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배전변압기용 절연지의 전기적 특성

Electrical Characteristics of Insulation Paper for Distribution Transformers

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Abstract

This paper describes the electrical characteristics of Nomex paper employed as an insulating material of distribution transformers.

The relative permittivities(dielectric constants) and tanδ (dielectric dissipation factors) were measured as a dielectric characteristic and the partial discharge inception voltages(PDIVs) and breakdown voltages were also measured as an electrical strength characteristic of Nomex paper.

As a result, the permittivity and tanδ of Nomex paper showed temperature and frequency dependency. Especially, the permittivity of 0.18㎜ Nomex paper was 2.4 according to the ASTM condition. And the PDIVs and breakdown voltages were almost linearly increased with the thickness of Nomex paper and its electrical strength was better than conventional kraft paper.

Key Wards : Nomex paper, permittivity, tanδ, partial discharge inception voltage, breakdown voltage

1. Introduction

Nowadays, the transformer plays an important role in power systems. When it encounters a failure, which negatively and severely affects the power systems because economical loss and social confusion are unavoidable. Age related failures of transformers are generally due to the insulation failing electrically or because "structural" weakness predisposes it to other failure mechanisms[1], and the insulation failing is caused by the electrical strength reduction due to the electrical stresses which continuously or transiently act on the insulating materials. In case of conventional oil transformers, the insulating materials belonging to a cellulose family is used for the insulating parts such as jackets of conductors, spacers and barriers because of the cost and the limits of temperature rise of the transformers. However, when the operating temperature is over 120℃, the ageing is rapidly progressed because thermal strength of 105℃ class insulator is not good. Water is generated in process of insulator ageing, which makes the electrical strength of transformers weak and ultimately the withstand strength to the short circuit force of transformers is getting reduced. Considering that the temperature at hot spot during the short-term overload is mostly over 12 0℃, the ageing of the insulating materials is prevented by substituting aramid insulators for conventional cellulose insulators, which ultimately increases the transformer capacity. Nomex fibre is

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a kind of synthetic fibre of high thermal endurance, which was firstly researched successfully by DuPont Company in the sixties[2]. Aromatic Polyamide(aramid : generic name:Nomex) is employed as an insulator for 220℃ class since its ingredient is so stable. Nomex insulator does not make water or toxic gas in process of its ageing in mineral oil. Nomex is produced by the condensation of *meta*-phenylenediamine($H_2NC_6H_4NH_2$) and isophthaloyl chloride($ClCOC_6H_4COCl$), and composed of fibrid-combined molecular of fine fibre- to raise the electrical strength and floc-single fibre- to improve the mechanical strength. Fig. 1 shows the structural formula of Nomex aramid fibre.

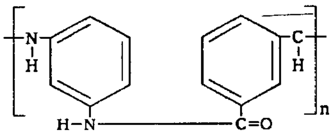


Fig. 1 Structural formula of Nomex aramid fibre (poly-*meta*-phenylenediamine-isophthalamide)

Since Nomex paper is differently selected by manufacturers according to the rating capacity and the application of the transformers, various kinds of performance test are strongly required to ensure the reliability of the produced transformers.

Therefore, we measured the Nomex paper's dielectric characteristics with temperature and frequency and electrical characteristics with its thickness in order to utilize them as fundamental data in designing and manufacturing transformers.

2. Experimental

2.1 Specimen

In the electrical strength characteristic test, three sheets of Nomex paper with different thickness tabulated in Table 1 were selected to find out the increasing trend of PDIV and breakdown voltage. Physical properties, provided by a manufacturer, for each specimen thickness are shown in Table 1.

Table 1 Physical properties of Nomex 410

thickness[mm]	0.13	0.18	0.25
weight[g/m²]	115.3	172.9	247.5

2.2 Dielectric characteristic test

WinDETA(Novocontrol Ltd.) was used to analyze the dielectric characteristics of the Nomex paper with three different thickness. Fig. 2 shows the schematic of the experimental apparatus.

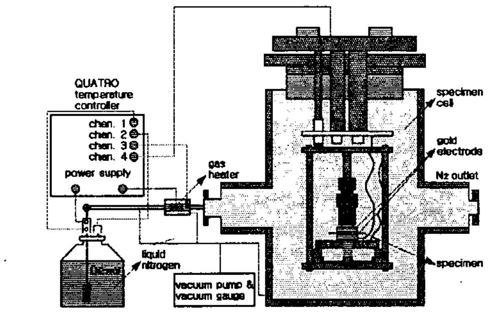


Fig. 2 Schematic of the experimental apparatus

As shown in Fig. 2, each specimen was placed between the upper gold electrode and lower one in the specimen cell. The electrodes was 20mm in diameter.

Temperature and frequency were taken as the experimental variables to the specimen. Temperature was increased from -50℃ to 250℃ at every thermal step of 2℃. The permittivity and tan δ to each frequency between 0.109Hz and 3MHz were measured at each temperature within error bound of ±0.5℃ and only their typical values of interest were plotted on the graph.

2.3 Electrical strength characteristic test

To measure the PDIVs and breakdown voltages for each thickness of Nomex paper, an experimental set-up shown in Fig. 2 was arranged.

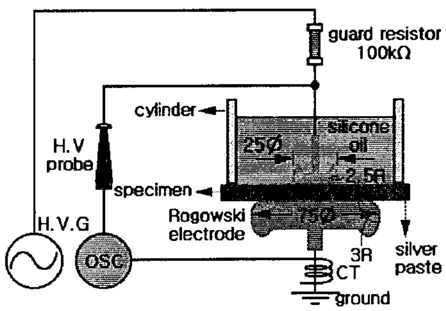


Fig. 3 Schematic of the experimental arrangement

As shown in Fig. 3, to measure the electrical strength, each thickness of Nomex paper was sheared by 100㎜ in diameter, and it was stuck on the bottom of the transparent short cylinder. And the bottom surface of Nomex paper was painted with silver paste. This specimen set was arranged on the lower plain stainless Rogowski electrode of 75㎜ in diameter and edge-rounded by 3㎜ in radius. The upper plain stainless Rogowski electrode(about 600g) of 25㎜ in diameter and edge-rounded by 2.5㎜ in radius was put on the Nomex paper. And then the upper electrode was impregnated in silicone oil. The upper electrode was connected to a high voltage generator(H.V.G) through a guard resistor and the lower electrode was grounded. The 100㏀ guard resistor was inserted in series to the specimen in order to protect the H.V.G from the impulse current and voltage at breakdown of the specimen. A high voltage probe(1,000:1) was installed in parallel to the specimen in order to measure the applied voltage, and a current transformer(CT : 1,000:1) was set around the grounding conductor in order to detect the partial discharge. With increasing the applied voltage at the rate of 0.5kV/s, we measured the PDIV and the breakdown voltage, repeated the measurement ten times and plotted maximum, minimum and average values on graphs[3][4][5][6][7].

3. Results and discussion

3.1 Permittivity of Nomex with temperature and frequency

With increasing temperature and frequency, we measured the permittivity of Nomex paper. Fig. 4 shows the results.

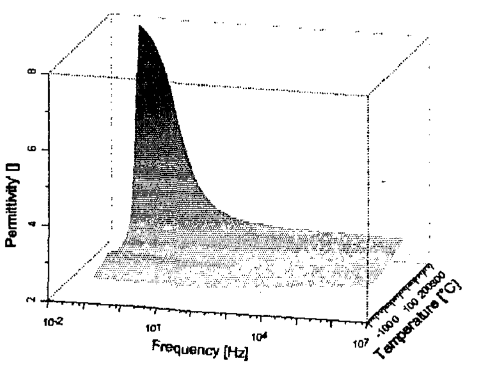
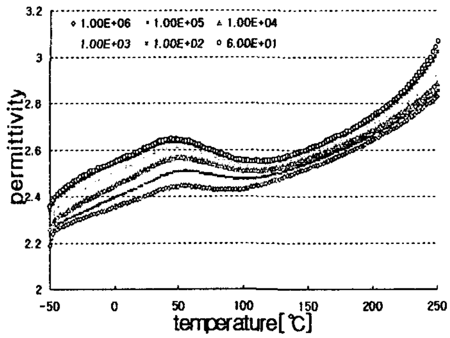
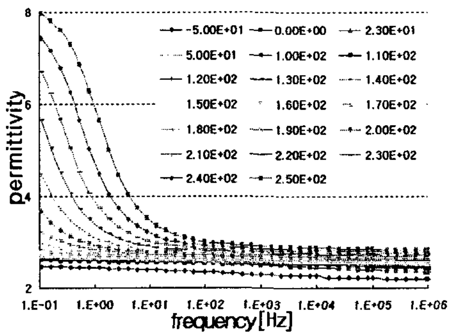


Fig. 4 Permittivity with temperature and frequency

As shown in Fig. 4, the permittivity of Nomex paper was increased with temperature and decreased with frequency. ASTM refers readers to the permittivity measured at 23℃, 1㎒, and the permittivity of 0.18㎜ Nomex paper was 2.4 to the standard. To understand the Fig. above easy, it was divided into the permittivies in temperature and frequency domain and Fig. 5(a), (b) show each of them, respectively.



(a) temperature domain



(b) frequency domain

Fig. 5 Permittivity with temperature and frequency

As shown in Fig. 5(a), (b), the permittivity between -50℃ and 220℃ varied about 2.19 to 2.83 at all frequencies. Over 220℃, however, the permittivity was exponentially increased in low frequencies less than 100㎐. Furthermore, as shown in Fig. 5(b), the permittivity was decreased with frequency, and this is considered because several kinds of dielectric polarization is superposed. In the same Fig., dielectric dispersion that the permittivity outstandingly varies was observed in the range of high temperature over 220℃, low frequency below 100Hz. Like this, the dispersion appeared by space charge polarization in the range of electrical frequency below 10^{12}Hz is so called 'relaxant dispersion' come from the molecular collision or the constraint subject to the surrounding molecules[8]. In this case, the permittivity with frequency moves from the constant high value in low frequency domain to constant low value in high frequency domain and no peaks are shown up on the permittivity curve. The dielectric loss factor in this case will be abruptly increased and decreased in the frequency range around 10Hz at which the permittivity is dispersed, thus will have a peak on the dielectric absorption curve.

3.2 tanδ of Nomex with temperature and frequency

With increasing temperature and frequency, we measured the tanδ of Nomex paper. Fig. 6 shows the results.

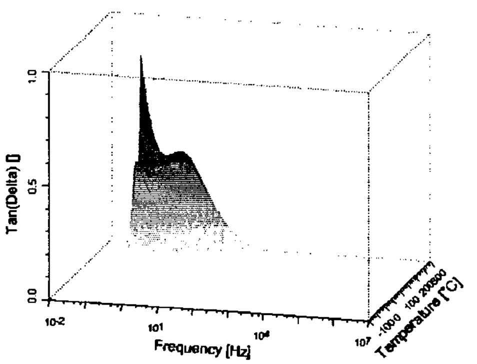


Fig. 6 tanδ with temperature and frequency

As shown in Fig. 6, the tanδ of Nomex paper was irregularly varied with temperature and frequency. Taking the depressing region out of interest, however, it generally tended to be increased with temperature and to be decreased with frequency. In Fig. 6, the tanδ for each frequency in temperature domain is shown in Fig. 7.

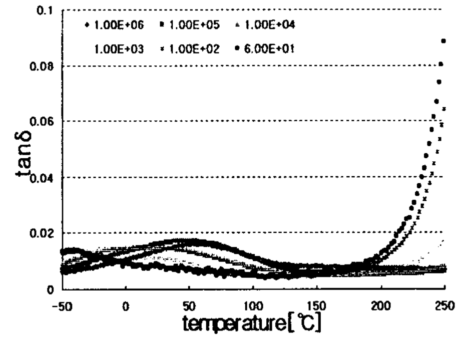


Fig. 7 tanδ for each frequency in temperature domain

As shown in Fig. 7, the tanδ of Nomex paper at low frequency tended to be shifted left with frequency in the temperature range below 180℃ and suddenly increased over 180℃. Particularly in this case, even tanδ at 1,000Hz began to be increased over 220℃. These phenomena showed that the tanδ curve in the low frequency range is shifted to the lower temperature region.

3.3 Electrical strength characteristics of Nomex

With increasing the applied voltage at the rate of 0.5kV/s, we measured the PDIV of each thickness of Nomex paper. Fig. 8 shows the results.

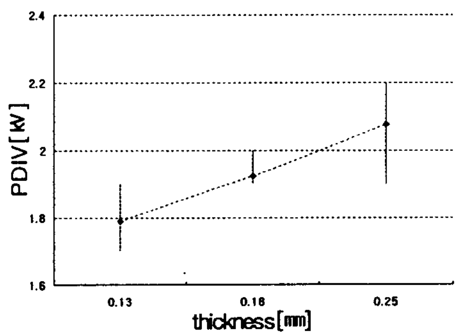


Fig. 8 PDIV with thickness

As shown in Fig. 8, the partial discharge of 0.13mm thick Nomex paper was first observed at 1.79$kV_{ave.}$ and the increasing rate with thickness was about 2.375kV/mm.

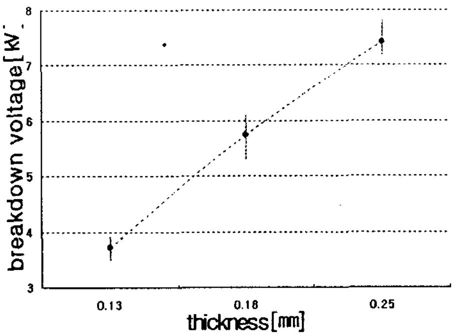


Fig. 9 Breakdown voltage with thickness

As shown in Fig. 9, the breakdown voltage of 0.13㎜ thick Nomex paper was $3.725kV_{ave.}$ and increased with thickness at the rate of about 30.83 kV/㎜.

4. Conclusions

We measured the dielectric and electrical strength characteristics of Nomex paper. As a result, this paper concludes as follows;

(1) The permittivity of Nomex paper was increased with temperature and decreased with frequency. Especially, the permittivity of 0.18㎜ Nomex paper was 2.4 according to the ASTM condition.

(2) Dielectric dispersion that the permittivity outstandingly varies was observed in the range of high temperature over 220℃, low frequency below 100Hz.

(3) Nomex paper's tan δ generally tended to be increased with temperature and to be decreased with frequency. And the tan δ curve in the low frequency range is shifted to the lower temperature region.

(4) The partial discharge of 0.13㎜ thick Nomex paper was first observed at $1.79kV_{ave.}$ and the increasing rate with thickness was about 2.375 kV/㎜. In addition, the breakdown voltage of Nomex paper was $3.725kV_{ave.}$ and increased with thickness at the rate of about 30.83kV/㎜.

We measured the dielectric and electrical strength characteristics of Nomex paper in order to provide the fundamental data which can be utilized in transformer design and manufacture. It was not easy to get aged Nomex paper because it has recently introduced into transformers. Therefore, further studies on the aged specimen are required.

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