Calibration of Gauge Blocks by using a Mechanical Comparator

Author: R Moganedi

Co- Author: O Kruger

NMISA (National Metrology Institute of South Africa)

Private bag

Pretoria

0001

South Africa

Tel: +27 841 2581 Fax: + 27 841 2131

Rmoganedi@nmisa.org

Abstract

Gauge block calibration is one of the oldest high precision standards in dimensional. Since gauge blocks were invented at the turn of the 19th century, gauge blocks have been the major source of length traceability for length measurements in industry.

With reference to ISO 3650 .The necessity to calibrate gauge blocks using the interferometer has become the primary method to calibrate grade k, grade 00 and grade 0 gauge blocks. Grades 1 and 2 gauge blocks are calibrated using the comparison method. The main focus of this study is to look at calibrating gauge blocks by comparison method. This means that the study defaults itself to examining the calibration of gauge blocks using the comparator. This is the universally used method by industries.

The investigation will centre itself around calibrating gauge blocks of the same material eg. steel vs steel, calibrating gauge blocks of the different materials ie. interchanging materials of gauge blocks and calibrating gauge blocks that are wrung together. An advance investigation of conducting temperature effects on gauge block calibration from the reference temperature will be conducted.

Introduction

A **gauge block** (also known as a **gage block**, **Johansson gauge**, **slip gauge**, or **Jo block**) is a precision ground and lapped length block used as a measuring standard. Invented in 1896 by Swedish machinist Carl Edvard Johansson (1), they are used as a reference for the calibration of measuring equipment used in machine shops, such as micrometers, sine bars, calipers, and dial indicators (when used in an inspection role). A gauge block is a block of metal or ceramic with two opposing faces ground precisely flat and parallel, a precise distance apart.

Gauge blocks made in several grades or degrees of accuracy. Grade 0 is the most popular grade of gauge blocks, as this grade is usually suitable for most applications and offers the best combination of accuracy and cost. Higher-accuracy grades of blocks, such as Grade 00, are primarily used as masters to check other gauge blocks and for applications that require extreme accuracy. Grade B (±50 µin.) blocks are relatively inexpensive but are limited to workshop use where exacting accuracy is not required. Various styles of gauge blocks are available, including rectangular, square, and heavy duty. The use of gauge blocks can also be extended by means of accessories that can be used with height gauges, snap gauges, scribers, and dividers. INSOLVENT

What is a calibration?

Operation that, under specified conditions, in a first step, establishes a relation between the **quantity values** with **measurement uncertainties** provided by **measurement standards** and corresponding **indications** with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a **measurement result** from an indication. (1.1)

Gauge block grade

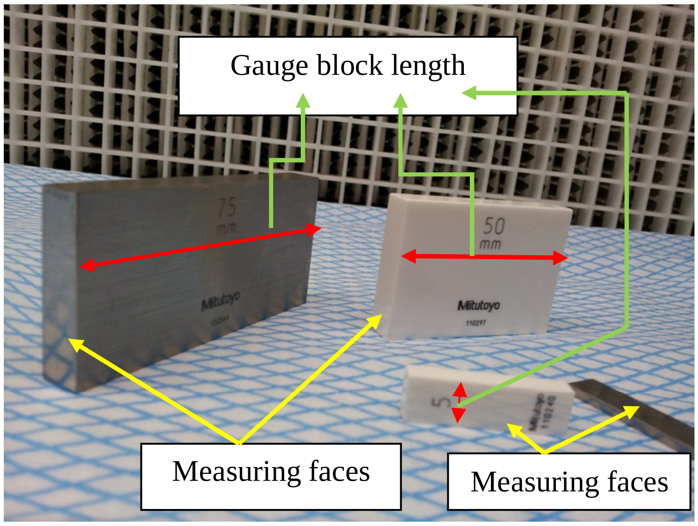
Grade 00, 0 and K are calibrated using the interferometer.
Grade 00, 0 and K should be used as the master set or for verification purposes.

Grade 1 and 2 are calibrated using the mechanical comparator.
Grade 1 and 2 are used in the industry for checking micrometer and vernier caliper measurements.

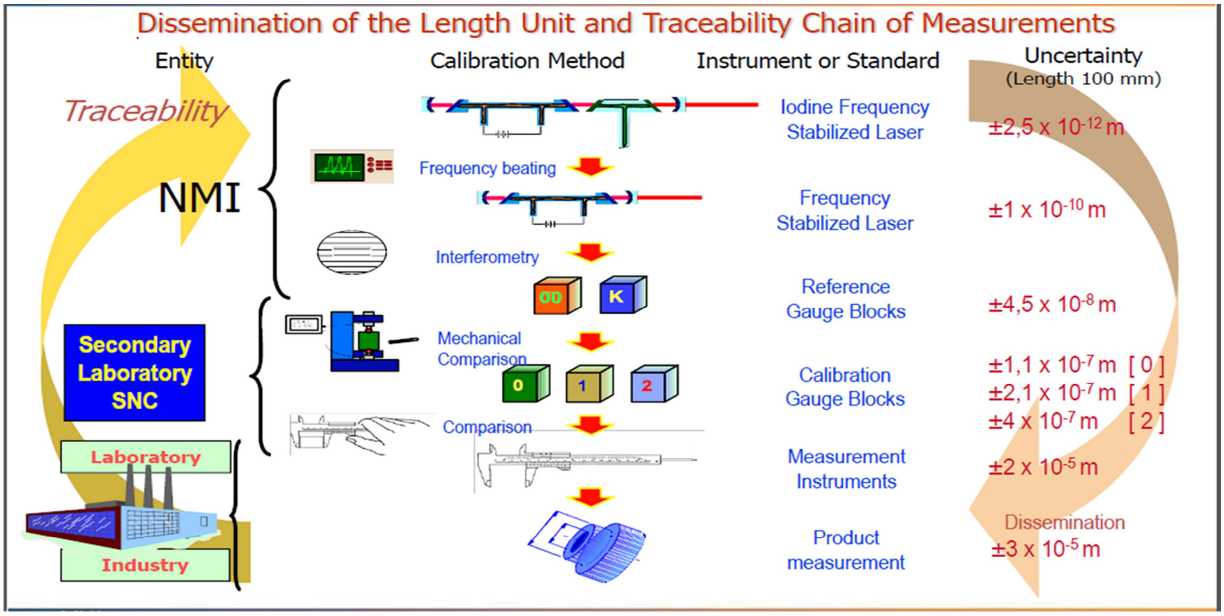
Properties of gauge blocks

Gauge block material	Advantages	Disadvantages
Ceramic	Very hard and Not easy scratchable Hardly breakable Maintenance free Corrosion resistant	CTE not too close to manufactured (steel) parts Expensive Difficult to wring

Steel	CTE very similar to manufactured (steel) parts. •Less expensive (most economical mechanical and properties are adequate in typical workshop environment)	Not too hard Easy to scratch Need maintenance Corrodes easily
Tungsten	Very hard and un-scratchable Hardly breakable Corrosion resistant Excellent wringing capability	CTE not close to manufactured (steel) parts Very low expansion coefficient (1/3 of steel) and because of the high density the blocks are deceptively heavy

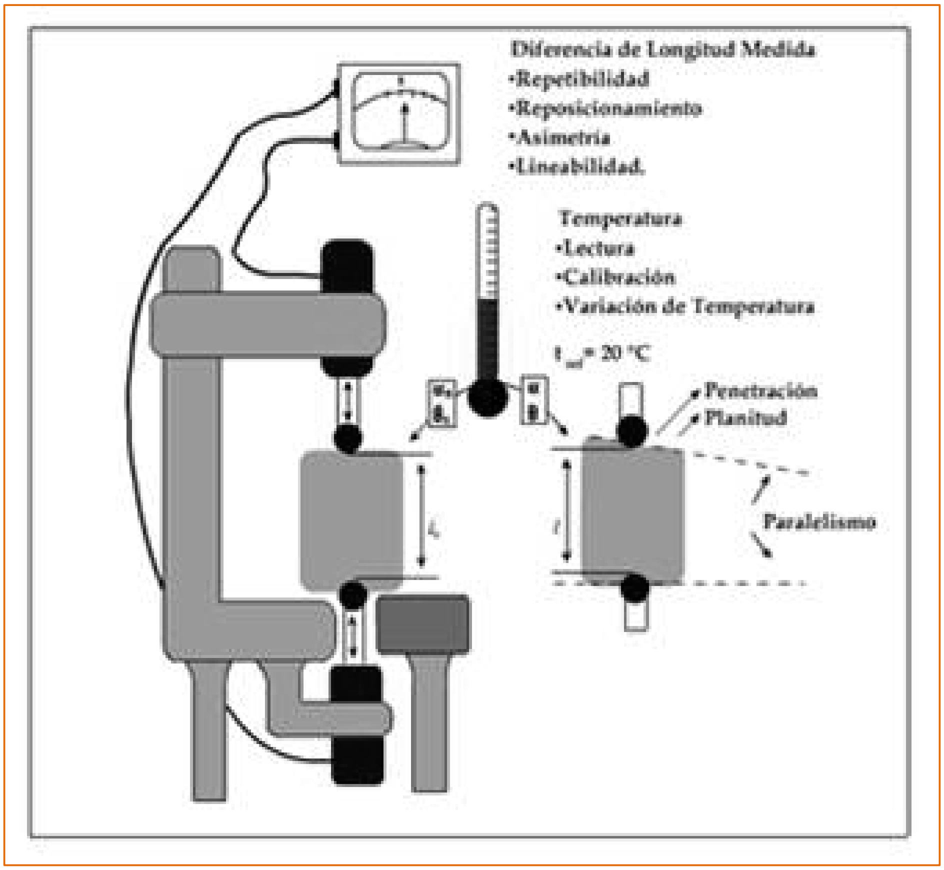


Gauge block traceability chain (1.2)



Calibration of gauge blocks using a mechanical comparator

Pictorial view of a mechanical comparator (1.3)



Equipment required

A GB comparator.
A set of Master GBs (Grades ISO 00, 0 or K)
Monochromatic sodium lamp and an Optical flat (not compulsory).
Thermometer (calibrated) with resolution of 0,1 °C.
Magnetic field indicator and demagnetizer (not compulsory)

Calibration Method

1. Pre and post handling and of gauge blocks.
2. Measuring face flatness
3. Verify if mechanical comparator is in calibrated state.
4. Calibrating gauge blocks of the same material. Can gauge blocks of the different material be calibrated?
5. Stabilise gauge blocks to equalize temperature between gauge blocks.
6. Any compensations made

The care of gauge blocks (Pre and post handling)

Accessories needed for the care of gauge blocks:

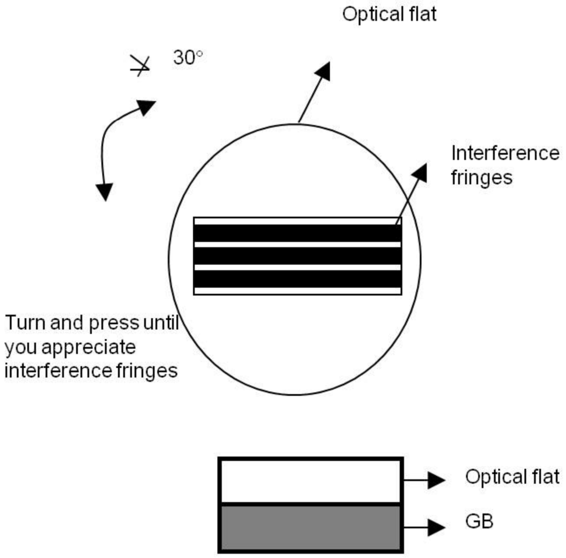
1. Vaseline
2. Paraffin
3. Ethyl esitate
4. Soft tissues
5. Lint free cloth
6. Substrate no. 1
7. Glove
8. Plastic gloves
9. Beaker
10. Gauge block holder (sucker)

Before measuring

Clean both sets of GBs, master and IUT.
Check magnetization and demagnetize if needed.
Leave gauge blocks to stabilize for a period of 25minutes per 20mm gauge block.

Measuring face flatness

Before measurement of each IUT GB, inspect the state of the measuring faces with a magnifying glass for burrs or scratches and check the flatness using the optical flat.



Verify if mechanical comparator is in calibrated state using the EAL-G21. Ceramic gauge blocks were used (1.4)

Pair No.	Nominal length A (mm)	Nominal length B (mm)
1	0,5	0,5
2	1,0	1,005
3	1,0	1,01
4	4,0	4,0
5	100,0	100,0
6	6,0	6,0*

Table: from the EAL-G21.

Calculating the correct size of the gauge blocks under test (UUT)

Std GB used (mm)	Reading on Std GB (µm)	Reading on UUT GB (µm)	Average reading of UUT (µm)	Corrected Size of UUT (mm)
15	-0,04	-0,05		
	-0,01	-0,05		$-3x10^{-8}$ X 1000
	0,00	0,04		-0.00003
	-0,02	-0,05	-0,03	
				15,00010 – 0,00003 =15,00007

Table 1: Verification of the same materials - Ceramic vs ceramic

Std GB used (mm)	Reading on Std GB (µm)	Reading on UUT GB (µm)	Average reading of UUT (µm)	Corrected Size of UUT (mm)
20	0,00	-0,13		
	0,03	-0,03		$8x10^{-8}$ X 1000
	-0,08	0,01		-0.00008
	-0,02	-0,06	0,08	$20{,}00001 + 0{,}00008 = 20{,}00009$

Table 2: Verification of different materials- Ceramic vs Steel

Std GB used (mm)	Reading on Std GB (µm)	Reading on UUT GB (µm)	Average reading of UUT (µm)	Corrected Size of UUT (mm)
10	0,05	-0.5		
	0,08	-0.5		1,8X10^{-8} X 1000
	0,09	-0.07		0,00018
	0,08	-0,06	0,18	
	0,10	-0,08		$9{,}99997 - 0{,}00018 = 9{,}99979$

Table 3: Verification of different materials- Steel vs Tungsten Carbide

Calibrating gauge blocks of the same material

Ceramic	**vs**	**Ceramic**	√
Steel	**vs**	**Steel**	√
Tungsten Carbide	**vs**	**Tungsten Carbide**	√

Calibrating gauge blocks of the different material

Ceramic	**vs**	**Steel**	√
Tungsten Carbide	**vs**	**ceramic**	√
Steel	**vs**	**Tungsten Carbide**	?

Thermal Expansion

In most materials, a change in temperature causes a change in dimensions. This change depends on both the size of the temperature change and the temperature at which the change occurs.

Formulae used for temperature calculations on gauge blocks:

$$\Delta L/L = \alpha L \, \Delta T$$

Where

ΔL = is the change in length of the object
L = is the length,
ΔT = change in temperature
α = is the coefficient of thermal expansion (CTE).

Measurements not made at exactly 20°C needs thermal expansion correction using CTE.

(1.5)

Material	**Material Thermal Expansion Coefficient** (10^{-6}/°C)
Aluminium	24
Free Cutting Brass	20.5
Steel Gauge Block	**11.5**
Steel Gauge Block (500 mm)	**10.6**
Ceramic Gauge Block (zirconia)	**9.2**
Chrome Carbide	**8.4**
Granite	6.3

Oak (across grain)	5.4
Oak (along grain)	4.9
Tungsten Carbide	**4.5**
Invar	1.2
Fused Silica	0.55
Zerodur	0.05

Example:

The steel gauge block can be used to gauge any material if corrections are made for the differential thermal expansion of the two materials involved. If a steel gauge block is used to gauge a 100 mm aluminium part at 25 ºC, a correction factor must be used. Since the expansion coefficient of aluminium is about twice that of steel, when the part is brought to 20ºC it will shrink twice as much as the steel. Thus the aluminium block must be made oversized by the amount.

$$\Delta L = (\alpha\text{Aluminium} - \alpha\text{Steel}) \text{ x } L \text{ x } \Delta T$$
$$= (24 - 11.5) \text{ x } 10\text{-}6 \text{ x } 100 \text{ mm x } 5^{\circ}\text{C}$$
$$= 6{,}25\ \mu\text{m}$$

So if we make the cube 6,25 µm larger than the steel gauge block it will be exactly 100 mm when brought to standard conditions (20 ºC).

Elastic Properties

When a force is exerted on any material, the material deforms. For steel and other gauge block materials this effect is small, but not completely negligible. There are two-dimensional effects due to the elastic properties of gauge blocks. The first, and least important, is the compression of blocks under their own weight. When a block is supported horizontally, the force on each point is the weight of the steel above it, and the steel is slightly compressed. The compression is, however, not in the direction of the gauging dimension of the block and the effect is negligible. If the block is set upright, the force is now in the direction of the gauging surfaces, and for very long blocks the weight of the block can become significant. Solved analytically, the change in length of a block is found

Formulae used for Elastic compression calculations on gauge blocks:

$$\Delta L = \rho g L2/2E$$

Where

ΔL = length of shortening
ρ = density of material
g = acceleration of gravity
L = total length of block
E = Young's modulus for material

For steel gauge blocks, the shrinkage is
$\Delta L = (7.8x103(kg/m3) \text{ x } 9.8 \text{ m/s2 x } L2)/(2 \text{ x } 210x109 \text{ N/m2})$
$= 0.18x10\text{-}6 \text{ x } L2$ in meters.

For a 500 mm gauge block the correction is 45 nm (1.8 μin). The corrections from this formula are made at NIST on demand, but are negligible for blocks less than 300 mm (12 in). When using long gauge blocks supported horizontally, some care is needed to assure that the block bends properly. Since the sides of the gauge block are not precision surfaces, no matter how flat the surface where it is placed it will touch only at a few points, therefore bending, and in general producing some small angle between the two gauging faces. The proper way to support the block 25 so that the two end faces are parallel, and thereby produce an unambiguous length, is shown in figure. This assumes, however, that the gauging faces are parallel when the block is vertical.

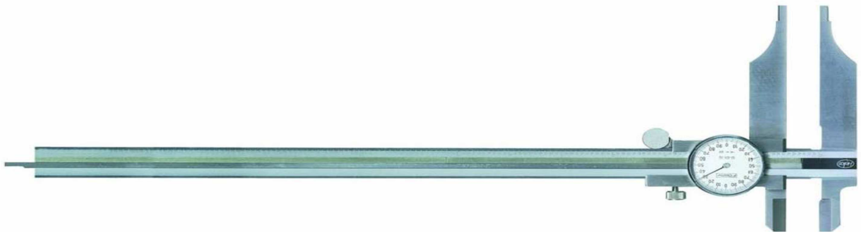
Uses of gauge blocks

Micrometers

Height Standard and verification assembly

Kinds of callipers

They can have an inside, outside, depth and step measurement capabilities
They can be digital, analogue with vernier scale or analogue with dial
They are in Imperial, SI or both
They can be bench or handheld instruments
Measuring range or
Resolution type of jaws etc.



Conclusion:

All Gauge blocks of the same material eg. steel vs steel could be calibrated using the mechanical comparator. Any ceramic vs steel or tungsten carbide gauge block could be measured using the mechanical comparator. Ceramic blocks have favorable mechanical and thermal properties that compare the closest to steel of any alternative gauge block material. Steel vs tungsten carbide gauge blocks **could** be measured using the mechanical comparator **but** temperature and elastic compression corrections have to be made with the steel vs tungsten carbide gauge blocks.

References:

Introduction: (1) C.E. Johansson [C.E. Johansson Corporation], LCCN 74219452.

Definition of calibration: According to BIPM (1.1)

Traceability chain of gauge blocks (1.2) – From Dr. Miguel Viliesid (Mexico)

Pictorial view of a electromechanical comparator (1.3) Dr. Miguel Viliesid (Mexico)

Verification of mechanical comparator’s calibration state: From the EAL-G21 (1.4)

Table of all the thermal Expansion Coefficient (1.5) - The Gauge Block Handbook
By Ted Doiron and John Beers Dimensional Metrology Group Precision Engineering Division National Institute of Standards and Technology

Verify if mechanical comparator is in calibrated state using the EAL-G21