# PC-CONTROLLED TEMPERATURE-RISE TEST OF POWER TRANSFORMERS

Zdenko Godec
Transformer Department
Končar - Institut za elektrotehniku, d.d., Zagreb, Baštijanova bb, Croatia
Phone: +385 1 3667340, Fax: +385 1 3667306, E-mail: zgodec@koncar-institut.hr

*Abstract* - **Temperature-rise test is the most complex and time-consuming factory test of transformers. It consists of several measurements that have to be performed in sequence. First, it is necessary to measure winding(s) dc resistance at a known temperature. Then transformer should be heated with ac supply up to oil steady-state temperature-rise. At the same time ac voltages, currents, powers, frequency, and temperatures should be measured. Since the temperature-rise of windings is determined from dc resistance increase, the winding(s) resistance should be measured again at the end of the heating. The paper presents reasons for development of computer program for automation of: test engineer guidance, measurements, recording, storage, data processing and test reports creation. It also describes management of the project and how hardware and software are selected. Test automation has decreased test costs, increased transformer test station capacity, increased accuracy and reliability of measurement results, and made easier the work of test engineer. With LabVIEW it is possible to develop applications for complex measuring processes. LabVIEW simplifies programming and it is fun to work with it, but it is large, complicate, and does not yet attain the level of user friendliness that would satisfy the needs of test engineers in test stations.**

## I. INTRODUCTION

With temperature-rise test (heat-run test) the manufacturer proves transformer's power rating. During the test, transformer loading is simulated by short-circuit method, and oil and windings steady-state temperature-rises are determined [1]. Temperature-rises should not exceed defined limits. Temperature-rise test is a process consisting of four sequential parts: the reference measurement of winding(s) resistances at a known temperature, heating with constant total losses and simultaneously measuring oil and external cooling medium temperatures, heating with constant current and simultaneous temperature measurements, and measurements of winding(s) resistances during cooling after shutdown. Oil temperature-rise is determined as difference of oil temperature and temperature of external cooling media (air or water). Temperature-rises of windings are determined by means of windings resistance increase method. Typically temperature-rise test lasts from 12 to 24 hours. At the end the test engineers compute oil and windings steady-state temperature-rises using extensive data processing of several thousands measurement results.

Under demands of the market, the management of Končar Power Transformer factory required reduction of test costs and increase of test station capacity. Test engineers proposed automation of the demanding, long-lasting and exhausting temperature-rise test. Research engineers of the Institute, who had been for years included in solving the factory problems, were willing to accept the challenge of automation of the most complex test in the factory - although they had no experience in programming with text based languages or programming packages intended for automation of measurements.

The paper describes the way in which heat-run test has been automated in Končar Power Transformer factory, and presents research of LabVIEW possibilities.

## II. STATE BEFORE TEST AUTOMATION

In factory test station temperature-rises of transformers are tested according to standards [2], [3] and [4], or as specified in contract. Winding resistance is measured using the voltmeter-ammeter method by means of stand-alone digital multimeters with GPIB communication interface [5] (system DMMs). Temperatures are measured with thermocouples by means of multichannel digital thermometer, which has GPIB interface (system DTM). Three phase ac voltages, currents and frequency are measured with analogue instruments or DMMs connected to instrument transformers, and active powers (losses) are measured with three analogue wattmeters.

Number of test engineers at winding(s) resistance measurements is from 2 to 4, and depends on the number of simultaneously measured winding(s) resistances (1 to 3). During transformer heating, one test engineer maintains constant losses or currents (and records times, voltages, currents and powers), and the other measures temperatures on 6 to 9 points every 15 minutes. Since winding resistance is measured with direct current, and the transformer is heated with alternating current, the windings resistances cannot be measured during the heating. Therefore winding resistances should be measured every 15 seconds during 10 to 15 minutes immediately after shutdown of ac supply, and then they are extrapolated back to the instant of switching off ac supply - using the least squares method [6]. For transition from heating to measuring dc resistances, and for the very measurement of windings resistances, it is necessary to have at least 3 to 5 test engineers. As the time of transition cannot be exactly predicted, the whole test team must be present during the entire test or its major part.

The program ZAGIH [7] developed with Fortran IV is used for extensive processing of measurement results and creating test reports. Data gathered during the temperature-rise test must be transcribed manually and stored in databases that ZAGIH calls for creation of test reports.

## III. DEFINING THE PROJECT

The objective of the project was to automate the entire temperature-rise test. Interactive program for personal computer (PC) with Windows operating system and graphical or menu-based programming language should be developed. Program should guide the test engineer step by step through measuring process. Also it should record, save and process measurement results, and create test reports. Usage should be made of the existing equipment, and only indispensable new one may be purchased. The regulation of ac source and connection of measurement circuits will be manual.

We divided the project in two parts. In the first part it had to be checked whether there already existed a PC-based solution of automated temperature-rise test for oil-immersed power transformers, than appropriate hardware and software for automated measurement had to be specified, and a solution proposed. In the second part the program for automation of temperature-rise test should be developed and implemented in transformer test station.

## IV. SPECIFICATION OF HARDWARE AND SOFTWARE

By searching CURRENT CONTENTS, INSPEC and COMPENDEX databases, and Internet by means of www.google.com search engine and www.copernic.com intelligent agent, I have found nothing that would indicate that the described problem has already been solved. I have found several articles on automated measurements in transformer test stations that are performed with central computer and programs developed using Basic or Fortran [8], [9] and [10], or automated measurements of temperature-rise of dry-type transformer windings [11]. I have also found that Tettex manufactures a device that can be used for measurements of winding temperature-rise by extrapolation of resistance curve during cooling.

Than I made the following inquiry and sent it to several manufacturers:

**Concern:** COMPUTER AIDED TEST
**Application:** Temperature-rise test of power transformers (according to IEC 76-2)
**Description:** Test comprises repeatable measurements in specified time intervals of:

- DC voltage (from 10 mV to 100 V) and simultaneously dc current (for calculation of dc resistance), every 3 s to 30 s,
- Oil temperature (from 0 $^0$C to 200 $^0$C) and ambient temperature (from 0 $^0$C to 40 $^0$C) on several points (from 10 to 20), every 1 min to 15 min,
- AC power (short-circuit load losses), ac voltage, ac current and frequency.

Temperature is measured with T-type thermocouples (TC) during transformer heating with specified ac power. Duration of complete test can be from 6 hours to more than 24 hours.

We consider two solutions:

1. With system stand-alone instruments and PC as controller, and
2. With extension module plug-in card(s) for TC-temperature and voltage measurements, system instrument for power and frequency measurements, and PC as controller.

For the first solution the instruments are:

- DMM Model x (with GPIB), 3±1 peaces
- DTM for 9 channels Model xx (with GPIB)
- AC-Power analyser (PA) Model xxx, (with GPIB)

For the second solution the instruments are:

- Extension module plug-in card(s) for TC-temperature and voltage measurements (with 10 to 20 channels)
- AC-Power analyser (PA) Model xxx, (with GPIB)

The measuring system used for the tests shall have certified traceable accuracy and be subjected to periodic calibration according to ISO 9001. For this purpose we need information and guides for evaluation of measurement uncertainty and for possibility of calibration (for documented traceability).

**PC configuration:** Pentium, 32 MB RAM, disc about 2 GB, CD-ROM, Widows 95, or Widows NT.

**Software package for development of automated measurement system:** decision should be made between LabVIEW, HP VEE, and TestPoint.

Do you have instrument drivers for instruments of the first and the second version of considered measurement system and recommended software package?

Please send us detailed technical information and offer for recommended GPIB card for PC with instrument drivers, software package (for Windows 95 and Windows NT), extension module plug-in card(s) for TC-temperature and voltage measurements, and all necessary accessories.

Even after several iterations the final offers for the second solution were not complete, especially not as regards traceability. For this reason, and for the fact that the test station had necessary system instruments (system PA was purchased meanwhile), our choice was the first solution. A shortened analysis of offers for GPIB card and cable, and for graphical or menu-driven programming package is given in Table I.

The most difficult was selection of programming package. On the basis of catalogues, demos, CDs and seminars novice is not capable to assess objectively the power, user friendliness, compatibility, quality and technical support of the considered software packages. It is likely that developing several smaller problem-related applications using all three programming packages could attain this. But for reasons of time and costs this was out of the question, and the decision had to be made on the basis of available information.

The best known and most popular of them is LabVIEW, HP VEE is less so, and TestPoint is the least known. It is known that in developing automated measurement systems the most frequent are incompatibility problems of system instruments and GPIB communication cards - when they are not from the same manufacturer.

Since NI does not produce stand-alone instruments, the policy of the company is that products and programs shall be compatible with instruments of other manufacturers. LabVIEW drivers for instruments of various manufacturers are numerous. If NI products are used in measurement automation, problems to be expected should be minimum. Technical support is said to be good, i.e. in the case of any problem the representative in Zagreb claim they would help.

Hewlett Packard (HP) has products of high quality. Although HP claims that HP GPIB system and HP VEE programming package are compatible with products of other manufacturers, compatibility problem is frequent,

Table I. Characteristics and relative prices of GPIB card, cable, and programming language

| Manufacturer | National Instruments (NI) | Hewlett Packard (HP) (Agilent) | Keithley |
|---|---|---|---|
| Representative office in Croatia | Yes | Yes | No |
| GPIB card for buses,<br>with drivers,<br>with debug software,<br>cable (2 m) | PCI (32 bit)<br>+<br>+<br>+ | ISA/EISA (16 bit)<br>+<br>-<br>+ | ISA (16 bit)<br>+<br>-<br>+ |
| Relative price | 1.00 | 1.13 | 0.89 |
| Programming package<br>Drivers for:<br>DMM type x<br>DTM type xx<br>PA type xxx<br>Drivers, total<br>Options:<br>Multithreading<br>Development of menus<br>"Undo" function | LabVIEW<br><br>+<br>-<br>+<br>> 600<br><br>+<br>+<br>+ | HP VEE<br><br>+<br>-<br>-<br>> 450<br><br>-<br>-<br>- | TestPoint<br><br>-<br>+<br>-<br>> 100<br><br>?<br>-<br>- |
| Total relative price | 1.00 | 0.74 | 0.37 |
| Delivery time | 1 month | 2 months | 2 months |
| Warranty | 24 months for GPIB | - | - |

because HP is oriented to their own products. There is a large number of drivers for HP VEE, but most of them are for HP instruments. HP representative in Zagreb promised technical support in case of difficulties.

Similar applies to Keithley products, yet there are considerably less TestPoint drivers. Technical support is more difficult to obtain because there is no representative office in Croatia.

In our case there are LabVIEW drivers for all the instruments except for DTM, there is HP VEE driver for DMM only, and TestPoint driver for DTM only. It is probably easier to develop a driver for DTM than for PA.

On the basis of these considerations our choice was LabVIEW and GPIB card and cable of the same manufacturer. We also decided to use a conventional PC as controller, and UPS. If conventional PC should be found unsatisfactory as regards electromagnetic disturbances, it can be replaced with industrial computer.

## V. REQUIREMENTS AND GUIDE FOR APPLICATION DEVELOPMENT

Programming should be in accordance with instructions given in "LabVIEW Style Guide". A detailed description of all routines should be given. Application should be split in program modules (and sub modules) with appropriate names and VI extension (VI - Virtual Instrument), which can be more easily solved, described and tested. Care should be taken to make source programs easy to read and understand, with description clear enough to make its maintenance and extensions easier. User manual should be created as well.

The program should guide test engineers through preparations for heat-run test and measuring process, automatically measure and save measurement results, give alarms in cases of irregularities, process data, and generate test reports.

Appropriate graphs and important data should be shown during measurements on man-program interfaces (MP interfaces).

Blackout during the heat-run test is possible, and program should make feasible the continuation of the test without loosing previously acquired data.

Measurement results should be reported in shortened form (low level expression [12]), but it should be possible to express them in their complete form, i.e. with best approximation of the measured quantity, standard uncertainty and degrees of freedom [13].

Specific requirements for each program module were given.

After calling application AMTRT.VI (Automated Measurement in Temperature-Rise Test), input data for transformer identification and its properties should be entered in the form. After that, appropriate program modules are to be selected.

AM-RES.VI (Automated Measurement of RESistance). This is program module for measurement of resistance of cold windings by means of voltmeter-ammeter method. It guides the test engineer through preparation and measurement, automatically measures resistances and temperatures, calculates arithmetic means and standard deviations of resistances and generates test report. It should be possible also to use the module independently - only for measurement of resistances.

AM-POWER.VI (Automated Measurement of POWER). This is program module for measurements of active power, voltage, current and frequency with PA Model xxx. It guides the test engineer through the measurement, measures, gives alarms, and generates measurement documentation. It should be possible also to enter manually unavoidable measurement results of these quantities (obtained with e.g. analogue instruments), by subsequent entering in appropriate sections of MP interface of AMTRT.

AM-TEMPERA.VI (Automated Measurement of TEMPERAtures). This is program module for temperature measurements during the heating of transformer with constant power or current by means of TCs at 6 to 9 points with DTM Model xx. It guides test engineer through the measurement, measures, calculates and generates measurement documentation. The module should also be capable of independent usage for temperature measurements.

AM-COOL.VI (Automated Measurement of Resistances at COOLing). This is program module for measurement of windings resistances at cooling, and for extrapolation of resistances back to the instant of switching off ac supply. It guides test engineer through the measurement, measures, calculates and generates test report.

AMTRT-REPORT.VI (Automated Measurement in Temperature-Rise Test - REPORTs). This program module integrates all the data for creation of test reports. Two kinds of output documentation should be generated: test reports and complete documentation with all measurement results.

After that, detailed instruction and requirements for each of these program modules are made. To illustrate, I give some segments of them.

In the instructions for AM-RES.VI it is for example stated: "... on MP interface test engineer (TE) selects the number of simultaneously measured winding resistances (one, two or three); than selects measuring circuit diagram; the program proposes the configuration of measuring system (see e.g. Figure 1) and diagram of dc measuring circuit; ... program computes range of values of direct current for which criteria are fulfilled that transformer core is saturated, that voltage drop on windings exceeds 20 mV, and that self-heating of windings is negligible; TE selects the current; program computes voltages on each voltmeter and indicates that instruments should be turned on; on the MP interface TE selects in sequence ranges of DMMs and checks GPIB communication with instruments; on next MP interface TE adjusts interval of resistance measurements (3 min to 30 min) and reading interval (5 s to 15 s); ... TE starts automated measurement of winding resistances; ... on MP interface the notice that measuring circuit should be closed; TE starts current measurement; on MP interface currents should be shown digitally and graphically for check of stability (because for correct resistance measurement the current must be stable [14]); after stabilization of the current, program should instruct TE to connect voltmeter inputs to winding(s) terminals; on MP interface graphical representation of resistance points; ... after TE confirms intention to interrupt the measurement, TE should be warned by the program that he has to disconnect voltmeter inputs from windings first; ... TE can select on the graphs of resistance measurements the interval for which the average resistance and standard deviation in percent will be computed; ... program calculates average oil temperature and associates it to the measured resistances; ... TE starts generation of test report with all measuring points and data relevant for the measurement (transformer type, factory No., vector group, terminals in the measuring circuit, position of tap changer, average oil temperature, average windings resistances in ohm, standard deviations in percents, selected interval of resistance measurements, date and name of test engineer); TE starts transfer of data in Excel for print out ... ", and so on.

In the instructions for AM-POWER.VI it is stated that "... ac powers, currents, voltages and frequency should be measured every five seconds regardless of selected frequency of temperature measurements; TE enters in the VI front panel the power for transformer heating, rated frequency and rated current; ...the power should be maintained within the adjustable range ± x %, the frequency within the range ± y %, and the current in the part of the heating with rated current within the range ± z %; ... program checks whether the regulated quantities are within the limits; if not, it makes acoustic and visual alarms..." etc.

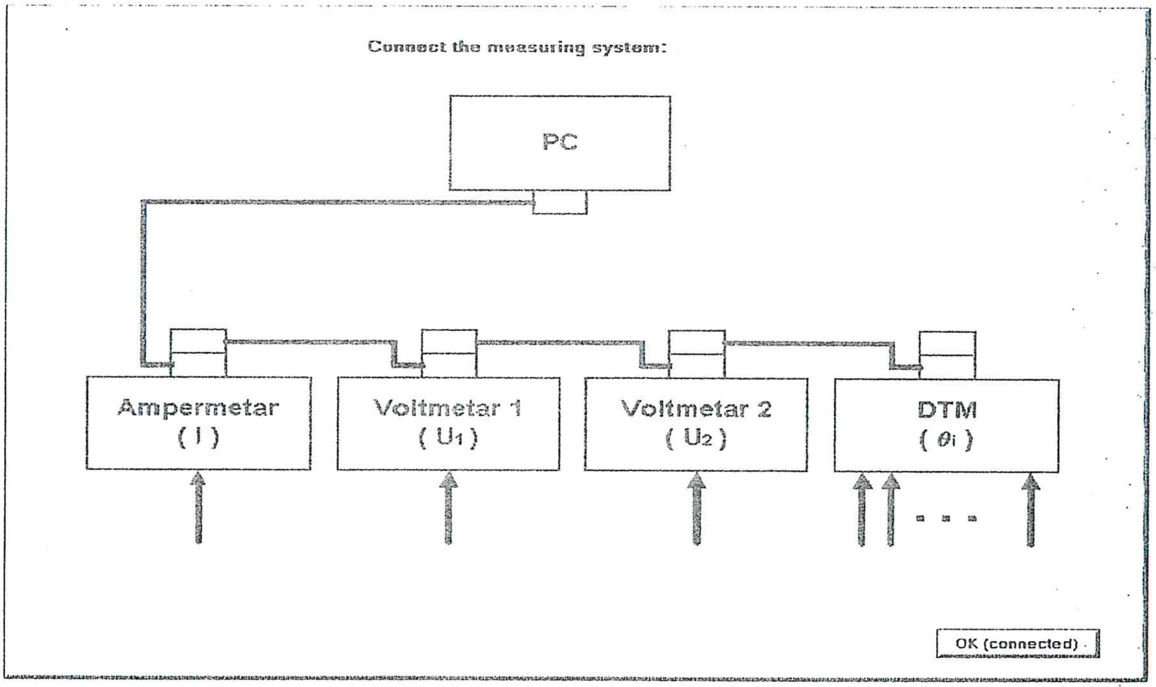


Figure 1. PC and instruments connected by GPIB cables form measuring system for automated resistance measurements of two windings, and for oil temperatures measurements with multichannel digital thermometer

In the instructions for AM-TEMPERA.VI there is for example: "... on MP interface it should be shown how to connect TCs at DTM inputs when temperature-rise of transformers with ONAN, ONAF, OFAF and ODAF types of cooling (see [15]) is tested, and how when transformers with ODWF and OFWF cooling; ... by means of special MP interface it should be possible to plan the duration of a temperature-rise test by evaluation of thermal time constants [6], ... after two time constants of top-oil temperature-rise VI should compute steady-state oil temperature-rises and the time remaining to fulfilment of criterion for steady-state top-oil temperature-rise (TE can choose one of the following criteria: 1 K/h + 3 h, $0.95\Theta_{ts}$, or in the form $\Delta\Theta/\Delta t + t_1$ - where $\Theta_{ts}$ is the program-estimated steady-state value of top-oil temperature-rise, $\Delta\Theta$ is the temperature-rise change in interval $\Delta t$, and $t_1$ is the additional time) ..." etc.

In the instructions for AM-COOL.VI there is for example: "... after completion of resistance measurements, VI should generate a database and compute windings average temperature at the instant of interruption of heating, using non linear least squares method; ... the best approximation and uncertainty of extrapolated temperature should be displayed on MP interface ..." etc.

## VI. PROJECT REALISATION

The project was realised by a team with an expert in measurements as the leader and two newly graduated research engineers. We have started programming with LabVIEW 5.0 FDS (Full Development System), which has no possibility of making the exe version of the program. The application of the program in its source form is very risky, because it is not protected against unauthorized changes. After we had become fairly sure of project success, we have bought the upgrade of the PDS (Professional Development System) LabVIEW 5.1, containing Application Builder for making exe versions of programs. The transition to the new LabVIEW version made no problem.

During the development of a program for measurement automation, the measuring system has to be complete, because of need to test newly made program modules (Figure 2). To make the testing as reliable as possible, we have made a physical model of a small single-phase transformer immersed in a container with oil. On this model we have tested actual situations encountered in the power transformer test station. In this way we shortened considerably the time of implementation of the application in test station. Nevertheless the testing took much time, because of rather slow processes (heating and cooling), and numerous program modules (about 600) and their combinations: 18 variants of windings connections and phases, two kinds of system DMMs, manual or automatic selection of DMMs ranges, automated or manual reference temperature measurements, 6 combinations of TCs connections, 8 types of cooling, 5 criteria for termination of transformer heating and calculations of steady-state temperature-rise, 3 possibilities for continuation of the heating, automatic or manual measurements of ac powers, voltages, currents and frequency, and 3 different possibilities of successive resistance measurements during the cooling. Development of application took approximately 16 months in total, without learning time (about 2 months per man). The AMTRT source code "weighs" approximately 60 MB, and the application (exe version) 20 MB. A brief presentation of application performance with figures of some interfaces is given in [15]. In this paper the MP interface during heating with constant current is given on figure 3.

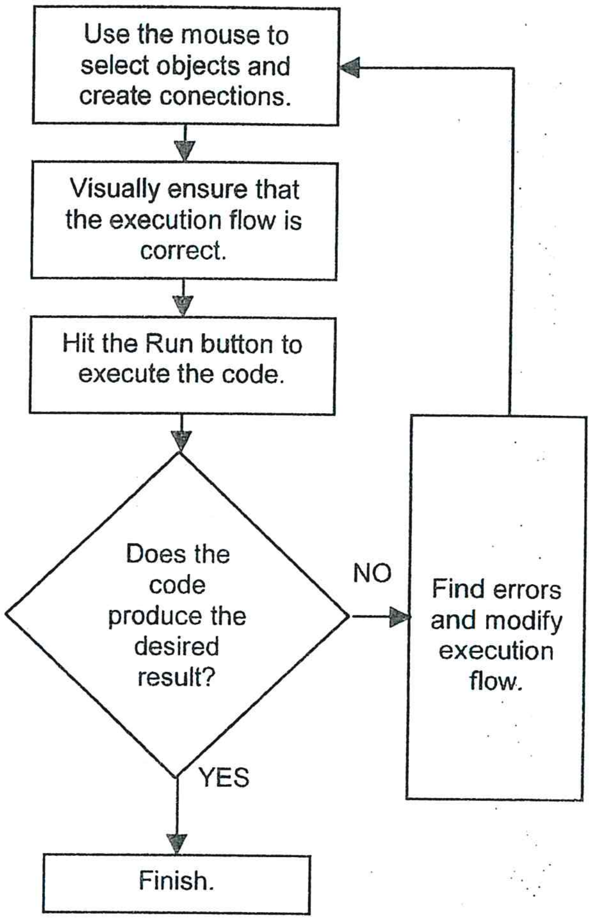


Figure 2. The process of creating a graphical program

In practice, requirement arose for processing the temperature-rise test afterwards - by a PC outside the measuring system. Therefore, additional program called "TRTprocessing" has been developed. This application makes test reports from databases generated during automated temperature-rise test (these databases are transferred into PC by means of floppy disk). Input of measurement results can be also manual – if temperature-rise test has been made in the conventional way. When once entered, data can be processed in accordance with three standards [2], [3] and [4], and test reports can be printed out in several foreign languages. The application is suitable for research, analyses and statistics. A brief performance description of this application is given in [16].

## VII. CONCLUSION

The project has been successfully completed and verified on 13 transformers with nameplate rating from 8 MVA to 500 MVA. Automation of measurements, data processing and generation of test reports halved the number of test engineers during the heat-run test, made possible energy savings, shortened time of test, and reduced measurement uncertainty. With LabVIEW it is possible to make applications for control of complex measurement processes. However, application development was far more time-consuming than was anticipated at start of the project. LabVIEW, the graphical programming tool for automation of measurements, has not yet attained the level of user friendliness that would satisfy the requirements of test engineers in test stations. Nevertheless, we are now programming new LabVIEW-based applications for automated measurements of load losses, no-load losses, no-load current harmonics, zero impedance and resistance measurements by inductive voltage correction method.

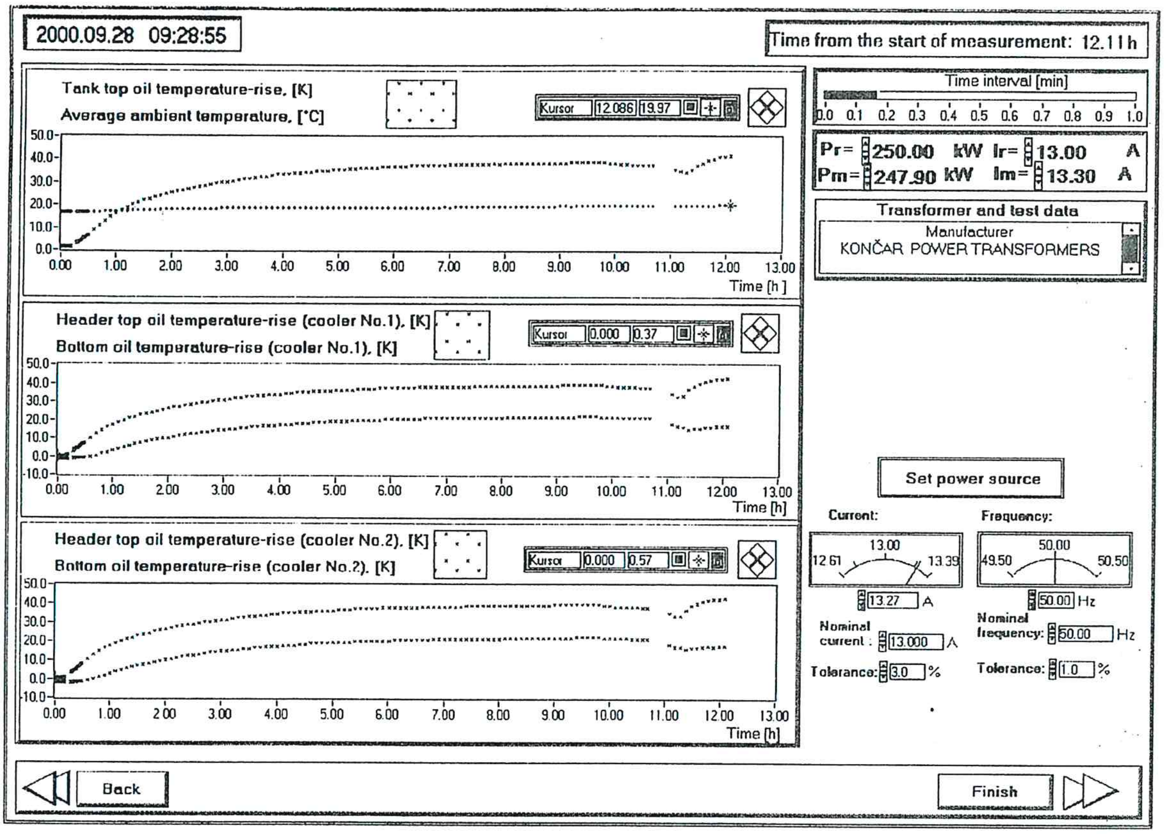


Figure 3. Man-program interface during the heating with constant current (graphics of air ambient temperature, temperature-rises of top oil, oil at inlet and outlet of two coolers, ac current, frequency, etc.)

## REFERENCES


[1] Godec, Z.: Steady-state temperature rise determination, AUTOMATIKA 33(1992)3-6, 129-134

[2] IEC 76-2 (1993.) Power transformers, Part 2: Temperature rise

[3] IEEE Std C57.12.90-1993. IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers and IEEE Guide for Short-Circuit Testing of Distribution and Power Transformers

[4] IEC 76-2 (1976.) Power transformers, Part 2: Temperature rise

[5] IEC 625 (1993.) Programmable measuring instruments – Interface system (byte serial, bit parallel)

[6] Godec, Z.: How to eliminate some systematic errors in transformer temperature-rise measurements, CIGRE, PARIS, 1990, ref. 12.101

[7] Rezić, A., Godec, Z.: Computer Program for Processing of Transformer Temperature Rise Test Results, MODELIRANJE U ZNANOSTI, TEHNICI I DRUŠTVU, Prvi kolokvij: MODELI IZMJENE TOPLINE U ELEKTRIČKIM UREĐAJIMA, CROSS, Zagreb, 1992., 167-171 (in Croatian)

[8] Klein, H.: Automatische Messungen in Grosstransformatoren-Pruffeld, Elektrizitatswirtschaft, 75(1976)8, 192-194

[9] Woschnagg, E., Koglek, H.: Einsatz eines Processrechners im Grosstransformatoren- und Maschinenepruffeld, Elin-Zeitschrift 1978., H.3, 119-125

[10] Woschnagg, E., Ortmann, O.: Computer Aided Testing of Transformers and Rotating Electrical Machines, Elin-Zeitschrift, 1983, H.1/2, 48-53

[11] Sandeen, A. L., Smith, J. L.: Automated transformer temperature rise tester, IBM Technical Disclosure Bulletin, 22(1979)6, 2424-2425

[12] Godec, Z.: Standard uncertainty in each measurement result, explicit or implicit, MEASUREMENT 20(1997)2, 97-101

[13] Godec, Z.: Expression of measurement result, Graphis, Zagreb, 1995. (in Croatian)

[14] Godec, Z.: Measurement of large power transformers winding temperature by inductive voltage correction method, ETZ ARCHIV 11(1989)2, 63-70

[15] Godec, Z., Cindrić, V., Banović, M.: Automated heat-run test of power transformers, National Instruments Days Europe 2000/2001, One-Day Technical Conferences on Measurement and Automation, Aplikacije korisnika, Hemen Zdenko (ed.), - Ivanić Grad, Hermo lab, 2000, I-1 to I-6, Zagreb, 14. 11. 2000. (in Croatian)

[16] Godec, Z., Cindrić, V.: Processing of measurement results of oil-immersed power transformer heat-run tests, National Instruments Days Europe 2000/2001, One-Day Technical Conferences on Measurement and Automation, Aplikacije korisnika, Hemen Zdenko (ed.), - Ivanić Grad, Hermo lab, 2000, IV-1 to IV-4, Zagreb, 14. 11. 2000. (in Croatian)