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Surface imperfection and wringing thickness in uncertainty estimation of end standards calibration

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ABSTRACT

Empirical estimation of uncertainty in dimensional metrology is a vital part in calibration processes. Uncertainty estimation in gauge block measurement mainly depends on three major areas, thermal effects, dimension metrology system that includes measurement strategy, and end standard surface perfection grades. This paper focuses precisely to estimate the uncertainty due to the geometrical imperfection of measuring surfaces and wringing thickness $U(L_g+L_w)$ in calibration of end standards grade 0. An optomechanical system equipped with Zygo interferometer and AFM techniques have been employed. A novel protocol of measurement covering the geometric form of end standard surfaces and wrung base platen was experimentally applied. Surface imperfection characteristics of commonly used 6.5 mm GB have been achieved by AFM in 2D and 3D to be applied in three sets of experiments. The results show that there are obvious mapping relations between geometrical imperfection and wringing thickness of the end standards calibration. Moreover, the predicted uncertainties are clearly estimated within an acceptable range from 0.132 to 0.202 μm respectively. Experimental and analytical results are also presented and discussed.

1. Introduction

In dimensional metrology, the uncertainty estimation is always influenced by the procedures and the conditions of length measurement. End-to-end effects in calibration of end standards are constantly a necessary part in length metrology. From the calibration of primary length standards (a stabilized laser wavelength) to the calibration of secondary end standards (gauge blocks, GBs), it was important to accurately identify the major impacts on the uncertainty estimation [1]. There are many grades of gauge blocks (K, 0, 1 and 2 (commonly working as end standards in different accurate industrial applications, especially in molding, automotive and aerospace industries. Out of dimensional tolerance can produce a number of engineering problems, vibration, frictional wear and noise [2,3].

One must know the requirements of gauge blocks: (1) the surfaces must have a smooth finish, (2) the surfaces must be flat, (3) the double faces must be parallel and (4) the actual size must be known as a natural expression of the nominal size [4]. Materials of GBs are made including specific conductions such as hardness, temperature stability, corrosion resistance and high quality finish.

Fig. 1 emphasizes the truth of metrologists say "No surface is perfectly smooth", the surface of GB is rarely so flat, or smooth, but most commonly it is a combination between the tolerances limit t_1 and t_2 due to the surface finish quality. In dimensional metrology, such calibration should be performed to specified tolerance (permissible deviation).

The main purpose of gauge blocks is to provide standard linear dimensions known to within a given precise tolerance. The gauge block grade 2 is intended for shop floor use to set and calibrate fixtures as well as precision instruments. Grade 1 is used within an inspection area to verify the accuracy of plug and snap gauges as well as for setting electronic measuring devices. The gauge block grade 0 is higher accuracy gauge and is intended for use within a controlled environment by skilled inspection staff. GBs are mainly used as reference standards for setting high precision coordinate measuring machines and for the calibration of lower grade gauge blocks [5]. Gauge block grade K has the highest accuracy and intended for use within a temperature controlled inspection room or calibration laboratory. Gauge block grade K should be used as masters with certificates against other gauge blocks which are calibrated by comparison.

The main purpose of gauge blocks is to provide linear dimensions known within a given precise tolerance. The four grades of GBs include different tolerances "t_1 and t_2" as follows: reference grade $A^3 \equiv 00$ with higher tolerance ± 0.05 μm (50 nm), calibration

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grade $A^2 \equiv K$ with tolerance from $+0.10$ µm to -0.05 µm, inspection grade type $A \equiv 0$ with tolerance from $+0.15$ µm to -0.50 µm, and industrial workshop grade with lowest tolerance (from $+0.25$ µm to -0.15 µm) [4,6]. GB grade 0 is the most popular grade in the large range in length metrology; it is usually suitable for most applications and offers best combination of accuracy. Laser interferometry may be considered as a primary method in the calibration of end standards. One of advantages in using the Zygo interferometric system with a novel protocol is to avoid the phase change effects which is an important condition to adhere/wring a gauge block to a base platen having the same material and surface perfections properties which is practically difficult to guarantee. An atomic force microscope (AFM) technique is an advanced nanometrology tool used for surface characterization of GBs faces in 2D and 3D profiles. Uncertainty evaluation for the measurement of GBs by a popular optical laser measurement method is estimated [6,7]. A multi-wavelength interferometer using a pattern analysis method based on a fringe fraction method has been referenced [8]. There are different measuring techniques that can be used for surface characterization in micro- and nano-scales [9]. Using a compatible measuring technique including the optomechanical system with the Zygo measurement interferometer system, it is possible to consider a new method.

Because of ultraflat surfaces of gauge blocks and base platen, they get wrung to each other tightly with little force. Properly wrung locks may withstand a 330 N pull [10]. Indeed, the exact contact mechanism that causes wringing are as follows: (1) molecular attraction occurs when two very flat surfaces are brought into contact, this force causes GBs to adhere even without surface lubricants; (2) air pressure applies contact pressure between the blocks surfaces because the air is squeezed out of the joint. Giving quantitive information about the degree of imperfectness of geometric features on work pieces (gauge blocks–base platen) is very important for further improvement of accuracy on dimensional metrology. The traceability chain is achieved by calibration of the gauge blocks according to defined international standard ISO 3650 "the perpendicular distance between any particular point of the measuring face and the planar surface of an auxiliary plate of the same material and surface texture upon which the other measuring face has been wrung". One can say that, the minimum conditions for wring-ability (the ability of two surfaces to adhere tightly to each other in the absence of external means) are a surface finish of 0.025 µm or better and flatness of at least 0.13 µm [10,11]. Recently, some published work interests to study the surface profile of GB ends using AFM compared to reference flat mirror to verify standard/reference measurement accuracy [12–14]. Another research work studied the roughness of the surface of the GB measuring face were obtained using an interferometer method [15].

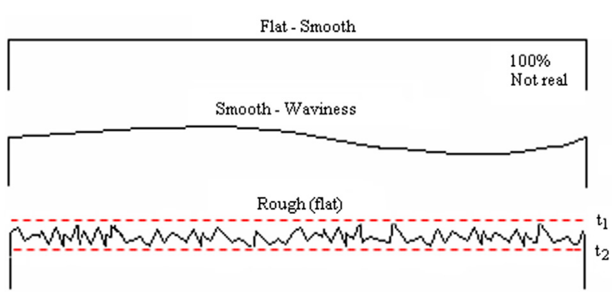

Fig. 1. Surfaces of GB measuring faces are commonly a combination of tolerance limit.

In this paper, a novel measurement strategy uses a compatible measuring technique for emphasizing accurate dimensions measurements in order to estimate the impacts of surface finishing imperfection (L_g) and of wringing thickness (L_w) onto an end standards, see the proposed method in Fig. 2. The major advantage of the developed work is for estimating and accurately determining the actual empirical values of uncertainty using a novel protocol which includes AFM and optomechanical system equipped with the Zygo measurement interferometer for further improvement of accuracy on dimensional metrology.

To achieve this goal, an equipped compatible measuring technique has been proposed. Characterization of surfaces imperfection of the common used 6.5 mm GB ends has also been investigated using AFM to be more suitable for the proposed three experimental sets. The estimated uncertainty $U(L_g+L_w)$ based on the previous mentioned conditions for wide range of GBs were practically determined and interpreted.

2. The conceptual measurement process

Traditionally, calibration of gauge blocks is very important for the traceability in length metrology. Geometric imperfections of end standard surfaces cause the most pronounced variation in gauge length which represents a value to be considered. The slight deviations in end standard geometry by either imperfect flatness or parallelism of measuring faces have a gross contribution in an added uncertainty for the measured length [4,16]. Fig. 3 shows plan of three experimental sets preserved for calibration. Three sets of gauge blocks including lengths (6.5 mm with 30 mm, 6.5 mm with 60.0 mm, and 6.5 mm with 90.0 mm) have been selected. Indeed, three sets of wrung GBs 36.5 mm, 66.5 mm, and 96.5 mm that selected in order to cover suitable range of GBs in the short range. The shortest GB size 6.5 mm has been used in all sets of experiments to avoid any sources of other errors. Determination of L_w due to the wringing thickness between measuring faces and L_g due to the geometrical form of surface imperfections for these range of GBs was the aim of these calibrations.

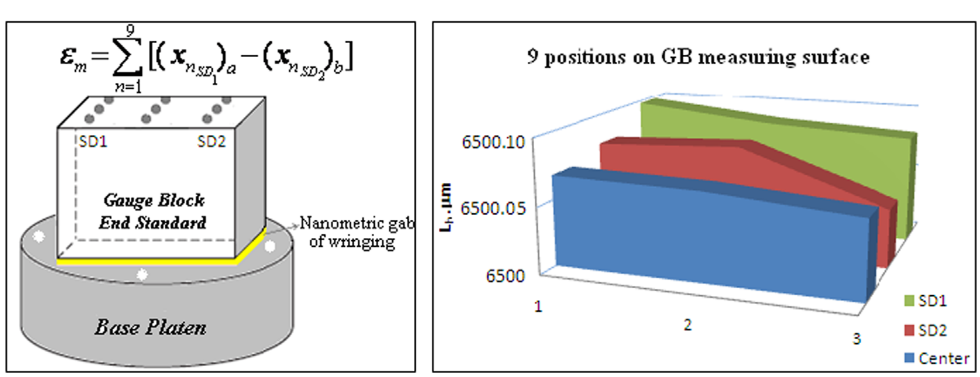

Fig. 2. Novel protocol of gauge blocks calibration.