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The use of DC current to testing condition of the insulation of electrical machines

Abstract. *Condition diagnostic of turn-to-turn insulation, using the method of fuzzy wave is based on breaking the passage of current in the circuit with tested coil or winding what generate a voltage wave. This voltage is exactly the same on each turn. The frequency of generated voltage depends solely on the parameters of the winding and insulation, not on the parameters of supply. Described method is a supplement of diagnostic method of main insulation with DC voltage, named method of prof. Glinka*

Streszczenie. *W niniejszym artykule zaproponowano zastosowanie w diagnostyce układów elektroizolacyjnych maszyn elektrycznych metody rozmytej fali napięciowej, która stanowi uzupełnienie stosowanej od wielu lat kompleksowej oceny izolacji głównej metodą polaryzacyjną prądu stałego tzw. metodą T.Glinki. (**Badanie stanu technicznego izolacji maszyn elektrycznych metodami prądu stałego**)*

Keywords: *diagnostic , fuzzy wave,*
Słowa kluczowe: diagnostyka, izolacja, fala rozmyta.

Introduction

Most of insulation system's damages begin in insulation between turns, which lead to damage of main insulation - grounding or short–circuit between phases.

There are several methods to evaluate a technical condition of electrical machine's insulation. Those methods could be divided into two groups:

- On-line methods – for monitoring the technical condition of insulation all the time,
- Off-line methods – to test actual technical condition of insulation (once in longer period of time).

The on-line methods gave a possibility to reduce the time for reaction of user when the technical condition gets worse for example increase of leakage current or number of PD (Partial Discharge). Those methods need to place inside of machine (in windings) special sensors. It has to be done during production process for example testing on-line or off-line with PD method using very expensive and complicated testing equipment.

Complex and simply diagnostic method was developed to evaluate the technical condition of insulation. It may be used in industry without building a difficult measuring and testing equipment.

This new method is based on few diagnostic tests which use dc polarization method (prof. Glinka method) to evaluate the technical condition of main insulation and a fuzzy wave method to evaluate the technical condition of insulation between turns.

Evaluation of technical condition of main insulation.

There is a method promoted from many years in Poland, Czech and Slovakia. This is dc polarization method (prof. Glinka method). The method consists of three tests:

- designating the characteristic of R_{60}=f(U), if possible - range of voltage from 0 up to $2U_N$,
- characteristic of leakage current i_p after the nominal voltage is connected on the absolutely discharged winding,
- charging the winding to the nominal voltage, then disconnecting the source of voltage and fault to frame the capacitance of winding for the time t_z, and next opening the circuit and recording the characteristic of the voltage rebuilding on the insulation of the stator winding U_{od} *(t).*

First two procedures are universally used during inspection routine tests, since they are recommended in instruction manuals of electrical machines. However, the scope of these tests is usually limited to one voltage value (2500 V, 1000 V or 500 V).

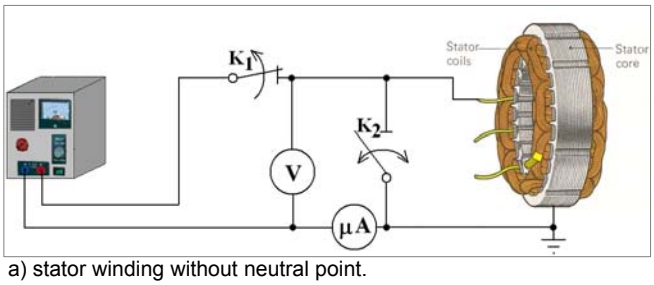
The recommended procedure covers entire characteristic R_{60} = f(U), if possible up to voltage equal to $2U_N$ and course of leakage current i_p = f(t) at U_N. The program of those tests is included in Polish Standard No. PN-E-04700 as additional test.

The third procedure is most important in assessment of insulation's technical condition and its degree of wear.

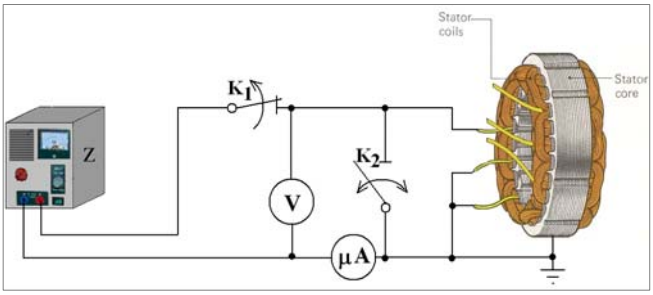
The tests are made in a circuit as shown on Fig.1. The basic elements of this circuit are:

- regulated DC supplier Z,
- micro ammeter □A,
- voltmeter V with high internal resistance (R_{in}>1T□),

switches K_1 and K_2 allowing the implementing of particular tests.



a) stator winding without neutral point.



b) stator winding with all (6) terminals.

Fig. 1. Schema of the measuring system for diagnostic of technical condition of main insulation.

On the basis of the measurements, the following characteristics and parameters of insulation are calculated:

- value of resistance R_{60} by the voltage U_N,
- absorbency index i_{p15}/i_{p60},
- the level of fluctuation of the leakage current i_{p60min} and i_{p60max} in the time over 60 sec from the moment of connecting the voltage,

- a chart of voltage rebuilding $U_{od}=f(t)$ on insulation which shows the time of rebuilding and the maximum value of the rebuilt voltage.

Many years of experience in diagnosing electrical machines windings insulation have helped the author to develop ranking system for evaluating insulation's technical condition [3].

Further increase of the popularity of the main insulation diagnostic method is due by:

- availability of measuring equipment necessary to perform measurements,
- short time of realization the measurements,
- clear interpretation of test results.

Table 1. Assessment of Electrical Machines Windings Insulation System Technical Conditions – Ranking System

Lp	Parameter of insulation		Insulation system rank					
			5	4	3	2	1	wet
1	Resistance R_{60N}/U_N [k□/V]	przy U_N = 6kV	>50	>20	>10	>10	>10	<3
		przy U_N < 1kV	>50	>20	>10	>3	>1	<1
2a	Short-circuit time t_z	dla U_N = 6kV	30	30	30	1	1	0
		dla U_N<6kV	10	10	10	1	0	0
2b	*Recovery voltage maximum value Uod max/Uo*		>0,1	□0,1	□0,05	□0,01	0	0
	Restoration voltage time t_{od} [s]	dla U_N =6kV	>240	>120	>30	~10	0	0
		dla U_N <1kV	>120	>60	>15	~5	0	0
3	*leakage current variation at UN* $\frac{i_{p60\max} - i_{p60\min}}{i_{p60\ śr}}$		<0,5	<1	>1	>1	>2	0
4	i_{p15}/i_{p60}	U_N =6kV	>1,5	>1,2	>1	1	1	1
		U_N < 1kV	>1,3	>1,1	>1	1	1	1

The method of fuzzy voltage wave.

The method of fuzzy voltage wave is a supplement of the method of DC voltage, which is used for many years to evaluate the insulation's technical condition. This method consists on generating voltage in the tested winding at the time of breaking the passage of DC current. This voltage is evenly distributed on each turn The frequency of generated voltage depends only on the parameters of the winding and insulation between turns, as described in [1] and [3].

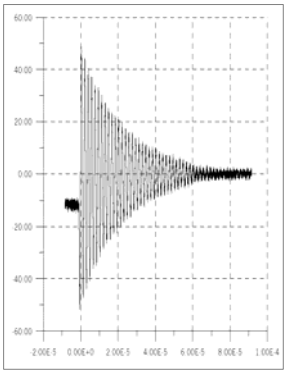
Brief description of the fuzzy voltage wave measurement method.

The proposed methodology of test is based on supplying tested circuit by the DC current, which value is between 5-10% of machine's nominal current. Each phase must be accessed separately, if possible, but each of measurements can be performed in the windings connected together, if disconnection is not possible.

The evaluation of insulation's technical condition is based on the following parameters:

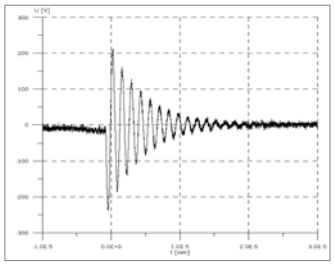
- the frequency of oscillation,
- the shape of voltage waveform at the terminals of the coil,
- logarithmic dumping decrement after breaking the current.

Figures 2 to 4 show registered voltage waveforms, that induced on terminals of coils, which conditions were different. The degree of suppression of the waveform was calculated by logarithmic decrement-Λ



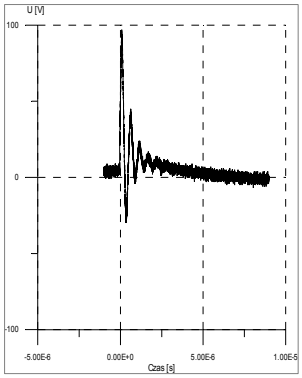
f=555kHz; Λ=0,11

Fig. 2. The voltage waveform on terminals of coil for motor type Sh355H2C, which is in good technical condition.



f=737,6kHz; Λ=0,35

Fig. 3. The voltage waveform on terminals of coil for motor type SZDVc198rE which is in bad technical condition.



f=1942.0kHz; Λ=0,55

Fig. 4. The voltage waveform on terminals of motor coil which insulation between turns is destroyed.

Condition determination of turn-to-turn insulation basing on results of tests.

Assessment of technical conditions of insulation between turns may be done to measurements performed on identical coils or the diagnosis may be done basing on the changes observed during a period of time.

Examples of measurements are presented in table 2.

Notice: Determined value of logarithmic decrement can transparently assess the level of voltage attenuation.

Realizing only one test, there is possible to find only completely destroyed insulation. In the case that insulation is in bad condition, determination of haw the condition is bad is impracticable. This is possible to note, comparing results of tests presented on figures 6 and 7.

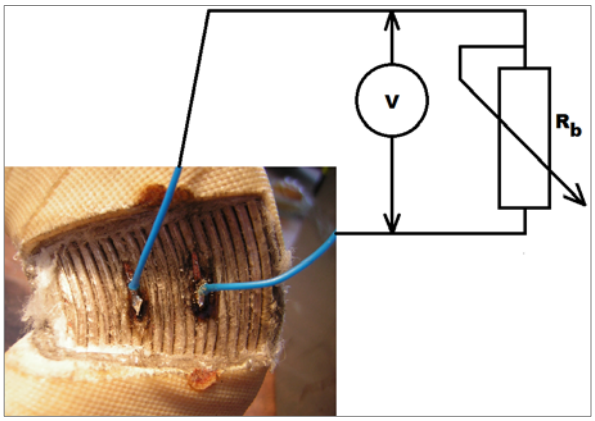
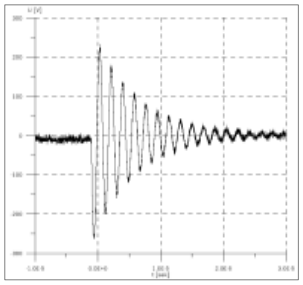


Fig. 5. Measuring circuit with coil – turn-to-turn insulation damage modeling.

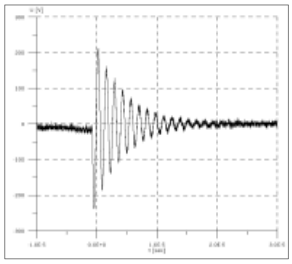
Table 2. Measurements of the frequency of voltage generated at different values of resistance RD.

No	R_D kΩ	f kHz	□
1	—	541	0,16
2	100000	598	0,18
3	10000	595	0,18
4	1000	586	0,20
5	100	588	0,19
6	10	587	0,21
7	<1	543	0,54



$f=541kHz;\ \Lambda=0,31$

Fig. 6. The voltage waveform on terminals of coil for motor type SZDVc198rE - new coil



$f=737,6kHz;\ \Lambda=0,35$

Fig. 7. The voltage waveform on terminals of coil for motor type SZDVc198rE – used coil

This method can be used to diagnose the main insulation of electrical machines also. The winding's insulation measurement can be performed even if the phases are galvanic connected (without possibility to disconnect, for example: winding without brought-out neutral point or delta circuit inside connected).

In that case, the result of measurement is condition of insulation between all windings and the iron core. The same situation occurs in the evaluation of insulation's condition by other methods. Only technical condition of insulation between winding and iron core of tested machine (motor or generator) is evaluated.

Many of failures are the result of the winding insulation breakdown between two phases. These failures are often classified as damage of turn-to-turn insulation. This is a mistake, because these are examples of failure of main insulation.

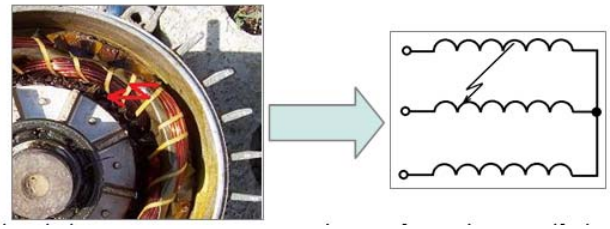


Fig. 8. Short - circuit between phases

The reliable assessment of insulation's technical condition by these methods is possible to perform only, if there is access to both ends of the winding of each phase and it is possible to disconnect each connected point of winding.

If, there is no possibility of disconnection phase of windings, it seems appropriate to use methods for testing insulation between turns, such as the method of fuzzy voltage wave.

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