A versatile automation program using LabVIEW for low dc current measurement

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The need for precision measurement of dc current in the nanoampere and picoampere ranges is continuously increasing. The present paper discusses in detail the establishment of measurement facility for the first time at NPLI for these low level DC current ranges by using primary measurement standards of DC voltage and DC resistance. The same has been implemented by developing the fully automated system. The automation provides an efficient way for the low level current measurement as measuring sub nanoampere current manually is subjected to various sources of errors.

Keywords: precision, current measurement, electrometer, automation.

Introduction

An accurate measurement of low currents down to pA range is in extreme need nowadays for the calibration of current detectors, picoamperemeters[2, 3], electrochemical transducers and dosimeters for ionizing radiation. In response to these technological needs, instrumentation manufacturers have marketed picoamperemeters and electrometers, which are capable of measuring currents in the fA range with a resolution of a few aA.

NPLI has already established the traceability of DC current up to micro-ampere range. In recent years, NPLI is extending its traceability and calibration capabilities in nanoampere and picoampere ranges[1]. This paper reports the development of measurement facility for the first time at NPLI for precision low dc current (1 nA to 1 pA) by establishing the traceability by using measurement standards for DC voltage and DC resistance using automation program. As the current level falls into subnanoampere ranges, its measurement process is subjected to various sources of error that have a serious impact on its measured value and measurement uncertainty. In precision low level current measurement[4], electrostatic pickup has a significant impact on the measurement results. Any charged body with some potential, including the presence of human being near the measurement set up will induce a noise current of the order of nA, which can deteriorate the measurement uncertainty. Therefore certain extra precautions were taken while performing low current measurements in addition to general precautions for measurements like; measurements were taken in environmentally controlled chambers, cleaned the traces of contaminants like dirt, grease, fingerprints, etc on connectors, used low noise cables, which uses an inner insulator of polyethylene coated with graphite underneath the outer shield and also the connections with the cables were kept short and the cables were tied to a non vibrating surface.

A careful analysis of the sources of instability eventually leads to the conclusion that the electrostatic effects due to human intervention prevalent in manual measurements as the only possible cause of low repeatability. Hence the automation program using LabVIEW programming environment has been developed to control the whole calibration process through automation which simplifies and improves the precision current measurement process. In this program the data acquisition, data processing and uncertainty computation are simplified by communicating instruments using IEEE 488.2 interface.

The program minimizes the human intervention and therefore reduces the errors introduced by the human while recording the measurement data and also reduces the error caused by the electrostatic effects due to the presence of user near the instruments. To summarize the objectives for automation are primarily the reliability of measurements, repeatability, consistency and minimization of various influences causing substantial measurement errors.

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Measurement method

In the reported work, the low level DC current ranges of Keithley 6517A, the electrometer are calibrated using standard resistors (1 GΩ and 100 GΩ, make Tinsley) and Fluke's 5720A, the precision multifunction calibrator (used as a constant voltage source). The calibrator used is calibrated in DC ranges using zener reference standard which is the secondary standard or national standard of DC voltage, and this secondary standard is calibrated against the JSAVS (Josephson Series Array Voltage Standards) which is the primary standard of DC voltage. The resistors used are calibrated against standard 1 kΩ resistor and this 1 kΩ resistor is calibrated against QHR (Quantum Hall Resistance) standard, which is the primary standard of DC resistance.

Immediately before the current measurement, the high value resistors to be used are calibrated against a standard resistor of known value, to minimize uncertainty contributions from resistance drifts caused by humidity and temperature variations. Owing to the short time between the calibration of the resistor and the current measurement, changes of all the environmental parameters affecting the resistor value are negligible. Thus the uncertainty contributions from the high value resistor are kept within acceptable values.

As shown in fig 1, the precision multifunction high stability dc calibrator (V) and a set of high value three terminal resistance standards (R) connected with low noise triaxial and coaxial cables to the electrometer under calibration (I). With extremely low input offset current and minimal input voltage burden, an electrometer can detect currents as low as 1 fA. Since the voltage drop across the meter is negligible, essentially all the voltage appears across R. Hence the resulting current as measured by an electrometer is
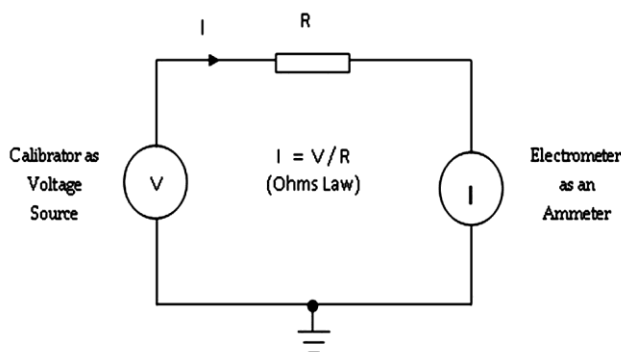
equal to voltage divided by the resistance as stated by Ohm's law.

The program developed using LabVIEW provides the fully automated system for the calibration of low level DC current ranges of Keithley's 6517A Electrometer. It has user friendly graphical interface which simplifies the whole measurement process. All instruments used in the automation process are programmable and have the IEEE-488 standard interface, GPIB (General purpose Interface Bus). By using SCPI (Standard Commands for Programmable Instruments) commands, the instruments are controlled and raw data is acquired from them. The LabVIEW module discussed here can be used for the calibration of current ranges of any other electrometer with slight modifications in the SCPI commands, which are instrument specific.

The functionality of the automated program is broadly divided into following five modules:

Electrometer setup

- This module initializes the electrometer and enables the user to configure its settings.
- The user has been given an option to select the measurement resolution, type of filter and measurement speed required.
- User has the choice to enable or disable features like damping and guarding.
- The user can select the range of measurement automatically or manually.

Calibrator setup

- This module initializes the voltage source (calibrator) and enables the user to change its settings.
- The user can set the calibrator for required voltage according to the standard resistor used to obtain the desired current.

Test Specifications

- This module lets the user to define the number of dc current values to be calibrated,
- It allows the user to calibrate any number of inputs repeating any numbers of times.
- It also allows the user to feed information such as temperature and relative humidity of the measurement environment.

Uncertainty Parameters

- This module allows the user to enter various type B parameters[6] like uncertainty of the standard voltage source and standard resistors used.

Fig. 1—Equivalent circuit

Table 1—Measurement Results

Value Calibrated	Voltage, Volts	Resistance GΩ	Current Calculated	Unit	Current Measured	% Uncertainty Automation	% Uncertainty Manual
1 nA	1.000005	1.00096	0.9990	nA	0.9984	0.08	0.2
100 pA	0.099999	1.00096	99.904	pA	99.915	0.03	0.1
50 pA	0.050000	1.00096	49.952	pA	50.043	0.2	0.5
10 pA	0.010001	1.00096	9.9914	pA	9.9939	0.2	0.5
5 pA	0.500002	99.847	5.0077	pA	4.9949	0.2	0.5
2 pA	0.200001	99.847	2.0031	pA	2.0020	0.3	0.8
1 pA	0.099999	99.847	1.0051	pA	1.0028	0.4	1.0

Table 2—Uncertainty Budget for 100 pA (Automation Set up)

Quantity X_i	Estimates x_i	Limits $\pm \Delta x_i$	Probability distribution Type A/ B	Standard Uncertainty $u(x_i)$	Sensitivity coefficient, c_i	Uncertainty Contribution u_i (y)	Degree of freedom v_i
Repeatability	99.915 pA	-	Normal, A	1.15×10^{-2} pA	1	1.15×10^{-2} pA	19
Standard Resistor	1.00096 GΩ	$2\times10^5 \Omega$	Normal, B	$1\times10^5 \Omega$	-9.98×10^{-20} A/Ω	-9.98×10^{-3} pA	∞
Resolution of Electrometer	–	0.001 pA	Rectangular, B	5.77×10^{-4} pA	1	5.77×10^{-4} pA	∞
Standard Voltage Source	0.0999997 V	0.00000095 V	Normal, B	0.00000048 V	9.990×10^{-10} S	4.75×10^{-4} pA	∞
Current Measured	99.915 pA					0.0152 pA	59 Veff
Expanded Uncertainty, pA		at $k = 2$				0.03 pA	

- The user has been given the option to select the distribution for the calculation of respective uncertainty contribution.
- In this module the uncertainty in measurement result is computed and the calculated expanded uncertainty in the measurement is displayed along with the measured value of the current.

Results and Data

- This module records as well as displays the measured data.
- It also shows the variation in the measured data graphically which makes the review of the results quicker and easier.
- The program developed stores the measurement results with calculated expanded uncertainty in an excel format.

Results

Table 1 illustrates the measurement results obtained for low level dc current from 1 nA down to 1 pA. As per Keithley 6517A manual[7], the current measurement accuracy for 2 nA, 200 pA and 20 pA range is ± (% 0.2 reading + 30 counts), ± (% 1 reading + 5 counts) and ± (% 1 reading + 30 counts) respectively. It has been found that results obtained in

each range of electrometer are within the specifications. The results also illustrates the % Uncertainty achieved through automation and manual measurements set up.

Table 2 illustrates the various uncertainty parameters taken into consideration for the calculation of expanded uncertainty for 100 pA current. The various uncertainty contributions that are taken into account are uncertainty in the measurement value of standard resistor used, voltage source used, and resolution of device under calibration (electrometer).

Conclusion

The new measurement system for calibrating low level dc current described in this paper has been developed to ensure that NPL-CSIR can extend its calibration capability for the measurements of dc current below 1 nA down to 1 pA. The fully automated program developed by authors minimizes human errors and also minimizes the process time. Automation program has been practically validated and implemented at NPLI. Thus the traceability for the low DC current from 1 nA down to 1 pA with an uncertainty from 0.08% to 0.4% respectively has been achieved successfully by using standards of DC voltage and DC resistance through automation.

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