Routine Monitoring DCC CMM using Laser Interferometer

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Abstract. Manufacturing deals with the high quality product due to the accuracy which produced by measuring machines. In other case, the performance of regular diagnostic of measuring machine should be maintained to aim confidence and reliability in the measurements result. One of the equipment that can reach high accuracy is Direct Computer Control Coordinate Measuring Machine (DCC CMM). The accuracy of DCC CMM is a critical factor that affects result of product measuring. Operator need the higher accuracy machine to maintain the DCC CMM Performance and the consequent of the machine should has better accuracy than the DCC CMM accuracy it self. One of that tool is laser interferometer which has better accuracy than DCC CMM specification and produce the data and can be analyzed for DCC CMM performance. The consistent performance of the DCC CMM is constrained by the errors that brought by the machine error that occurs on a periodic basis on the account of machine usage, machine age and operating temperature. DCC CMM accuracy was compensated and improved by identifying the machine condition. This condition also applicable for predict the machine errors.
Keywords: DCC CMM, Accuracy, Laser Interferometer, Confident

1. Introduction

Manufacture industries are growing and request high quality product. To maintain high quality product, it is necessary to have high quality measurement equipment. Coordinate Measuring Machine is invented to gain the requirement of high accuracy measurement tools with the flexibility as the benefit. Moving parts as the Coordinate Measuring Machine should be calibrated and verified in order to ensure the machine's performance. This research has a purpose that Laser Interferometer's application can be applied as a Direct Computer Control (DCC) Coordinate Measuring Machine (CMM) routine monitoring and verification. In the last decade, DCC CMM has become main quality machine which inspect the final products that have a lot off accuracy and tolerance. Modern machining combined with CMM maker have developed the technology as higher measurement accuracy for a 3 + 2 axis DCC CMM. To gain the machine standard specification, calibration is a preventative action which conducted as basic machine specification by using a standard measuring artefact and compared to the machine scale. The test should be done several times to get the repeatability and the value of true scale reader. The value represented by scale and compare to the artefact / reference [1]. Routine monitoring for DCC CMM accuracy has a relation with the calibration of the DCC CMM. Calibration result will show the whole DCC CMM performance and capability. The capability is represented by the machine accuracy. Accuracy that showed in the parameter requirement affects to criterion of machine performance including quality assurance, quality inspection product, and traceability. Calibration results will maintain the machine performance for further processing of measuring requirement. DCC CMM performance should be maintained to ensure the measuring of the products can be accounted for. The monitoring results applied as one of the maintenance action for several DCC CMM to keep the performance after the machine calibrated. This action is important for maintaining confidence and reliability in the measurements [2].

2. Coordinate Measuring Machine

In the ISO 10360-2, a Coordinate Measuring Machine is a measuring system that has a moving probing system that has a function as a sensor. As the sensor, the probing will have a trigger and send to the machine controller to determine spatial coordinate as X, Y, Z position on the work piece surface. [2]. Coordinate Measuring Machine also gives a Cartesian coordinate that has a physical realization with whole system. CMM is used to measure the dimension of work piece by calculating Cartesian coordinate, and by the new technology, the machine has a capability measure the error of the work piece and compare to measurement request that provide by original drawing. The information of the workpiece will be shown as actual shape, size, form, location, and orientation and will be used for metrological evaluation. Workpiece will be evaluated using collecting data on its surface at certain points or an area generated by software calculation. The software will store different of sensors, both contact or laser/noncontact sensors, continuously/ scanning or discreetly. Each measuring point is determined in terms of its measured coordinates. The probing and sensors collect the direction of vector for each measuring point which usually provide better accuracies. [3]. Every Coordinate Measuring Machine have to mention the term of Maximum Permissible Error (MPE). The standard machine accuracy showed in the MPE value. Maximum Permissible Error contains Maximum Permissible Error (MPEE), Maximum Permissible Probing Tolerance (MPEP). Specifications are referred to as just E, P, THP etc. The most common accuracy terms of CMM mentioned in ISO 10360-2 : Volumetric Length Measuring Error E or MPEE.[4]

3. Laser Interferometer

Laser is a beam of concentrated light which possesses enormous amount of energy. The word LASER stands for: Laser Amplification by the Stimulated Emission of Radiation, which means that energy is coming from stimulated light produce by electromagnetic radiation[5].Using a laser for a measurement is a method that using phenomenon of interference of frequency that produce by waves (usually light, radio or sound waves). In the interferometry, a user will measure the wavelength difference that produced by a laser equipment. The difference of laser gap is happened when the additional equipment such like an optical device is moving. The moving devices will produce characteristics of the waves themselves and the materials that the waves interact with. Characteristic of the wave has a displacement result. The study of the techniques that use light waves for measure wave displacementIn addition, are described as interferometry. By measure the displacement, laser can be used for calibration and mechanical stage motion control in precision machine [6].

3.1. Principles of interferometry

Laser light

The output from a laser can be considered as a sinusoidal wave of light.

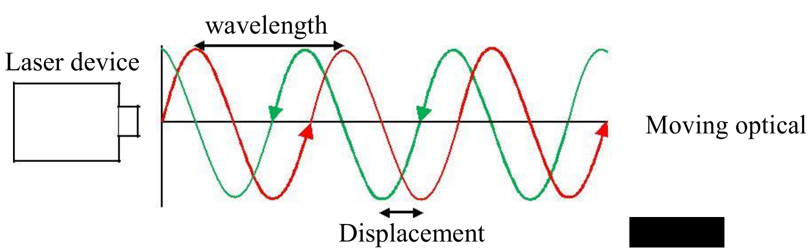

Figure 3.1. Picture of Laser Wavelength

Laser emerging light wave with the properties as:

- The wavelength of laser is precisely known, produce by laser equipment, determine accurate measurement. The accuracy is 0.5 ppm
- The wavelength is very short,that produce high resolution and precise measurement. The resolution is 0.1 nm
- All waves are in-phase, allowing interference to occur

Due to the modern technology, laser displacement interferometers utilise Helium Neon (HeNe) laser tubes. The HeNe tubes have a 633 nanometre (nm) wavelength output [7]. The homodyne interferometer using a HeNe laser as its source is a commonly used position sensor. By calculate using Michelson setup, there will be minimum two optical. One is fixed optical and the other one is moving optical. The moving optical can move and create relative displacement. The distance of the moving optical can be calculated with sinusoidal pulses. The speed information can thus be obtained by measuring its frequency. Other optical needed to determine the direction of the travelsuch like angular, rotary, linearity, etc. [8]

Figure 3.2. Laser Optics

4. CMM Verification : ISO 10360

ISO 10360 explains about standard CMM verification. The CMM verification are done periodically. Usually once a year and done by CMM maker. This standard currently has six parts consist of acceptance and reverification test for CMM that used for linear measuring dimension, CMM with the axis of rotary table and fourth axis, CMM with scanning application, CMM that using multiple-stylus probing system, and estimation of errors in Gaussian feature [2].

When verify CMMs, basically concentrates on two parameters which as probe error and length measuring error using a probe and stylus sensors that represented by ISO 10360-2. Verification of probe error has purpose to know character of probe, module and stylus that assembled as a machine sensor to get the value of repeatability in the measurement action. The sensors is calibrated using calibrated sphere with a specified value, the number of probing touch/points and determining a limiting value (probing error) from the range of the individual points around the sphere as an associated element. Length measurement causes error which takes several factors into error account include the probing behavior of the sensor, the length-dependent measuring error resulting from mechanical guideway errors, software geometry correction, and the length-dependent measuring error resulting from thermal behavior [3].

4.1. ISO 10360-2 (2009)

ISO CMM verification, especially 10360-2: Part 2 (ISO 2001a, 2009a) this standard is focused on the CMM structure accuracy including the scale reading and software. Standard tests of ISO 10360-2 is measuring the length of five calibrated block of artefact in each of seven different position, locations and orientations within cover minimum of 75% the CMM working volume. The position and orientation are recommended by parallel axis X, Y and Z of CMM and along the four diagonals volumes of the CMM (see Figure 4.1). The length of five block gauge measured three times each. Total measurement is 105 value of length measurements. Measure Permissible Error of E (MPEE) is measured of 105 errors, is plotted in machine specification and machine figure issued by manufacturer's maximum permissible error specification (see Figure 4.2) [2]

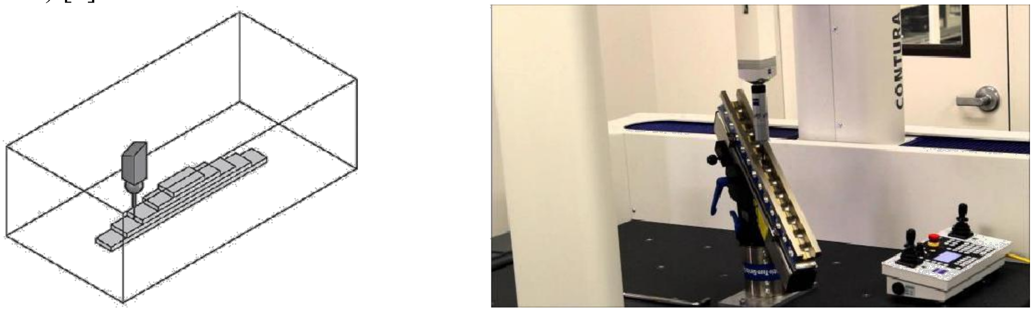

Figure 4.1. Measurement line in calibration procedure on five calibrated lengths reference block along a CMM axis.

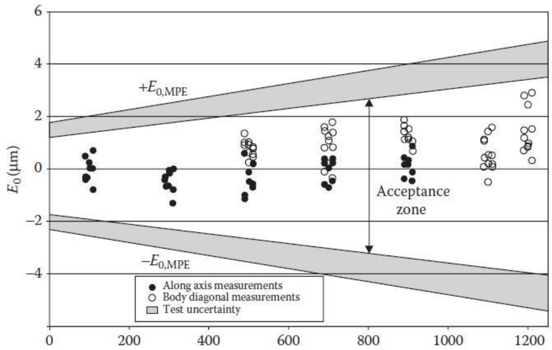

Figure 4.2. Machine verification result E values from the ISO 10360-2 testing procedure; the grey area shows the manufacturer specification an acceptance value.

In CMM Terminology, maximum permissible error is a indication of a CMM for size measurement error, EL, MPE, is stated in one of three forms:

a) E_L, MPE = ± minimum of (α + L/K) and B;
b) E_L, MPE = ± (α + β/K) ; or
c) E_L, MPE = ± B

where :

α is a value of positive constant, by unit in micrometers and stated by the manufacturer; K is a constant value/ dimension supplied by the manufacturer (ussually 1000 mm);

L is the measured size, in millimeters; and

B is the maximum permissible error EMPE, L, in micrometers, as stated by the manufacturer

Figure 4.3 DCC CMM Crysta Apex S by Mitutoyo and Prismo by Carl Zeiss

Measuring range	X axis	19.68"(500mm)	
	Y axis	15.74"(400mm)	27.55"(700mm)
	Z axis	15.75"(400mm)	
Resolution		0.000004" (0.0001mm)	
Guide method		Air bearings on each axis	
Drive speed		8-300mm/s (CNC mode), max. speed: 519mm/s	
		0 - 80mm/s (J/S Mode: High Speed)	
		0 - 3mm/s (J/S Mode: Low Speed)	
		0.05mm/s (J/S Mode: Fine Speed)	
Max. measuring speed		8mm/s	
Max. drive acceleration		2,309 mm/s2 (3D)	
Workpiece Maximum height		21.45"(545mm)	
Maximum mass		396.8lb(180kg)	
Mass (including the control device and installation platform)		1,135lbs.(515kg)	1,377lbs.(625kg)
Air supply Pressure		58 PSI (0.4MPa)	
Consumption		1.76CFM (50L/min) under normal conditions	
Air source		3.53CFM (100L/min)	
Probe used		Maximum permissible error (E0,MPE) ISO 10360-2:2009	Maximum permissible probing error (PFTU,MPE) ISO 10360-5:2010
SP25M (Stylus: ø4 X 50mm)		1.7+3 L/1000 (temperature environment 1)	1,7
		1.7+4 L/1000 (temperature environment 2)	1,9
TP200 (Stylus: ø4 X 10mm)		1.9+3 L/1000 (temperature environment 1)	1,9
		1.9+4 L/1000 (temperature environment 2)	1,9
TP20 (Stylus: ø4 X 10mm)		2.2+3 L/1000 (temperature environment 1)	2,2
		2.2+4 L/1000 (temperature environment 2)	2,2
		Temperature environment 1	Temperature environment 2
Limits within which accuracy is guaranteed	Temperature Range	20±2 °C (64.4-71.6 °F)	16 - 26 °C (60.8-78.8 °F)
	Rate of change	1 °C per hour or less 2 °C in 24 hours or less	1 °C per hour or less 5 °C in 24 hours or less
	Gradient	1 °C or less per meter	1 °C or less per meter

Table 4.1. The CMM sepecification due ISO 10360 (Crysta Apex S 500 Series, Mitutoyo Corp.)

5. System Qualification, Verification, Calibration and Machine Error

In field of manufacturing, Operator and Original Equipment Maker (OEM) CMM are using terms Calibration instead of Verification. CMM operators and OEM do the calibration by the probe the probe or getting the CMM calibrated to ISO 10360. Most of the calibration refers to ISO 10360-2 and ISO 10360-4 (Probing Error) since the Repeatability and Probing sensors has the main influence of the machine accuracy. To avoid confusion the correct terms are listed below:

There is one part of CMM that should be qualified by a task every day to determine the radius of stylus tip. Stylus or Probing system qualification will do before the CMM operator measure part to verify stylus tip diameter, stylus position compare to master ball.

CMM verification is a regular job that do by periodically by CMM engineer to check the machine accuracy still meet the specification. CMM calibration is a twenty one kinematic error checking to determine the errors. The calibration will put the machine as brand new due to mechanical and software system. On the performance checking, this activity applied as error mapping a CMM [2]

5.1. Twenty-one kinematic error

Error mapping activity is provide by maker to calculate the 21 geometric error and deviations that can occur in an articulating machine including CMM and machining centers.

The software will work for processing measurement result and all the data input. The software will compensate all the data to the controller of the machine. The deviations are majorly of these types (see Fig 5.1): (a) Linearity (3), (b)Straightness (6), (c)Rotation (9), (d)Squareness (3).

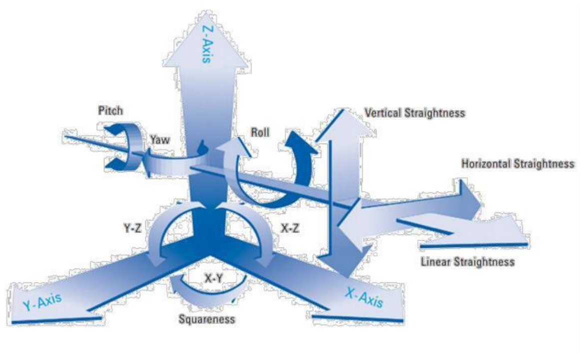

Figure 5.1. Twenty-one geometric deviation

5.2. Basic machine tool measurements using laser

Twenty-one geometric deviation that happen as a machine error can be captured by Laser Interferometer. Following measurements can be performed using lasers (Figure 5.2): (a) linear pitching and positioning accuracy. This linear and positioning also provide repeatability of axis, (b) straightness of axis, (c) squareness between axis, (d) flatness of surface, (e) rotary axis angular positioning, (f) angular pitch of axis, and (g) dynamic characteristics of machine tool. these factors.

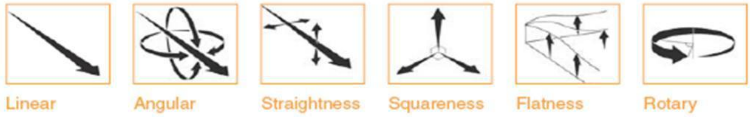

Figure 5.2. Basic Measurement using Laser

Laser interferometer provide the actual movement of the machine. The actual movement will be compared to the software result and for mapping of the machine error. The benefit for using laser interferometer is the uncertainty of measurement caused by external factor such like Environmental compensation (see figure 5.3), and material thermal compensation (see Table1). All the measurements provided by laser interferometer has been calculated in 20º C as the International temperature reference.

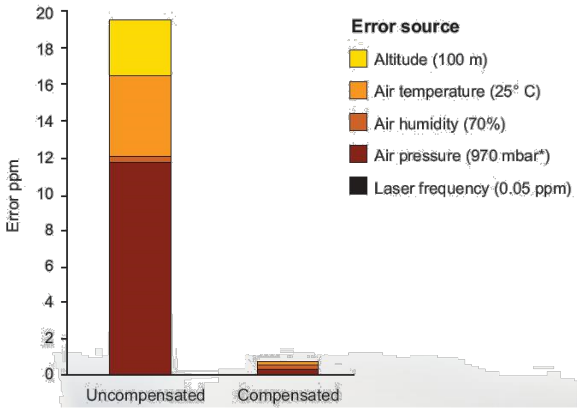

Figure 5.3. Comparison of environmental compensation refer to error source

Table 1. Coefficient of thermal expansion

	Application	Expansion coefficient Ppm/ºC
Iron/steel	Machine structural elements, rack and pinion drives, ballscrews	11,7
Aluminium alloy	Lightweight CMM machine structures	22
Glass	Glass scale linear encoders	8
Granite	Machine structures and tables	8
Concrete	Machine foundations	11
Invar	Low expansion encoders/structures	<2
Zerodur glass	"Zero" expansion encoders/structures	<0.2

6. Routine Monitoring DCC CMM

The matter of this paper is using laser interferometer to do routine monitoring for DCC CMM. Due to terms of verification of CMM, which mentioned that verification is a task carried out at periodic intervals (often annually) to determine if the CMM still meets the manufacturer's specification, ISO 10360-2 is a acceptance and re-verification tests for coordinate measuring machines (CMM) for measuring linear. While the machine will operate for whole day, error will occur during the operation. CMM has characteristic that the component will wear due to the usage. The error will be check periodically in linear movement. A linear error means that the component error increases linearly with a proceeded length. A harmonic error has the form of the corresponding term of the Fourier series. [9]. Laser interferometer measurement can represent the performance of DCC CMM report in order to accuracy information. CMM and Machine tools have the location and position error. Since the accuracy is determine by 105 error as mentioned before, and will takes a time, the machine performance can be monitored by linearity checking using Laser Interferometer. Laser will provider error position and location direct in true condition. Pitching error or location error can be collect thru the axis movement..

6.1. Why choosing Laser Interferometer

When the operator facing multi-brand machine, the operator has to verify the machine regularly. The DCC CMM machine has several checking parameter that could be maintain fast. The linearity, positioning and repeatability each axis are enough parameter to check the machine performance fast. Measurements on different CMMs can be related to the international standard of length in a variety of ways depending on the design of the CMM and the transfer standards used. Figure 6.1 shows how the laser interferometer accuracy can be adapted to CMM accuracy. With the 0,5 ppm (part per million accuracy) laser interferometer achieve the golden rule of calibration which has 1:10 better accuracy. Also at the top there is the wavelength of the iodine-stabilized HeNe laser, which is measured relative to the frequency of the atomic clock. Second level of pyramid shows laser Interferometer has better accuracy and traceability. With 0,5-1 part per millionth, laser interferometer can measure CMM movement and give the feedback for maintanance.[3]

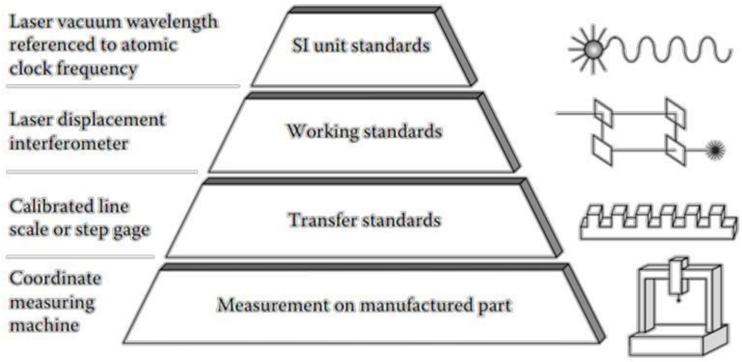

Figure 6.1. Pyramid of measurement with the best accuracy.

With the higher accuracy (0.5ppm) and higher resolution (1nm) compare to DCC CMM accuracy (1.7 µm + 3L/1000 mm), laser interferometer is applicable for doing CMM verification and calibration. Environmental and Thermal compensation make laser interferometer is traceable. All the task of calibration and verification already compensate to 20ºC as ISO 10360-2 standard. Flexibility and ease to use application are become added value.

7. References

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