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STATE STANDARD OF ELECTRICAL RESISTANCE ON THE BASIS OF VON KLITZING CONSTANT

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ABSTRACT

In this work we discuss the development problem of the high-precision reference standards. We propose to develop the state Ukrainian standard of electrical resistance based on a permanence of an inverse of conductance quantum or von Klitzing constant. Its numerical value is determined by two physical constants of substance. Therefore there exist some discussed and solved problems of numerical value of aforementioned quantity implementation to the performance of current state standard of electric resistance.

Index Terms **–** State standard of electrical resistance, von Klitzing constant, Hamon network.

1. INTRODUCTION

In this work we discuss the problem of implementation of the high-precision reference standards just as it was regarded by participants of Royal Society Discussion Meeting, for instance by [1]. We consider the state standard of electrical resistance. This standard is proposed to develop by applying the latest nanotechnology achievements, such as research of electrical conductivity of carbon nanotubes.

2. STATE OF PROBLEM

According to the state primary standard unit of electrical resistance, physical value or range of values of a physical quantity that is realized by standard is equal to 1 ohm and 100 ohms. State primary standard provides storage, verification and supervision of the mentioned unit with standard deviation measurement result S_m not exceeding $3{\cdot}10^{-8}$ ohm at 10 independent observations. Non-eliminated component of systematic constituent of relative error is $30{\cdot}10^{-8}$ (Fig.1).

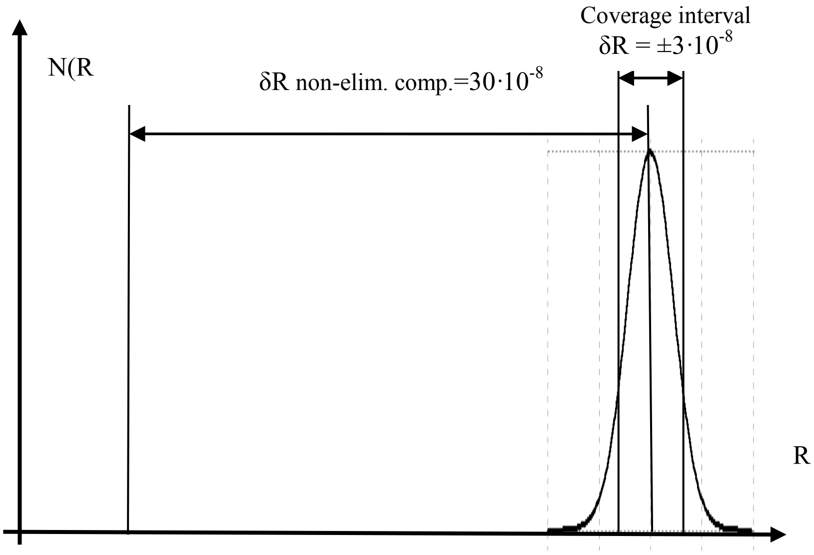

Fig.1. Instrumental error of Ukrainian state electrical resistance standard

3. WORK GOAL

The work goal is the metrological study of nanoobjects information parameters and the creation of state standard of electrical resistance on the basis of the von Klitzing constant or/and inverse of conductance quantum due to the achievements in the nanotechnological principles development.

4. BASIC METHODOLOGY AND DETERMINING ROLE OF INVERSE OF CONDUCTANCE QUANTUM IN RESISTANCE STANDARD CREATION

4.1. Nanotechnological achievements and von Klitzing constant

It was found earlier that under certain conditions the electrical resistance of nanotubes does not depend on their size and substance; since they are inherent in superconductivity. Simultaneously a measured resistance determined by the resistance transient contacts constitutes von Klitzing constant and inverse of conductance quantum $R_0 = \frac{h}{2e^2}$ =12906.4037217 *ohm*, where h – Planck constant [6.62606957(29)·10^{-34} J/s], e – charge of electron [1.602176565·10^{-19} C].

So, standard unit of electrical resistance realized by CNT is determined by only two mentioned fundamental physical constants. Latest are defined with high precision by means of a set of different physical methods. To study the Planck constant are applied the research methods: Watt balance, installations of studies of X-rays crystal density, Magnetic resonance, Faraday constant, Josephson constant. CODATA 2010 recommended value of weighted mean Planck constant relative uncertainty is $u_h = 4.4\times10^{-8}$ [2]. The same concerns the charge of electron, which uses the results of different research and its evaluation methods: Millikan's oil-drop experiments, E.Rutherford and other scientists' investigations: relative standard uncertainty of electron charge determination is $u_e = 2.2\times10^{-8}$ [2].

4.2. Nanometrological research of the CNT resistor performance

Basing on the aforementioned data we have estimated the relative uncertainty resistance of CNT resistors: $u_R = \pm\left(u_h + 2u_e\right) = \pm\ 8.8 \cdot 10^{-8}$. Transition to the mean square error is made by the equation: $\sigma = \frac{u}{\sqrt{3}} = \pm 15.242 \cdot 10^{-8}$ (Fig.2). Absolute value of proposed standard tolerance limit is defined as ± 0.0019672 ohm.

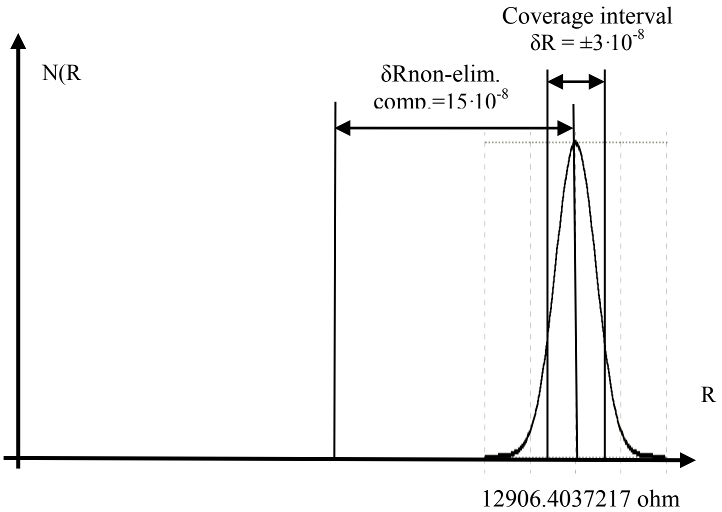

Fig.2. Instrumental error of state electrical resistance standard, based on the inverse of conductance quantum

Our studies permit to concern the relative non-eliminated component of systematic constituent of relative error of the proposed resistance standard (Fig.2). It is twice lesser than a similar error of current Ukrainian state standard (Fig.1). At the same time, the relative standard instability, as such, cannot exist since the Planck constant and electron charge are basically unchangeable. Their meanings can only be defined more exactly while further developing the experimental research methods.

4.3. Agreement with the published data

Simultaneously in [3] there was submitted a value of relative standard uncertainty of von Klitzing constant (25812.8074434 ohm) – 3.2 $\cdot 10^{-10}$, or it is much more precise than the obtained value. May be, it refers to the coverage interval of the results of repeated measurements of resistance standard.

5. DEVELOPMENT OF METROLOGICAL ASSURANCE

5.1. Measurement scheme

Standard 4-wire scheme is sufficient to measure the resistance of carbon nanotube: current is fed by one pair of subminiature electrodes; another pair of electrodes is used to connect a voltmeter. The ordinary error of resistivity value gauges due to leakage current is absent since nanotube is characterized by perfect conductivity.

5.2. Proposed resistance pattern

It may be metrologically expedient a real resistance standard composed of two rows (7 + 6) of 13 superconducting nanotubes that together form a resistance value $R_{\sum} = \frac{h}{26e^2} = 992{,}8002863\ ohm$. Then a relative non-eliminated component of systematic constituent of relative error is the same and equal to $15.24 \cdot 10^{-8}$.

5.3. Transfer size scheme and method

Transfer size scheme of electrical resistance unit is realized as follows.

5.3.1. First stage of transfer

First of all, the size is transferred to a higher value - 1000 ohm resistance that has been formed by 13-parallel-connected carbon nanotubes (992.8 ohm) with 7 connected in series resistance of 1.0 ohm value. Transfer is realized by the method of substitution while equalizing the values of 2 compared resistances – standard one (999.8 ohm) and ten working standards with a nominal value 100 ohm of each (the Hamon network is made up of ten resistors). Then a high precision measurement is reached because the measurement error does not depend on the errors of measuring instruments; it is determined only by their quantization error. The latter can be reduced to the required value by selecting the minimal resistance of bridge circuit branch.

According to [4], the Hamon network is placed inside a cylindrical box which contains also the guarding resistors and the servocontrol to perform the parallel connection. The device is directly connected to the input of the pico-ammeter under calibration in order to minimize the leakage current, triboelectric effects and electromagnetic noise.

5.3.1. Second stage of transfer

In the second stage, with previously determined numerical value of 10 mentioned working standards we transfer an electrical resistance unit from proposed resistance pattern (p.5.2) to a certain 100 ohm working standard of electrical resistance.

For this aim we again apply the method of measuring the ratio of two similar values resistances. The mentioned 9 working standards are switched in parallel connection (3 branches with 3 working standards in each), aiming to form 100 ohm resistance value. Then similarly the specified on the 1st stage measurement method is carried out to measure the ratio of this composed 100 ohm resistance to the tenth one working standard of 100 ohm denomination.

As a result, the non-eliminated component of systematic error of inverse of conductance quantum (12906.4037217 ohm) is successfully transferred to the 100 ohm current working standard while maintaining the sustainable improved value size of latter – the current numerical value of the State standard.

6. CONCLUSIONS

1. Simple result of nanotechnology achievements direct implementation seems to be the creation of the Ukrainian state standard of electric resistance based on inverse of conductance quantum; its calculated value is determined as (12906.4037 ± 0.0020) ohm.
2. Such standard may be successfully realized on any superconducting nanotubes, for example CNTs.

3. Due to array of world-wide previous researches we can argue that non-eliminated component of systematic constituent of relative error of proposed electrical resistance standard is twice reduced in comparison with the current standard.
4. Questions of technical realization and transmission of unit dimension are considered, in particular by a Hamon network application.

References:

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