AN AUTOMATED SYSTEM FOR THE CALIBRATION OF HIGH ACCURACY MULTIFUNCTION INSTRUMENTS

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Abstract - *This Paper gives a summary of a completely automated system that was developed for the high accuracy calibration of multifunction measuring instruments (like the Fluke 5720A calibrator or HP3458A multimeter, for example). The system is capable of calibrating all the functions (ranges: Vdc: 10 mV ... 1 kV; Vac: 2 mV ... 1 kV; Idc: 10 μA ... 2 A; Iac: 10 μA ... 2 A) of digital calibrators and multimeters at very high accuracy. Additionally, efficiency and facility of operation are characterizing the system, which became a powerful tool in electrical metrology.*

Key-words: Automated potentiometer, High accuracy automated calibration, Traceability.

1. INTRODUCTION

The Electrical Voltage and Current Laboratory (LATCE) of INMETRO is responsible not only for the reproduction, maintenance and dissemination of the voltage and current quantities in Brazil, but also it performs the calibration of high resolution multifunction instruments.

Until a few years ago LATCE used to calibrate such instruments manually, through caparisons with the national standards. To perform a whole calibration in all the functions and ranges (AC and DC voltages and currents) was normally a much time consuming procedure. In recent years the demand for the calibration of such instruments has increased sharply, as many laboratories from the industry and university also need to have their instruments calibrated. To solve this problem, LATCE began developing a new automated system with which the laboratory would be able to meet all the increasing requirements.

The core of the new system is an automated, commercially available potentiometer and its extender (MIL 8000A and 8001A), capable of measuring DC voltage, ranging from 10 mV to 1 kV, achieving an accuracy level of approximately ±1 μV/V.

As the original control program of the potentiometer, developed by the manufacturer [1], do not facilitate the integration of other instruments into the program, in the original form it was inadequate to be a module of a complex automated system. As a result, the control program of the potentiometer had to be completely re-written, to ensure an "open system".

The automated system was designed to perform calibration in DC and AC voltages and currents, by taking into account various resources of the system. To calibrate in AC voltage and current it was necessary to apply an AC/DC transfer standard as well as a set of resistors and shunts. All the instruments applied are traceable to national standards. As a final product, the software calculates the uncertainty budget and elaborates the calibration certification, automatically.

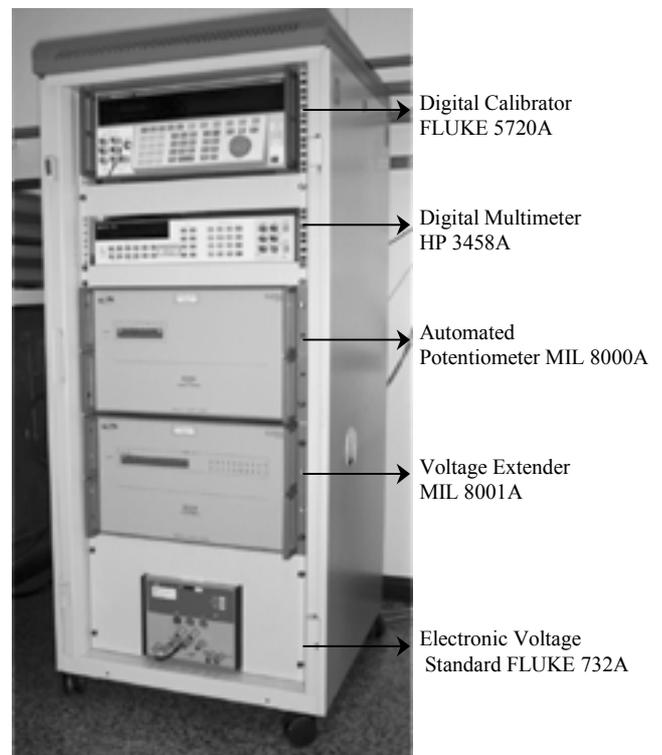Layout of the calibration system is shown in Fig.1.

Fig.1 – Layout of the calibration system.

2. POTENCIOMETER AND EXTENDER

The Potentiometer performs DC voltage measurements in the 10 mV to 10 V range, together with the Extender (a high precision resistive divider) DC voltages can be measured up to 1200 volts. Both instruments are controlled by a PC through the IEEE 488.2 interface. The instruments' manual control serves only to execute some diagnosis tests. Fig.2 shows the simplified circuit of the MIL 8000A potentiometer.
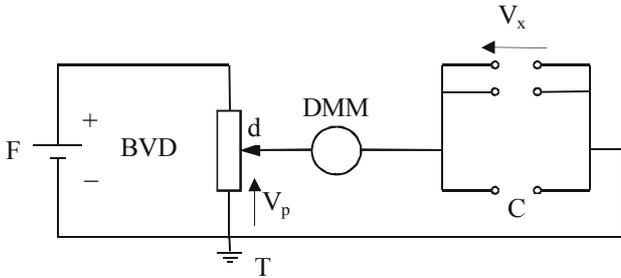

Fig.2 – Simplified circuit diagram of the potentiometer.

The Binary Voltage Divider (BVD) consists of 13 stages of identical resistances. A high stability source (Fluke 732A), F, is used to supply 10 volts to the potentiometer and the DMM is a high-resolution digital multimeter (HP 3458A). The potentiometer has 20 input channels, C, to measure an unknown voltage V_x.

As the binary divider resolution is limited, the traditional potentiometer null method is not applicable. The steps of the measurement procedure are as follows:

a) The derivation (d) of the BVD is connected to earth and in this position the DMM measures the unknown voltage V_x;

b) From this value the control software calculates an ideal ratio and connects the BVD's derivation to the nearest, physically existing ratio. Normally, the voltage V_p, thus set, is not equal to the voltage V_x to be measured;

c) The DMM measures the difference between those two voltages, V_p - V_x, and the software calculates a virtual ratio (as the divider has a finite ratio);

d) Multiplying the virtual ratio by a standardization factor (approximately 10 V, according to the source F) and taking into account the parasitic voltage effects (coming from the relay contacts and DMM's offset) the software calculates the voltage to be measured, V_x.

In order to assure the potentiometer's high accuracy the software performs a self-calibration and a standardization procedure. The self-calibration consists of comparing the elements of BVD with each other, by taking advantage that they have the same value. The software calculates and stores a correction factor for each element and, during the measurement calculates a resultant correction factor, which takes into account all elements involved. Procedure of the standardization is similar to that of a measurement, the difference is that in this case a known voltage of a reference source, V_x, is measured. From the virtual ratio and from the known voltage, the software calculates and stores the Standardization Factor. The software will use this factor to calculate the voltages to be measured, until a new standardization is carried out.

The MIL 8001A Extender is a resistive voltage divider with the ranges: 30 V, 120 V, 300 V and 1200 V. The use of a guard circuit, thermal insulator, etc, assures its high accuracy and stability. The program performs a self-calibration procedure that helps to eliminate long-term drifts in the extender. During this process the potentiometer measures the ratios, first measuring the applied voltage then the divided one. In the first two stages 10 V is applied and then 100 V. The software calculates and stores the correction for each stages that will be applied in the measurements.

3. FUNDAMENTAL CALIBRATION METHODS

This paragraph gives a brief summary of the fundamental methods and resources used for the various kinds of calibrations of digital calibrators and multimeters.

3.1 DC Voltage

For the calibration of DC voltages of calibrators the Potentiometer and the Extender are used directly, as described in paragraph 2. For multimeters the calibrator of the system is used to generate the DC voltage to be measured simultaneously by the multimeter and by the potentiometer system.

3.2 AC Voltage

The model 792A AC/DC Thermal Transfer Standard of Fluke is used to measure an unknown AC voltage, V_{acx}. Currently the instrument is traceable to PTB (Physikalisch-Technische Bundesanstalt). The calibration procedure consists of the following steps.

a) The calibrator generates a DC voltage (V_{nom}) of nominally equal value to V_{acx}, which is measured by the potentiometer (V_{ref}).

b) The calibrator generates sequentially positive DC voltage, negative DC voltage and AC voltage, which are applied to the input of Fluke 792A. The corresponding output voltages are measured by a multimeter, giving the following readings: V_{dc+}, V_{dc-} and V_{ac}, respectively.

The correct DC voltage average (V_{dc}) is calculated by (1).

$$V_{dc} = \frac{V_{nom}}{V_{ref}} \times \left(\frac{V_{dc+} + V_{dc-}}{2} \right) \qquad (1)$$

where V_{nom} is the AC nominal voltage to be measured. The error of the AC/DC difference, using the known data of AC/DC difference of the Fluke 792A ($dif_{ac/dc}$), is calculated by (2).

$$error = \frac{V_{ac} - V_{dc}}{V_{dc}} + dif_{ac/dc} \qquad (2)$$

Finally, the V_{acx} voltage is obtained by (3).

$$V_{acx} = V_{ac} \times (1 + error) \qquad (3)$$

3.3 DC Current

For the calibration of a calibrator the DC current I_{dcx} is measured by using the Potentiometer, measuring the voltage drop across a standard resistor (a set of standard resistors, models 5685A, 5685B and 5686 of Tinsley is available).

The calibration of multimeters is carried out using the calibrator of the system to supply the current to be measured by the multimeter and this value is compared to the value obtained by the voltage drop across a standard resistor and measured by the Potentiometer.

3.4 AC Current

The Fluke 792A AC/DC thermal transfer standard and the set of matching model A40/A40A shunts (Fluke) are used to measure the current I_{acx} generated by calibrators to be tested. The standards were calibrated by and are traceable to PTB and NIST. The calibration steps are similar to the ones outlined for the AC voltage calibration (par. 3.2). In this measurement the DC reference current I_{ref} is calculated from the voltage drop across an adequate standard resistor, measured by the Potentiometer.

For the calibration of multimeters the calibrator of the system is used to supply the current that will be measured simultaneously by the 792A AC/DC transfer standard and by the multimeter.

4. COMBINED METHODS

4.1 Application of he FLUKE 5720A calibrator

As repeated calibrations of LATCE's Fluke 5720A calibrators have proved their excellent performance, concerning accuracy and long term stability, their direct application as reference standards to calibrate digital multimeters was justified. In all the functions, as DC voltage, AC voltage, DC current and AC current, the necessary accuracy can be ensured in such calibrations. Additionally, the calibrator can play the role of a DC voltage reference source for AC/DC transfer procedures.

In order to use the Fluke 5720A calibrators as reference standards, their high precision calibrations must be carried out periodically. The calibration results are maintained in a database and the values are used, as corrections, when carrying out automated calibrations of other instruments.

4.2 The Swerlein Algorithm

In 1991 R. Swerlein [5] published an article where a sampling method was described that takes advantage of the programmable digitizing facilities of HP 3458A multimeters. The algorithm offers an accuracy of within ±10 ppm for AC voltage measurements. Experiences of leading laboratories have proven that even better accuracy can be reached at low frequencies and low voltages, within about ±3 ppm. In the past decade several national laboratories of metrology have tested and adopted this method. The algorithm can be used up to 700 volts, up to about 200 Hz, in the presence of purely sinusoidal waves.

The algorithm, which was written originally in Basic, was implemented in language C and was integrated to the software of the automated system.

LATCE has performed many tests using the Swerlein algorithm and compared the results to the values obtained by the traditional AC/DC transfer method. It could be proved that both methods had a good agreement. However, due to the limitations of the algorithm, it is used especially for AC current measurements (by measuring the voltage drop across an AC standard resistor), when only low frequency calibrations are requested. As AC voltage calibrations are generally requested up to 1kV, the 700 volts' limitation do not facilitate the application of the algorithm (nevertheless, it was implemented in the program also for this purpose).

5. TRACEABILITY

Fig.3 shows a simplified traceability diagram for voltage and current quantities.
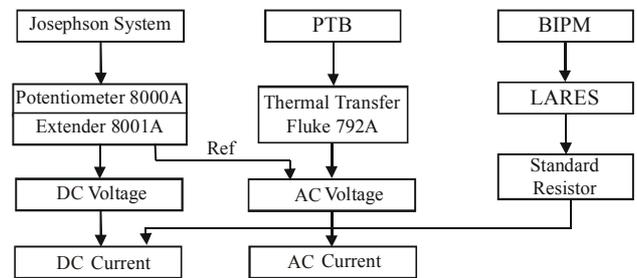

Fig.3 – Traceability diagram

DC voltage

The DC voltage, reproduced by the Josephson system of INMETRO, assures the value of the 1,018 V, with an uncertainty of ±0,05 ppm. This DC voltage is transferred to the potentiometer system, through electronic standards (Fluke model 732B), with an uncertainty of ± 0,5 ppm. Standardization of the potentiometer is carried out practically daily.

The expanded uncertainty calculated for DC voltage measurements is ± 1 ppm ± 0,15 µV from 10 mV to 10 V, increasing up to ± 2 ppm at 1200 V.

AC voltage

The AC voltage standard of INMETRO (Fluke model 792A) was calibrated by PTB from 2 mV to 1000 V and from 40 Hz to 1 MHz. The certified uncertainty varies from ± 10 ppm to ± 0,04 %, depending on voltage and frequency combinations, having its main contribution to the uncertainties the values declared by Fluke for the 792A.

DC current

This quantity is measured by the voltage drop across standard resistors and covers the range from 10 µA to 2 A. The standard resistors are a set of model 5685A and B

AC/DC resistors and model 5686 DC resistor of Tinsley, ranging from 10 mΩ to 1 kΩ. They are traceable to BIPM (Bureau International des Poids et Measures) through the Laboratory of Resistance (LARES) of INMETRO. The expanded uncertainty is approximately ± 5 ppm.

AC current

The AC current is also measured by voltage drops across the standard resistors and/or shunts. The set of Fluke A40/A40A shunts were calibrated by NIST.

Values from 10 μA to 2 A can be measured with an uncertainty of approximately ± 50 ppm, using this method.

6. CONTROL PROGRAM

The program to control the whole automated system was developed in language C, in the LabWindows/Cvi environment (product of National Instruments).

All the inputs and outputs as well as the whole control of a calibration procedure are made through user-friendly control panels that are accessed choosing items in the main menu and sub menus.

There are two different groups of panels. One controls the data banks, where various kinds of stored data files (clients, instruments, calibration data of standards, correction tables, etc.) can be selected and read. The other types of panels control the whole calibration process, in an interactive way (defining measurement parameters, remote control of the instruments involved in the calibration, beginning and interruption of the measurement, etc.).

As an example, Fig. 4 shows the main panel to control the calibration procedure (detailed later). On the header the items of the main menu are seen, offering the following options.
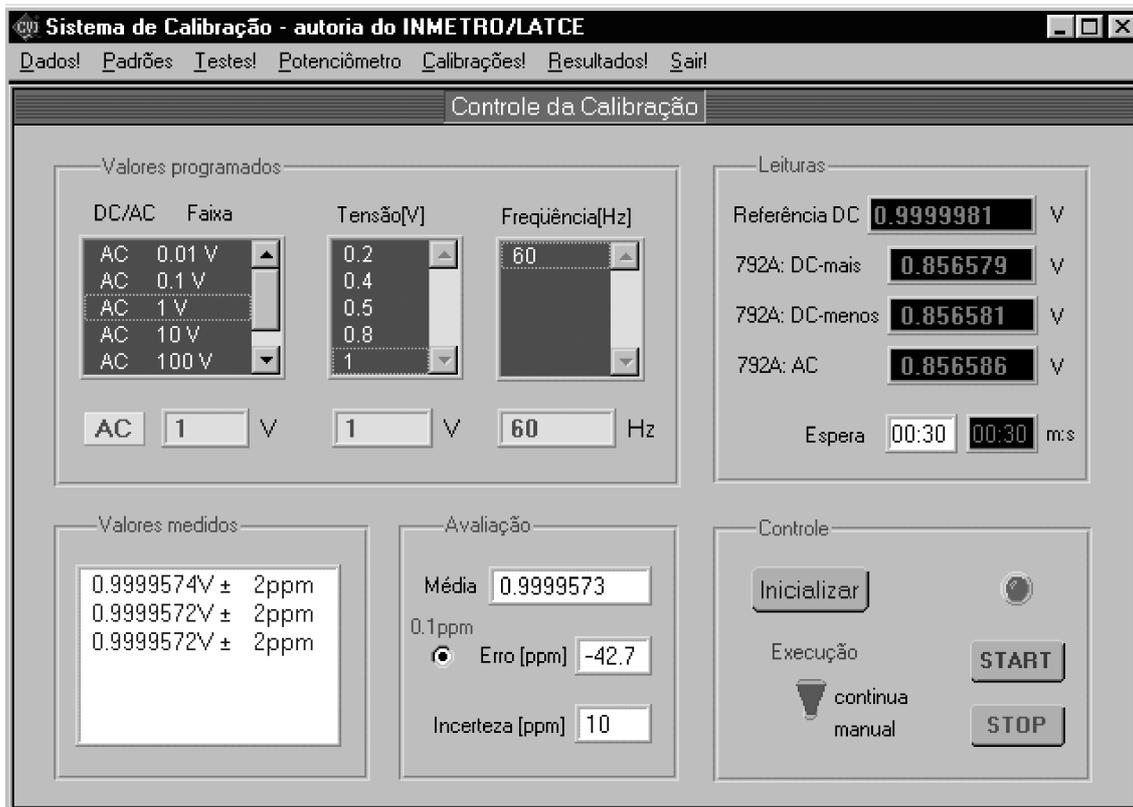

Fig. 4 – Calibration control panel

Dados (Data): serves to introduce and store the data for clients and for the instrument to be calibrated. Among all the parameters of an instrument, the specific IEEE 488.2 commands to control the instrument can be introduced on a separate panel, as shown in Fig.5. In the course of the calibration procedure the program applies these commands automatically. By this facility any new type of instrument can be integrated to the control system.

Padrões (Standards): in this panel the operator can introduce the calibration data of the instrument used as the reference standards, such as:
. Fluke 792A AC/DC certified calibration data, both for voltage and current;
. The calibrated values of the standard resistors;
. Calibration values of the system's calibrator, both for voltage and current, DC and several frequencies.

Fig. 5 – IEEE 488.2 commands entries.

Testes (Tests): in this item the quantity, the values and ranges to be calibrated, as well as frequencies (in the AC voltage or current calibration) can be programmed.

Potenciômetro (Potentiometer): the operator can initialize the instruments of the potentiometer system remotely, perform the Potentiometer and Extender self-calibration and the Potentiometer's standardization. On a special panel all the functions of the system can be tested interactively. Direct measurements by the potentiometer system can also be carried out, where the instruments to be measured are controlled manually.

Calibrações (Calibrations): Fig.4 shows the activated control in a state when a calibration was just finished. To facilitate better orientation, the different functions are found in separate frames, as follows.

"Valores Programados" (Programmed Values): on the three lists the pre-programmed values are appearing, from where the operator can choose an initial point of calibration. When the calibration procedure goes on automatically, the actual combination of parameters are appearing in the related windows.

"Leituras" (Readings): in the related windows the actual auxiliary measurement data are appearing. The information displayed depends on the measurement method that was chosen.

"Valores medidos" (Measured Values): the readings of a measurement of an instrument under test are displayed in the window.

"Avaliação" (Evaluation): show the results after completing the measurement of a point. In the related windows the mean value of repeated measurements, the calculated error (in ppm) and the calculated expanded uncertainty are displayed. There is an option to indicate even fractions of ppm, which (taking into account the high accuracy of the system) is a realistic representation in many cases.

"Controle" (Control): the buttons in this frame facilitate the interactive control of the system.

Resultados (Results): the final results of a calibration are stored in tables that can be accessed selecting this item in the main menu. These data can be passed directly to Microsoft Excel where the operator can easily elaborate the calibration certificate in a standardized form.

SUMMARY

The development of the automated calibration system is a significant advancement in the calibration services of the laboratory for the following reasons.

- By the application of the Potentiometer System high accuracy measurements can be carried out in the full DC range automatically, without involving such time-consuming and disputable procedures as the stepping-up methods. Measurement data obtained by the Potentiometer serve as a basis for all other kinds of measurements.

- Partially due to the availability of a Josephson system, partially due to international comparisons, full and reliable traceability can be achieved for all kinds of calibrations.

- The accuracy level attained ensures the reasonable calibration of even the highest quality commercialized instruments (like the FLUKE 5720A calibrator or the HP 3458A multimeter, for example).

- All measurement procedures are completed automatically, under the rigorous control of a program. Procedures and results became more reliable and more coherent, unpredictable human errors of manual procedures were completely eliminated.

- Productivity and efficiency rate of the Laboratory has been increased significantly (time of calibrations was reduced at least to one third or less).

In spite of the complexity of the control program, it is easy and straightforward to operate the system, which facilitates a lot the work of the operators.

REFERENCES

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