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Physics Procedia 72 (2015) 249 – 252

Physics Procedia

Conference of Physics of Nonequilibrium Atomic Systems and Composites, PNASC 2015, 18-20 February 2015 and the Conference of Heterostructures for microwave, power and optoelectronics: physics, technology and devices (Heterostructures), 19 February 2015

Precise Measurements of Surface Roughness with the Induction Method: Restrictions on the Sensitivity due to Thermal Fluctuations

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Abstract

The perspectives for the increase in the accuracy of optical frequency standards by means of the development of "nuclear clocks" – a novel frequency standard based on the nuclear transition to the long-living isomer nuclear state of thorium-229 with energy ~7.6 eV are discussed. Theoretical estimations give a possible accuracy Δν/ν ~1×10-20, that allows wide scope of applications for a frequency standard, from satellite navigation systems to experimental verification of the principles of the general theory of relativity. The results are presented and the future prospects for research are discussed on the measurement of the isomeric transition in the nucleus of thorium-229 and creation on its basis the frequency standard of the new generation.

Peer-review under responsibility of the National Research Nuclear University MEPhI (Moscow Engineering Physics Institute)

Keywords: Local electrochemical deposition, thorium oxide clusters, nuclear frequency standart

1. Introduction

Control of tribological properties of surfaces in a nanometer scale and on a large measurement base is one of challenging trends of nowadays nanotechnology industry [1]. These properties closely related to surface roughness essentially manifest itself in many precision High Tech instruments and technological processes, for example, in the wear resistance of movable joints and sliding bearings, sealing of mobile connections in the flow of liquids and

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Peer-review under responsibility of the National Research Nuclear University MEPhI (Moscow Engineering Physics Institute)
doi:10.1016/j.phpro.2015.09.076

gases through pipelines, adhesion friction coatings, in the reflectivity of aspheric mirrors with large radii, as well as in the electronic properties of thin-film structures used in the semiconductor industry, and so on and so far. As a rule surfaces besides of macro-scale roughnesses have roughness values that lie in the region of tens of a nanometer [2]. To provide necessary physical and mechanical properties of surfaces their roughness's needed to be measured and controlled with a high enough accuracy. Moreover, the nanometer accuracy should be guaranteed on a large measurement bases exceeding 100 mm. Standard methods such as probe microscopy, profilometry and interferometry are found to be ineffective for these purpose. In Ref. [2] the authors proposed the so-called profilography as one of the possible effective methods allowing to measure geometric surface parameters with the resolution below 10 nm on bases of size greater than 100 mm. The latter is important for certification of industrial surface samples with dimensions exceeding the specified range.

In this paper we firstly recall the scheme and functional properties of a profilograph as a device that implements the induction method for precise measurements of surface roughness, and the results of its calibration. The limit sensitivity of this method is estimated via the calculated maximum mean value of the induced magnetic flux due to current fluctuations.

2. Profilograph: the working scheme and results of calibration measurements

The sketch of a profilograph presented in Fig.1 is reproduced from Ref. [2]. The scheme includes a few working elements. Linear guide (1) is made [3]of a Si(100) plate 300 mm in diameter. Specially made fluoroplastic carriage(3) is equipped with the profilograph probe (4) contacting the sample surface (2) and performs precision displacements along the base of the linear guide [3] provided by a micro screw-and- step motor (5) having a summary motion accuracy of 2 nm per step.

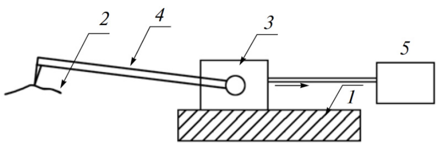

Fig. 1. Scheme of the profilograph: (*1*) linear guide, (*2*) sample surface, (3) fluoroplastic carriage with built in sensor, (*4*) profilograph probe, and (*5*) step motor with microscrew drive.

The key working element shown in Fig.2 is a differential induction sensor. Being connected with the probe axis and integrated with the fluoroplastic carriage it records the vertical deviations of the probe height in the process of scanning the surface.

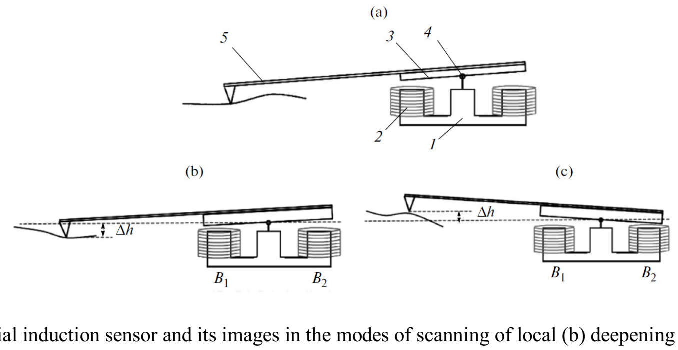

Fig. 2. (a) Scheme of differential induction sensor and its images in the modes of scanning of local (b) deepening ($\Delta B = B2 - B1 < 0$, $\Delta h < 0$), and (c) lifting ($\Delta B = B2 - B1 > 0$, $\Delta h > 0$): (*1*) E_type ferrite core, (*2*) inductance coils, (*3*) ferrite bar, (*4*) pivot axis of ferrite bar, and (*5*) profilograph probe.

The sensor comprises an E-type ferrite core [3] having a magnetic permeability of 2000, with two identical inductance coils wound around its end arms. Being located parallel to the core a ferrite bar is separated from the