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Fault detection in the manufacturing process of form-wound coils by means of dissipation factor and hipot tests

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1. Introduction

High voltage electric motors and generators are essential components of the electrical power systems since their perfect operation determines the quality of power supply. Moreover, faults affecting these machines are usually serious for the electrical facility and the production process in which they are involved. Insulation faults are the most critical breakdown on electrical rotating machines. This reason makes the prevention of insulation faults on the stator windings of rotating machinery an important goal to improve the quality of electrical power systems. To achieve such an improvement two different tasks must be carried out: on the one hand, periodical revision of the insulation systems must be performed. On the other hand, a precise and reliable quality control must be applied to the coils manufacturing process in order to prevent manufacturing defects that could lead to a latter insulation fault. This quality control is carried out by means of tests similar to those ones used in periodical maintenance [1]. This paper presents a study about the effectiveness of some of these test procedures in the detection of manufacturing defects.

2. Form-wound coils

Medium voltage rotating machines have stator windings made up of form-wound coils. Each coil has two or three different insulation components, but the main insulation is the groundwall, which must be capable of operating at the rated voltage of the motor. Asymmetries, irregularities or defects may appear in the coils during the manufacturing process. In order to detect these problems, several tests are available in the industry [1], but two of them are especially used: dissipation factor test and hipot test. These two tests will be used in the present study to check their ability to detect failures in the manufacturing process of form-wound coils.
For this purpose, twelve coils were manufactured in two different ways, in order to obtain a group of four healthy coils and a group of eight faulty coils. In both cases, coils were built according to a resin rich process and to the specifications of a 5 kV, 5 MW motor. The difference between healthy and faulty coils is due to the manufacturing process that, in the latter case, is intentionally done with a faulty impregnated tape (not enough resin) which causes a lack of compaction in the groundwall insulation.

3. Test procedures

All coils manufactured for this study were built according to the specifications explained in point 2 and they were tested with dissipation factor tip-up and hipot tests.
The dissipation factor test was performed by increasing voltage from 0 V to Un kV (Un being the rated phase-to-phase voltage of the coil) in 0.2·Un steps [2, 3]; i.e. 1 kV, 2 kV, 3 kV, 4 kV and 5 kV. For each voltage, dissipation factor value is recorded. The parameters and acceptance levels used for diagnosis were the following:

Parameter	$\mathrm{tg}\,\delta_{0.2}$	$\frac{1}{2}(\mathrm{tg}\,\delta_{0.6} - \mathrm{tg}\,\delta_{0.2})$	$\Delta\,\mathrm{tg}\,\delta$	tip-up
Value	$300\cdot10^{-4}$	$25\cdot10^{-4}$	$30\cdot10^{-4}$	$50\cdot10^{-4}$

Every coil was subjected to an AC hipot test after a dissipation factor test. Hipot test consisted of a quick voltage increase to their maximum test value keeping it on this status during 1 minute. After this period voltage was quickly decreased to 0. Since this is a go no-go test, the only result after performing it is a coil without or with a puncture in the groundwall. The maximum test voltage was 11 kV.

4. Results and conclusions

Tables I and II show the results achieved in dissipation factor and hipot tests. From these data, values of the parameters selected for diagnosis were obtained and analysed. To carry out the study the complete set of coils was split up into three groups:

1) A group of completely healthy coils (Group G) which showed a good behaviour during the tests (Fig. 1).

2) A group of faulty coils (Group B) which did not clearly pass the acceptance levels (Fig. 2).

3) A group of *pseudo*-healthy coils (Group P): the rest of the faulty coils. Despite the fact that they were actually faulty coils due to the flawed tape used, they passed the acceptance levels during the tests (Fig. 3).

TABLE I. – Dissipation factor values (x 10^{-4})

#COIL	$tg\delta_{0.2}$	$tg\delta_{0.4}$	$tg\delta_{0.6}$	$tg\delta_{0.8}$	$tg\delta_{1}$
#1	70	70	71	77	86
#2	61	61	62	70	81
#3	60	61	61	67	80
#4	58	58	59	67	78
#5	71	72	73	86	103
#6	74	74	81	112	133
#7	70	71	86	129	148
#8	74	75	75	79	87
#9	65	66	72	89	140
#10	57	58	60	71	84
#11	60	60	61	67	78
#12	57	58	60	75	106

TABLE II. – Hipot test results

	#COIL											
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
Passed	X	X	X	X	X	X		X		X	X	X
Failed							X		X			

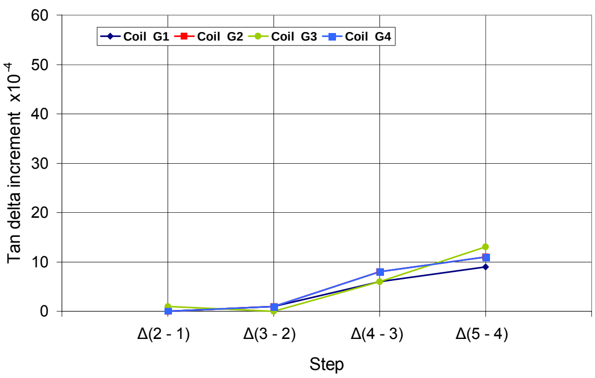

Fig. 1. Dissipation factor increments between two consecutive testing voltages. Coils from group G.

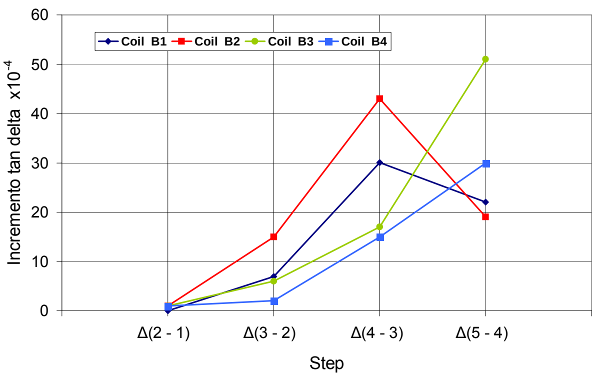

Fig. 2. Dissipation factor increments between two consecutive testing voltages. Coils from group B.

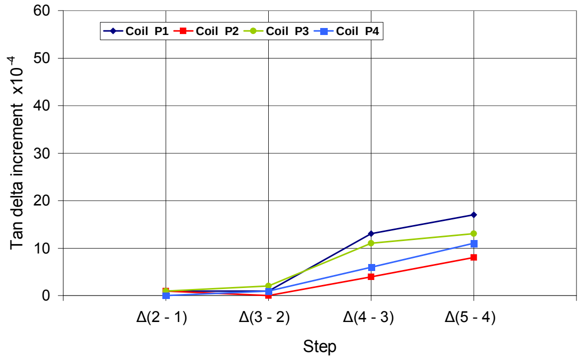

Fig. 3. Dissipation factor increments between two consecutive testing voltages. Coils from group P .

These results point out the difficulty for the detection of faults derived from the use of flawed tape in the wrapping process of form-wound coils with epoxy-mica insulation. The healthy coils, as they were supposed, showed a good behaviour during both tests. The values obtained of dissipation factor agreed with the commonly admitted criteria to accept a coil correctly manufactured.

The faulty coils showed a different behaviour during the tests and it was observed that another two groups of coils could be formed from them. The first one composed by coils which did not pass the acceptation criteria. Thus, as it was expected, these coils would be rejected for a reliable rewinding. The other group of faulty coils was formed by the coils whose test results were positive for dissipation factor and hipot tests. If these coils were intended for rewinding, they would be used without any restriction, since the tests did not reveal the actual condition of their insulating systems.

In this way, the insensitivity of dissipation factor and diagnosis parameters commonly used for the detection of faults in the groundwall of epoxy-mica insulating system has been demonstrated. In fact, in the analysed case (5 kV, 5 MW coils) variables and admissible values defined by the standards are not capable of correctly classifying the coils as healthy or faulty. This erroneous diagnosis is probably caused by the combination of dissipation factor tests insensitivity to taping flaws with the rated voltage and power of the studied coils that locate them in the lowest applicable limit defined by the standards.

For this reason the need of developing new diagnosis variables, limits for their values and or tests to correctly classify *pseudo*-healthy coils is clearly demonstrated. In this way, the possibility of rewinding or manufacturing a machine with coils that would reduce its useful life and, as a consequence, would limit its continuity in service would be drastically reduced.

References

[1] Greg C. Stone, Edward A. Boulter, Ian Culbert, Hussein Dhirani, Electrical Insulation for Rotating Machines, Wiley-IEEE Press, USA 2004. ISBN 0-471-44506-1.

[2] IEC 60894-1987, “Guide for a test procedure for the measurement of loss tangent of coils and bars for machine windings”

[3] EN 50209-1998, “Test of insulation of bars and coils of high-voltage machines”