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Perforation Of Insulation On Head Windings Of Low Voltage Motors

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***Abstract*—Insulation puncture on winding is a frequent failure of electrical motors.**

This consists of current shunt to ground which produces damage to the magnetic package and winding in a faulty zone, thus breaking the machine.

Therefore, it was decided to conduct research in order to understand the phenomenon and propose improvements to avoid such failure. First, we looked for a relationship between the voltage surges the machine suffers and the failure.

Then, we performed tests with different types of insulation, different construction conditions and state of the windings, in order to assess the value of the insulation resistance before and after the test.

It was concluded that voltage surge was not the cause of the insulation puncture. As a future step, we propose to look for possible relationships with other variables which may attack the integrity of the insulation of electric motors.

Keywords—Insulation puncture; electrical motors; voltage surges

I. INTRODUCTION

The Electrical Engineering Department wishes to give an orientation towards electrical machines (Transformers, DC motors and AC motors) because of the vast experience of some of the professors in this field, both in industry and in academia. When the research group was built, it was oriented toward the study of some phenomenology of failures that occur particularly on some devices.

In the industry, which is a great user of electrical machines, it was noticed that failures in AC motors (one of the most widely used machines) are produced most frequently on certain points of their internal structure, as it can be observed in Table I.

TABLE I. FAILURES ON ELECTRICAL MOTORS STATICS

BEARINGS	**41.00%**	**STATOR**	**44.00%**	**ROTOR**	**3.00%**
Ball bearing	16.00%	Ground Insulation	29.00%	Cage	2.00%
Bushing	8.00%	Winding Insulation	8.00%	axis	1.00%
Winding packaging	6.00%	Magnetic slot wedges	1.00%		
Thrust bearing	5.00%	Frame	1.00%		
Lubrication	3.00%	Magnetic Core	1.00%		
Others	3.00%	Others	4.00%		

Taking into account these data, it was decided to focus the research on the problems on slots insulation of low voltage machines (AC motor), in order to understand the origin of the phenomenon and suggest some possible improvement. The aim is to avoid this kind of failures and improve the machine's lifespan, therefore preventing the operative units affected from being taken out of service, with the resulting economic losses.

Given the characteristics of the failures that were studied, specifically, perforation on head windings, and considering the equipment available for the research group to carry out these experiences, a first test was designed to determine the breakdown voltage needed to perforate different kinds of insulations of different thickness by means of a series of static tests. The tests were performed on both windings with insulation in good condition, without any kind of mechanical (vibrations), thermal (overloads), electrical (overvoltage), or environmental (humidity pollution) decline, to state a relation between the voltage breakdown needed to perforate the insulation on test conditions and the ones present on normal operation of the machine.

II. Development Applied Voltage Test #1

A. *Objective*

The objective is to determine at what A.C. voltage level (50 Hz) the slots insulation gets perforated on the stator and where exactly it is produced.

a 50 Hz AC voltage was applied to each of the four windings between one of its ends and the frame's potential, with a transformer connected as shown in figure 1 (test circuit 1). The test was started at 0 V and the voltage was raised progressively with a Variac, on the low voltage side.

B. *Methodology*

An applied voltage test was conducted to the stator of a three-phase motor, of 1/2 HP, 380 V through a transformer of 13,200/110 V, supplied through its low voltage side using a Variac, in order to reach high voltages, over the nominal voltage of the machine.

Voltage was measured on the supply circuit with a multimeter, and a 2 A thermal-magnetic protection was inserted on the primary circuit, to protect the equipment from overcurrent.

The process is performed in order to detect evidence of electrical breakdowns, to the point of the activation of the switchgear aforementioned, as a result of the current increase when the electric arc is produced.

C. *Characteristics of the testing windings*

On the stator, four windings were winded with 1:4 coil pitch with 60 winding turns made of copper wire IMSA (Edflex) of a 0.7 mm diameter, without varnish, with four kinds of insulators, looking for evidence of the possible variations on the performance of the different types of insulators that are normally used in the design of electrical motors. Data is presented on Table II.

D. *Results*

During the test, it was observed that, because of the applied voltage between winding and magnetic core, the current did not perforate the insulation, but it travelled from the copper wire to the magnetic core of the packet of the stator. The test was repeated twice in each winding, and the results shown in tables III, IV, V and VI were obtained.

In all cases, at the moment before the electrical breakdown ozone was detected, as a first manifestation of the leakage produced by the application of the overvoltage

Insulation resistance was measured before and after the tests, for each winding, using a FLUKE megohmmeter, model 1550B, 500 DC voltages. The results are shown in Table VII

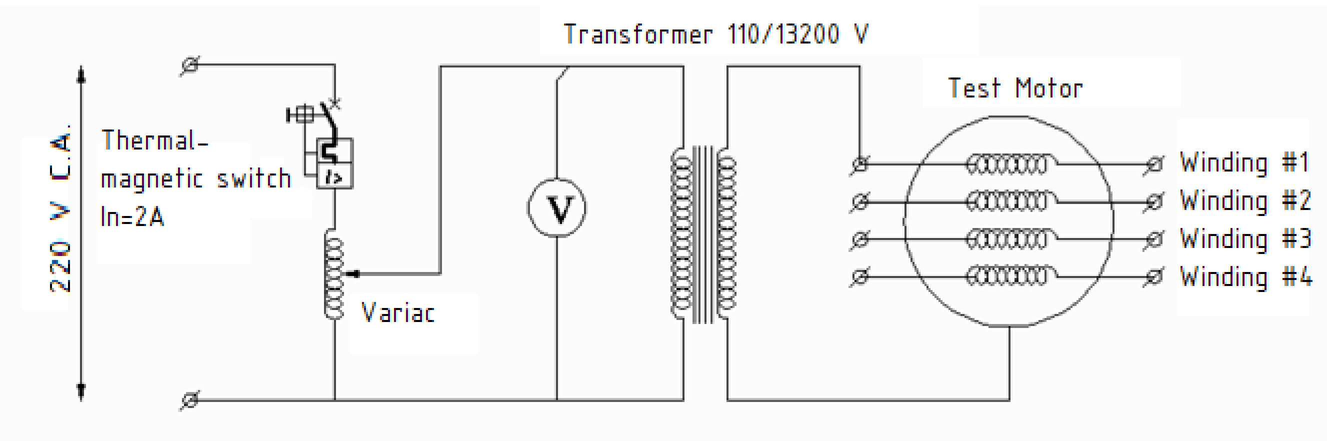

Fig. 1: Test circuit #1

TABLE II. CHARACTERISTICS OF TESTING WINDING

Number	Slot insulation	thickness	Spaghettis	Diameter
1	Nomex-Mylar-Nomex	0.24 mm	Alkyd glass	1 mm
2	Nomex-Mylar-Nomex	0.30 mm	Alkyd glass	1 mm
3	Mylar	0.19 mm	Varnished fabric	1 mm
4	Pressmyl	0.24 mm	Varnished fabric	1 mm

TABLE III. BREAKDOWN VOLTAGE WINDING 1 (0.24MM NOMEX-MYLAR-NOMEX)

Test	Voltage – LV side [VCA]	Voltage – HV side [AC] (real)
A	65.00	7800.0
B	65.70	7884.0
C	64.08	7689.6

TABLE IV. BREAKDOWN VOLTAGE WINDING 2 (0.30 MM NOMEX-MYLAR-NOMEX)

Test	Voltage – LV side [VCA]	Voltage – HV side [AC] (real)
A	67.70	8124.0
B	66.70	8004.0
C	65.73	7887.6

TABLE V. BREAKDOWN VOLTAGE WINDING 3 (0.19 MM MYLAR)

Test	Voltage – LV side [VCA]	Voltage – HV side [AC] (real)
A	61.64	7396.8
B	62.48	7497.6
C	60.44	7252.8

TABLE VI. BREAKDOWN VOLTAGE WINDING 4 (0.24 MM PRESMYL)

Test	Voltage – LV side [VCA]	Voltage – HV side [AC] (real)
A	62.95	7554.0
B	20.85	2502.0
C	10.24	1228.8

TABLE VII. INITIAL AND FINAL VALUES FOR INSULATION RESISTANCE OF THE WINDINGS

Winding	Initial insulation	Final insulation
1	>519 GΩ	>519 GΩ
2	>519 GΩ	>519 GΩ
3	>519 GΩ	>519 GΩ
4	>519 GΩ	3,10 KΩ (5 volt)

E. *Conclusions*

- Voltage values at which leakage to ground was produced are much higher than the nominal voltage of the motor, approximately 36 times higher.
- Overvoltage about that order is rare on low voltage circuits and its presence may damage other components of the circuit. Therefore, it is concluded that it is not the main cause of the phenomenon on study.
- Insulation materials with higher thermal class did not show deterioration even after three electrical breakdown events were reached by the application of very high voltages.

Only winding with organic insulation (cellulose) with less thermal class got more deteriorated with every overvoltage applied, unlike the others, as can be seen on table VI: Breakdown voltage Winding #4

As a next step, we decide to conduct applied voltage tests with varnished windings, to get closer to the operating conditions of the machine.

III. APPLIED VOLTAGE TEST #2

A. *Objective*

As the windings used in the applied tension test No. 1 were not varnished, an abnormal situation for a machine in service, it was proposed to make a winding in the stator of similar characteristics, varnished with impregnation varnish.

Given the very high voltages needed to obtain electrical breakdowns, it was proposed to measure leakage current to ground in order to observe its dependency on applied voltage and state a relationship between them.

B. *Characteristics of the testing winding*

Based on the previous suggestion, a winding was made with varnished wire, 0.7 mm of diameter, insulated with nomex-mylar-nomex of 0.24 mm width and varnished by dripping (thermal class F – 155 °C).

TABLE VIII. INSULATION RESISTANCE OF VARNISHED WINDING

Insulation resistance [GΩ]	Leakage current [mA]	Applied voltage time [min]
69	7.2	1
126	4.13	1.5
144	3.4	2
188	2.75	2.5
227	2.28	3
301	1.7	3.5
323	1.6	4
320	1.57	4.5
511	1	5
519	1	5.2

Before the test, both insulation resistances to ground on the winding and leakage current were measured using a FLUKE megohmmeter, model 1550B, during five minutes, at 500 DC voltage Results are shown on Table VIII:

C. *Methodology*

1) Leakage current measured on primary circuit with current clamp

A current clamp was used to measure the leakage current. To adapt the scale, the cable was turned five times on the primary circuit at the clamp sensor, in order to move the reading closer to full scale of the measuring instrument, and enable the measurement of low currents. The results can be appreciated on table IX:

Measures made on the proposed circuit (fig. 2) were affected by no-load current, therefore, it was considered necessary to measure its value at the different voltages used in order to discount it from the values obtained in the test.

Measuring no-load current with the proposed circuit, no coherent values were obtained because of the low accuracy of the measuring instruments used.

2) Leakage current measured on primary circuit with multimeter

After realizing that the current clamp used did not have enough accuracy on the value range for the currents present in the test, it was replaced with a multimeter with a milliameter connected in series, to the primary circuit of the transformer.

Two open-circuit tests were made placing a digital multimeter in series with the primary side of transformer; the results are shown on Table X.

Based on the data obtained with the multimeter, the values on the test made with the current clamp were discarded, and it was decided to repeat the leakage current test with a FLUKE multimeter, model 179, in series on the primary side. The results are shown on Table XI.

Voltage increased until 2940 V was reached, because current exceeded 200 mA, which is the full scale of the milliameter.

3) Leakage current measure on high voltage side with multimeter

TABLE IX. CURRENT MEASURED ON PRIMARY CIRCUIT WITH CURRENT CLAMP

Applied voltage	Primary Current	Observations
1200 V	20 mA	Nothing was noticed
1800 V	40 mA	Ozone and noise were perceived
2400 V	100 mA	Increase of ozone and noise
3000 V	180 mA	Same as previous, visible breakdowns were not appreciated
3600 V	240 mA	Same as previous
4200 V	340 mA	Visible breakdowns on head windings and slots

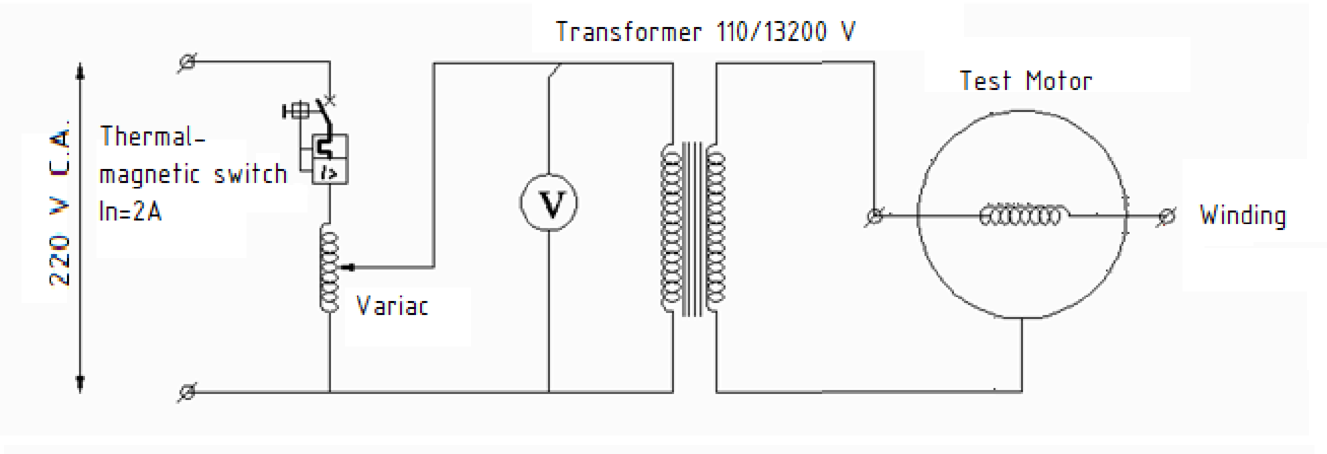

Fig. 2: Test circuit. Test #2

TABLE X. OPEN CIRCUIT TEST

Voltage	Open circuit current
1200V	20mA
4200V	50mA

TABLE XI. LEAKAGE CURRENT MEASURED ON PRIMARY CIRCUIT WITH FLUKE MULTIMETER

Voltage	Current
1200V	41.6mA
1800V	79mA
2400V	125 and 130mA
2940V	196 and 200mA

After introducing some changes to the test circuit, the milliameter was connected in series to the secondary of the transformer, (fig. 4).

D. Conclusions

We can see from fig. 3 to fig. 5 that leakage current, with respect to applied voltage, does not have a lineal dependency.

Observing the shape and taking into account the results of the experiences from test #1, it can be inferred that it has an exponential growth with a tangent on the voltage breakdown value, the one at which leakage current shoots up reaching high values, limited only by the impedance of the leakage path.

Law of variation between leakage current with respect to applied voltage could not be stated yet.

IV. EQUIPMENT USED

- CEGELEC transformer 13200/110 V; 400 VA, class 0.5, type UR22, #M5252
- VARIOSTAR Variac, 220/250 V, Imax. 8 Amp.
- FLUKE megohmmeter, model 1550B.
- FLUKE multimeter, model 179.

V. STATOR CHARACTERISTICS

A stator from a ½ HP was used, with the following characteristics:

- Number of slots: 24
- Voltage design: 380 V
- Number of windings: 4
- Number of coils on each winding: 60

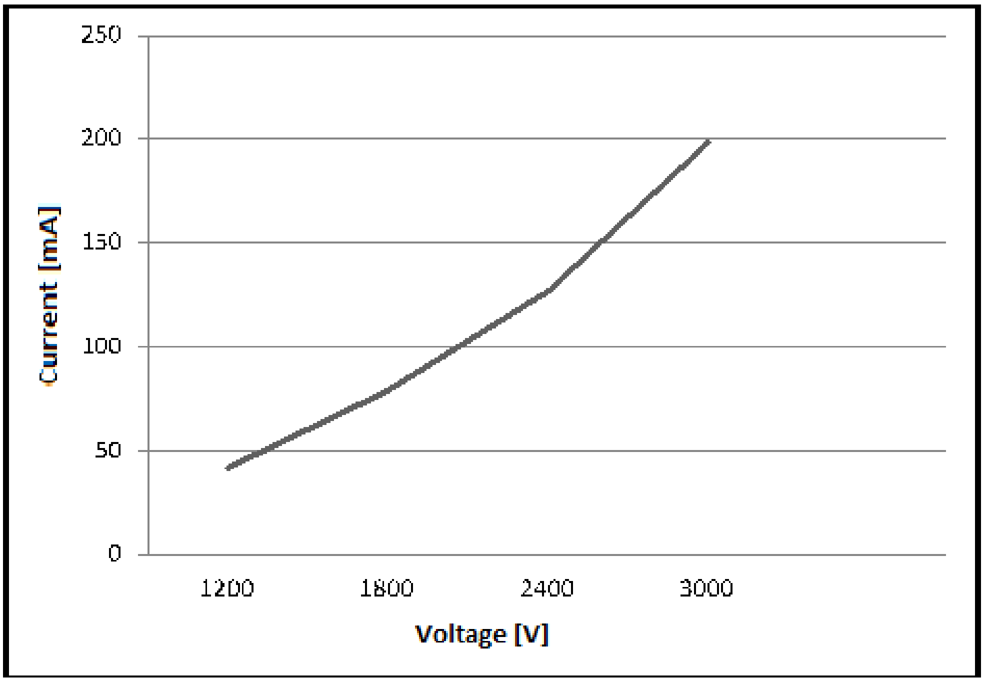

Fig. 3: Voltage vs current plot (L.V. side)

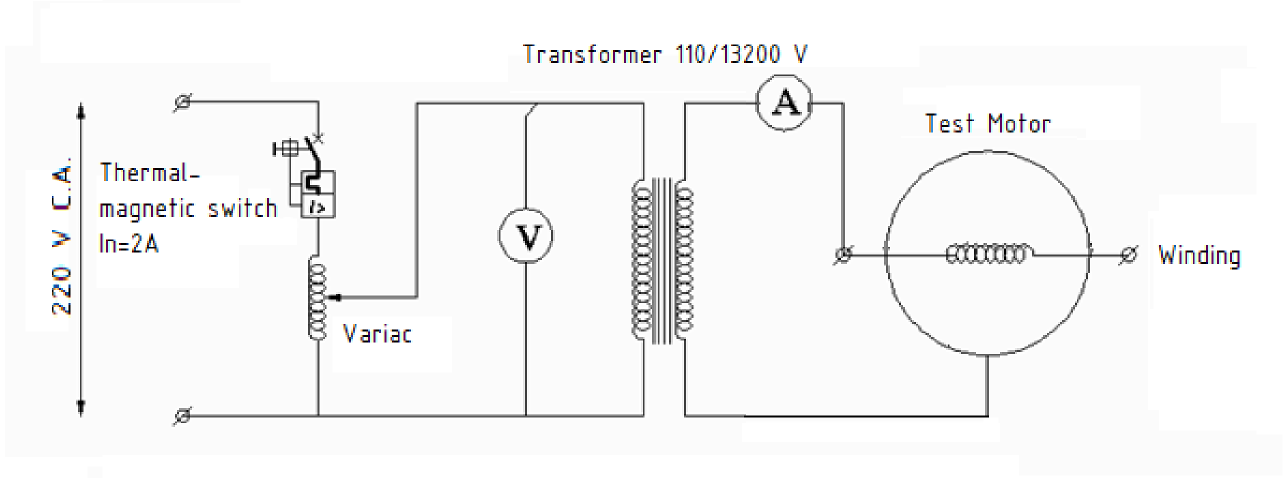

Fig.4: Test circuit. Measures on H.V. side

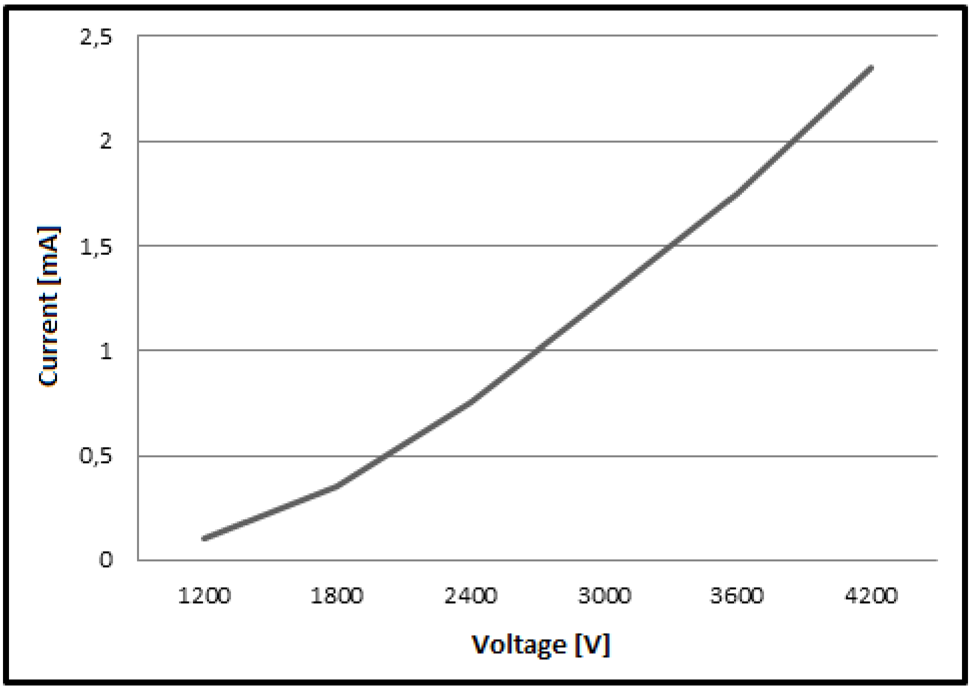

Fig. 5: Voltage vs current plot (L.V. side)

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