer is the dominating factor this different geometry should results in different recovery voltage measurements. Comparing the measured voltage in Fig. 8 and Fig. 6, the differences are significant indeed. The peak voltage increases at least five folds and there is noticeable increase of time to reach peak recovery voltage at all temperatures. The polarisation spectrum in Fig. 9 shows a general trend of reducing recovery voltage at higher temperatures. Reducing the moisture level of insulating oil has little impact on faster responses but increases the responses from 100s to 1000s depending on the temperature. These observations generally agree with the findings in [4] and suggest that the fast response is related to charge transfer between the electrode and paper surface while the slower response is related to charge transport along the surface of paper.

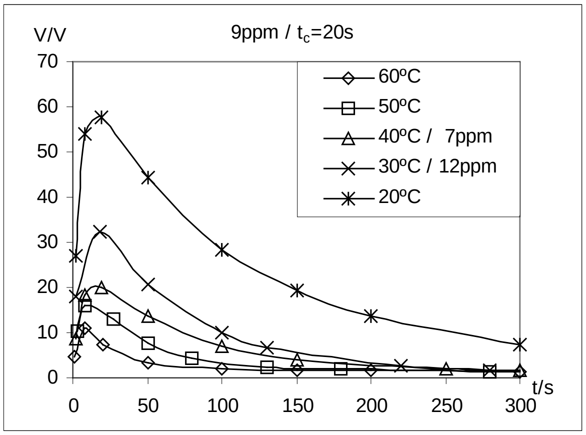

Fig. 8: Recovery voltage at various temperatures (Sample B)

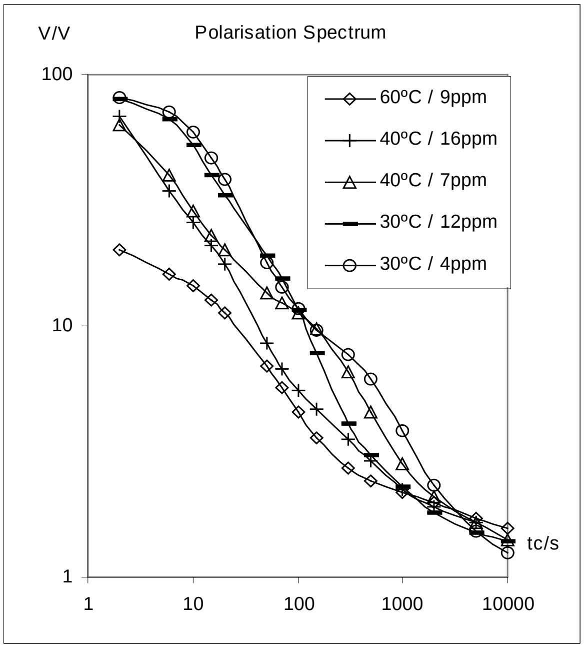

Fig. 9: Polarisation spectrum of Sample B

Sample C

Considering the impact of sample geometry to its recovery voltage as shown above it is interesting to find out what the recovery voltage would be like if the electrode is enclosed by insulation so that the charge transfer between electrodes is very difficult. This is the situation of the core of high voltage transformers. However there is a big hole at the top of the sample to enable reasonable moisture exchange between the insulating oil inside and outside of the pressboard sample. Fig. 10 shows a series of recovery voltage measured at different temperatures. The effect of different measurement temperatures is no longer as simple as in Sample A and Sample B.

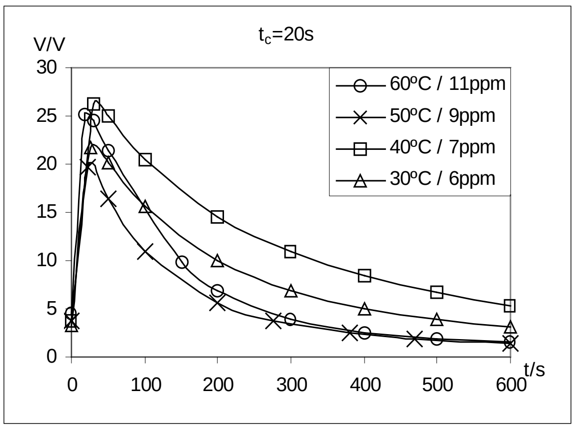

Fig. 10:Recovery voltage at various temperatures (Sample C)

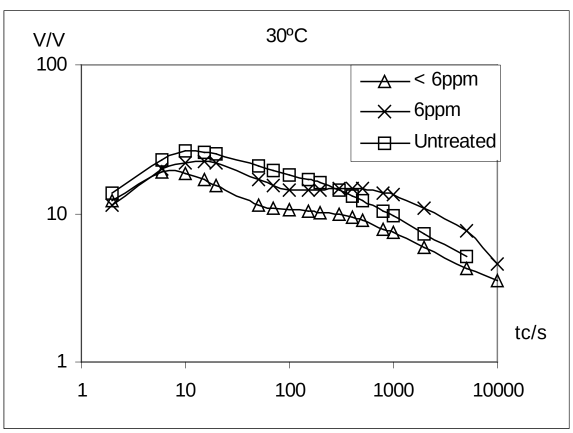

Fig. 11: Polarisation spectrum of Sample C

The polarisation spectrum of Sample C (Fig. 11) shows that the peak voltage of shorter charging time is lower compare to those of Sample B but the peak voltage at longer charging time becomes comparable in magnitude. Like temperature, the effect of different moisture levels to the recovery voltage is becoming more complicated as in Fig. 11. At first, the recovery voltage of longer charging time increases as the moisture level drops. This is followed by overall drop of recovery voltage as the moisture level drops further.

Ageing

Recovery voltage of aged samples are also measured. The preliminary results show that the recovery voltage is only significantly affected if the surface of paper is burnt or badly degraded oil left in the sample. Samples aged in vacuum where degraded oil is removed (along with moisture) show the response of new sample at very low moisture level.

CONCLUSION

The physical process responsible for the formation of recovery voltage in oil-paper insulation is found to be heavily dependent on the geometry of insulation and the surface condition of the paper. No evidence of significant bulk polarisation is found in this series of experiments. The bulk polarisation model of recovery voltage implemented by linear parallel RC-circuit cannot explain the observed variation of recovery voltage due to different sample geometries. The applicability of such model to the recovery voltage measurements of power transformers may be just a coincidence as the insulations are designed to discourage charge transfer between core and earthed parts.

ACKNOWLEDGEMENT

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