Conclusion

A wide-band partial-discharge detector has been presented, capable of measuring all of the observed discharge signals emerging from laboratory experiments and submarine cable power filters. For dc testing many specimens, the cost of a commercial amplitude-distribution analyzer attached to each specimen would be prohibitive. The combination of several detector circuits to form low-resolution analyzers appears to satisfy the function at a fraction of the cost.

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Voltage Endurance Test of Vacuum Insulation for Cryocables

J. JUCHNIEWICZ AND A. TYMAN

***Abstract*—Vacuum insulation with cylindrical ceramic spacer insulators has been studied with respect to changes of its ac flashover voltage with time. The distributions of times to failure, which were found to confirm Weibull's distribution, were used for plotting the regression curves for times up to 350 h. The results show that even at rather low stresses the flashover voltage decreased in time. This phenomenon is connected with the recorded deposition of metal particles from the electrodes on the surface of the spacers during the tests.**

This possibility of the decrease of the flashover voltage, induced by the deconditioning effects of contaminating conducting particles generated under the working stress by the system itself, must be taken into account when considering the suitableness of using special means of increasing the short-time flashover voltage of vacuum insulation for cryocables.

I. Introduction

One of the possible ways to meet the ever growing demand for underground transmission of electrical energy is the cryocables. To increase the transmitted power even these cables are expected to operate at high voltage. This in turn requires adequate high-voltage low-temperature insulation systems. One of the promising solutions looks to be the vacuum insulation. From the point of view of the cryocables its main advantage is that having good electrical properties it is simultaneously a good thermal insulation. Its main disadvantage is the necessity to use the spacer insulators greatly reducing the breakdown voltage of the system. Most of the ionic activity preceding and during breakdown takes place at the triple junction between metal, dielectric, and vacuum and along the dielectric surface.

The electrical properties of vacuum insulation with spacers are in general characterized by the highest flashover voltage (or withstand voltage) obtained after thorough conditioning. By analogy to the tests of solid dielectrics these voltages can be considered as short-time or instant voltages. This procedure is well grounded for the evaluation of the vacuum insulation designed to work at voltage stresses of short duration. As regards the cryocables where the voltage must be applied for a very long time the final valuation of the insulation depends on its long-time behavior in electrical field taking into account the eventual aging processes. The quality of such an insulation should be determined by the working stress which can be safely adopted.

If it is rather difficult to speak about the electrical aging of the vacuum itself the insertion of spacer insulators into the highly stressed region (the stresses here are much higher than those to be found in the insulators working in air) may bring with time the change of properties of the insulators leading to the reduction of the flashover voltage. Though Graneau [1], [2] has shown that flashovers in vacuum do not develop into short circuits nevertheless when the flashover voltage reaches the level of the system voltage the further working of the insulation would be impossible. The time-dependent decrease of the breakdown voltage of vacuum insulation with spacers was observed in earlier unpublished investigations made at the Technical University of Wroclaw. The deterioration of spacers was also signaled by others, for example, [1], [2]. In view of this the authors undertook tests whose aim was to estimate the

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intensity of the aging processes occurring under the influence of the ac electrical field in the vacuum insulation with spacer insulators. The obtained regression line, because of the rather short test times, should be considered as giving only general information on the trends of the changes of flashover voltage with time. No extrapolation to working stresses is yet possible.

II. Experimental Facilities and Techniques

The performance of vacuum insulation is known not to be much affected by the cryogenic cooling (in general, it slightly improves). Therefore, though the final aim of the investigated insulation was the use in cryocables it has been found useful to carry out the initial evaluation of the aging of spacers at room temperature.

The measurements were made in plane electrode system with cylindrical spacer insulators. The spacers (diameter 8 mm, height 5.7 mm) were made of special radioceramics selected in preliminary tests as the most stable material from the point of view of voltage endurance tests. Contrary to spacers made of various organic materials no visible erosion or tracking was noticed during the tests. The tested spacers were inserted between stainless-steel plane electrodes (diameter 35 mm) with the Rogowski profile. In order to make the statistical evaluation of the results possible the investigations had to be done on a greater number of samples. It was achieved by the use of a special high-voltage vacuum test arrangement in which tests of a set of 12 samples could be done simultaneously, Fig. 1. The test vessel made of stainless steel had a bushing insulator for voltages up to 80 kV and a glass window for optical observations. There were also high-voltage fuses provided for disconnecting samples on which flashover occurred and outside the vessel a recorder noting the times to flashovers. Magnetically operated shuntings cut off the fuses during the conditioning period. The test pressure was kept constant at 4.10^{-3} N/m^2. A liquid nitrogen trap separated the vacuum pumps from the test vessel. Both electrodes and spacers were thoroughly polished and cleaned. In this way efforts were made to simulate, but for the temperatures, the working conditions which can be expected in technical solutions of high-voltage vacuum insulation in cryocables.

Before the proper aging tests the samples were conditioned with shunted high-voltage fuses and 1-MΩ resistor in series. After conditioning, when the flashover voltage did not increase with the number of flashovers 20 additional measurements were made and the mean value of them was taken as short-time flashover voltage of a set of 12 samples. This voltage, depending on the set, was equal to ~ 40 kV whereas the conditioned flashover voltage of a single sample was equal to ~ 67 kV.

Thus determined short-time voltage of the system was used for defining the lower long-time test voltages. The series resistor and shunters of the fuses were then cut off and with the application of the ac test voltage the recorder was turned on. The test was continued until flashover occurred on all samples. With the test voltages ranging from 98 to 83 percent of short-time flashover voltage the longest recorded time to failure was equal to 350 h. The number of samples tested at each voltage ranged from 12 to 36.

In order to check what influence, if any, the possible migration of contaminants in the vacuum system could have on the decrease of the flashover voltage, parallel tests were made in which the voltage was switched off after conditioning. The flashover voltage was then measured after times equal to times of the voltage aging. No distinct change of the flashover voltage in relation to initial value was recorded.

III. Test Results

Proper interpretation of the results of aging tests is only possible when supported by suitable statistical descriptions. Very advantageous for the evaluation of aging tests of electrical insulation is known to be the Weibull's distribution. Thus proceeding to the statistical evaluation of aging tests of vacuum insulation with spacers it was necessary to check the applicability of Weibull's distribution also for this unconventional insulating system. Times to failure for the test voltages equal to 98, 96, 93, 90, 87, 85, and 83 percent of short-time voltage plotted in Weibull's charts gave single or broken straight lines. For the higher test voltages the results fulfilled the simple Weibull's distribution with the slope less than 1, Fig. 2, line A. For smaller voltages the results answered to complex distribution with the resultant slope greater than 1, Fig. 2, line B. These results confirm the usefulness of Weibull's distribution for the statistical description of aging also taking place in the investigated vacuum insulation.

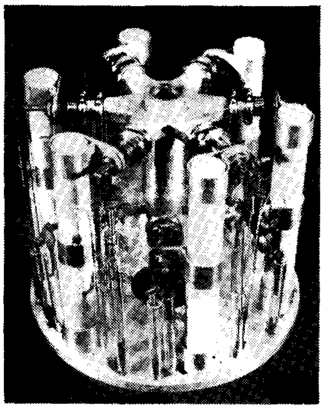

Fig. 1. Test arrangement with high-voltage fuses for simultaneous investigation of 12 samples.

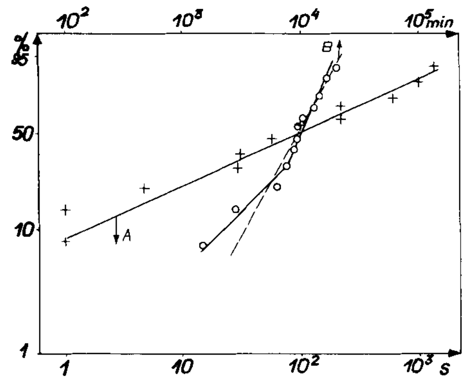

Fig. 2. Distribution of times to flashover for test voltages equal to the following.
A–96 percent of short-time flashover voltage.
B–83 percent of short-time flashover voltage.

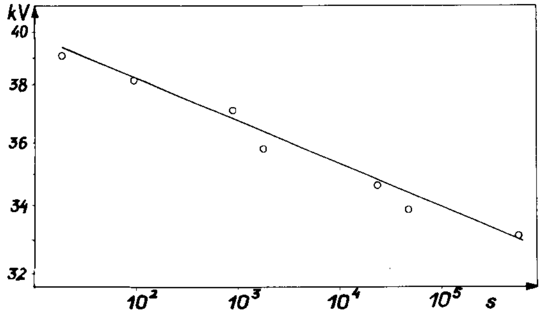

Fig. 3. Life curve (regression line) of the tested vacuum insulation with spacer insulators.

The median values of the distributions of the times to flashover at different voltages were used for plotting the life curve (regression line) of the tested insulation, Fig. 3. For complex distributions the median values corresponded to the resultant distributions.

Assuming the lifetime equation to be $t \cdot E^n$ = constant, the resultant exponent n for the investigated insulation was found to be equal to 55. The high value of n is most probably due rather to small test stresses imposed by the short-time flashover voltage of a set of 12 samples equal only to about 60 percent of the short-time flashover voltage of a single sample.

The quantitative and qualitative differences in the distribution of times to failure, Fig. 2, suggest that depending on test voltage the causes of failure are different. If at higher voltage the "weak points" of the insulation are deciding due, for instance, to not perfect conditioning, then with the lowering of the test voltage the aging phenomena begin to play an important part.

A spectrographic analysis of the surface of the spacers made after some time of voltage application showed the presence of metal particles not present there before the tests. These metal particles most probably deposited by the dark current and microdischarges [3]-[5] may enhance the local fields influencing the growing of surface space charges which in turn have been shown [6] to play an important part in the flashover in vacuum.

In this way the voltage and time-dependent process of deposition of metal particles originating from the electrodes on the surface of the spacer insulators can cause the aging of this insulation—the decrease of its flashover voltage with time—without any apparent structural changes of the material of the insulators.

The decrease of the flashover voltage with time is due in this case to the deconditioning effect of contaminating metal particles generated under the working conditions by the system itself.

IV. Conclusions

Vacuum insulation with spacer insulators has been proved to undergo aging changes diminishing the flashover voltage. Results obtained on cylindrical ceramic spacers have shown that at even low stresses—the mean stresses were < 7 kV/mm—the flashover voltage decreased in time. This decrease of the flashover voltage is thought to be induced by the deconditioning effects of conducting particles generated under the working stress from the electrodes settling on the surface of the spacer insulators.

Though the deterioration rate is rather slow the high exponent n of the regression line means that the occurring phenomena are very voltage dependent. Therefore, any attempt to increase the short-time flashover voltage of the vacuum insulation with spacers by the way of, for example, sophisticated conditioning or modification of the triple junctions, not taking account of this voltage aging, may be illusive from the point of view of long-time properties of this insulation in cryocables.

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