Evaluation of surface plate characteristics using laser system at Measurement Standards Laboratory

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ABSTRACT

Surface plate characteristics influence the calibration of artifacts, instruments, working gauges and, by extension, the quality of manufactured parts. Industrial surface plates are calibrated periodically. Moody or Union Jack Method is applied to calibrate the surface plate alongside the application of latest laser equipment. This procedure necessitates sophisticated tooling and the pertinent calibration sequence to obtain the reliable results. In this method, the residual height at each position on the surface is expressed in terms of measurement parameters. A statement of uncertainty for the surface plate calibration is needed for conformance testing and for estimating uncertainty in calibrations that rely on the surface plate. The maximum uncertainty is at the center of the surface as per the Moody Method and the calculated bounds compare well with values of closure from actual measurements. The uncertainty of height values is proportional to the measurement positions. Measurement Standards Laboratory (MSL) operates under the Total Quality Management Scheme and in conformity with ISO/IEC-17025: *General requirements for the competence of testing and calibration laboratories* guidelines. The paper discusses the novel approach towards determining the flatness characteristics of the surface plate measurement uncertainty of flatness measurement applying the universally most reliable Moody Method. Furthermore, the impact of grid parameters such as alignment side, measurement sequence and number of measurement steps on measurement results is evaluated. The reproducibility of the obtained results is ascertained using the laser optics. Subsequently, the measured data points are fed into a stand-alone computer program which displays numeric as well as isometric data plots for the surface plate in measurement.

Keywords: Flatness, laser optics, laser alignment, surface plate calibration, uncertainty analysis

INTRODUCTION

The surface plate is used as the datum plane for most measurements in the metrology laboratory or shop inspection station. Flatness, defined as the maximum separation of two parallel planes entirely enclosing the surface determined upon the successful inspection. The accuracy of these measurements is therefore limited by knowledge of the flatness of the surface plate [1].

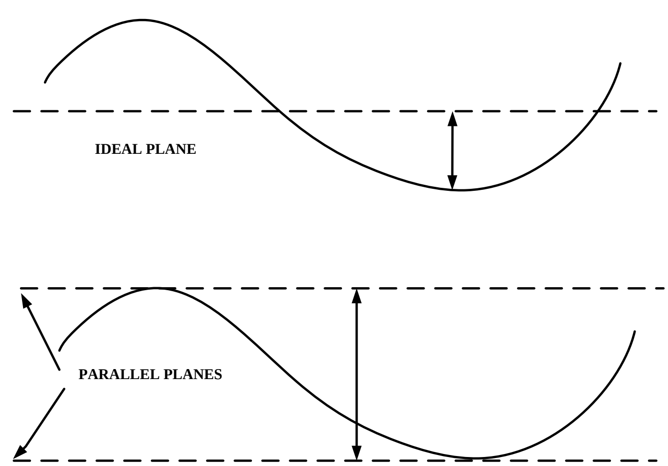

Figure1: Flatness Specifications [1]

LITERATURE REVIEW

The most familiar laser based optical nondestructive methods are based on the interference of the wave fronts of monochromatic light reflected from the test surface. Gryzagoridis [2] explored the origins, applications, advantages and limitations of Holographic Interferometry, Electronic Speckle Pattern Interferometry and Shearography. These methods are applied to the widest range of materials from metals to composites attempting to determine the conditions of the material that contribute to failure. It is well established that these laser based NDT techniques have found innumerable applications in the laboratory/field/factory environment and particularly Shearography.

Calibration of granite surface plates could be performed using different measuring systems. Zahwi, S. et al [3-4] investigated the calibration of granite surface plates using the autocollimator systems, laser systems and coordinate measuring machines (CMMs). A comparison among these methods of calibration has been carried out. Large reflecting mirror, angular retro reflector and sensitive probe are used with autocollimator, laser systems and CMM respectively to identify heights at each position on tested surface plates. Repeated results from the different methods are carried out and presented in the paper. Uncertainties associated with the measurement results of each method have been estimated using the "Evaluation of measurement data — Guide to the expression of uncertainty in measurement procedures, JCGM 100:2008 [5]" and given in the paper.

Anon [6] discussed the methods for setting up laser equipment and for making measurements at points 2 inches apart along lines on a grid pattern are described. The actual errors in flatness for a typical plate in microinch increments are shown at the individual measuring points and also were reproduced in isometric form.

Kuang-Chao Fan and Fang-Jung Shiou [7] described the work to develop a parallel beam scanning system (PBSS) for the noncontact measurement of surface flatness of such medium-sized surface plates, as sheet metals, sheet-moulding compound (SMC) plates, and glass plates, which are difficult to measure by traditional methods. The PBSS consists of a He-Ne laser source with good pointing stability, a scanner to create divergent scanning beams, a large aplanatic meniscus lens to convert the divergent beams to parallel beams, a linear stage to drive the test piece to each sampling position, a screen for the projection of reflected beams from the tested surface, and an image-processing unit to analyze the projected image. Because of the out-of-flatness of the surface, the straight line formed by the incident parallel beams will be distorted and magnified on the screen as it is reflected from the surface. A charge coupled- device (CCD) camera is employed to capture the image of the distorted line each time, and proceeds in line-by-line sequence. With the proposed mathematical model, the three dimensional (3-D) flatness data of the test piece can be converted from the input image data and analyzed by the least-squares method. Experimental results by the use of this system have shown good agreement with the results obtained from a coordinate measuring machine (CMM).

Haitjema and Meijer [8] proposed the method of determining the flatness deviation of a surface plate, using differential measurements based on electronic levels, an autocollimator or laser interferometer. However, for the transformation of these measured values into absolute heights relative to a reference plane, various methods are used which do not utilize the redundancy of the measurements in a proper way. This paper gives the theoretical background for a proper calculation method and a treatment of the uncertainties in the results.

Aketagawa [9] proposed a laser reference plane for measurement of the flatness of large-scale dimensional surfaces. A finely collimated laser beam is swept by rotating a pentaprism in an ideal plane parallel to the surface to be measured. The apex angle error of the pentaprism is the most effective one for measurement of the flatness. A practical method of compensating the apex angle error for a precision laser reference plane is presented. The measurement of the flatness of the Japanese Industrial Standard zeroth grade precision surface plate, whose deviation from flatness should be less than 7µm in an area of 1 m × 1 m, was performed using the proposed and conventional (Union Jack) methods. The results of the two methods coincided with each other and this clarified the feasibility of the proposed method.

BRIEF PROCEDURE

The dimensional lab at MSL is fully equipped to maintain prime ambient conditions needed for dimensional calibrations. As per the international standard for dimensioning and tolerancing ASME/ANSI Y14.5M standard, the temperature for dimensional measurements is standardized in as 20°C. The lab ambient parameters are maintained at temperature of about 20°C ± 0.5°C and relative humidity of about 40% ± 5%. The lab provides an excellent dust proof and vibration damping conditions as well.

The surface plate is calibrated using the widely accepted Moody [10] method of measuring flatness. In this method, the angular deflections of adjoining sections are measured along specific tracks on the plate surface and are converted to elevations from a datum using the sine function.

At MSL, an implementation of this method using a commercial two-frequency laser measurement system is employed. Laser light emitting from the laser is split into two beams perpendicular to each other by a remote-interferometer. One of these is turned 90° causing the interferometer/beam bender assembly to yield two beams that exit parallel (in two planes). A reflector carriage having rear and front feet incorporates two cube-corner reflectors such that the reflectors face the two beams and return them back to the interferometer on a slightly displaced path. The spacing of the feet of the reflector carriage is the same as the reflector spacing. Therefore, any rotation (pitch) of the reflector carriage because of elevation difference between its rear and front feet will be detected by the interferometer as one beam path length will change with respect to the other.

The surface plate bearing the tolerance limits for the flatness of ± 5 µm as per JIS B7513:1992 Precision Surface Plates Grade I tolerance serves as the test instrument for the calibration.

The ground floor of the dimensional laboratory at MSL is found to be robust enough not to affect the results and the floor is free from vibrations as well. An Agilent 5530 He-Ne Laser measurement system serves as the standard for the surface plate calibration at MSL. It is traceable to National Institute of Standards and Technology (NIST), USA. The necessary optics include Hewlett-Packard equipment primarily 10565B, 10558A beam bender and 10556A cube-corner retroreflector which are ably used in conjunction with reflector mount and square plates.

The preparatory steps include cleaning of surface plate using the cleaner and allowed to reach thermal equilibrium for at least 24 hours. A grid is drawn on the surface plate preferably with a lead pencil with suitable markings. A sample of the grid is shown in Figure 2 with clear illustration of the markings and the direction pointers.

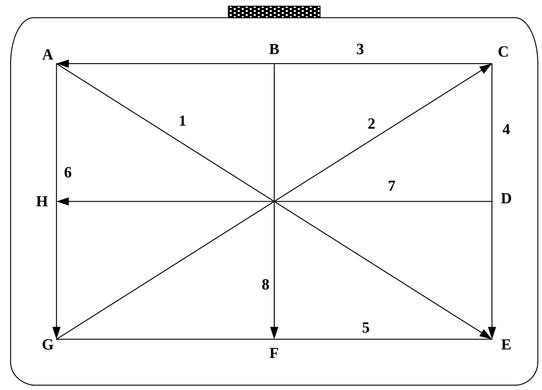

Figure 2: Grid map of surface plate [1].

The length of each line in this grid should be an even integral multiple of the foot spacing (2 inch) of the 10559A reflector mount. The laser head should be mounted such that the laser beam is pointed approximately parallel to the perimeter line GE and outside of the grid. Necessary care should be taken to ensure the alignment of laser beam (preferably>80%) with better reproducibility throughout the length measurement. The straight edge may be marked at intervals corresponding to the foot spacing for the reflector mount for ease in locating the reading positions. The interferometer and reflector positions and their movement should be properly taken care of. The test data is recorded properly in the data sheet with clear indications of line number. Enter + line number if the reflector mount moves away from the interferometer and vice-versa.

The test data for each line of the grid with proper designation of direction is recorded in calibration data sheet. This serves as input data for the stand-alone Visual Basic progam "*WinSurf Plate*" at MSL facility. The input data is fed to this program with clear feed of direction sense of eight lines including the diagonal ones. The first reading is zero for each line and the corresponding measurement data is fed for each line. This program yields results in contour formats and a sample of which can be depicted from Figure 3. The numbers are elevation from the base pate in micrometers.

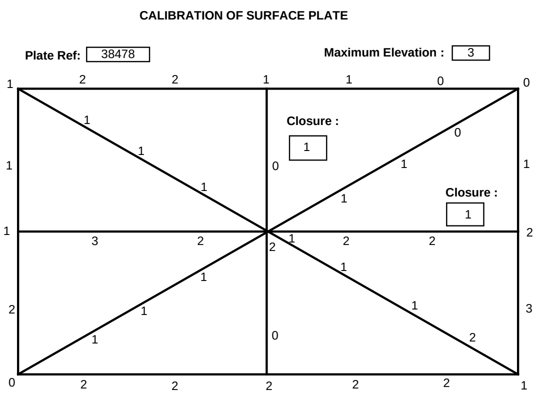

Figure 3: The pattern of tracks explored in testing the flatness of surface plate.

As per the Moody Method, the expanded uncertainty with a coverage factor, k=2, is obtained from the repeatability of measurements as reflected in closure error, which denotes the mismatch of the center point where the diagonals and centerlines cross. The maximum uncertainty is at the center of the surface and the calculated bounds on error compare well with values of closure from actual measurements.

CONCLUSIONS

This research based assessment of the surface plate calibration will enhance the existing metrological capabilities and will be of greater importance to the industrial community at large in Saudi Arabia.

ACKNOWLEDGEMENT

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