JOINT INSTITUTE FOR NUCLEAR RESEARCH
Veksler and Baldin laboratory of High Energy Physics

FINAL REPORT ON THE SUMMER STUDENT PROGRAM

Modernization of software for SC-coils quality control

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Abstract

NICA is a new accelerator collider complex under construction in JINR, Dubna. More than 280 superconducting magnets need for the NICA booster and collider. SC-magnet should be checked for insulation and turn to turn breakout failure before every stage of assembling and cryogenic testing. Software, modified during summer student practice, is described in this report.

Introduction

It is unacceptable to have SC-magnet faults such as interwinding breakdown, insulation failure and yoke breakdown. For controlling of electrical properties and coil quality it is performing some tests by following devices.

Figure 1. Hameg HM8118

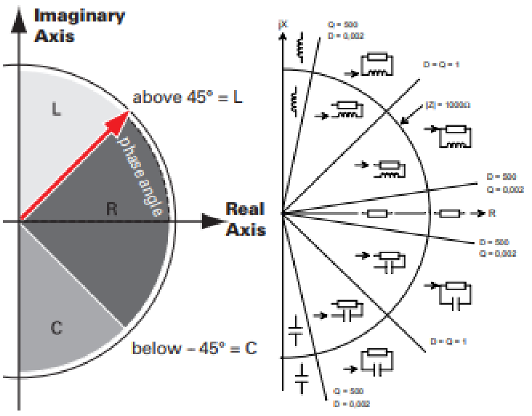

Figure 2. HM-8118 Phase diagram

RLC meter Hameg HM8118 (Figure 1) measures electrical properties of the coil in the range 20 Hz – 200 kHz. This device based on measuring of impedance and phase degree [1]. Measuring functions (L, C, Q and others) are defining by Phase diagram at Figure 2. Circuit connection is defining by module of impedance (series or parallel).

Coil to yoke insulation is measured by Fluke 1550c (Figure 3**Error! Reference source not found.**). Voltage range is 200 kOhm – 2 TOhm, voltage test (250V – 10kV).

Direct current resistance of coil is measured by microohmmeter Metrel MI 3250 (**Error! Reference source not found.**).

Figure 3. Megaohmmeter Fluke 1550c

Figure 4. Microohmmeter Metrel MI 3250

Figure 5. Aktakom-3083

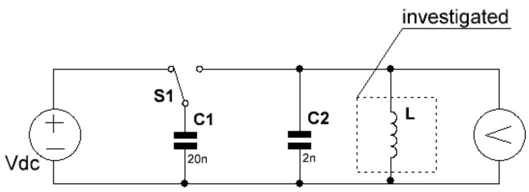

Figure 6. Schematic diagram Aktakom 3083

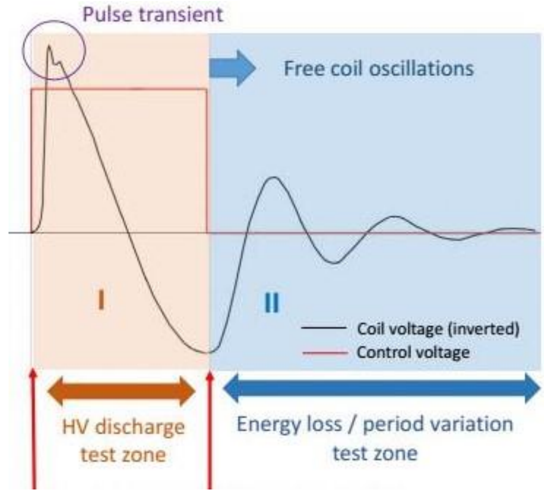

Figure 7. Graph of oscillations

Testing for turn to turn breakout failure [2] is performed by Aktakom 3083(Figure 5). Circuit diagram of this device is shown at Figure 6. Pulse transient process is shown at *Figure 7.* Figure 7. Device measures transient process in RLC circuit, where R is an active resistance of coil; L is inductivity of DUT and C is output capacitance of device. First of all, capacitor C1 is charged by required voltage Vdc. Than C1 connects to circuit by switch S1 and starts to discharge on the DUT (High voltage discharge zone). After that C1 disconnects and energy loss test zone starts.

Frequency of transient waveform isn't depends on testing voltage for good coil. In case of damaged insulation breakdown, frequency would change. Aktakom AM3083 operates by next tests of transient process [3].

1. **Area size test.** The area sizes of both standard waveform and the tested waveform are calculated between A and B. The percent deviation is the ratio of the area size difference to the area size of the standard waveform between A and B, expressed as a percentage. The area size of the waveform is nearly proportional to the energy loss in the winding. When a sample winding has a short circuit between layers, the short circuit area is reflected as an increase of energy loss.

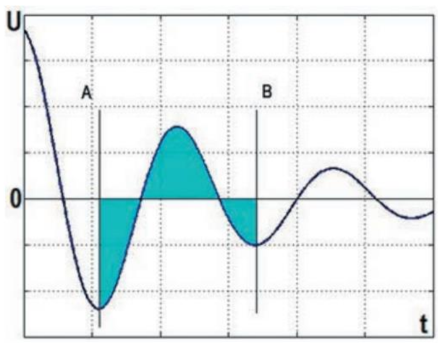

Figure 8. Area Size Comparison

$$\Delta\% = \left|\frac{S_{test} - S_{standart}}{S_{standart}}\right| * 100\%.$$

2. **Differential Area comparison.** This method calculates the area size of differential portion between the standard waveform and the tested waveform from A to B. The differential area size reflects the value of inductance and total energy loss. This method is especially effective when the inductance between the standard winding and the tested winding is different.

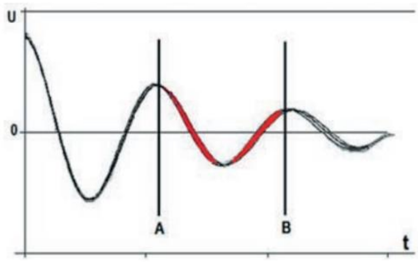

Figure 9. Differential Area Comparison

$$\Delta\% = \left|\frac{S_{differentail}}{S_{standart}}\right| * 100\%.$$

3. **Phase difference test.** AM-3083 measures the time difference (AB) between the standard waveform and tested waveform at their third zero-crossing points and the period time (CD) of the standard waveform. The percent deviation is the ratio of the time difference at the chosen zero-crossing points to the period time of the standard waveform, expressed as a percentage.

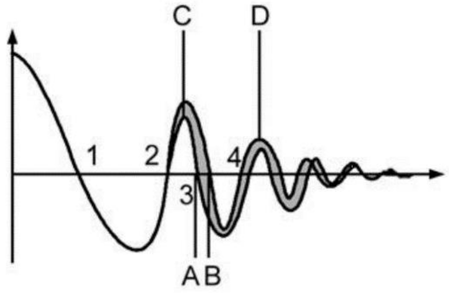

Figure 10. Differential Phase Comparison

$$\Delta\% = \frac{T_{AB}}{T_{CD}} * 100\%.$$

For automation of coil measuring and analyzing «Coil tester» software (Figure 11) was developed. Graphical programming environment LabVIEW [4] was used to develop this program.

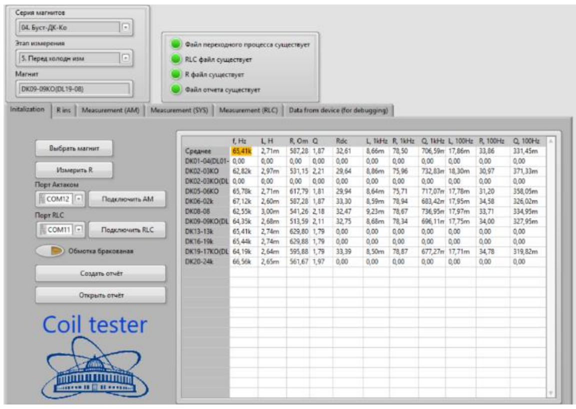

Figure 11. Main panel of"Coil tester"

This software can:

- perform measuring by HM8118 in required frequencies range (Figure 12);
- perform measuring and analysis of transient process results by Aktakom AM-3083 (Figure 13);
- store results of insulation resistance and direct current resistance (Figure 14);
- report generation

Software interacts with devices via RS-232 interface. Results are store in the database. Tested magnet characteristics are comparing with other magnets of series.

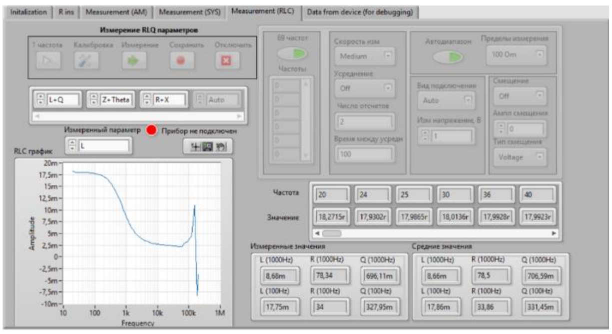

Figure 12. RLC Measurement

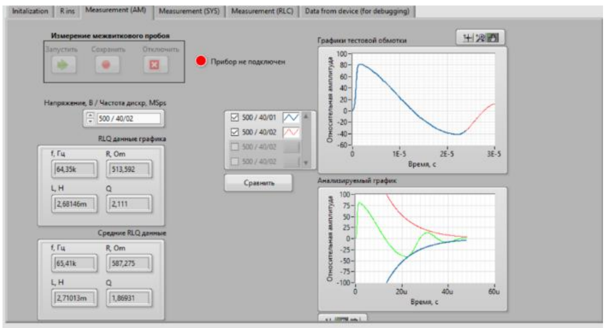

Figure 13. Aktakom Measurement

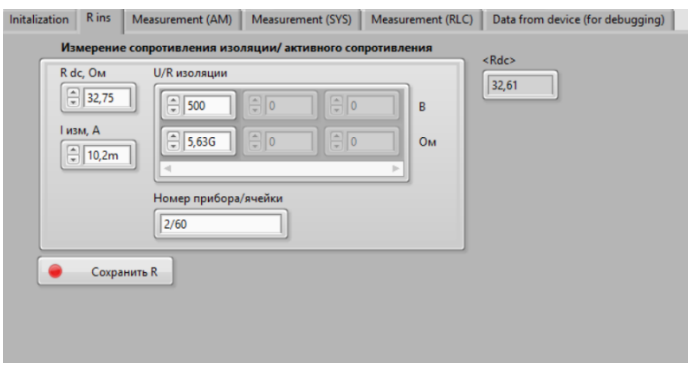

Figure 14. Save ohmmeters measurement

Software modification

Additional program module for data calculations by EPOWERSYS CDG7000 (**Error! Reference source not found.**5) was implemented during summer student practice. CDG7000 is a inter turn insulation faults tester. Unlike AM-3083 it have higher voltage range (up to 7kV), higher ADC data resolution (13 bit; AM-3083 – 8 bit). CDG 7000 has 20uF output capacitor that remains connected during test. It eliminates parasitic capacity of a coil, but it increases period of oscillations and reduces periodic oscillations condition (According to this condition oscillation frequency should be a lot more than damping factor). Other con is impossible to control device in automation mode. It can only save file in csv format and after that load to the program by flash device (Figure 17).

It was implemented calculation model for analyzing CDG 7000 and AM-3083 oscillation data. Oscillations in RLC coil are described as (1)

$$F(t) = U_0 e^{-\beta t} Cos(\omega t) \qquad (1)$$

Where U_0 is discharging voltage, damping factor β defines as (2)

$$\beta = \frac{R}{2L} \qquad (2)$$

Oscillations frequency ω defines as (3)

$$\omega = \sqrt{\frac{1}{LC} - \beta^2} \qquad (3)$$

Figure 15. EPOWERSYS CDG7000

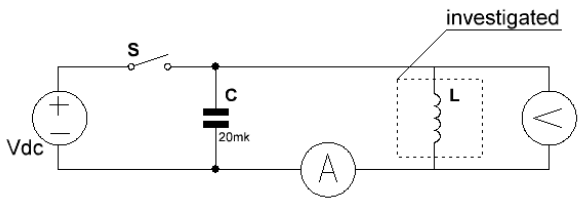

Figure 16. Schematic diagram CDG7000

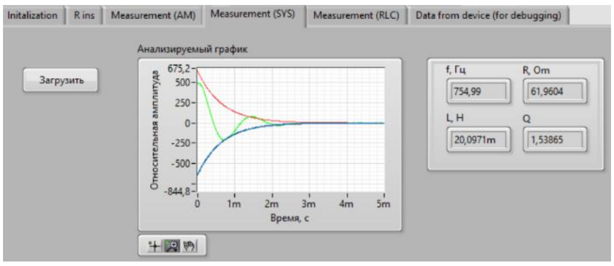

Figure 17. Module mesurements CDG7000

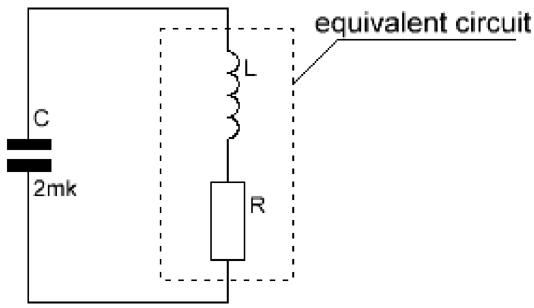

Figure 18. Equivalent circuit iductance

L, R, Q, ω, β values gets by fitting of oscillations model [5]. Parasitic coil capacity neglects in this model.

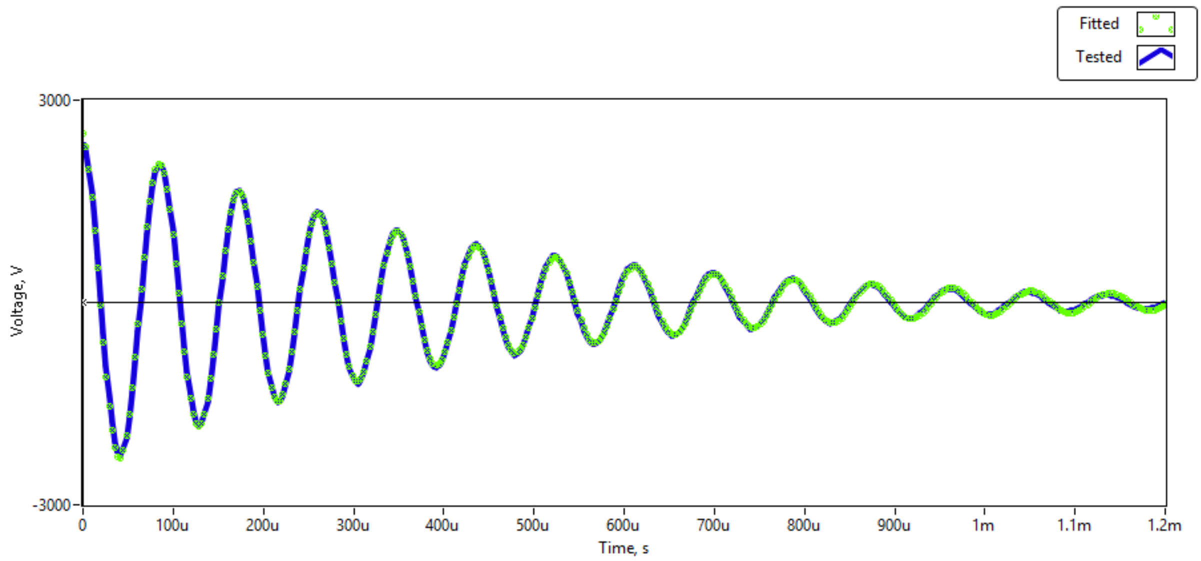

Figure 19 In the graph, the blue line shows the transition process in the test coil, at a discharge voltage of 2500V. Green line shows fitting function (1), with the calculated parameters L, R,ω, β.

Figure 19 shows the result of fitting the experimental data with function (1). It is seen that the green line (fitting function) fit well on the experimental data.

	f, Hz	L, H	R, Om	Q	Rdc	L, 1kHz	R, 1kHz	Q, 1kHz	L, 100Hz	R, 100Hz	Q, 100Hz
Среднее	146,72k	544,30u	117,10	4,26	152,41m	443,95u	183,11m	15,24	447,13u	153,96m	1,82
M22-N	146,02k	542,47u	117,22	4,25	153,23m	442,03u	168,51m	16,47	446,75u	153,74m	1,83
M22-N - fail	109,32k	962,61u	183,89	3,60	153,23	444,21u	181,65m	15,37	447,90u	152,07m	1,85
M22-V	148,79k	522,47u	114,78	4,26	152,26m	441,83u	168,97m	16,44	446,26u	154,18m	1,82
M22-V - fail	115,97k	855,15u	174,60	3,57	152,26m	444,21u	182,28m	15,31	447,77u	152,89m	1,84
M23-N	145,52k	553,80u	140,41	3,61	160,21	443,64u	184,13m	15,14	446,70u	153,10m	1,83
M23-V	142,49k	577,57u	138,31	3,74	155,91	443,65u	183,09m	15,22	446,68u	152,71m	1,84

Figure 20. A fragment of a summarized table of the magnets with well and fail coil. f – frequency of the transition process, and L is the calculated inductance of the winding, R is calculated winding resistance, Q – calculated quality factor, 5-11 column is the values measured by RLC-meter at frequencies 1kHz and 100Hz, respectively.

A fragment of a summarized table is shown at Figure 20. First row shows mean values of measured functions. The coils with measured values, that differ a lot, were labeled as fail. As it turned out, these coils had a defect. Parameters changed after coil fixing. So, AM-3083 helped to find fail coil.

Conclusion

During summer student practice I was implemented module for working with EPOWERSYS CDG7000 that allowed analyzing data from this device in automation mode. I also implemented mathematical model for defining AM-3083 and CDG-7000 parameters from transient process waveform that helps to find deviation of coil in summarized table.

Acknowledgements

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References

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