. Introduction

Accurate length measurement plays a vital role in meeting the needs of industry and commerce for traceability to common national and international standards, especially in view of the common market and world trade. Such measurement needs arise across a wide applications base, from large-scale engineering projects such as dam construction, aerospace and shipbuilding, through automotive engineering and components manufacture, to precision engineering and nanotechnology[1]. The lowest uncertainty attained in dimensional measurements of a material object occurs in semiconductor industry and integrated circuit (IC) production. The dimensional feature of interest in a line scale is the critical dimension (CD). The CD corresponds to the width of the smallest line that can be produced on a wafer with an acceptable yield of manufactured devices; presently this parameter is less than 0.1 µm. Requirements in other areas, such as manufacture of precision instruments, large machines (e.g. planes), and others also rise fast. In all these areas the principle “to stop means to fall behind” is in force. Development of measurement systems is impelled by the augmentation of customer needs as well as by steadily evolving state-of-the-art measurement technologies [3]. Length metrology has a fundamental role to maintain the primary standard of length, the metre, and to provide the infrastructure to enable a wide range of dimensional and positional measurements to be made traceable to the metre. National metrology institutes (NMIs) in a number of countries and companies that produce precision high-tech products pay much attention to accuracy-related research with the aim to improve properties of length calibration systems and to specify their uncertainty budget.

Metrological programmes in the area of length measurement are consistently carried out in the USA, Japan, UK, Germany [1 & 3 & 4], and other countries. The programmers impel the creation of metrological infrastructure that increases industry competitiveness, supports industrial innovations, and improves control of manufacturing processes and quality. For example, systematic research of accuracy of vacuum nano-comparator, performed in German National Metrology Institute (PTB) in 2000 – 2006, resulted in reducing the measurement repeatability error from 14 nm down to 0.2 nm. NIST, the National Metrology Institute of the USA, is carrying out research on nm-accuracy one dimensional (1D) metrology with the development of components of next generation length scale interferometer. In conceptual design, the system would have a range for 1D measurements from 100 nm to 1 m with a target expanded uncertainty of from 1 nm to 10 nm.

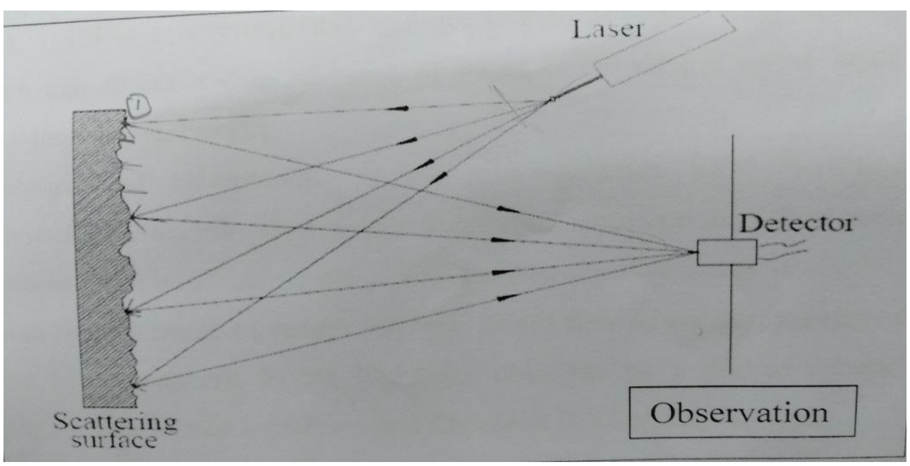


Figure (1) , Speckle Formation (3) [1 & 3 & 4]

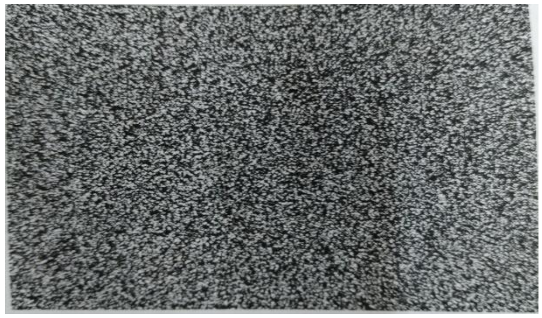


Figure (2), Speckle (2). [1 & 3 & 4]

One of the most sophisticated challenges for science and the high technologies engineering is the growing need to address real industrial problems rather than the ideal measurement situation and embed the traceable length metrology directly into technological processes by performing precise dynamic measurements in more demanding environments than those of calibration laboratories.

This chapter will present a synopsis and analysis of literature and existing scientific and technical solutions of precision length calibration. It covers analysis of laser interferometers, line detection systems, measurement signals and algorithms, as well as measurement capabilities of state-of-the art calibration systems worldwide. The contribution also addresses a thorny issue of achieving reliable measurements and meeting contradictory requirements of accuracy and productivity of line scale calibration in non-ideal environmental conditions, under the influence of many external influencing factors. The problems will be also upon the anvil of the development of an interferometer-controlled comparator that is operated in dynamic mode and enables to trace the calibration of line scale of up to $L \leq 3.5$ m long to the wavelength standard

CHAPTER ONE

1.1. Length metrology

The basis of any dimensional measurement technique is found on the realization of the SI unit of length via frequency-stabilized lasers and displacement interferometry. The measurement technologies employed include laser-ranging devices, large-scale coordinate measuring machines (CMMs), optical- and ultraviolet-light microscopes, scanning electron microscopes (SEMs), atomic force microscopes (AFMs), and scanning tunneling microscopes (STMs).

Both direct and indirect high accuracy measurements of length, distance and displacement make use of wavelength or optical frequency sensing techniques. Direct measurement techniques include laser interferometer calibration of computer numerical controlled (CNC) machine tools and CMMs, and commercial laser-based instrumentation is widely used both nationally and internationally for this purpose, to measure displacements and distance from typically a hundred nanometers to tens of meters. Multiple wavelength instrumentation is used to extend accuracy within well-controlled environments, whilst modulated laser ranging techniques (electronic distance measurements) are now widely applied in surveying over distances up to a few kilometers with, in some cases, sub-millimeter precision. Such precision instrumentation comprises laser wavelength sources as measurement transducers of varying degrees of stability and accuracy. Dimensional metrology covers measurement of dimensions and in principle also geometries based on distance measurements in a wide range of more specific measurements, targeted on from primary sources, i.e. lasers to geometrical measurement of complex profiles, which typically include;

- measurement of laser wavelength/frequency, stability, drift and line width of radiation sources that are used for interferometry and distance measurement;
- measurement of size or geometric features, like pitch, of 1D artifacts, for example end standards and linear scales or encoders;
- measurement of size and/or locations of features in 2D structures common in the semiconductor industry, such as in the complex patterns of integrated circuits
- measurement of size location and orientation of features in 3D patterns;
- measurement of deviations from ideal geometric forms, i.e. flatness, roundness, etc.;
- measurement of surface texture.

Calibration of a variety of parameters associated with the source, such as absolute wavelength or frequency, linewidth, stability or drift, are thus of primary importance to high precision length traceability. In parallel, techniques in wavelength metrology are targeted on other applications. These include spectral bandwidth characterization by wavelength division multiplexing (WDM) for optical communications, high resolution spectral analysis using Fabry-Perot standards, and high accuracy measurement of spectroscopic phenomena, which has strong input to scientific spectroscopy. Precision length metrology also plays a key role in the realization of derived units of pressure and current, for example. The highest wavelength/frequency accuracy and stability available contributes to the leading-edge determination of fundamental physical constants [2].

There are a number of sensor technologies and instruments with nanometer, or better, accuracy for measuring length that repeat well if used carefully, including the scanning probe and electron microscopes and some optical devices. However, universal measurement standards have not yet been established and even apparently sophisticated users of atomic force microscopes can produce large variations in their measurements of the same artifacts. Without agreed standards, tools or machines cannot be calibrated at the nanometer scale [3].

Line graduated geometric bodies, with graduation spacings representing known distances, are the bases for all direct measurements of specific distances. It follows that instruments having line graduated elements as integral members may be considered the only mechanical means capable of carrying out direct measurements without complementary equipment or processes [4].

The need for reduced uncertainty in the “primary standard” aspect of length, i.e., in its definition and realization, and in the “secondary standard” aspect, i.e., in its transfer and dissemination through dimensional metrology, is linked strongly to tightening tolerances in industrial manufacturing.

1.2 Definition and realization of meter

The definition of the meter—whether in terms of a prototype meter bar, a wavelength of light, or the propagation of an electromagnetic wave in an interval of time—has provided the basis for the lowest-uncertainty realization of the unit. In 1983, the meter was re-defined again to the one in effect today, namely: “The meter is the length of path traveled by light in vacuum during the interval of 1/299 792 458 of a second”. At that time, the International Committee on Weights and Measures (CIPM) gave three basic methods for the practical realization of the meter: time-of-flight, using time intervals, and interferometry, using wavelengths or frequencies. CIPM gave five recommended radiations with assigned frequencies, wavelengths, and uncertainties [5]. Of the recommended radiations, that of the iodine stabilized helium-neon (He-Ne) laser is the most widely used for practical realization of the meter. It has a wavelength of He-Ne = 632.991 398 22 nm, [5] with a relative standard uncertainty r u of 2.5×10–11[10].

The effect of the re-definitions and advances in measurement of the frequencies of recommended radiations was to decrease the relative uncertainty attainable in realization of the meter by five orders of magnitude [5]. Measurements of dimensions of material goods are most often referenced to the SI unit of length through material artifacts calibrated as dimensional standards. The meter, the basic unit for length, is usually transferred to measurement standards in the form of line scales or photoelectrical incremental encoders by length measuring machines that typically use a laser interferometer in air as reference measuring system. The measurement results are traceable to the meter due to the use of the wavelength of the laser interferometer.

1.3 Laser interferometry

Since practical realization of meter is closely related with the radiation of stabilized frequency lasers, laser interferometers are utilized for precise and traceable length measurements. Currently the detection principles of laser interferometer systems can be distinguished between homodyne and heterodyne techniques [6]. Homodyne interferometers utilize one frequency laser, and heterodyne two frequencies laser respectively. Heterodyne interferometry is inherently more resistant to noise due to its heterodyne frequency and the design of common-mode rejection which cancels out common noises coming from both reference and measurement signals, and though heterodyne techniques are susceptible to larger nonlinearity errors a large number of commercial systems uses namely this technique. Nevertheless the main parameters that determine the quality of laser interferometric systems are [6]:

- resolution,
- measurement accuracy,
- repeatability of results,
- dynamic and measurement range,
- measurement speed.

A homodyne laser source is typically a He-Ne laser with a single frequency beam as output consisting of either a single polarization under 45° or a circularly polarized beam. The beam is split into the reference arm and measurement arm of the interferometer by a beam splitter. Following a reflection off their respective targets, the beams recombine in the beam splitter. In order to observe interference the two beams must have equal polarizations.

This is accomplished using a linear polarizer oriented at 45° to the beam splitter. The photo detector signal is run through electronics which count the fringes of the interference signal. Every fringe corresponds to a path difference of half a wavelength. After superposition of measurement and reference beams a polarizing beam splitter is used to generate two 90° phase shifted signals. The direction of movement is determined at zero crossings of the interference signal using the other signal. Counting of the zero crossings of both interference signals provides a resolution of $\lambda/8$ which is not sufficient for precision length measurements and therefor it has to be enhanced by interpolation techniques. In homodyne interferometers the amplitudes of the interference signals are used; the phase of the signal can be determined from intensities of perpendicular polarized signals. Manufacturers of homodyne interferometers are Renishaw, Heidenhain, Sios and recently Interferomet.

In heterodyne interferometers double frequency radiation source is required since the interfering measuring and reference beams must have slightly different frequencies and photo detectors detect the phase shift between these two beams.

CHAPTER TWO

2.1 .INTRODUCTION

If a high coherent light such as laser is incident on a rough surface , the coherent light will be back scattered in all direction as shown in figure .If there is a detector such as an eye observer , the object surface will cover by speckles which are dark and bright spots as shown in figure(2).

Speckle phenomena were viewed in the past as a disturbance that must be suppressed or eliminated . however , the measurements that based on the speckle phenomenon become an important subject in the optical metrology which gives an accurate measurement.

Many techniques were used to detect a statement of the sample under the test . these techniques may cause a failure into the sample or may don't reach every point on it , or their detection confined to a point or small area of the sample.

Inter ferometry is a strong optical tool that has several applications within physics and engineering . when two or more partially coherent light beams are superimposed , a locative pattern of modulated intensity is recognized in the region of superposition [4].

ESPI is one of the non-destructive optical testing techniques give a full field map detection of the tested sample [5].Electronic speckle pattern-interferometry (ESPI) combines double ray interference technology with digital recording devices[6].ESPI can be classified as in-plane ESPI (two speckle fields) in it the measuring direction are X and Y-directions , and rough surface ESPI (on speckled filed and a reference beam) in the Z-direction [7] .

ESPI is Avery sensitive technique that detects a very small displacement sample which can detect a displacement of some order of the using laser wavelength which is used into the design [8].

Some application of electronics speckle interferometer ESPI techniques include; material defect detection , vibration mode shape measurement, full filed measurement of surface deformations , shape and slope , the measurement of residual stress[9].

2.2. Theoretical background of rough surface pleat displacement by ESPI

The speckled fringe patterns in the ESPI are obtained by a digital subtraction of two speckled images. One image is before, and the other is after displacement.

The intensity of the light fall on the CCD camera before displacement (I_1) is given by[10]:

$$I_1 = I_0 + I_r + 2\sqrt{(I_r I_0} \cos\phi \quad \text{………………..(1)}$$

Where I_r = is the reference beam intensity;

I_0 = is the object beam intensity;

ϕ = is the phase difference of the reference and the object beams [10].

The irradiance of the both beams is assumed to be steady over the filed , and the phase of the reference beam is assumed to be equal to the mean phase of the image beam over the field because they both appear to emit from the exit pupil [11].

Deformation of the object changes the relative phase of the interference patterns, thus another speckle pattern is formed [7].

(I_2) the intensity recorded in the deformed state becomes[10]:

$$I_2 = I_0 + I_r + 2\sqrt{(I_r I_0}\cos(\phi + \Delta) \quad \ldots\ldots\ldots\ldots(2)$$

Where:

Δ : the additional phase difference which caused by the object displacement [10].

So ,the maximum co rrelation between Equationsl and 2 occurs when

$\Delta = 2\,n\pi$ and the minimum is occurs $\Delta = (2n+1)\,\pi$

Where n is an integer number [11].

When the optical setup shown in figure 3 is used to determine the rough surface displacement , the laser beam is split into two beams, reference beam fall perpendicularly on the CCD camera after the beam passes through a beam splitter , and the second beam which is the object beam that illuminates test sample by a Θ_0 which the angle with the Z-axis. The relationship of additional phase shift and rough surface displacement is [10]:

$$\Delta = 2\pi/\lambda \quad (1+ \cos\Theta_0)\, dz \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

When the additional phase shift equal to $2n\,\pi$, where n is the dark fringes number = 1,2 …….., the displacements in the Z-direction are given by[7]:

$dz = n\lambda/(1+\cos\Theta_0)$……………(4)

By counting the fringes number (n) , the displacement (deformation) of the object's surface in fraction of the laser wavelength is obtained.

2.3. ESPI experimental work:

Since ESPI is a coherence light dependence , the interference between two beams will be easy , so in this experimental work a green coherence laser light was used as a source . A concave lens was adjusted in front of the laser to diverge the laser beam in order to illuminate the sample surface . A beam splitter of a 50:50 division of the input power was used to split the laser beam into two beams. One of the two beams falls on the fixed mirror which is called a reference beam and the other beam falls on the rough surface of the object and called the object beam . the reflected beam of the reference beam and back scattering light of the rough object was interfered and imaged a speckled interference pattern on the CCD camera. This pattern is the reference pattern A convex lens was adjusted in front of CCD to collimate the interference light conto the CCD detector , as shown in figure (3).

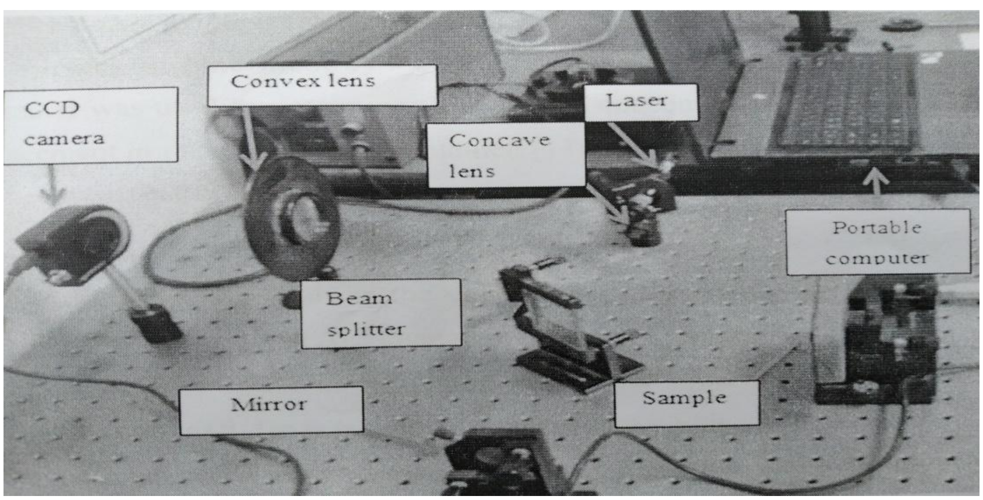


Figure (3) .Experimental setup

When the displacement of the sample takes place due to the applied load , the interference pattern was changed . by a digital image subtraction of the two interference , a fringes pattern was resulted . by using equation (4) the 0ut-of plane displacement was determined .

2.4. samples:

The dimensions of pure Germanium Grade (1) which were used in this work as a tested sample is shown in figure(4) . Ge samples with same chemical composition , and dimensions are used in work, one of them was displaced by a tension load above the yield point of Ge metal , and this sample was a reference sample to the others , the other samples were displaced by loads tension above the reference load . Regular squares of 10x10 mm were drawn at the back face of the specimens in the effective area . these squares were followed by measuring their dimensions before and after displacement.

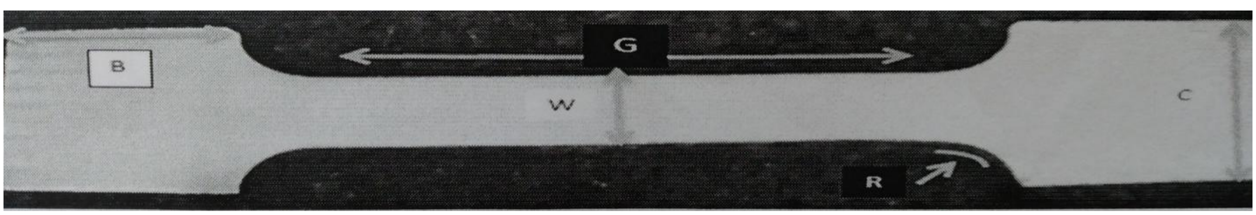


Figure (4).Tensile Ge sample.

Where G : the effective area length (gauge length) was equal to 50 mm , W: effective area width was equal to 12.5mm, R: the radius of fillet that equal to 20mm . the specimen was uniform over a gage length (effective area) with a thickness of 0.3mm.

2.5. Rough surface displacement by mechanical measurement

A micrometer was used to determine the micro displacement in the X and Y directions. The displacement in the Z-axis can be obtained [11]:

$$ex=\frac{\Delta l}{l},\ \ ey=\frac{\Delta w}{w},\ \ ez=\frac{\Delta z}{z}\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

where ex : the engineering strain in the X-direction of the square , L: is the square length which was equal 10 mm , and Δl : change in the square length . ey: is the engineering strain in the Y-direction of the square , w equals to 10mm which was the square width , and Δw is a change in the square width.

ez:the engineering strain in the depth, Δz the depth change , and Z is the initial square depth[11].

$$\varepsilon = \ln(1+e)\ldots\ldots\ldots\ldots\ldots(6)$$

Where ε: the true strain. The summation of true straian in three directions must equal to zero as follow[11]:

$$\varepsilon x + \varepsilon y + \varepsilon z = 0 \ldots\ldots\ldots\ldots\ldots(7)$$

Where $\varepsilon x, \varepsilon y, \varepsilon z$: are the true strains in the X,Y and Z direction progressively .

By substituting the displacement in the Z-direction , (Δz) was obtained which is called rough surface displacement.

CHAPTER THREE

3.1 Result and discussion :

Figure (5) shows a simple ESPI set-up for rough surface displacement measurement depending on the principle of Michelson interferometer. By the interference between the reference image (laser beam which reflected from the plane mirror), and the object beam (the back scattering laser light from the tested sample), a speckled was resuited and imaged on the CCD camera . the speckled interference pattern of the reference Ge sample is shown in figure (6).

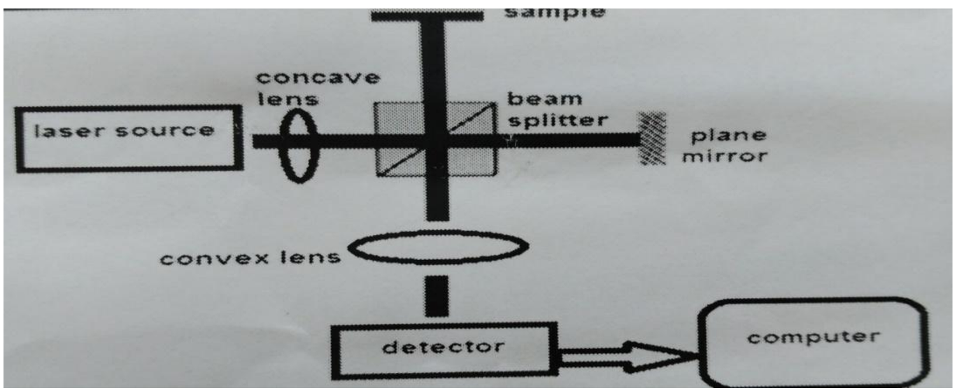
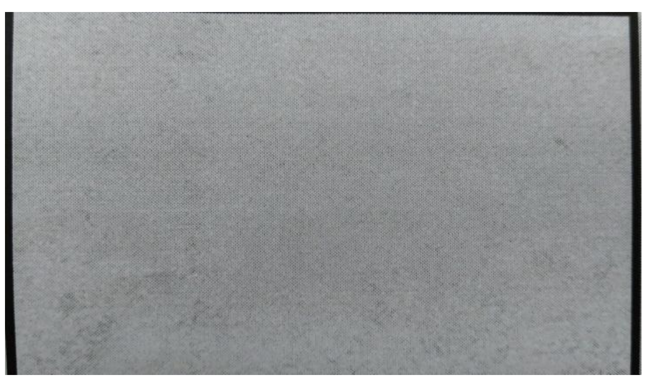


Figure (5) ,Rough surface ESPI setup.



Figure(6).Speckled interference pattern with a reference Ge sample.

After displacement was taken place into the sample this speckled pattern was varied . by using image processing technique the resulted fringes pattern with a displacement value of 1.064µm is shown in figure (7).

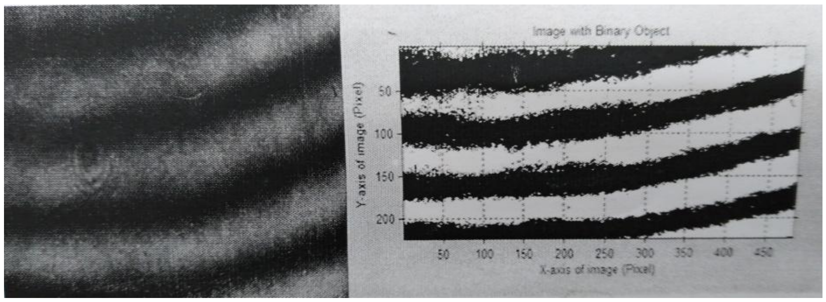
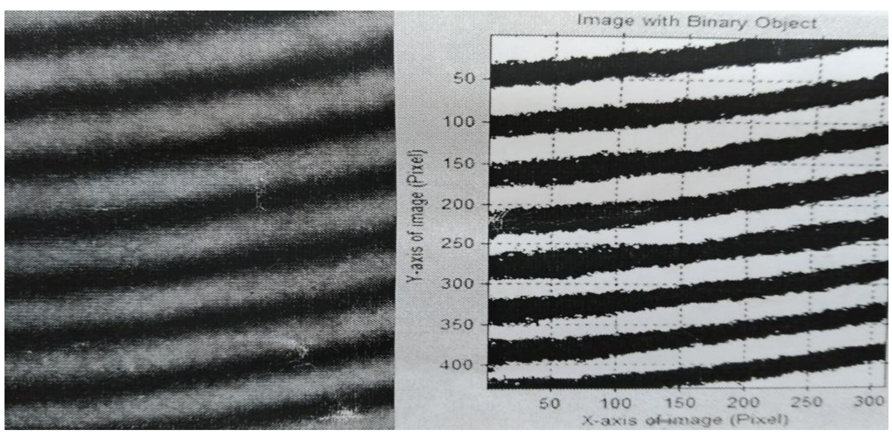


Figure (7) fringes pattern by ESPI technique and related binary interference fringes pattern.

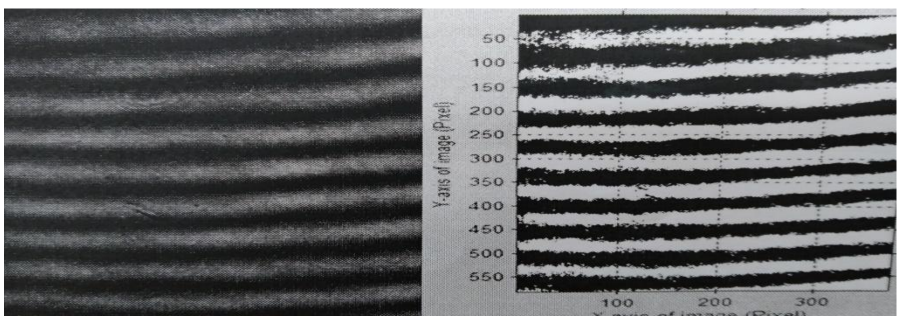
With a displacement value of 2.128µm , the fringes number was increased with increasing the occurred displacement , this is show in figure (8).



Figure(8) . Resulted image with a displacement of 2.128µ by ESPI with a corresponding binary image.

With increasing the displacement value into the Ge sample the fringes number was increased too. The resulted fringes image with a splacement value of 2.66µm in the Z-direction is illustrated in figure (9).

Figure (10) illustrate a schematic graph that shows the rough surface displacements obtained by mechanical and nondestructive optical ESPI measurements . from this graph shows that the ESPI technique was more useful , by not affecting the testing sample and it was more sensitive since the value of displacement reached to some order of the laser wavelength which was used the ESPI experimental setup.



Figure(9). Resulted image by ESPI technique for the displaced Ge sample and converted binary image for the same sample.

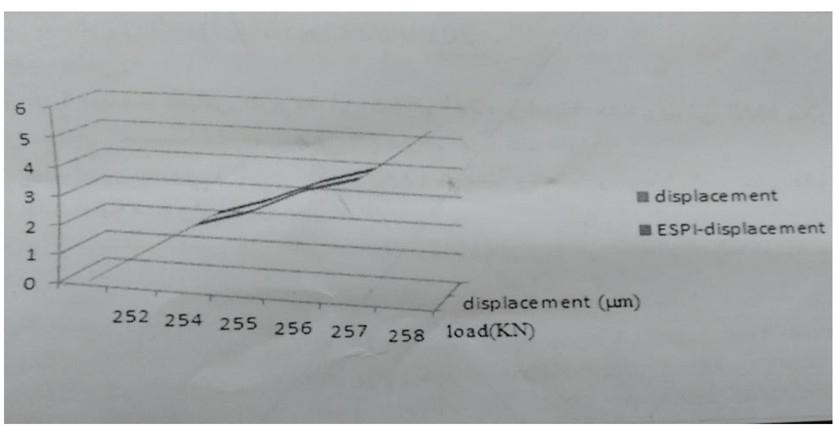


Figure (10)-D Load-displacement Curves.

3.2 Conclusions

1. Precision measurements based on the length standard are very important , and their significance is growing with the advancement of science and industrial technology. Particularly important is product quality improvement in production processes. The development of metrology standards follows the needs of technology.

2.Diversity of tools and measurement techniques in dimensional metrology require significantly more mature set of standards for characterization of the measurement process used to obtain measurement data, e.g. what sampling strategy was used, what filtering was applied and what measurands definition was applied. It will also expect more know-how on the user level of the metrology involved in operating modern measurement equipment.

3.In industrial metrology, several issues beyond accuracy constrain the usability of metrology methods. These include, among other factors, the speed with which measurements can be accomplished on parts or surfaces in the process of manufacturing, and the ability of the measurement system to operate reliably in a manufacturing plant environment considering temperature, vibration, dust, and a host of other potential hostile factors. The relevance and necessity of addressing the problem of precision and high-speed line scale calibration is primarily driven by the rapid increase of demands on calibration efficiency of precision scales. Considerably higher precision and efficiency requirements are set for new systems, besides, it is aimed at traceability of precision line scale parameters during manufacturing process in the technological line, and calibration process should be as short as possible.

4.This chapter comprehends a synopsis and analysis of literature and existing scientific and technical solutions of precision 1D length calibration. It addresses also the problems of the research and development of an interferometer-controlled comparator that is operated in non-ideal environmental conditions and enables to trace the calibration of line scale of up to $L \leq 3.5$ m long to the wavelength standard.

5.The analysis and research results represent both systematic methodology and knowledge base for evaluation the length calibration accuracy that involve current and new technologies, and can be applied gradually in various precision machinery and instrumentation.

6.ESPI is one of anon-destructive techniques ; it is a full imaging tool to the testing sample which does not affecting it, and is very sensitive to very small displacement reach to some orders of laser wavelength . however , it gives a very accurate displacement values which are close to theoretical values.

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ABSTRACT

An electronic speckle pattern interferometer (ESP) is one of optical

Non-destructive techniques, which used to find out a very small displacement due to the applied load on the sample or by its movement .

In this work the surface pleat or rough surfaces displacement was measured by designing a simple setup of ESPI depending on the principle of Michelson interferometer. Using this design and utilizing an image processing technique , a displacement in the Z-direction of Apure Germanium Grad I sample was measured that caused by applying a tension load upon it .the measured displacement cannot be noticed by A naked eye . ESPI is a very sensitive , non – destructive , noncontact , and full field imaging tool for detecting a small displacement/deformation by utilizing a fringes pattern which resulted by a digital subtraction of two speckle patterns that imaged on a CCD camera , a reference speckled interference pattern and a speckled interference pattern when the sample is displaced.

The Ministry of Planning
Organization for Standardizition
And Quality Control (COSQC)
Metrology Department/Dimensional Section

SEARCH

Measurement The Displacement &Leveling of Surface Plate Using Laser Electronics Speckle Pattern Interferometer Technique

Preparation

Thalfaa Racheed Ajeel

Senior Chief Programmer

1442 هـ 2020م

نـــــــبذة مختصــــــــــــرة

مقياس التداخل الإلكتروني لنمط البقع (ESP) هو مقياس بصري

التقنيات المنتظمة والعشوائية الغير مدمرة ، والتي تستخدم لمعرفة درجة خشونة او الازاحة وان كانت إزاحة صغيرة جدًا بسبب الحمل المطبق على العينة أو بحركتها.في هذا العمل ، تم قياس ثنية السطح أو إزاحة الأسطح اوالخشنونة من خلال تصميم إعداد بسيط لـ ESPI اعتمادًا على مبدأ مقياس تداخل ميكلسون. باستخدام هذا التصميم واستخدام تقنية معالجة الصور ، تم قياس الإزاحة في الاتجاه Zلعينة Apure Germanium Grad I الناتجة عن تطبيق حمل التوتر عليها وايضا درجة خشونة العينة. لا يمكن ملاحظة الإزاحة المقاسة و درجة الخشونة بالعين المجردة ESPI .هي أداة تصوير حساسة للغاية وغير ملامسة وكاملة المجال لاكتشاف إزاحة صغيرة / تشوه/خشونة من خلال استخدام نمط هامش ناتج عن طرح رقمي لنمطين بقع تم تصويرهما على كاميرا CCD ، وهو تداخل مرجعي مرقط النمط ونمط التداخل المبقع عند إزاحة /خشونة العينة.

3.3.Recommendations

I recommend that the device be used after its calibration in the dimensional engineering laboratory as a roughness tester

Indexing

وزارة التخطيط
الجهاز المركزي للتقيس والسيطرة النوعية
دائرة التقييس/قسم المقاييس
شعبة الابعاد الهندسية

بحـــــث

قياس خشونة الاسطح باستخدام تقنية مقياس التداخل بنمط نقطة الليزر الالكترونية

اعداد
ذلفاء رشيد عجيل
ر.مبرمجين.اقدم

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١٤٤٢ هـ

الهدف من البحث

بناء منظومة ليزرية خاصة لفحص الخشونة لغرض اغناء مختبر الابعاد الهندسية الخاص بقسم المقاييس في دائرة التقيس احدى دوائرة الجهاز المركزي للتقييس والسيطرة النوعية والتي يمكن استخدامها باحدى فعاليات المختبر وهي فعالية قياس الخشونة وذلك بعد معايرة الجهاز.

chapter one

Chapter Two

Chapter three

References

شكر وتقدير

اقدم جزيل الشكر والتقدير لاعضاء اللجنة الكرام للملاحظات القيمة التي ساهمت في اغناء البحث

الباحثة