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A Comparison of Mechanical Artefacts used in Calibration of Coordinate Measuring Machines (CMMs)

Mendiratta Karun

Assistant Professor, Mechanical engineering Department, NIET, Greater Noida, India.
(karunmendiratta@yahoo.com)

Abstract

In last 50 years, Coordinate Measuring Machine's (CMMs) accuracy has improved dramatically from 25 microns to 0.5 micron. Achieving such high accuracy while manufacturing CMMs can be very challenging, especially when it comes to inherent geometric errors. Various artefacts are being used to measure these errors and to calibrate the machine, and selection of right artefact can put user in disarray. The proposed research aims to clear out this cloud of confusion by comparing four such mechanical artefacts which are frequently used in calibration of CMM. All four artefacts were carefully studied and scored on the basis of five parameters, namely: error detection capability, accuracy, measuring range, cost and ease of automation. It was observed that Ball Plate (BP) gives best results, and thus it can be preferred over the other three artefacts.

Keywords

Coordinate measuring machines (CMM), Mechanical Artefacts, Parameters, Comparison.

1. Introduction

Measuring Machines (CMMs) are the most widely used gauge for evaluating any product's dimensional quality. CMMs are being used in metrology labs or/and on the manufacturing floors in either or both a point to point or scanning mode to measure the complex geometries [1]. Since the time, CMMs first became available, both the user and manufacturers have a consistent desire to comprehensively evaluate their performance. Recently, many standards have been introduced to obtain machine's performance, including International Standard [2]. And with increasing demand for high product quality, improving the measurement accuracy of CMMs has become an important area of investigation [3]. CMMs are subjected to progressive errors, which degrades

their accuracy over time, thus, CMMs must be rectified consistently [1]. There are a total of 21 error components (geometrical, parametric, or partial errors) associated with CMMs [3], [4], [5].

Various artefacts are available, being designed and used to estimate performance characteristics of CMM. A new artefact has been designed and then calibrated by Nardelli & Donatelli [6], which proved to be light in weight, fast and simple to calibrate. Antunes & Vicente [7], discussed and validated a new type of artefact which was introduced by S.D Antunes *et al.* [8], to determine the global errors of coordinate measuring machine. Phillips *et al.* [9], [10] recommends the use of BB to evaluate the volumetric performance of CMMs according to ANSI/ASME B89.1.12M, [11]. Step Gauges are found to have considerable advantage in practical use and for CMM testing. However, BBs are considered as easy and economical to determine volumetric errors in CMMs.

Various testing methods, specifications, conditions, and procedures are being surveyed and designed for the calibration purpose these days. A quick check method has been described by Curran & Phelan [12], to evaluate the performance of CMM by using Telescopic Ball Bars (BB). Arriba *et al.* [13] developed methods for full-scale error analysis of large CMMs using light weight and disassemble-able Ball Plates (BP), and disassemble-able BB. Liu *et al.* [14] developed and implemented a measurement system to simultaneously measure pitch, yaw and roll. A new method was proposed by Sultan & Puthiyaveettil [15], which used a master cuboid fixture to calibrate CMM. Itabashi *et al.* [16] used quick check and ball pyramid which can be used for daily CMM inspection. Krajewski & Wozniak [17], proposed a new method to identify and evaluate the dynamic errors in CMM using simple master artefact.

As there are very few papers that give any explanation for the slection of artefacts. Users usually found them in a state of dilemma about the slection of appropriate artefact for machine calibration. This paper is an effort to clear out this cloud of confusion by comparing four frequently used mechanical artefacts in CMM calibration. Ball Plate (BP), Ball Bar (BB), Slip Gauge (SG) and Square Master (SM), have been compared and scored on the basis of five different but very important parameters.

2. Work Methodology

CMMs can be inspected and calibrated using various artefacts, but selection of the right one is a problem. Thus, it seems reasonable to compare some of the frequently used mechanical artefacts in order to overcome this problem. Four artefacts based on five parameters have been compared in this study.

2.1. Parameters

The selected parameters considered in this study are of utmost importance when it comes to performance evaluation of CMMs. These are: error detection capability, accuracy, measuring range, cost and ease of automation. Each one of it has been given same importance level; thus, each contributes to 20% of the final score.

Error Detection Capability: there are 21 sources of errors in CMMs, Number of errors that each artefact can measure have been identified and shown in Fig-1.

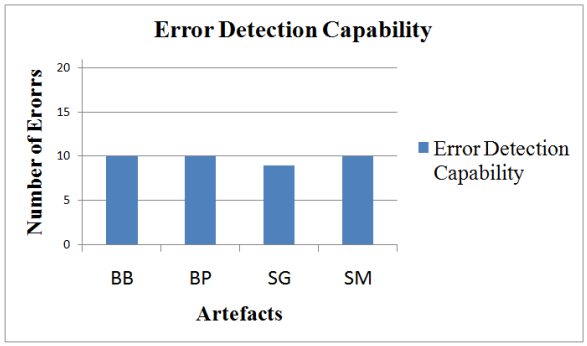

Fig.1. Comparison based on Error Detection Capability

Accuracy: measured in terms of micron (µ) or micrometer (µm), may differ from manufacturer to manufacturer. Before scoring, repeatability and expanded uncertainty of the measurements have also been considered. Accuracy levels of the selected artefacts are shown in Fig-2.

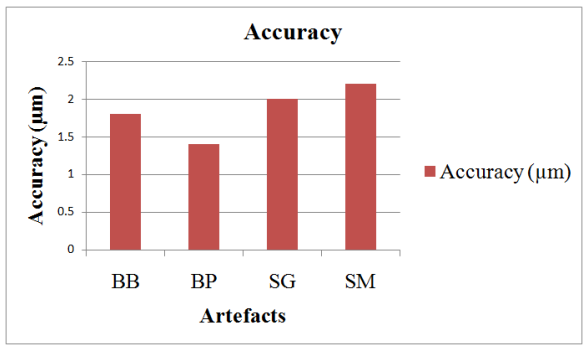

Fig.2. Comparison based on Accuracy

Measuring Range: all of the artefacts cannot be used to calibrate all machines of various sizes. Some artefacts are preferred for small size machines whereas, some for larger sizes. Fig-3 shows measuring range for each artefact.

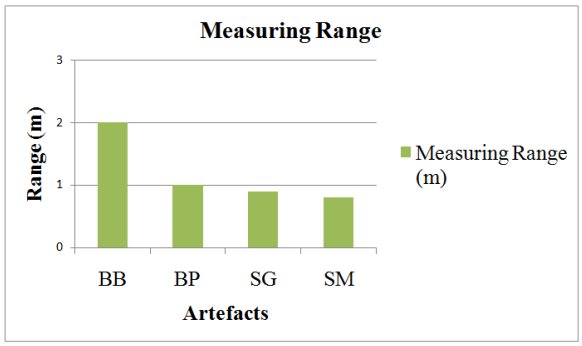

Fig.3. Comparison based on Measuring Range

Cost: is one of the major parameters while selecting any artefact for calibration. No artefact can have good accuracy, larger measuring range, and greater error detection capability yet being economical. Considering the buying cost, calibration and maintenance expenses, artefacts are compared in the Fig-4.

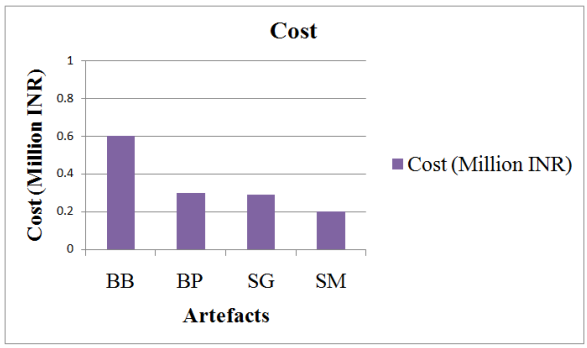

Fig.4. Comparison based on Cost

Ease of Automation: determining the automation level for each one of these artefacts is not easy. But, special attention is given to the industrial and practical use while doing so.

2.2. Mechanical Artefacts

Ball Bar (BB): available in two different forms; one has a single bar with two balls at the end with known ball centre distance, and the other has a holding stock of many precision balls

mounted with fixed distance. BB can be used to measure 10 of 21 sources of error in CMM. It has an excellent repeatability with accuracy up-to 1.8µm. It is costliest than the other three, with a measuring range of up-to 2 meters (m) as shown in Table-1.

Table 1. Ball Bar Specifications

Sr. No.	**Parameter**	**Ball Bar**
1	Error Detection capability	10
2	Accuracy (µm)	1.8
3	Measuring Range (m)	2
4	Cost (million INR)	6

Ball Plate (BP): geometric errors (or sources of errors) in CMM are measured with the ball distances in certain pattern. BP can be used to measure 10 of 21 errors in CMM. It has the best accuracy when compared to other artefacts in this study. It is quite affordable artefact when it comes to cost with a measuring range less than 1 meter (m) as shown in Table-2.

Table 2. Ball Plate Specifications

Sr. No.	**Parameter**	**Ball Plate**
1	Error Detection capability	10
2	Accuracy (µm)	1.4
3	Measuring Range (m)	Less than 1
4	Cost (million INR)	3

Slip Gauge (SG): also known as gauge block, is a universally accepted standards of length. It can measure up-to 9 errors of 21 with good accuracy. Averagely priced, it has a measuring range of up-to 1meter (m) as shown in Table-3.

Table 3. Slip Gauge Specifications

Sr. No.	**Parameter**	**Slip Gauge**
1	Error Detection capability	09
2	Accuracy (µm)	2
3	Measuring Range (m)	Up to 1
4	Cost (million INR)	Less than 3

Square Master (SM): have two side edges right angle to each other, with one side acting as a reference to the other. It can measure up-to 10 errors of 21 in CMM with an accuracy of 2.2 µm. It is economical and has a measuring range less than 1 meter (m) as shown in Table-4.

Table 4. Square Master Specifications

Sr. No.	**Parameter**	**Square Master**
1	Error Detection capability	10
2	Accuracy (µm)	2.2
3	Measuring Range (m)	Less than 1
4	Cost (million INR)	2

3. Calculations & Results

Based on the specifications and detailed study, these mechanical artefacts are scored out of a total of 1 in following ways;

1. To score on the basis of their error detection capability, the number of errors that each artefact can measure is multiplied by a factor of 0.2/21.

2. To score on the basis of accuracy, measuring range, cost, and ease of automation, a score of 0.2 and 0.15, 0.10, 0.05 is added to the final score accordingly. Where, 0.2 is the best and 0.05 the poorest.

The final score achieved by each of the artefact is shown in Table-5 separately.

4. Conclusions

Although there are no artefacts so far which can fully satisfy every need of a user, but based on this detailed comparative study, it can be concluded that;

1. Ball plate (BP) has achieved the maximum score of 0.7452 followed by the Ball Bar (BB), Slip Gauge (SG) & Square Master (SM).
2. Ball Plate (BP) can be preferred over other three choices.

Further research aims to include more artefacts, and to see if a combination of two or more artefacts can be used to calibrate the whole machine.

Table 5. Final Scores

S. No.	Parameter	Ball Plate	Slip Gauge	Ball Bar	Square Master
1	Error	0.0952	0.0857	0.0952	0.0952
2	Accuracy	0.20	0.10	0.15	0.05
3	Measuring Range	0.10	0.15	0.20	0.05
4	Cost	0.15	0.10	0.05	0.20
5	Ease of	0.2	0.10	0.15	0.05
Final Score		0.7452	0.5357	0.6452	0.4452

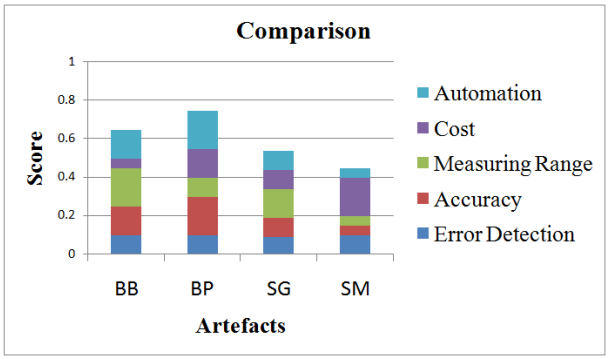

Fig.5. Final Score Comparison

It is clear from the Table-5 and Fig-5, that out of 1 (maximum), BP has achieved the highest score of 0.7452 and outclassed the other available artefacts; BB (0.6452), SG (0.5357), and SM (0.4452).

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