IMPROVEMENTS TO THE PFN CAPACITORS FOR THE KLYSTRON MODULATORS OF THE KEK 2.5-GeV LINAC

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Abstract

Some of the capacitors in the pulse-forming network (PFN: 20 sections) of 48 klystrons in the KEK 2.5-GeV linac had begun to break down since 1986. Since there is no difference regarding the operating conditions between breakdown and normal capacitors, the breakdown seems to be due to individual capacitors. Careful investigations of the breakdown are continuing. Along with these investigations, life-span tests have been performed in order to evaluate newly designed capacitors. From these results, about 700 new-type capacitors have already been fabricated and installed in the klystron modulators.

Introduction

In the KEK 2.5-GeV linac, 48 klystron modulators are supplying pulses of 22.5 kV peak voltage, 3600 A peak current and 3.5 μs pulse width for 30-MW klystrons. The output pulse waveform contains a wide frequency band ranging from dc to ~10 MHz. The pulsed power is formed by a pulse-forming network (PFN) which comprises 20 LC sections.

Since the PFN capacitors are used under severe conditions, compared with normal power capacitors, careful attention has been paid to the long-term variation of their characteristics: tanδ as well as the insulation resistance and capacitance of all the PFN capacitors have been measured periodically every year since 1982 when the PF linac operation started.

Figure 1 shows the tanδ data (the maximum,minimum,and average values of twenty capacitors of each modulator) measured in 1987. We can divide all of the capacitors into two groups in terms of the large difference in the measured values. In one group (group 1 in Table I), they exhibit a great increment of tanδ. The intial value of tanδ was 0.01 % on the average. In the other group (group 2 in Table I), they exhibit no deterioration. Some capacitors in the former group had begun to break down since 1986. No latter group capacitors have broken down up to now. Since all capacitors were fabricated to satisfy the same specifications and there is no difference among the applied voltages for the two groups, the breakdown seemed to be due to individual capacitors.

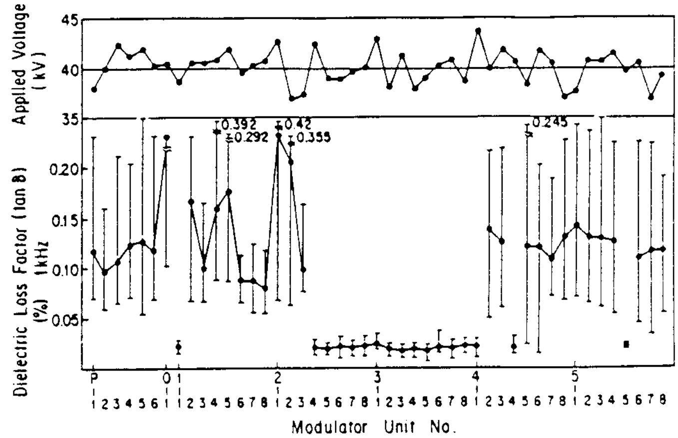

Fig. 1. The maximum, minimum and average tanδ values of twenty capacitors and the applied voltage for each modulator.

The number of breakdowns corresponds to 2.5 % of all capacitors. Once a breakdown occurs, it has great effect on linac operation. It was therefore necessary to solve this problem as soon as possible. In this report, outlines of the investigation of the breakdown and development of a new-type capacitor are described.

The Results of An Investigation Regarding Breakdown

The PFN capacitor has the following structure:[1] fifteen capacitor elements in series are oil immersed in a porcelain cylindrical insulator (see Fig. 2(a)). The dielectric of each element consists of a sheet of mica and two polypropylene films which are located just next to the electrodes (see Fig. 2(b)). To clarify the cause of breakdown, the same number of capacitors from both groups mentioned above were opened and investigated. Table I shows the characteristics of the samples. The following facts were found for both groups:

1. The insulating oil was not fully aromatic. (It is said that olefinic polymer (polypropylene) can

easily swell and hydrogen gas due to a corona discharge is not easy to be absorbed unless it is used in fully aromatic oil.)
2. The corona starting voltage (CSV) of elements is very close to the rated maximum voltage.
3. The value of the clamp ratio defined in Fig. 2(c) is very close to 100 %. This means that the insulating oil space between an electrode and the dielectric is very thin.
4. Line scratching along the electrode edge, resulting from corona discharge, was observed on the dielectric film , as shown in Fig.3.

Judging from these facts, it was found that the electrode-edge region of the dielectric had deteriorated owing to corona discharge in both groups. It also seems that swelling of polypropylene decreased the clamp ratio and ,consequently , the CSV of the capacitor elements.[2]) It is not known whether this deterioration of the dielectric is related to the breakdown , since no group-2 capacitors have broken down.

Although the cause of the breakdown is not clear, all of the capacitors in the KEK 2.5-GeV linac should be replaced with improved capacitors in order to prevent any further breakdowns from occurring.

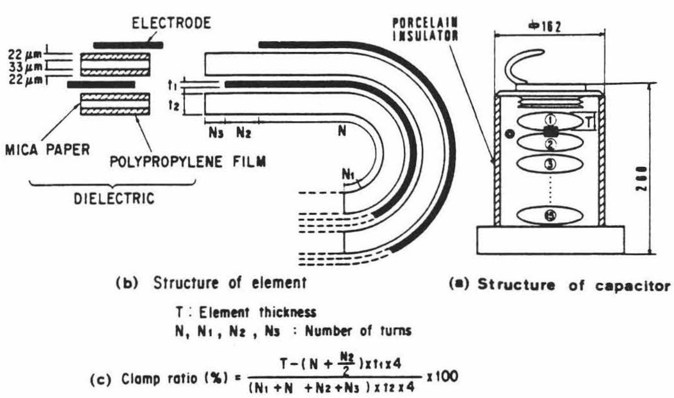

Fig. 2. The structure of capacitor and element,and the clamp ratio.

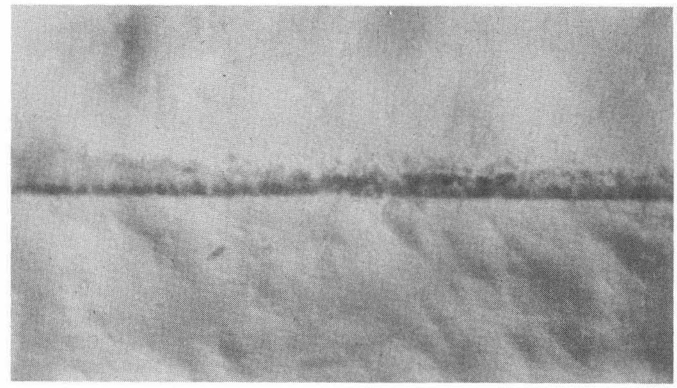

Fig. 3. Microphotograph (×65) of the dielectric film.Line scraching is marked along the electrode edge.

Life-Span Tests for A Newly Designed Capacitor

Life-span tests, in which a voltage higher than the rated maximum voltage (47 kV) was applied (but, of course, it was lower than the breakdown voltage), were performed at klystron modulators in the KEK 2.5-GeV linac in order to confirm new capacitor design. Two types of tests were designed. The first type (type-A) used mica as dielectric material and the second type (type-B) used low-density paper and polypropylene. For the type-A test capacitors (mica), three levels of electric-field strength (70, 110 and 140 V/μm) were applied, since mica has a large dielectric strength and is expensive compared with the dielectric of the type-B capacitors. For the type-B test capacitors (paper and polypropylene), three level fields around 60V/μm were applied according to the result of a preliminary test.

Table I
Characteristics of Sample Capacitors and Elements.

Group		1					2				
Sample NO.		1	2	3	4	5	6	7	8	9	10
Operation time ×1000 (hours)		14	14	13	21	21	16	25	25	25	25
Capacitor 1kHz tanδ (%)		0.57	0.18	0.19	0.11	0.09	0.03	0.02	0.02	0.03	0.03
Capacitor element	1kHz tanδ (%)	---	---	---	---	0.21	---	0.06	---	0.09	---
	60 Hz "	0.52	0.19	0.20	0.31	0.48	0.04	0.05	0.05	0.13	0.08
	CSV /Rating Voltage	1.1	1.2	1.2	1.1	1.0	0.9	1.2	1.1	1.2	1.1
	Clamp ratio (%)	---	---	---	97.5 ~102	97.2 ~101.5	---	98.9 ~103.5	98.1 ~106.6	100.9 ~103.3	96.7 ~105.6
	Average (%)	---	---	---	100.4	99.5	---	101.6	104.3	102	101.3
Insulating oil Tanδ (%)		0.28	0.94	1.29	0.84	0.58	2.5	2.2	1.5	1.2	1.3

In general, the shortest life-span(T) of practical operation can be estimated in terms of E,n,andT_0 by the euation:

$$T = T_0 \times E^n \quad . \qquad (1)$$

E: the ratio of the applied electric field strength of the test to the designed value.
n: the voltage acceleration coefficient.
T_0 : the shortest life span obtained by the test.

Figure 4 shows the dependence of the life-span for type-A test capacitors regarding the applied electric field strength. From this curve, an n of 13.1 was obtained by substituting E=1.57(the ratio of field level,110v/μm to 70v/μm),T_0=1.35 (life-span at field level,110v/μm),T=500(life-span at field level,70v/μm) in the eq.(1). The life-span test for the type-B test capacitors gave the shortest life -span of more than 2500 hours.

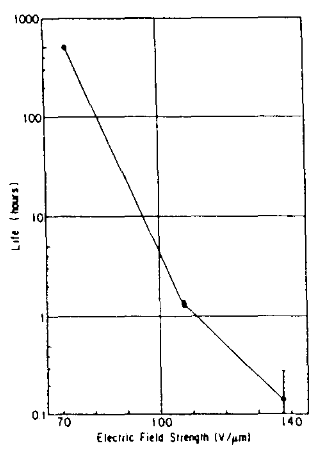

Fig.4. Life-span dependence of type-A capacitors on the applied electric-field strength.

The type-B capacitor was adopted as a new PFN capacitor. It was difficult to estimate the shortest life span of type-A capacitors owing to a lack of sufficient test data.

Though the tanδ value of the type-B capacitor is larger than that of old-type capacitor, there is no problem under our low-duty operating condition. By substituting E=1.5, n=15, T_0=2500 in eq. (1), the shortest life- span of a new PFN capacitor becomes more than one million hours, This value is sufficiently long to use them in the KEK 2.5-GeV linac.

From the result of this test, the new- type capacitors were fabricated and installed in the klystron modulators. Over 70 % of the PFN capacitors have been replaced by the new-type and successfully operated. Figure 5 shows the long-term variation of tanδ of both the new- and old-type capacitors. No deterioration of tanδ has been observed up to now.

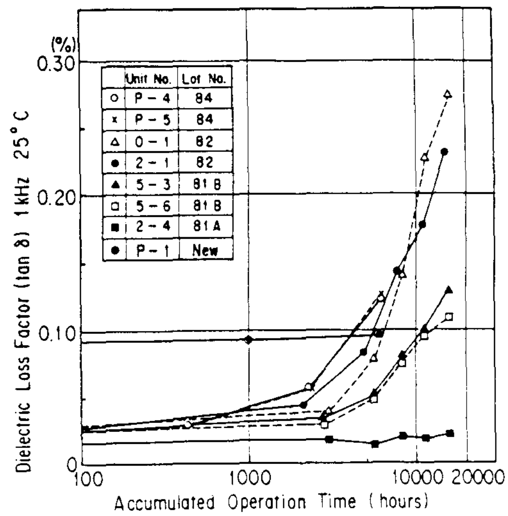

Fig. 5. Long-term variation of tanδ of both the new- and old-type capacitors.

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1. T. Shidara et al., "A pulse Forming Network with Specially Designed Capacitors for Klystron Modulators of The KEK 2.5-GeV Electron Linac", KEK Preprint 85-49, 1985.
2. R. J. Hopkins et al., "Development of Corona Measurements and Their Relation to the Dielectric Strength of Capacitors", AIEE Trans. Volume 70, 1643 (1951).