Temperature Differential Analysis of a Ball Plate Artefact in Standard Environmental Condition

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Abstract— In this work the study is performed on Steady State thermal analysis on a zirconia-dolerite ball plate type artefact which is used during calibration of CMM. To improve the efficiency the heat dissipation is an important factor to be considered during CMM calibration. Here the steady state thermal analysis is done on this ball plate type artefact in the temperature range of 20 to 22.50C which is standard temperature condition during which the artefact gives correct reading. The analysis intends to find the temperature distribution and deformation of a ball plate during the temperature range of 20 to 22.50C. The model and analysis of the ball plate is done by using ANSYS Workbench 15.0 Software. The Temperature distribution and temperature deformation are obtained to find the suitable temperature range for the ball plate. This analysis shows the potential areas of ball plate for temperature differential.

Key words: CMM, Ball Plate Artefact, Steady State Thermal Analysis, ANSYS Workbench 15.0

I. INTRODUCTION

International standard ISO 10360-1 is used to define a co-ordinate measuring machine (CMM) as a measuring system. In which means there is a probe moving on the workpiece. The capability is determine by spatial coordinates on a workpiece surface. Now a day's --demand of CMM has grown due to the advent of numerically controlled machine tools. There has been rising need to have a device that can do faster first piece inspection and many times, 100% dimensional inspection. In the process of inspection most important role is played by CMM. Some of the CMMs can be used as outline before machining and also for checking feature locations after machining.

CMMs are relatively recent developments and one of the best way in measurement technology. Basically, it is consist of a policy on which the work piece being measured is placed and moved linearly or rotated as per the requirement. A probe which has capability to move vertical and lateral is attached to head.

CMMs in other words are also known as measuring machines. They are versatile in their capability to record measurement of complex profiles with high sensitivity (0.25 µm). The speed of CMMs are built inflexibly and are very precise. They are prepared with digital readout or can also be linked to computers for online inspection of parts. They are also made more suitable for the environmental effects in manufacturing plants such as environment, temperature variations, vibration and dirt. There are different type of artefacts which used for the calibration of CMM. Following are the types of artefact,

A. Sphere Plate

The material used for this plate is special steel. On this sphere plate the ceramic spheres are specifically arranged. To allow for easy entree to the equatorial area in four sectors. Sphere plate design permits probing access on the both sides of the plate.

B. Ball Bar

It is the assembly which is ideal for calibrating large volume measuring devices.It is highly accurate portable, and also easy to assemble. A series of ceramic spheres balls are mounted along the top of the bar.

C. Step gauge

Step gauge is also called as master gauge block set because it has ultimate accuracy. It is also used as standardised artefact. It requires less time for measurement.

D. Sphere Beam

It is one type of non-demountable ball bar for monitoring and calibrating medium-sized CMMs. Ceramic spheres are mounted on the beam which is used as probing element.

E. Ball Plate

This is ball plate type artefact as shown in fig 1 in which the plate is made of dolerite material and the balls are made of zirconia material which having different material properties. Total 52 numbers of balls are kept on that plate. The ball is made of zirconia material. This artefact is generally used during the calibration of CMM. This type of ball plate artefact is used at the standard calibration temperature of 20^0C and gives correct range of reading up to 22.5^0C. It has low thermal conductivity and low coefficient of thermal expansion.

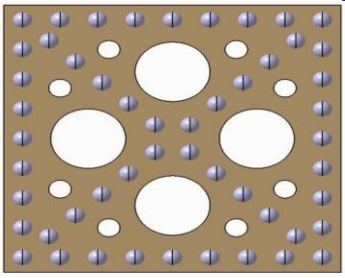

Fig. 1: Ball Plate Type Artefact

Fig. 1 shows the ball plate artefact which is made of dolerite material and the balls which are mounted on the plate is made of zirconia material. The ANSYS Workbench 15.0 software is used of this study to find out the total temperature distribution and the deformation of the plate at different temperature range.

II. LITERATURE REVIEW

V. A. Kulkarni and B.B. Ahuja[19] they have worked on developing and manufacturing the Zirconia-Dolerite ball plate. In this different geometric errors in three different plane position can be achieved. Uncertainty measurement of this ball plate artefact will affect calibration of CMM. CMM

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undergoing periodic temporary checks by ball plate measurement needs to compute uncertainty analysis over a calibration period.

E. S. Lee and M. Burdekin [3] has studied on hole plate artefact method for measuring the volumetric error of coordinate measuring machines (CMMs). By using the finite element method the deflection of the designed hole-plate is analyzed. The influence of inside hole roundness as a measuring standard is also studied.

Ramesh Sanas and V.A. Kulkarni[16] studied on the optimal design of ball and plate type artifact used for calibration of probe type CMM. In this they use different methods of calibration of CMM. They use a ball plate type artifact method for the calibration, and finally made a design of a ball plate artifact for the calibration.

B.Jayachandriah1, K. Rajasekhar[17] have worked on the thermal analysis of a tabular heat exchanger by using the ANSYS Workbench 15.0 to find out the temperature distribution and the total heat flux. To find out the stability of the material at different temperature range.

V. Thiruvengadam[21]has worked on steady state thermal analysis of a Disc Brake Rotor with Composite Material. To find out temperature distribution and total heat flux to improve the efficiency of the disc brake by using FEA method ANSYS Workbench software.

Anke Guenther, Dirk Stobener, GertGoch [20] have worked on the self-calibration method for a ball plate artefacts on CMM in which describes the testing and verification of this calibration method is applied to this artefact. The method was extended to calibrate not only the pitch position of the balls, but also their radial and height position on the circular ball plate (gear artefact).

De Chiffre et al[5] proposed the comparison between optomechanical hole plate with optical based CMMs with mechanical parts. This was equipped with 25 reference cylindrical holes with a pitch of 20mm in a 0.1mm stainless steel with a thermal expansion coefficient of $11.3x10^{-6}K^{-1}$. The optical and mechanical probe system can be verified by this artifact.

III. Scope of Work

The calibration of CMM takes place at 20^0C, and there are different types of artefacts used for the calibration of CMM. The ball plate is also one of the artefact which is used for calibration of CMM. This type of artefact is suitable for use up to 22.5^0C. It is made of plate of dolerite material and balls of zirconia material. It is important to find out the effect of temperature on a ball plate if the temperature is increasing up to 22.5^0C. In this research work, thermal analysis of the ball plate artefact is carried out. This gives the effect of temperature on ball plate in the form of deformation which takes place on the plate. In this research the main aim is to find out the effect of temperature on a ball plate type artefact. This gives the stability of the ball plate at different temperature ranges.

IV. Methodology Used

The methodology is carried out in three steps like first FEA, then second is experimental work and third is analytical method.

A. Finite element analysis (FEA)

FEA is a methodology which gives the solution to real life and engineering problem with the help of computers and different software's. This is most suitable for engineering structures that have complex geometry and loads, are either very difficult to analyze or have no theoretical solution. Analysis of any complex structure can be solved easily by FEA. FEA software gives a solution for deflections, deformation, temperature distribution, stresses, reactions, etc.

FEA solution of engineering problems, such as finding deflections and stresses in a structure, requires three steps:

– Pre-process or modeling the structure
– Analysis
– Post processing

1) Modelling of Ball-Plate

Modelling is a pre-processor tool, the modelling of ball plate is created using the Computer aided three-dimensional interactive application NX10 software tool. Module created in NX10 is exported as IGES or STEP file for the next pre-processor for meshing.

1	Density	3000 kg/m^3
2	Tensile Ultimate Strength	5 x 10^6 Pa
3	Compressive Ultimate Strength	1.07 x 10^8 Pa
4	Coefficient of Thermal Expansion	2.4 x 10^{-6} /^{0}C
5	Bulk Modulus	1.11 x 10^{11} Pa
6	Shear Modulus	3.7037 x 10^{10} Pa
7	Young's Modulus	1 x 10^{11} Pa
8	Poisson's Ratio	0.35
9	Isotropic Thermal Conductivity	2 W/m^{0}C
10	Specific Heat	790 J/kg^{0}C
11	Hardness	7 Mohs
12	Water Absorption	0.07

Table 1: Properties of Dolerite

1	Density	6.05 kg/m^3
2	Tensile Ultimate Strength	1.56 x 10^{09} Pa
3	Bulk Modulus	1.798 x 10^{11} Pa
4	Isotropic Thermal Conductivity	2 W/m^{0}C
5	Young's Modulus	2.05 x 10^{11} Pa
6	Shear Modulus	7.8244 x 10^{10} Pa
7	Coefficient Of Thermal Expansion	6.3 x 10^{-6} /^{0}C
8	Compressive Ultimate Strength	2 x 10^9 Pa
9	Poisson's Ratio	0.31
10	Specific Heat	2.3 J/kg^{0}C
11	Hardness	1350 BHN
12	Water Absorption	0.05

Table 2: Properties of Zirconia

a) Analysis

The further analysis is done in ANSYS Workbench 15.0 by importing the IGES/STEP file into ANSYS. Then meshing is done. Meshing can be defined as the process of breaking up a physical object into smaller sub objects (elements) in order to facilitate the numerical solution of a partial differential equation. Then steady state thermal analysis is carried out to find out the temperature distribution and the structural analysis is carried out to find out the total deformation of the ball plate at different temperature conditions within the range of 20 to 22.5^0C.

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2) Post Processing

After the analysis is carried out the results are found in the type of table and graph. So in this final step we get the results. This post processing results are showed in result section V and also the results obtained in the form of figures and table.

B. Experimental Work & Setup

The experiment is carried out on Bridge type of CMM. During this, the software is used for data collection is by using ACCUSOFT 4.01.008 CMM Software. In this, it is required to find out the deformation or the effect of temperature on that ball plate. So, after setting the temperature as pre required the next step is to put the ball plate on granite base which having zero flatness. The plate is kept in XY direction for the further reading, as shown in fig. By using the probe and the monitor which is handled by an expert. The multiple readings are taken, with the help of probe. The probe used is of RENISHAW A-5000-3604 FM KV type. The readings are taken at different temperatures with the help of probe. And the report is generated by the software. The deformation is find out by finding the change in length of the plate at different temperature range. The bridge type of CMM is most suitable for measuring the complex part. Hence, by taking readings in standard environmental condition with the help of probe.

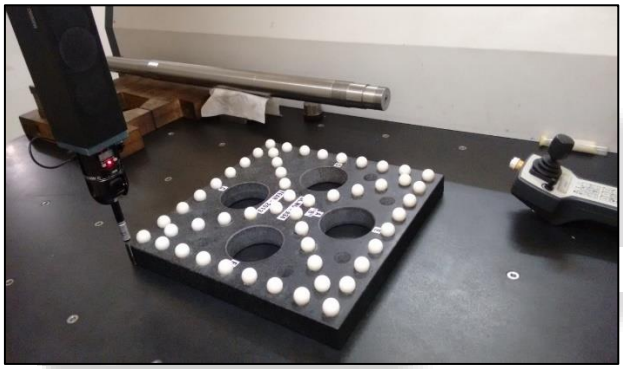

Fig. 2: Experimental Set-up

C. Analytical Method

Deformation of the material is of two types forced deformation and natural deformation. In forced type deformation some amount of force is applied on the material as the temperature is changing. This will results in deformation of the material. In this forced type the deformation there is change in length is due to applied force. The natural deformation is the type of deformation in which if the material is deforming due to change in surrounding temperature. Hence, in natural deformation no force is applied on the material. The material is only deforming due to the temperature is changing.

In this work, the plate is deforming due to change in length and this is happing because the temperature during the calibration is changing. So, this deformation is natural deformation. Following is the method which is used to find out the total deformation of ball plate artefact.

When body is subjected to temperature change, it elongates if temperature rises and shortens if temperature decreases. Stress are caused in material if the natural expansion or contraction is prevented.

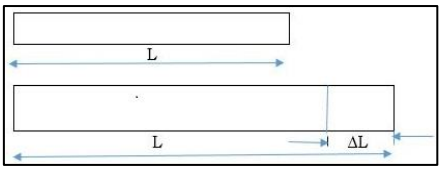

Fig. 3: Effect of Temperature

Consider a bar shown in fig 3 the length of bar is L at temperature t_1 ^{0}C and it is stress free. If the bar is now heated to the temperature of t_2 ^{0}C, it should increase the length but is, constrained. To find the stress in a bar, assume the bar is free to expand to a length L+ ΔL,

Where, ΔL = length x coefficient of thermal expansion x change in temperature = Lαt

Where, α is coefficient of liner expansion and is the change in length per unit length per unit degree ride in temperature.

t= (t_2-t_1) is change in temperature.

V. RESULTS & DISCUSSION

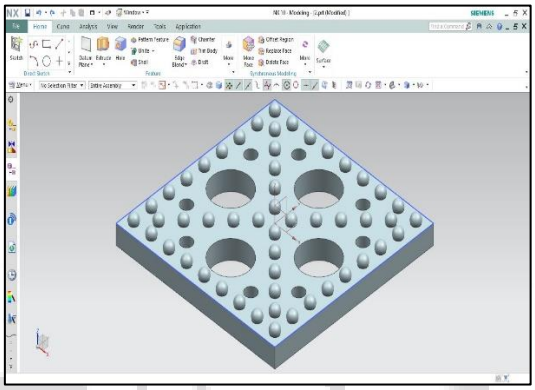

Fig. 4: Design of Ball Plate Artifact

Fig 4 shows the design of ball plate artefact which is drawn in NX 10 software of 450 x 450 mm dimensions and the balls which are mounted on the plate is of 25mm diameter. The center distance between these balls is 50mm.

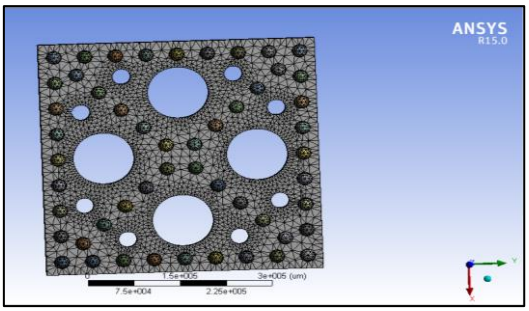

Fig. 5: Meshing of Ball Plate

Fig 5 shows the meshing of the ball plate which is carried out in ANSYS Workbench. Refine meshing is done for better results because of this complicated plate design.

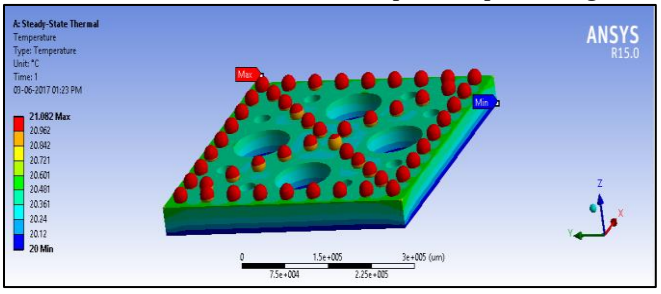

Fig. 6: Temperature Deformation

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Fig 6 shows the temperature distribution on a ball plate. In this, maximum temperature effect is on the ball of the plates as the temperature changes and the minimum temperature effect is taking place at the bottom of that ball plate type artefact.

A. Software Results

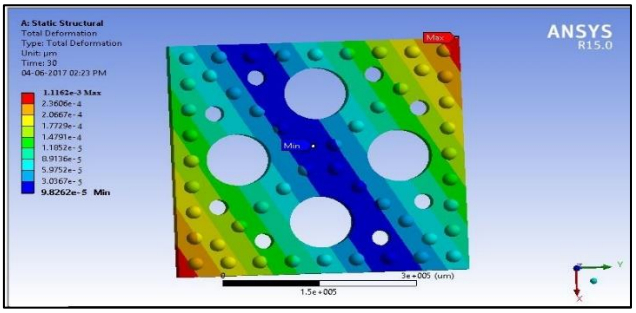

Fig. 7: Total Deformation at 200C

Fig 7 shows the total deformation of ball plate artefact at 20^0C. In this, the maximum deformation is 1.1162µm taking place at corners of that plate and minimum deformation is taking place at middle portion of that plate.

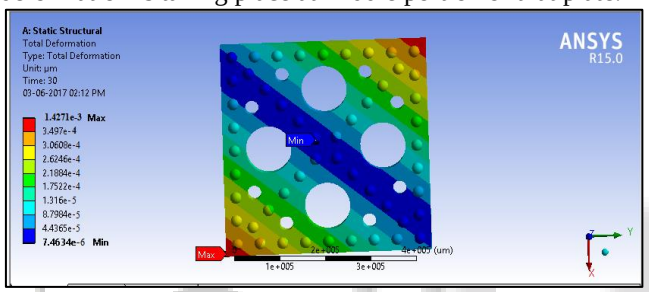

Fig. 8: Total Deformation at 210C

Fig 8 shows the total deformation of ball plate artefact at 21^0C. In this, the maximum deformation is 1.4271µm taking place at corners of that plate and minimum deformation is taking place at middle portion of that plate.

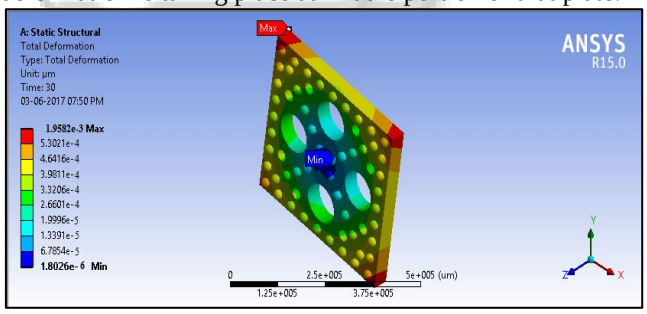

Fig. 9: Total Deformation at 22.50C

Fig 9 shows the total deformation of ball plate artefact at 22.5^0C. In this, the maximum deformation is 1.9582µm taking place at corners of that plate and minimum deformation is taking place at middle portion of that plate.

Sr. No	Temperature Range(^{0}C)	Total Deformation(µm)
1	20	1.1162
2	20.5	1.2381
3	21	1.4271
4	21.5	1.6187
5	22	1.7321
6	22.5	1.9582
7	23	2.5627

Table 3: Total Deformation from 20^0C to 23^0C

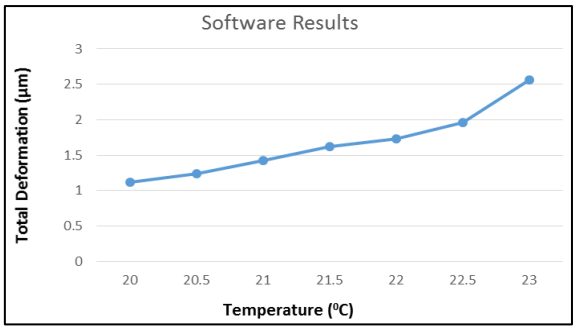

Fig. 10: Temperature v/s Total Deformation (Software Results)

From above figure 10 and the table 3 shows the deformation of ball plate type artefact at different temperature ranges. In this, as the temperature is changing from minimum to maximum the deformation in a ball plate artefact is taking place. At 20^0C the deformation is minimum and as the temperature is increasing the deformation is also increasing. At 23^0C the deformation is more than 2 µm which means that after 22.5^0C the ball plate deformation is more than 2 µm. So, this type of artifact is only allow to use up to 22.5^0C during which the deformation is less than 2 µm.

B. Experimental Results

Sr. No	Temperature Range (^{0}C)	Total Deformation (µm)
1	At 20^0C to 20.5^0C	1.1
2	At 20.5^0C to 21^0C	1.3
3	At 21^0C to 21.5^0C	1.5
4	At 21.5^0C to 22^0C	1.8
5	At 22^0C to 22.5^0C	1.9
6	At 22.5^0C to 23^0C	2.4

Table 4: Experimental Results

This table 4 shows that the deformation is taking place in that ball plate type artefact. So, from this it is concluded that some amount of deformation is taking place. Hence as the temperature is increasing the deformation is increasing. The soaking period of ball plate are also a considerable factor based on coefficient of thermal expansion of artefact material and standard metrological temperature. As the metallurgy says that this type of ball plate capable of giving the accurate results during the temperature range of 20^0C to 22.5^0C. And only deformation is allowable is up to 2 µm. Hence, from above results it is conclude after 22.5^0C the deformation is over 2 µm. So, this is clear that this type of ball plate artefact not having any temperature effect on material.

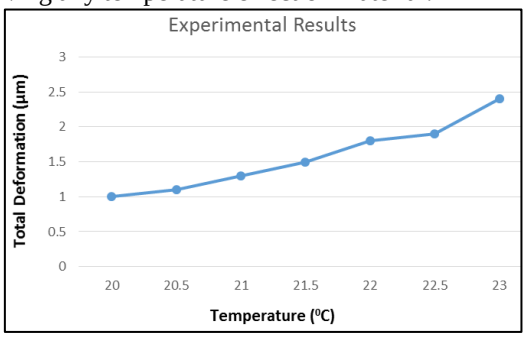

Fig. 11: Temperature v/s Total Deformation (Experimental Results)

Above fig 11 of the experimental results shows the increasing nature of deformation. As the temperature is increasing the deformation is also increasing. The minimum

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deformation is at 20^0C and the maximum deformation is at 23^0C.

C. Analytical Results

By using the natural deformation formula,

ΔL = length x coefficient of thermal expansion x change in temperature

$= L\alpha t$

Where, α is coefficient of liner expansion and is the change in length per unit length per unit degree ride in temperature.

$t= (t_2-t_1)$ is change in temperature.

For 20^0C the deformation will be only change in length, because we are considering the standard temperature as 20^0C. Hence, deformation is assumed to be zero.

Sr. No	Temperature Range (^{0}C)	Total Deformation (µm)
1	20^0C	-
2	20.5^0C	0.56067
3	21^0C	1.0813
4	21.5^0C	1.62203
5	22^0C	1.8262
6	22.5^0C	1.9621
7	23^0C	2.16

Table 5: Analytical Results

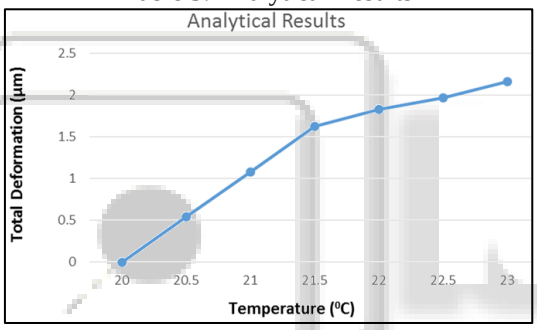

Fig. 12: Temperature v/s Total Deformation (Analytical Method)

From above table 5 and figure 12, it is concluded that the natural deformation takes place in the ball plate as the temperature changes. Temperature range 20^0C to 22.520^0C. The minimum deformation is zero and maximum deformation is 1.9621µm.

D. Compassion of Results

Sr. No	Temperature Range(^{0}C)	Total Deformation (µm)		
		Software Results	Analytical Results	Experimental Results
1	20^0C	1.1162	-	1
2	20.5^0C	1.2381	0.56067	1.1
3	21^0C	1.4271	1.0813	1.3
4	21.5^0C	1.6187	1.62203	1.5
5	22^0C	1.7321	1.8262	1.8
6	22.5^0C	1.9582	1.9621	1.9
7	23^0C	2.5627	2.16	2.4

Table 13: Final Results

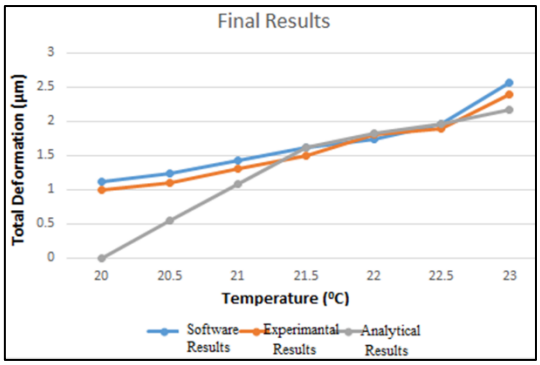

Fig. 13: Temperature v/s Total Deformation (Final Results)

After studying all these results it is concluded that the ball plate artefact is deforming during the standard environmental condition. As, the metallurgy says that this type of artefact is only capable to give the correct results up to 22.5^0C. Hence, after finding the results the ball plate is deforming less than 2µm up to 22.5^0C. But after 22.5^0C the deformation is above 2µm hence which is not satisfying with the metallurgy deformation limitation. So, this is clear that this type of artefact is only suitable to work up to 22.5^0C not more than that temperature range.

So, this may be concluded that this type of ball plate artefact is suitable for the use at standard environmental condition when the temperature is changing. The stability of this material very good to work in different temperature ranges. The property of low thermal coefficient of expansion is best property of this type of ball plate artefact.

VI. Conclusion

This presented work concludes that the heat dissipation is one of the most important factor to be considered to find out the stability of the material at different temperature ranges. So, from this research it is clear that this ball plate type artefact which is used for the calibration of the CMM is deforming as the temperature changes. But as per metallurgy of the material, the total deformation of this ball plate is allowable up to 2 µm. The deformation in the range of calibration is not more than 2 µm proved by different methods and experimentally. So, this type of ball plate artefact is found suitable for use at temperature ranges from 20^0C to 22.5^0C. After 22.5^0C the deformation observed is more than 2 µm, hence not recommended for use.

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