HIGH ACCURACY MEASUREMENTS OF RINGS, PLUGS, STEP-GAUGES AND BALL-BARS USING A CMM COUPLED WITH AN INTERFEROMETRIC LASER

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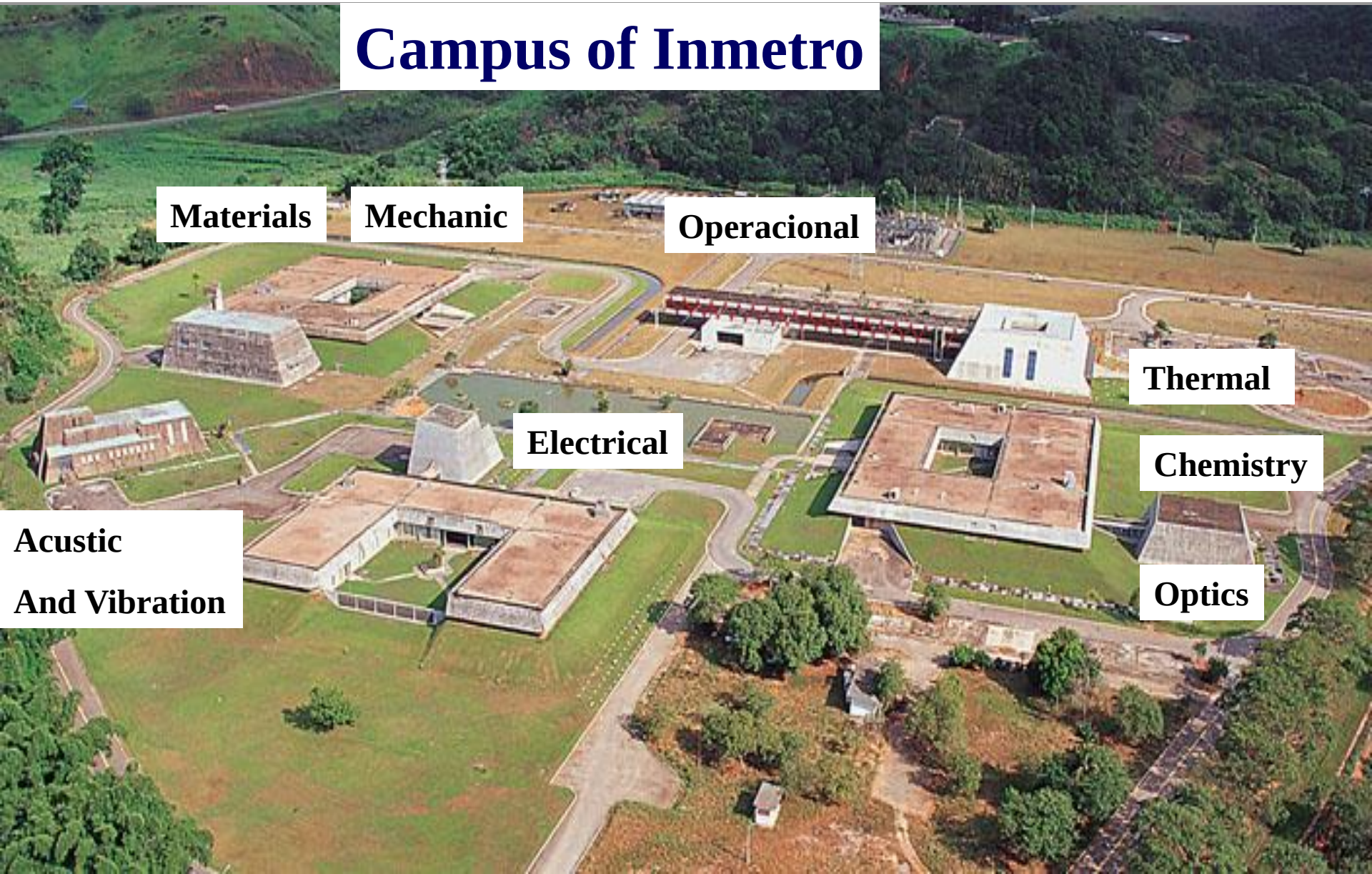
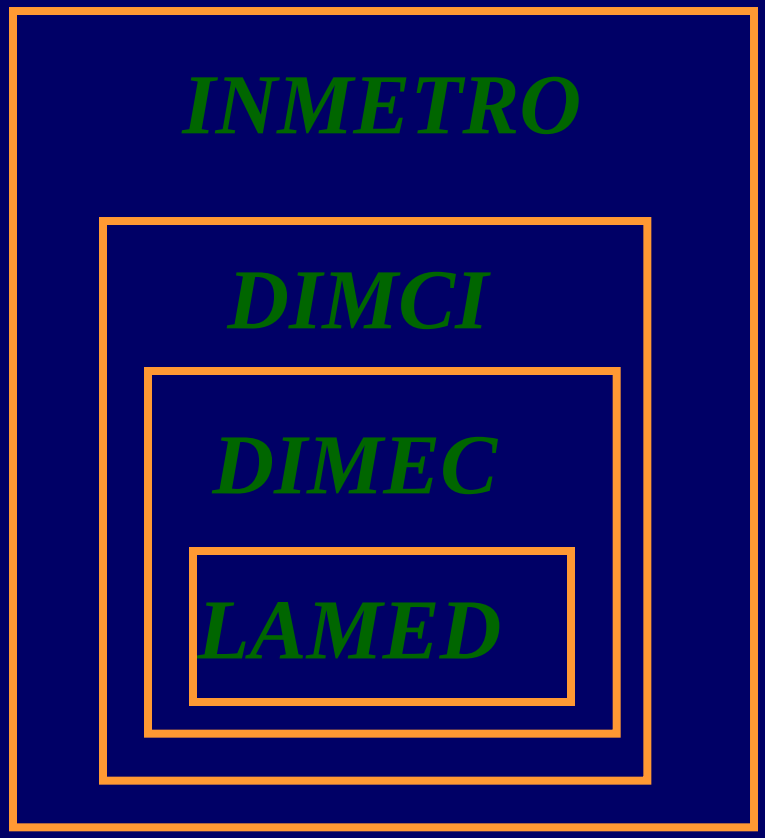
Campus of Inmetro



STUCTURE



LAMED-DIMENSIONAL METROLOGY LABORATORY

INMETRO/LAMED - SERVICES

- **Gage – blocks, bars;**
- **Roughness and depth set standards;**
- **Angular blocks, polygons;**
- **Roundness standards;**
- **Laser Systems for linear measurements;**
- **Step-gages, ball-bars, 2D artefacts;**
- **Rings, plugs and spheres;**
- **Scales;**

Industries and accredited labs

TOTAL : 26 SERVICES

CMM FACILITIES AT LAMED

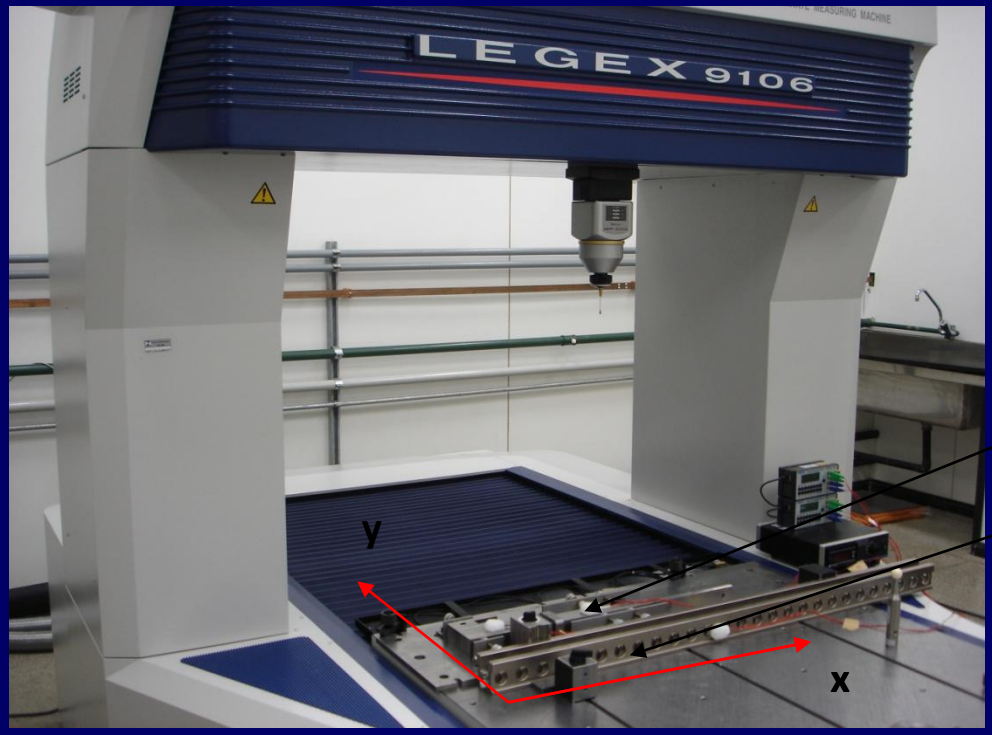
LEGEX -9106 – MITUTOYO

 # 2D ARTEFACTS
 # STEP-GAGES BY COMPARISON
#GENERAL MEASUREMENTS

UMM 500 – ZEISS

 # RINGS, PLUGS, SPHERES
 # STEP-GAGES, BALL-BARS
#GENERAL MEASUREMENTS

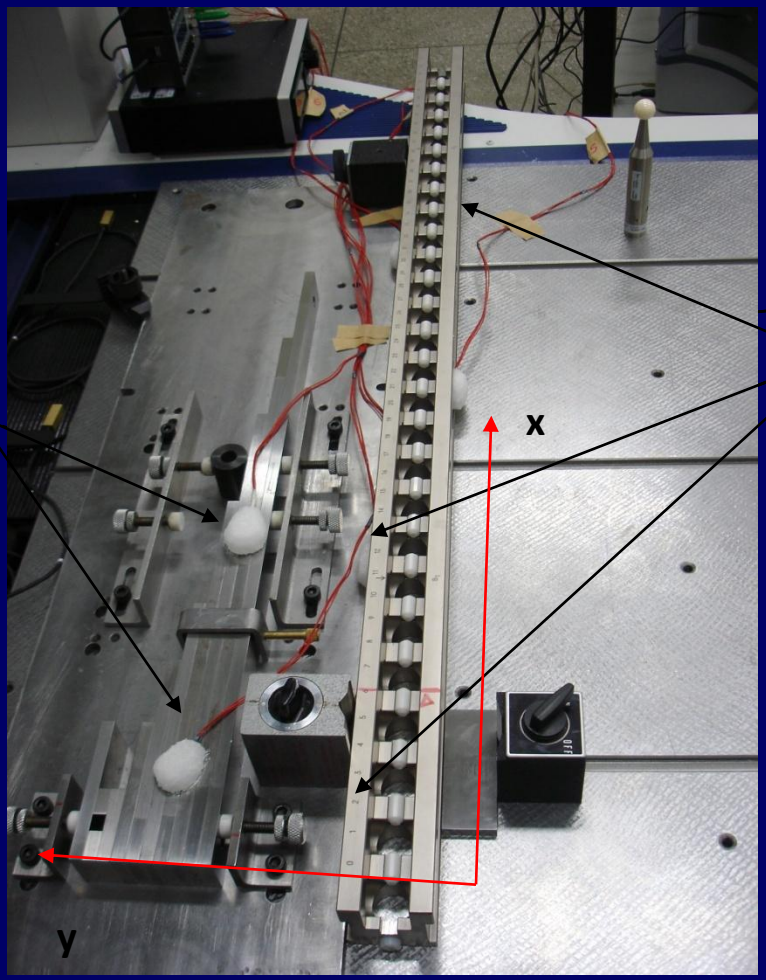
STEP-GAGES CALIBRATION



Gages positioning

Set-up

Position of the sensors on the gage-blocks



Position of the sensors on the step-gage

20mm, 50mm, 100m, 150mm,... 600mm

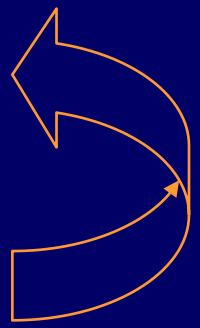
Calibration strategy

1 – Probing error determination

2 – Masurements of blocks.

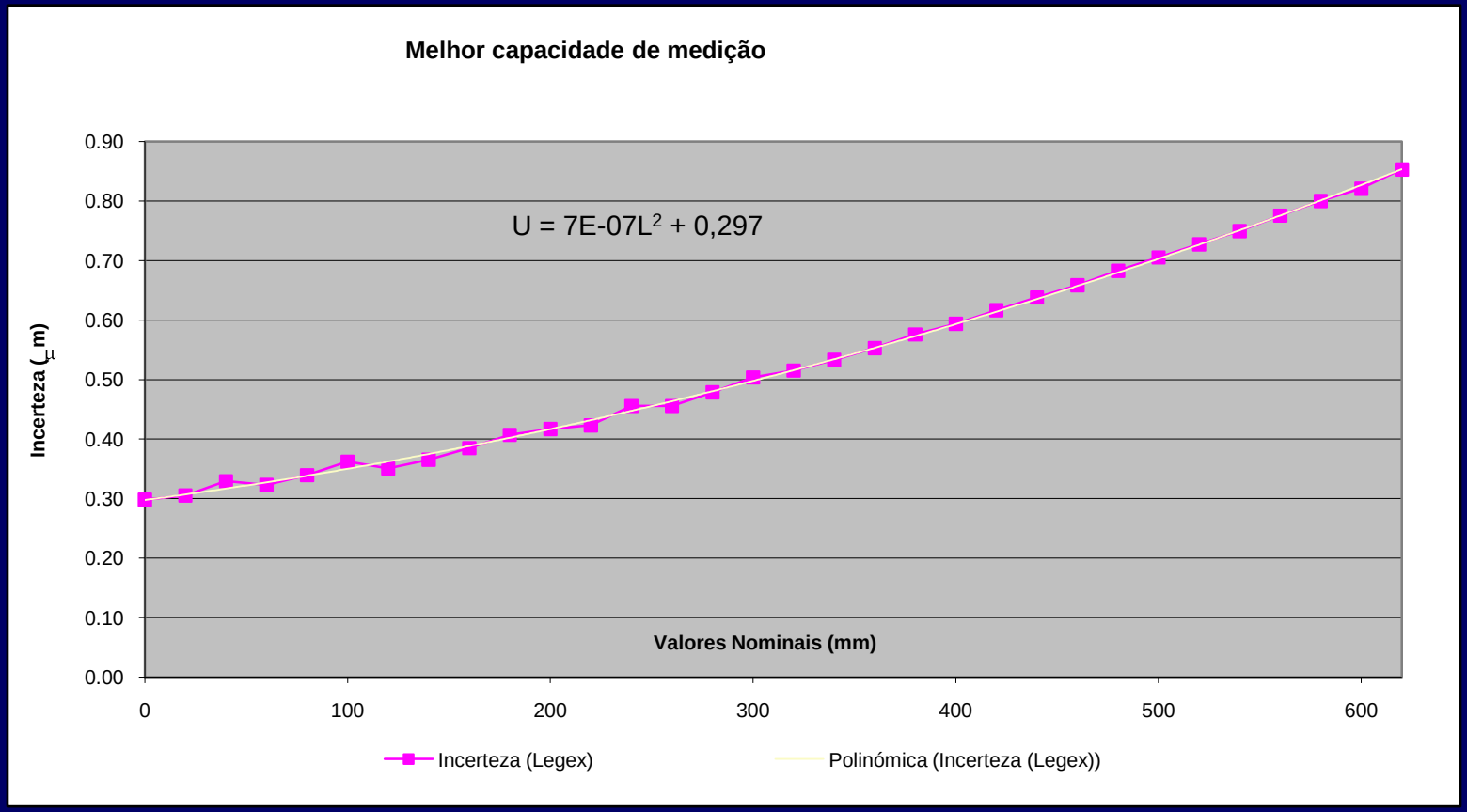
Smaller >>> Larger

3 – Step-gage measurement

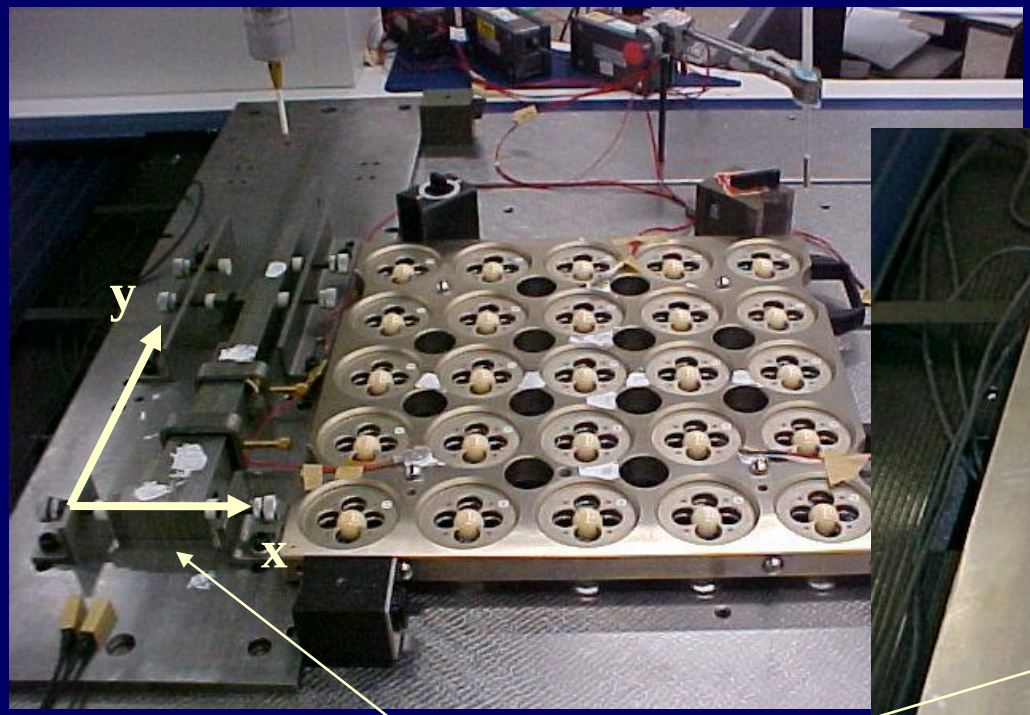


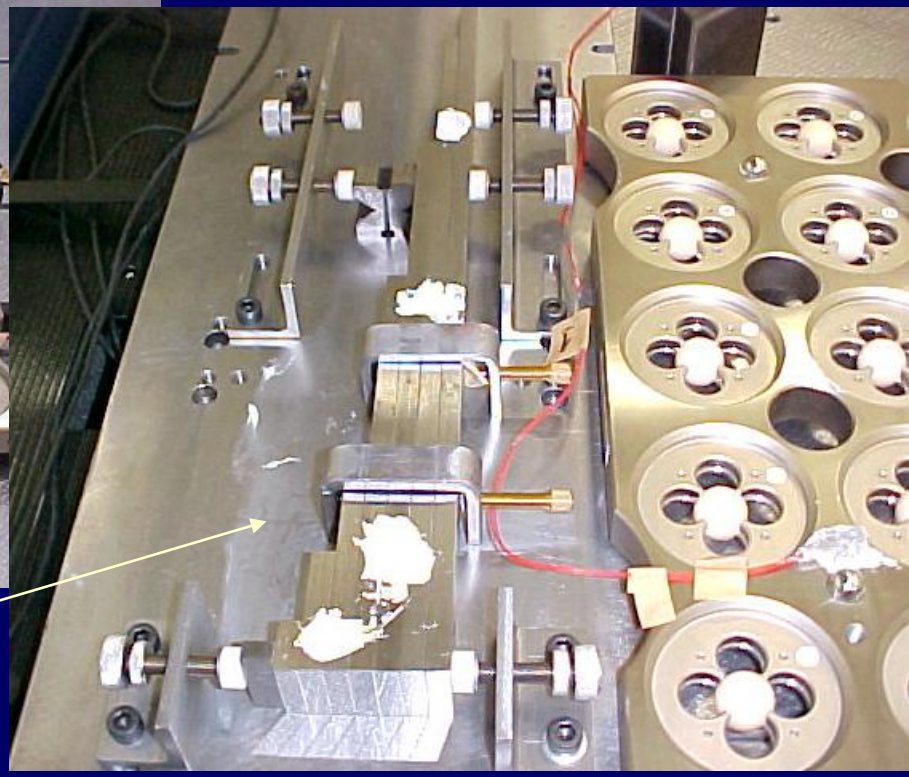
5 cycles

Measurement uncertainty



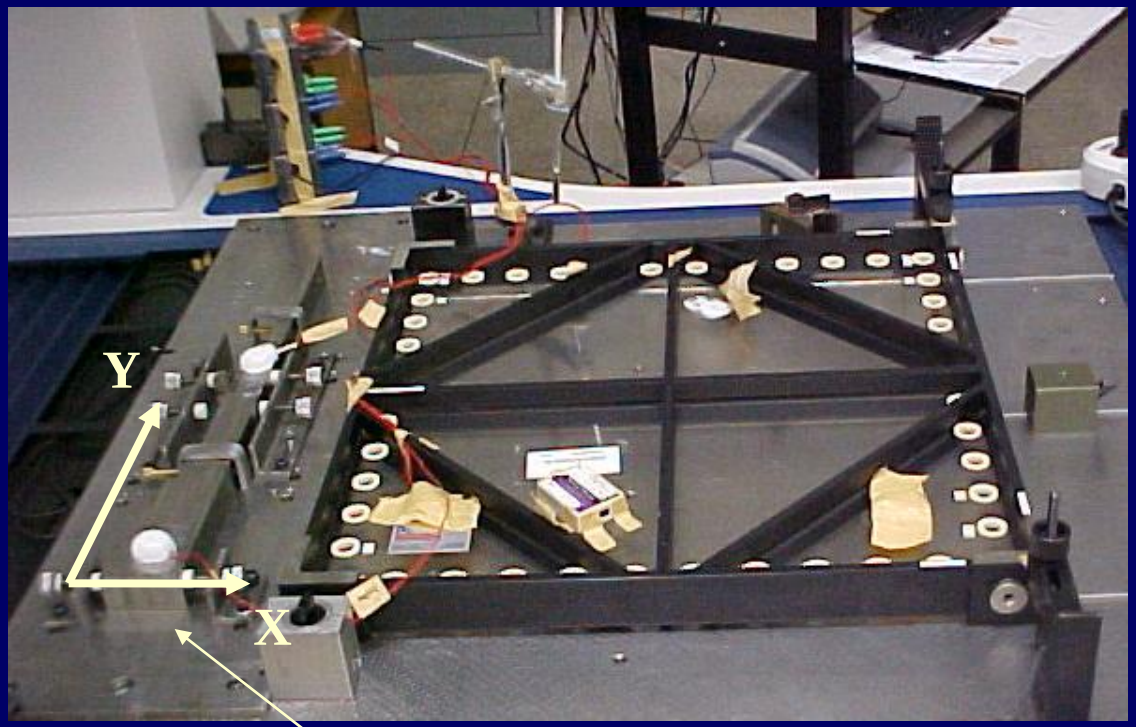
BALL - PLATE CALIBRATION





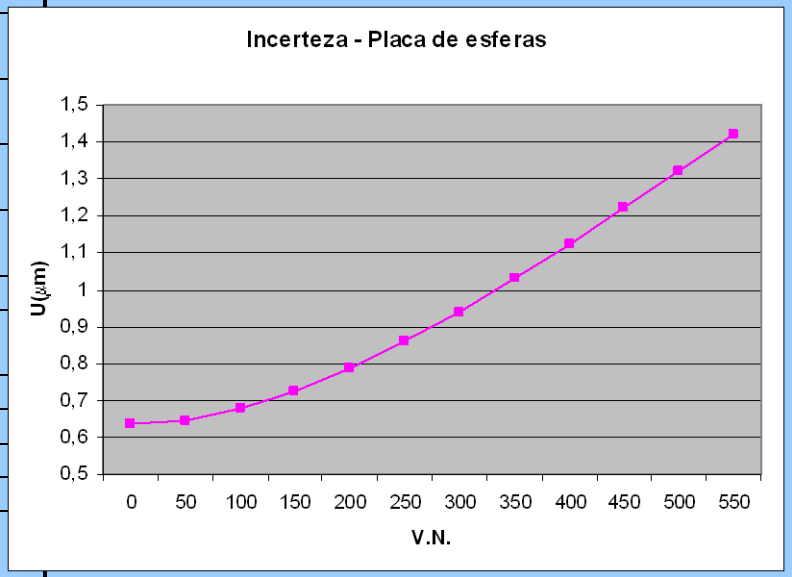
Gage-blocks

HOLE - PLATE CALIBRATION



Measurement uncertainty - Ball-plate

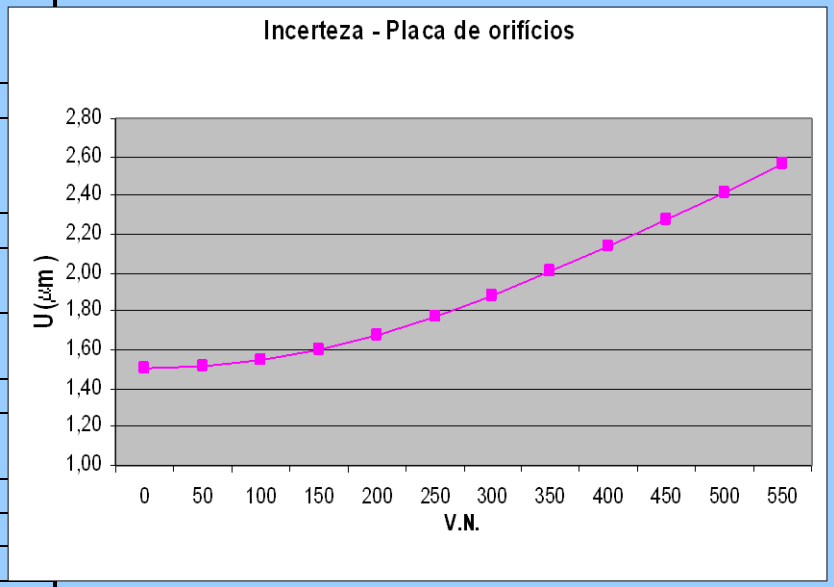
x_i	$u(x_i)$	ν_i	$c_i = \partial l/\partial x_i$	$u_i(l)$ / nm
Plate measurements				
Short Term Reproducibility (Plate)	0,173205081	Infinite	1000	173,2
Thermometer calibration	0,002	Infinite	11,5	0,02
Thermal Expantion Coeficient (Plate)	1,1547E-06	Infinite	125330	0,1
Gradients and Instability (Plate)	0,025980762	Infinite	11,5	0,3
Comparison				
Short Term Reproducibility (Plate)	0,083715789	infinite	1000	83,7
Reproducibility	0,111407653	4	1000	111,4
Gage-blocks calibration	0,03	Infinite	1000	30,0
Repeatibility - Blocks	0,193304565	4	1000	193,3
Repeatibility - Plate	0,117004273	4	1000	117,0
Thermal Expantion Coeficient (Plate and Gage-blocks)	1,1547E-06	Infinite	59170	0,1
Gradients and Instability (gage-blocks)	0,067261306	Infinite	11,5	0,8
Gradientes and Instability (Plate)	0,068704682	Infinite	11,5	0,8



Combined standard uncertainty: $u_c(l) = \sqrt{(318{,}397)^2 + (1{,}15671)^2 \cdot l^2}$ nm; l, in mm.

Measurement uncertainty - Hole-plate

x_i	$u(x_i)$	v_i	$c_i = \partial l / \partial x_i$	$u_i(l)$ / nm
Plate measurements	---	---	---	---
Short Term Reproducibility (Plate)	0,53982	Infinite	1000	539,82
Thermometer calibration	0,00200	Infinite	0,50	0,00
Thermal Expantion Coeficient (Plate)	0,00000	Infinite	236166,67	0,07
Gradientes and Instability (Plate)	0,11172	Infinite	0,50	0,05
Comparison	---	---	---	---
Short Term Reproducibility (Blocks)	0,173205	infinite	1000	173,20
Reproducibility	0,339664	4	1000	339,66
Gage-blocks calibration	0,065	Infinite	1000	65
Repeatibility - Blocks	0,230478	4	1000	230,47
Repeatibility - Plate	0,259808	4	1000	259,81
Thermal Expantion Coeficient (Plate and Gage-blocks)	1,15E-06	Infinite	145333,33	0,17
Gradientes and Instability (gage-blocks)	0,110274	Infinite	11,5	1,27
Gradientes and Instability (Plate)	0,121532	Infinite	11,5	1,40



Combined standard uncertainty: $u_c(l) = \sqrt{(749{,}416)^2 + (1{,}89671)^2 \cdot l^2}$ nm; l, in mm.

Comparison with pilot results- Ball plate

Esfera	INMETRO		NMIJ		INMETRO			
No.	DX [mm]	DY [mm]	U_x [um]	U_y [um]	U_x [um]	U_y [um]	Emx	Emy
1	0,0000	0,0000	0,12	0,12	0,75	0,75	0,00	0,00
2	0,0002	-0,0001	0,15	0,12	0,76	0,75	0,26	-0,08
3	0,0001	0,0000	0,20	0,12	0,77	0,75	0,10	-0,03
4	0,0002	-0,0001	0,27	0,12	0,80	0,75	0,29	-0,07
5	0,0002	0,0000	0,34	0,12	0,84	0,75	0,17	0,00
6	-0,0001	0,0001	0,12	0,15	0,89	0,75	-0,09	0,14
7	0,0002	0,0002	0,15	0,15	0,94	0,75	0,18	0,32
8	0,0001	0,0001	0,20	0,15	1,00	0,75	0,09	0,13
9	0,0001	0,0001	0,27	0,15	1,07	0,75	0,10	0,14
10	0,0001	0,0001	0,34	0,15	1,14	0,75	0,07	0,15
11	0,0000	0,0002	0,12	0,20	1,21	0,75	-0,04	0,20
12	0,0001	0,0002	0,15	0,20	1,28	0,75	0,10	0,22
13	0,0001	0,0001	0,20	0,20	0,75	0,76	0,08	0,09
14	0,0002	0,0001	0,27	0,20	1,28	0,76	0,12	0,13
15	0,0001	0,0001	0,34	0,20	0,75	0,77	0,12	0,18
16	-0,0001	0,0000	0,12	0,27	1,28	0,77	-0,07	-0,03
17	0,0002	0,0001	0,15	0,27	0,75	0,80	0,21	0,09
18	0,0001	-0,0001	0,20	0,27	1,28	0,80	0,06	-0,16
19	0,0002	0,0000	0,27	0,27	0,75	0,84	0,26	0,03
20	0,0002	0,0000	0,34	0,27	1,28	0,84	0,14	-0,01
21	-0,0002	0,0001	0,12	0,34	0,75	0,89	-0,21	0,11
22	0,0001	0,0002	0,15	0,34	1,28	0,89	0,07	0,19
23	0,0000	0,0002	0,20	0,34	0,75	0,94	0,00	0,17
24	0,0002	0,0001	0,27	0,34	1,28	0,94	0,12	0,14
25	0,0001	0,0001	0,34	0,34	0,75	1,00	0,14	0,09

$$En_{x,y} = D_{x,y} / \sqrt{(U\text{^}2 + Ur\text{^}2)}$$

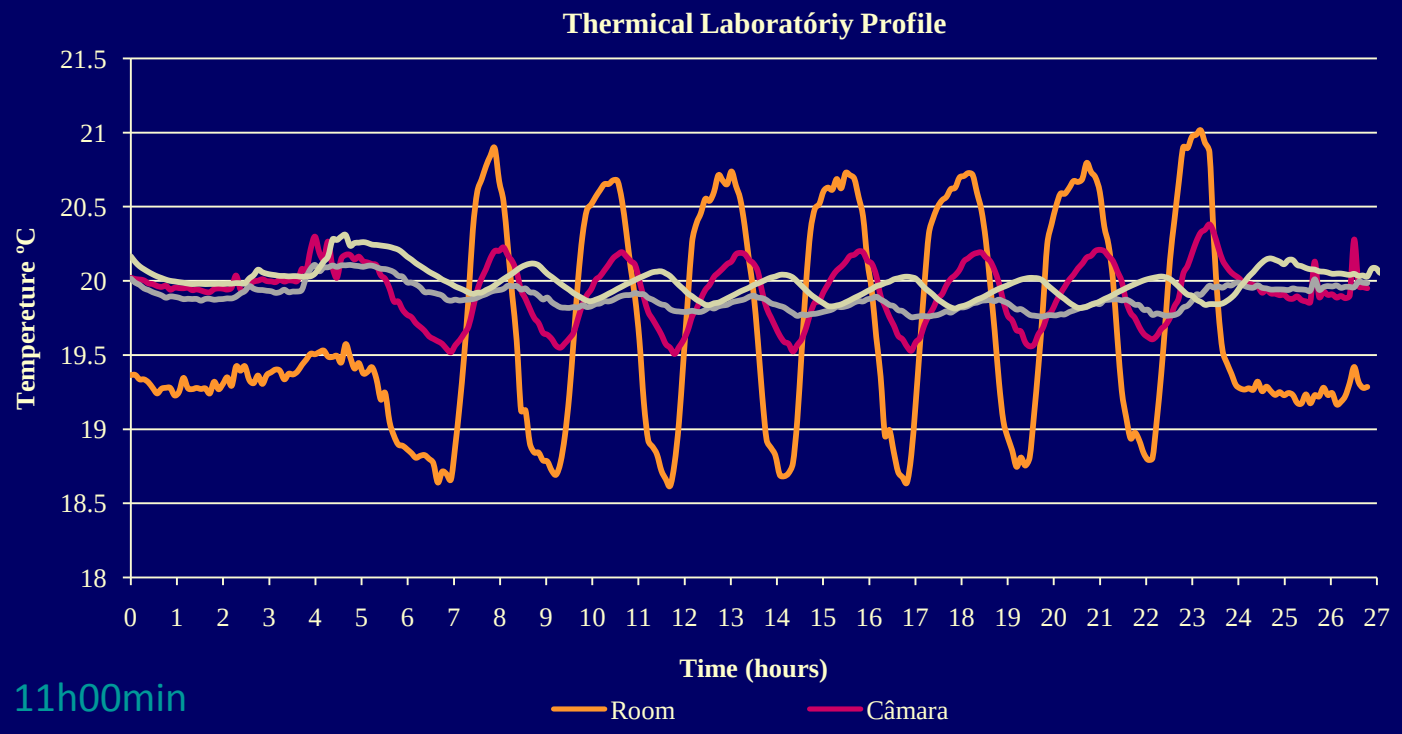
Maximum value

0,32

CMM – LASER SYSTEM

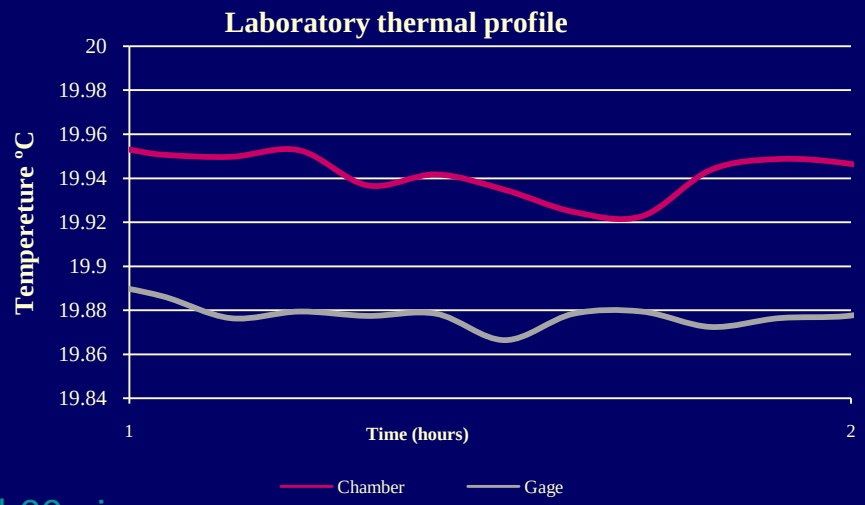
UMM 500 – ZEISS

Environmental conditions- Room 2 – long period



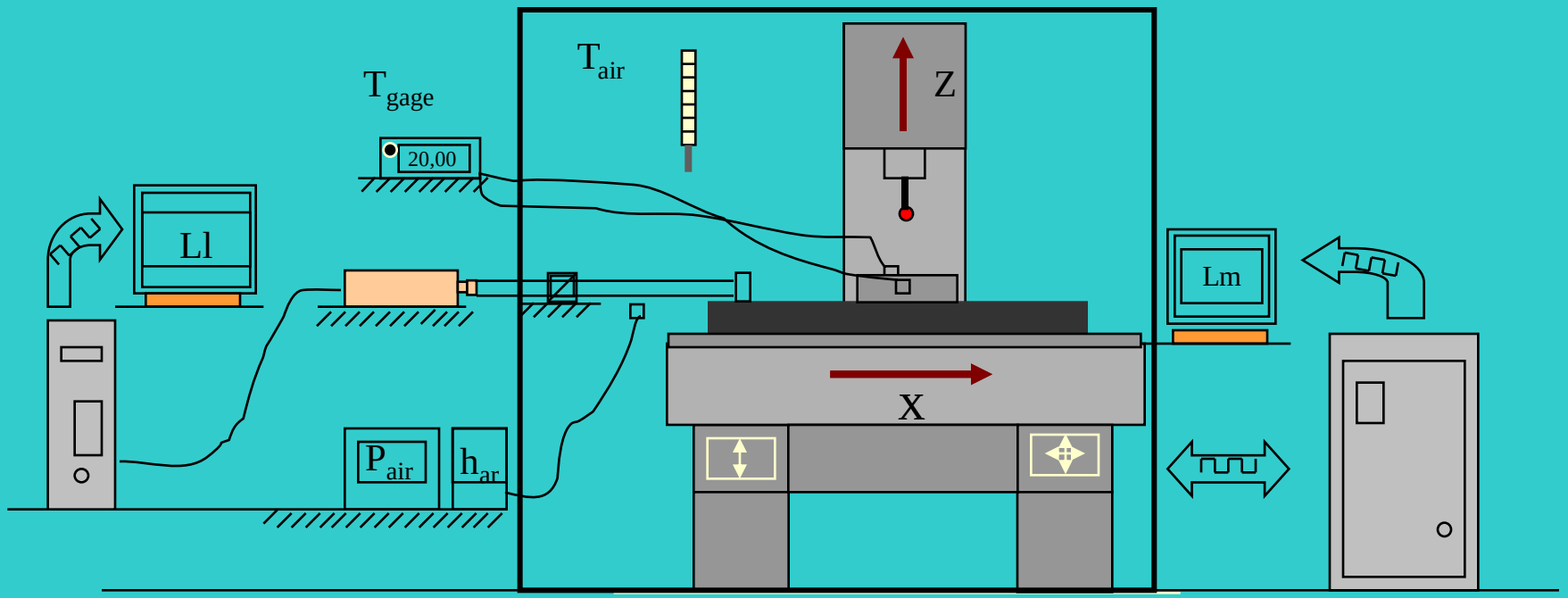
11h00min

Environment condition - Room 2 – short period

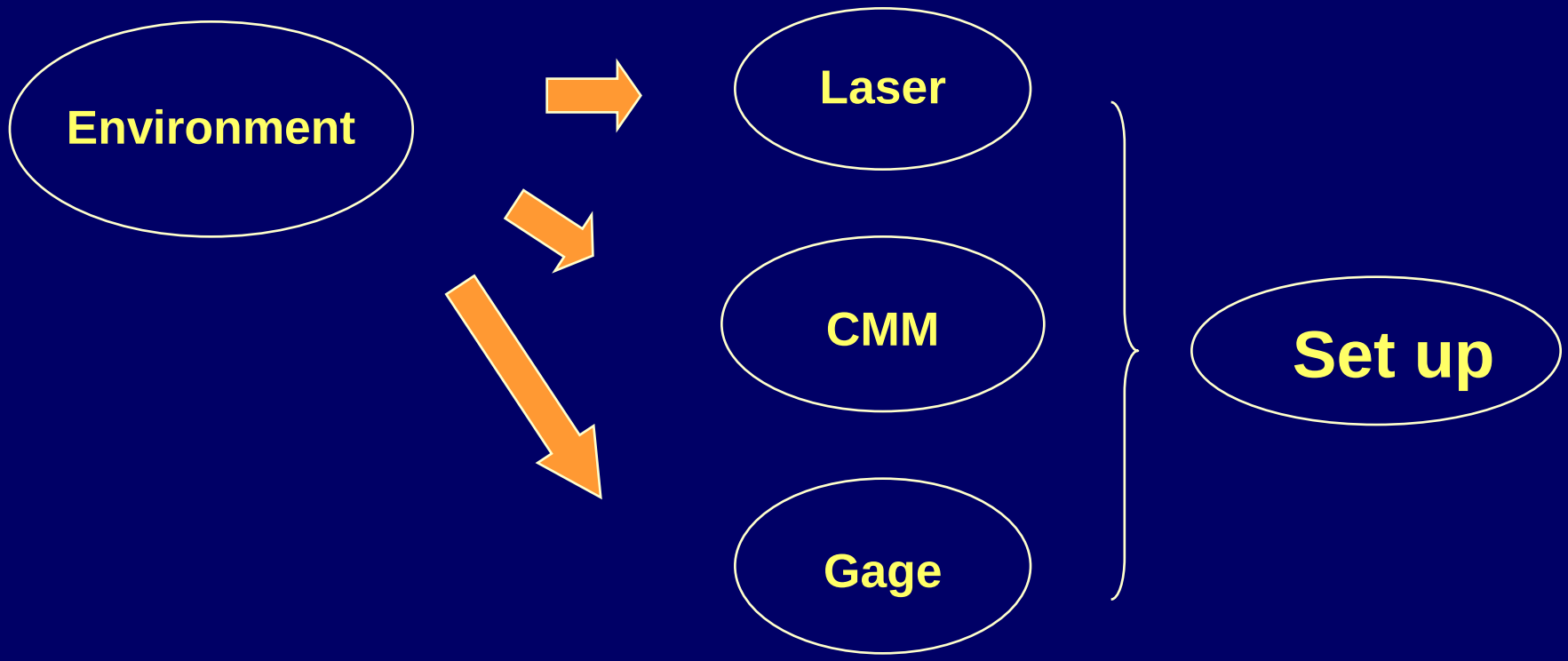


12h00min

LENGTH MEASUREMENT SYSTEM



Error sources



Refraction index of the air

$\lambda_{air} < \lambda_{vac}$

$\lambda_{vac} = \eta \lambda_{ar}$

η Refraction index of the air
λ_{vac} wave-lenght in vacuun;
λ_{air} wave-lenght in air;

Refraction index of the air - Edlén :

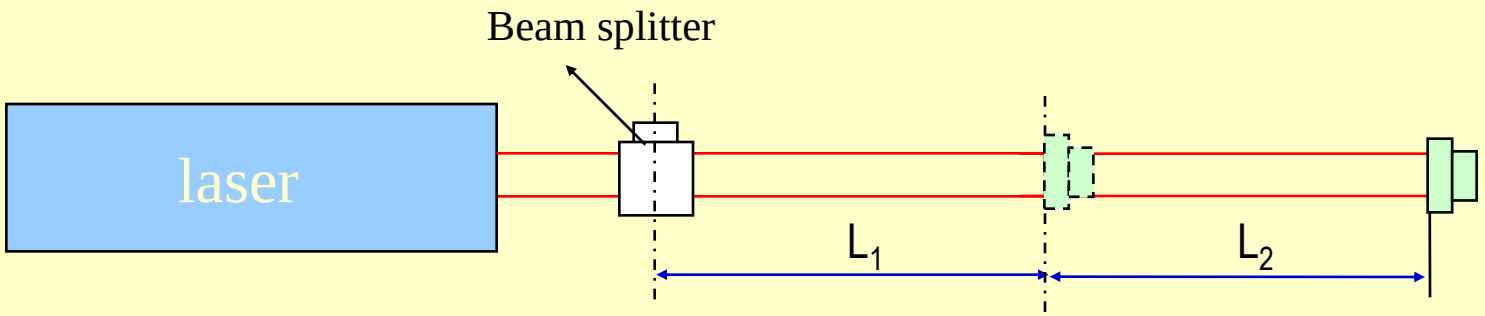
$$\eta = \left[p \times \frac{(\eta_s - 1)}{K_1} \right] \times \frac{\left(+10^{-8} \times (K_2 + K_3 T) \times p \right)}{(1 + K_4 T)} - f \times \left[K_5 + K_6 \times \left(\frac{1}{\lambda} \right)^2 \right] \times 10^{-10} + 1$$

where :

p	Air pressure - Pa;
f	Parcial pressure for moist air - Pa;
T	Air temperatue - °C;

K_i are constants

Dead-path

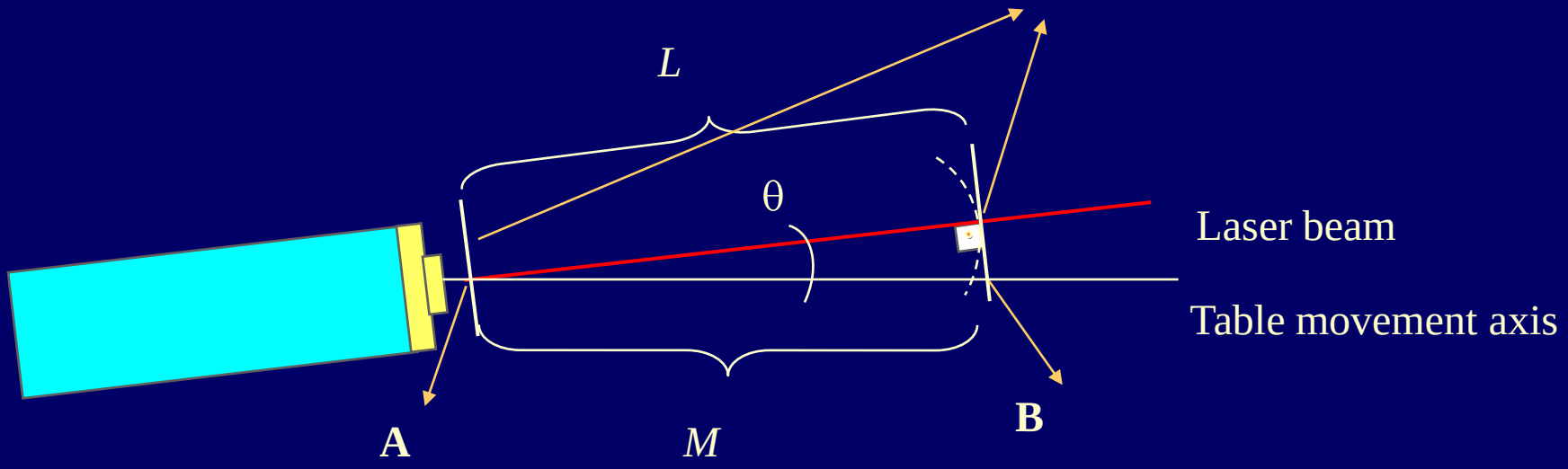


L1 - ”Dead path L2 - Measured lenght

$$DP = L1 * \alpha * (\Delta T)$$

"Cossine error"

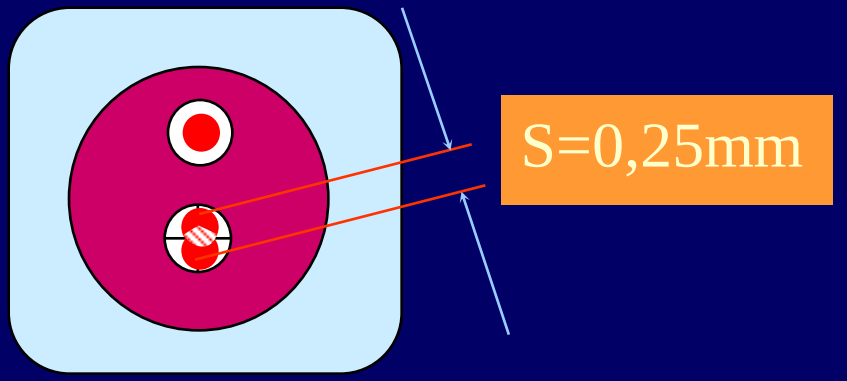
L = Laser displacement
M = Table displacement



$$\xi = \frac{M - L}{M} = 1 - \cos\theta = \frac{\theta^2}{2}$$

"Cossine error"

$$\xi = \frac{S^2}{8L^2}$$



Gage temperature

$$L_{20} = L_e /(1+\alpha * (T_e - 20)$$

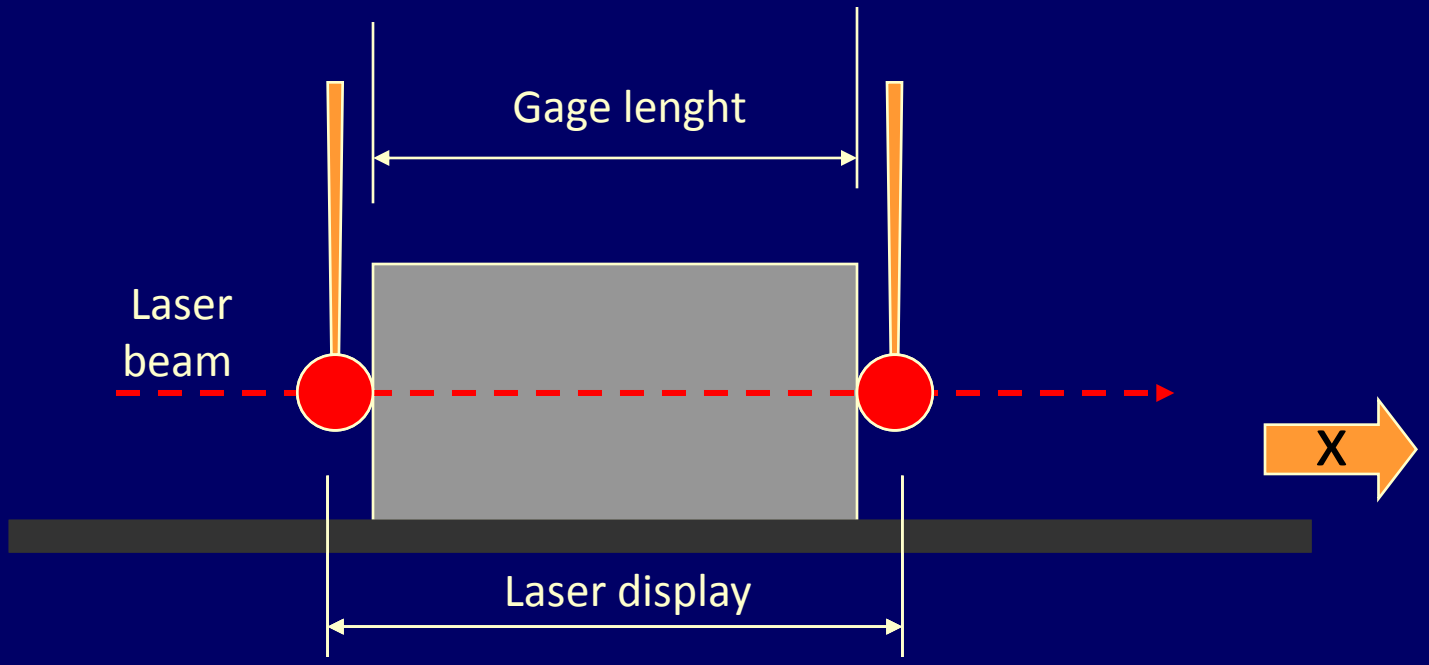
α = Thermal expansion coeficient;

L_e = Lenght at environmental temperature;

L_{20} = Lengh at 20 ^{0}C;

T_e = Calibration temperature;

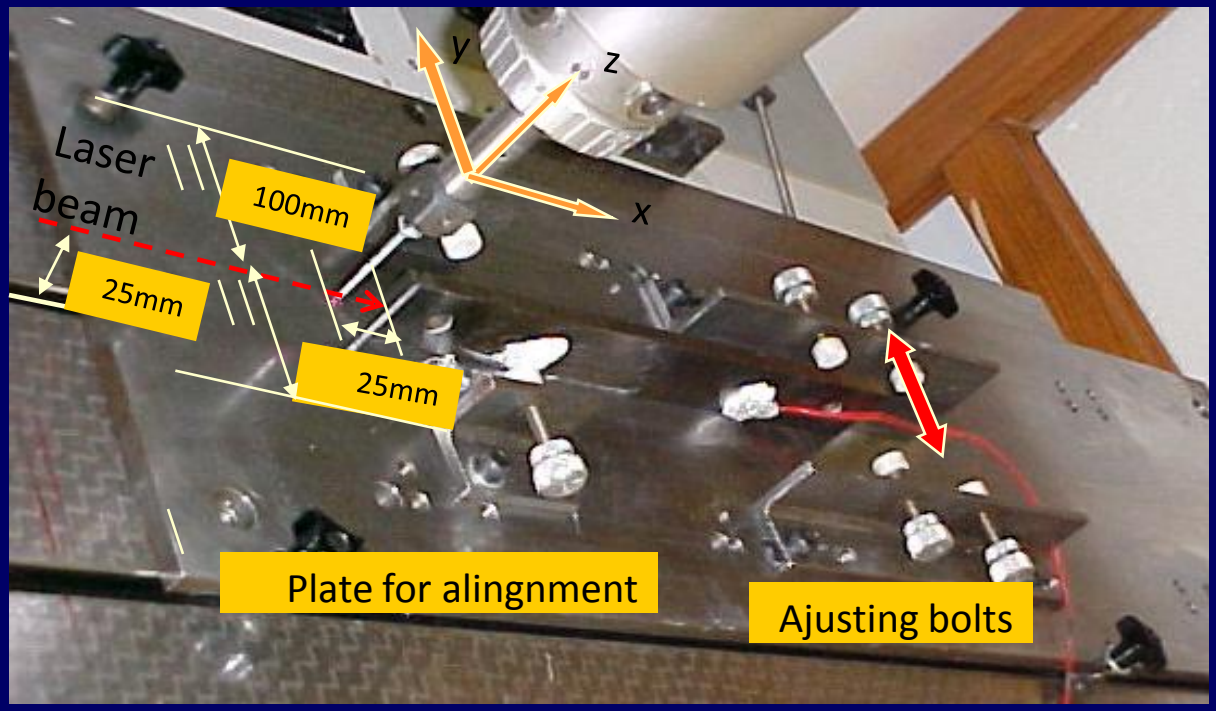
Ideal model



Difference = diameter of the probe

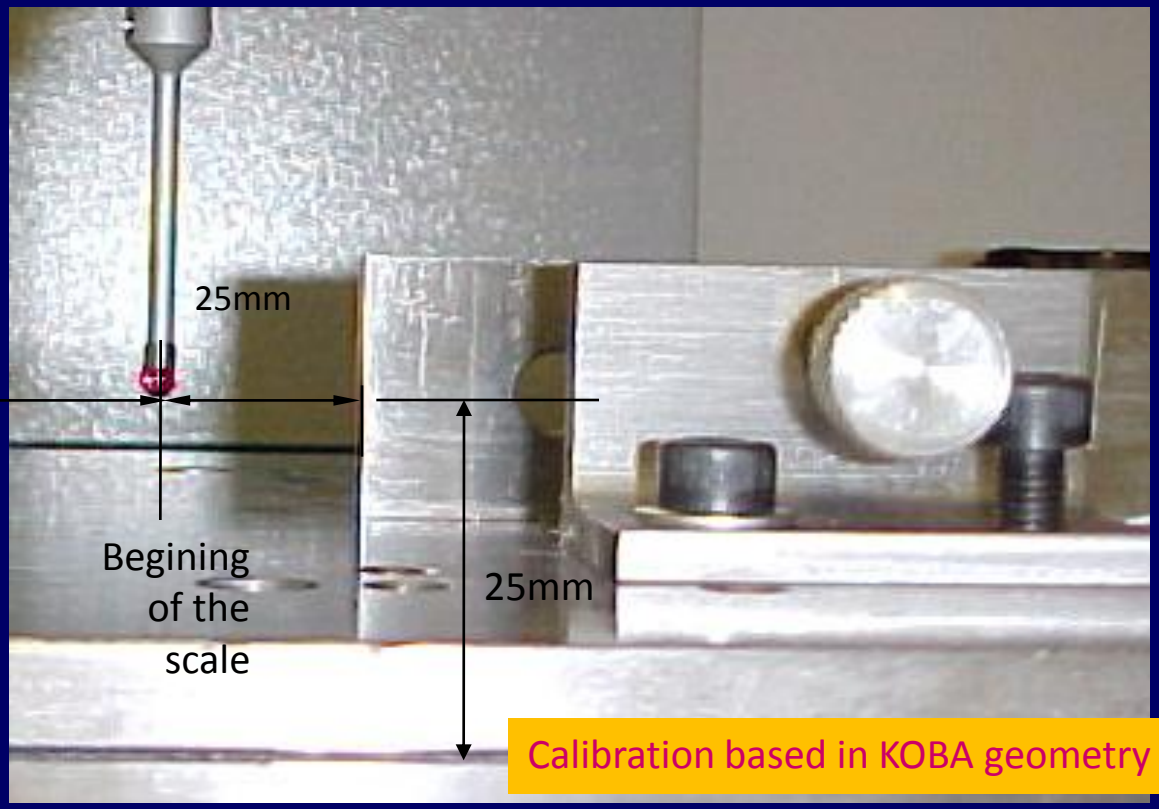
Abbè principle → ***Only if in laser direction***

Set up - Alignment and fixation of the gage

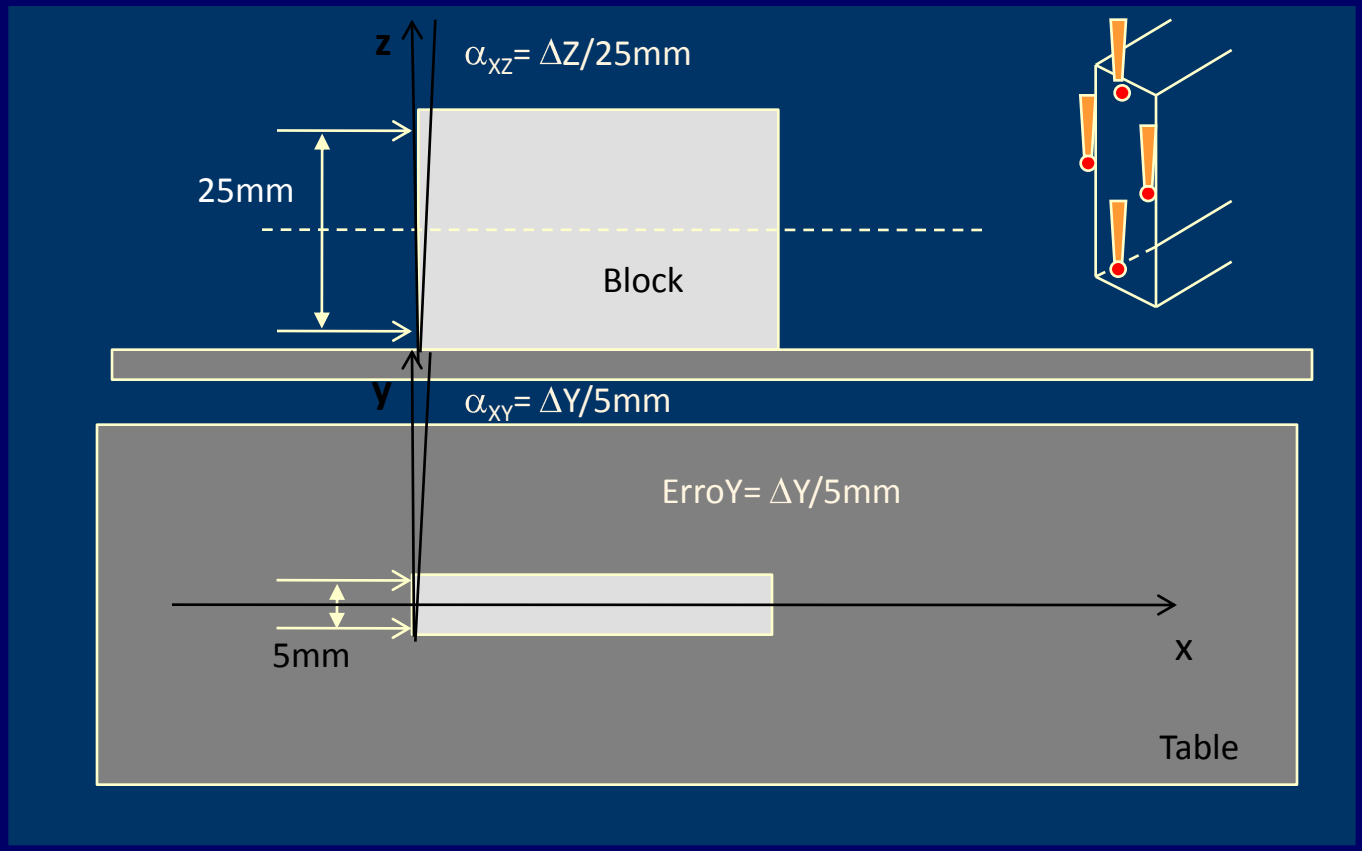


Calibration based in KOBA geometry

Horizontal positionning



Alignment error



ErrorΔZ~ 5μm

ErrorDZ ~ 1μm

- Actual model

$$l_g = l_l \pm d_p - E_{la} - E_{ga} - E_{dl} - E_{sys}$$

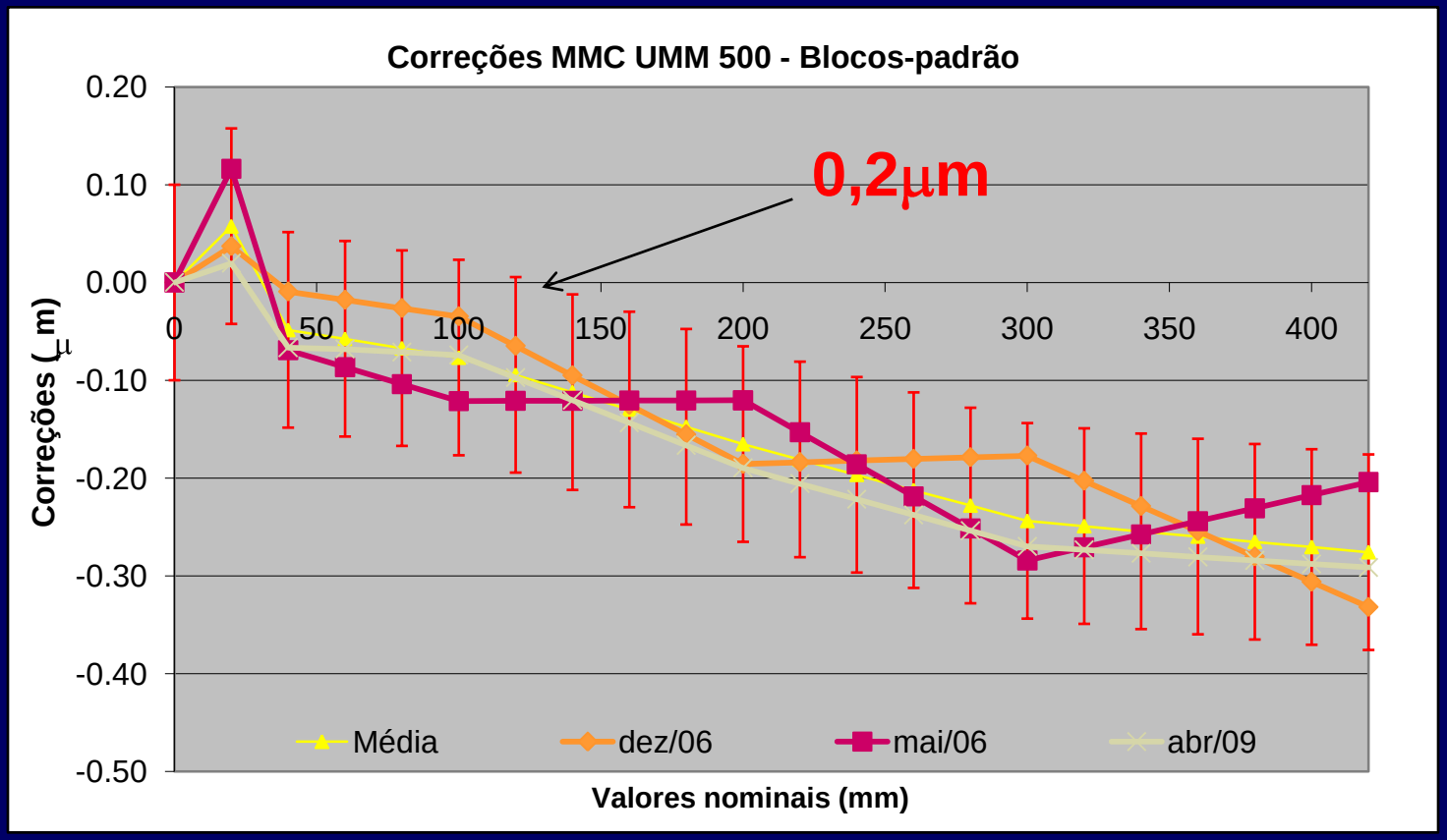
$$l_g = \bar{l}_l * \frac{n0}{n} * \frac{1}{(1+\alpha*(T_g - T_r))} \pm \frac{d_p}{(1+\alpha*(T_g - T_r))} - E_{la} - E_{ga} - E_{dl} - E_{sys}$$

Gage-block measurement

5mm → Determinação do erro de apalpação

20mm
50mm
100mm
200mm
300mm
400mm → Determinação do erro de posicionamento

Systematic errors



Using the calibrated system

Step gage calibration

0mm – 420mm – $(0,4^2+(1,2*10^{-3}*(L))^2)^{0,5}$

420mm – 880mm – $0,7+(0,4^2+(1,2*10^{-3}*(L-420))^2)^{0,5}$

880mm – 1060mm – $1,4 +(0,4^2 +(1,2*10_{-3}*(L-880))^2)^{0,5}$

L in mm

Using the calibrated system

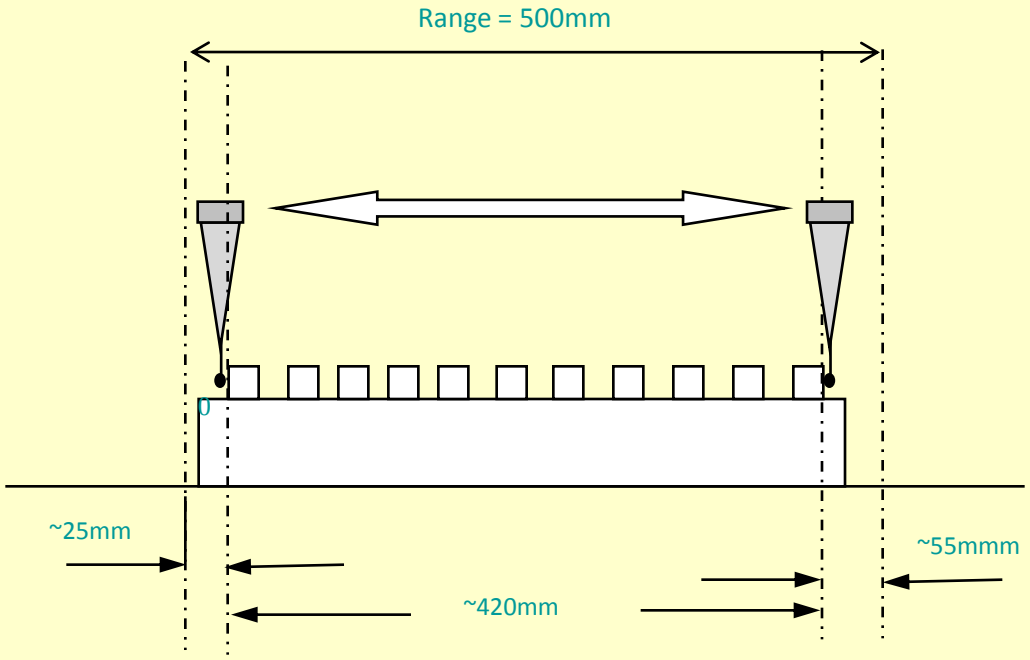
One single client

Tree-spheres Ball-bar

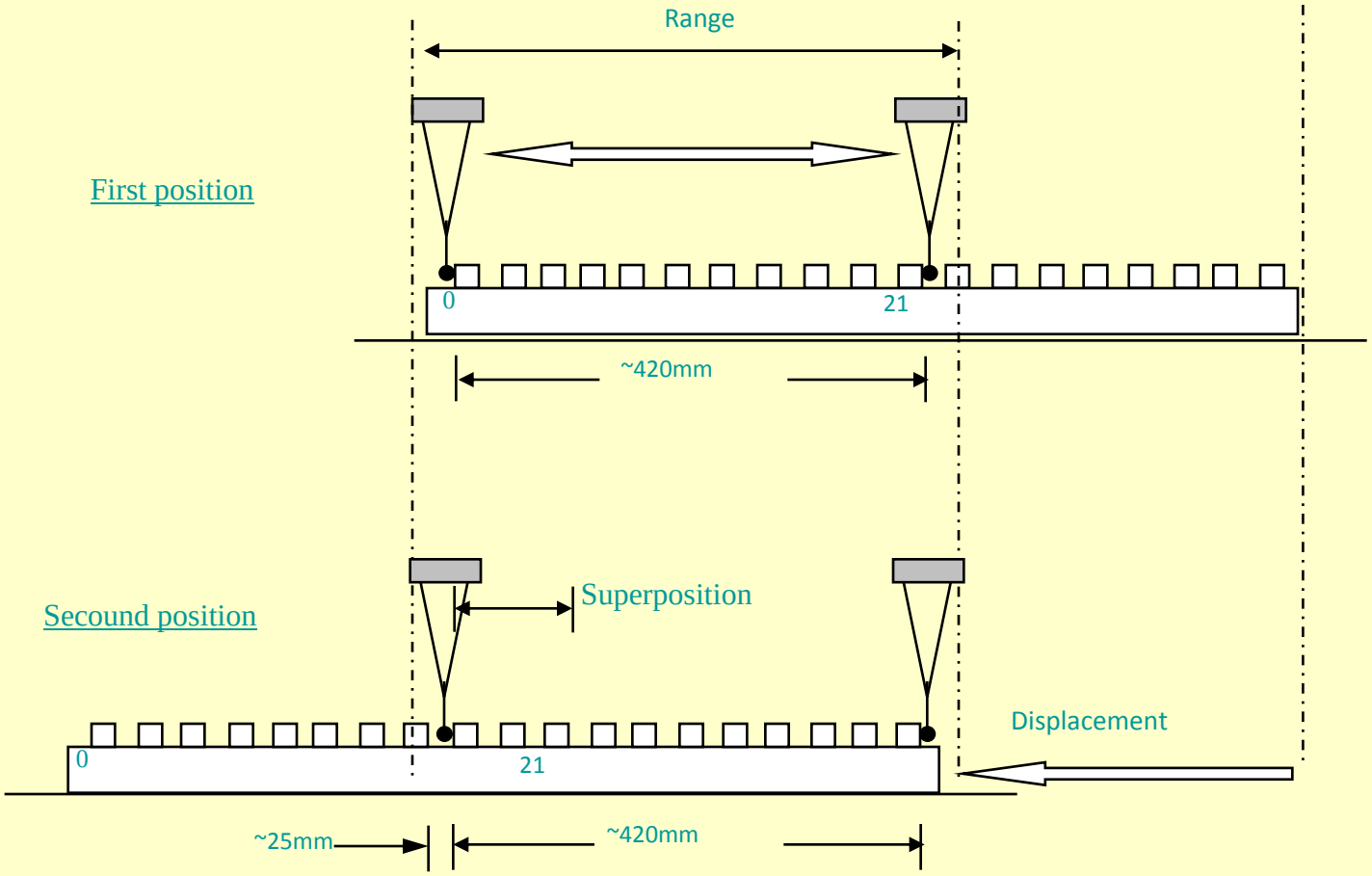
Sphere - 1 to 2 = 221mm
Sphere – 2 to 3 = 311mm

$$0mm - 420mm - (0{,}2^2+(1{,}2*10^{-3}*(L))^2)^{0{,}5}$$

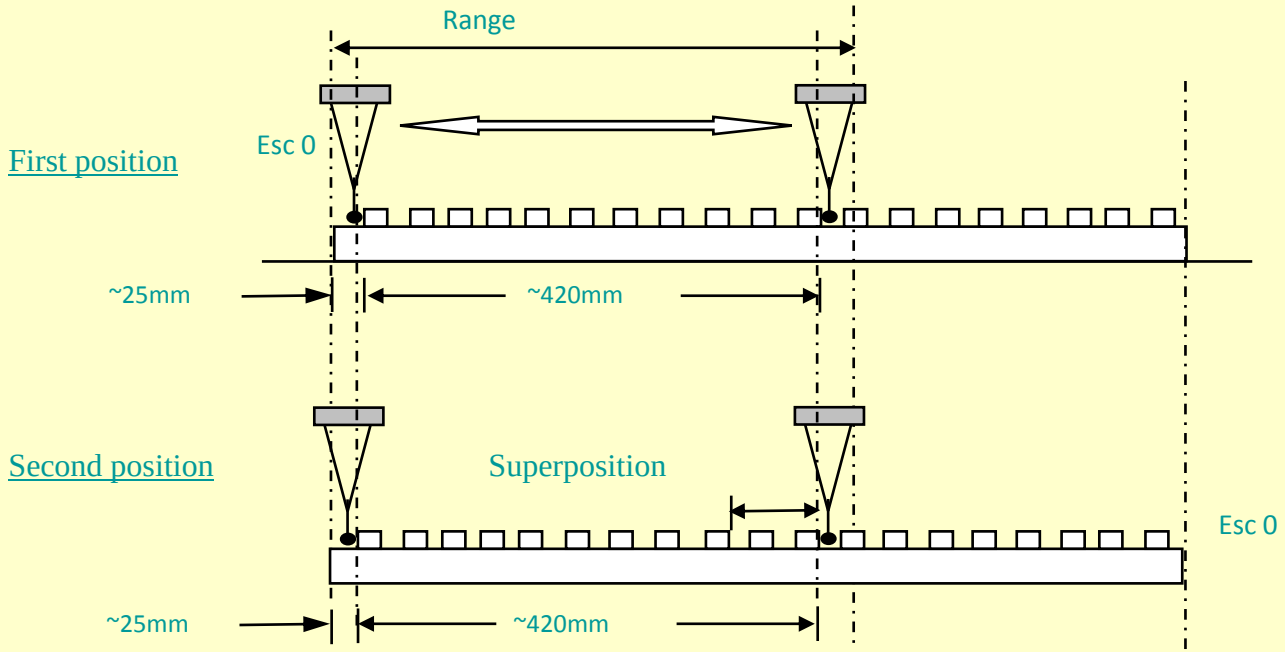
Step gages – Nominal Lenght up to 420mm

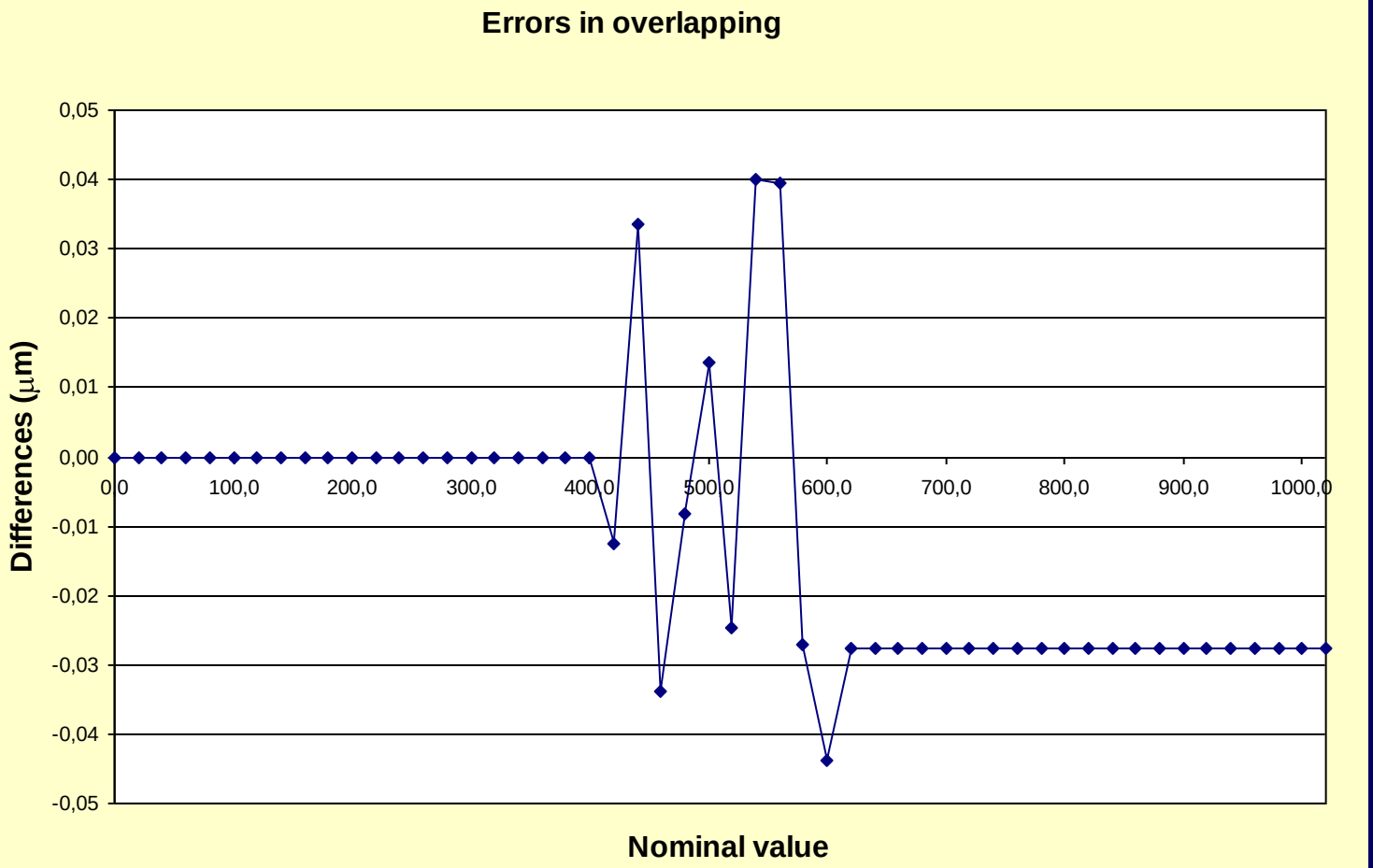


420mm < Nominal Lenght < 620mm



620mm < Nominal Lenght < 1060mm




Errors in overlapping
Differences (μm)
0,05
0,04
0,03
0,02
0,01
0,00
-0,01
-0,02
-0,03
-0,04
-0,05
0,0
100,0
200,0
300,0
400,0
500,0
600,0
700,0
800,0
900,0
1000,0
Nominal value

DATA-SHEET – CONSTANT PART

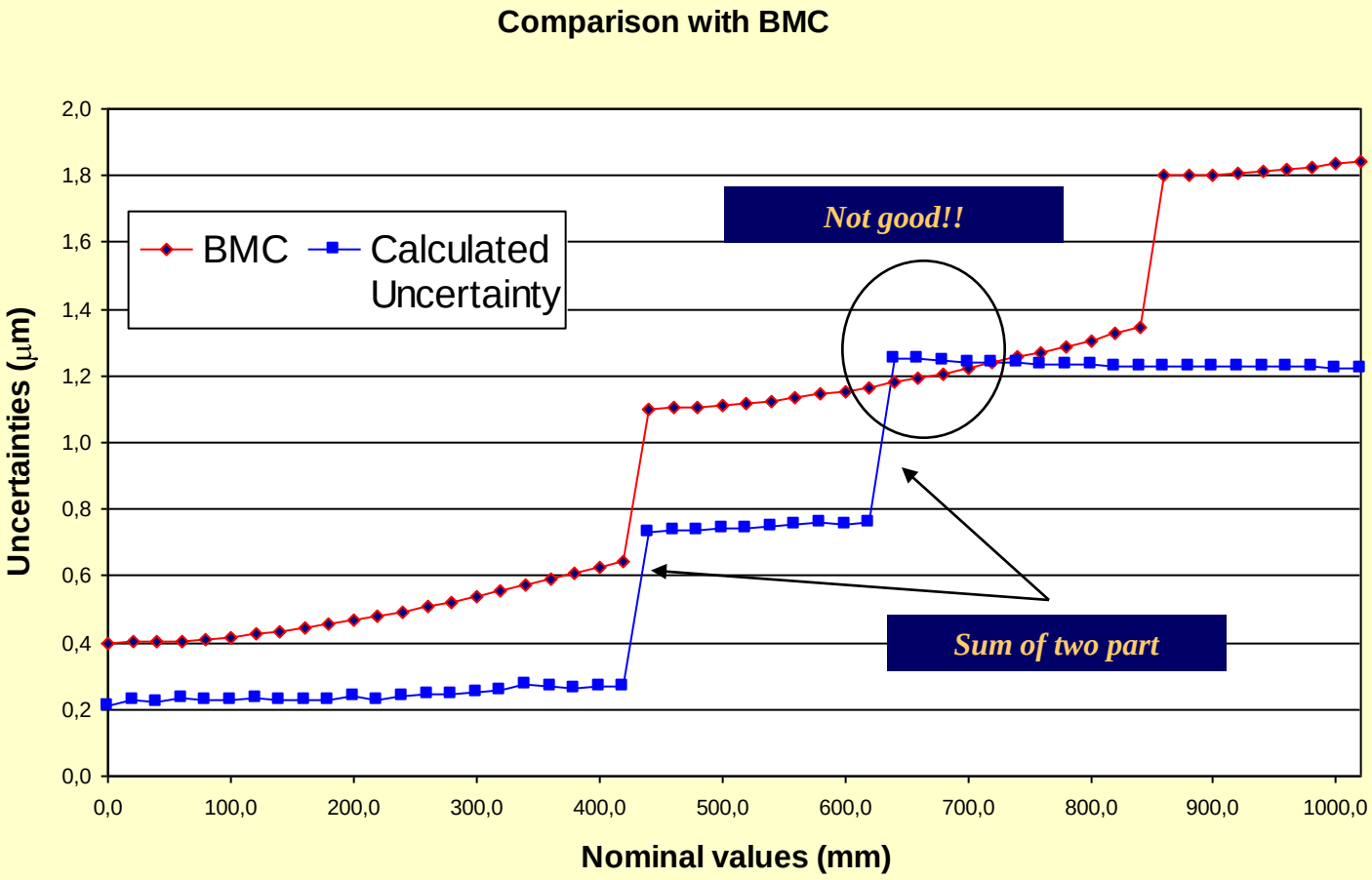
3 - Planilha de incerteza

Grandezas de Influência	Estimativa	Distribuição	Divisor	Incert. Padrão [μm]	Ci	Contrib. ui [μm])	ui^2 [μm]²	νi
Contribuições independentes do comprimento								
Resolução	[μm] 0,0100	Retangular	3,4641	0,003	1	0,0029	0,0000083	
Instabilidade	[μm] 0,0100	Retangular	1,73205	0,006	1	0,00577	0,0000333	
Alinhamento Laser	[μm] 0,0313	Retangular	1,73205	0,018	1	0,01804	0,0003255	
Padrão	0,0100	Retangular	1,73205	0,006	1	0,00577	0,0000333	
Comprimento morto	[μm] 0,0230	Retangular	1,73205	0,013	1	0,01328	0,0001763	
Apalpador	[μm] 0,2	Normal	2	0,075	1	0,07500	0,0056250	
						Total 1 =	0,0062019	

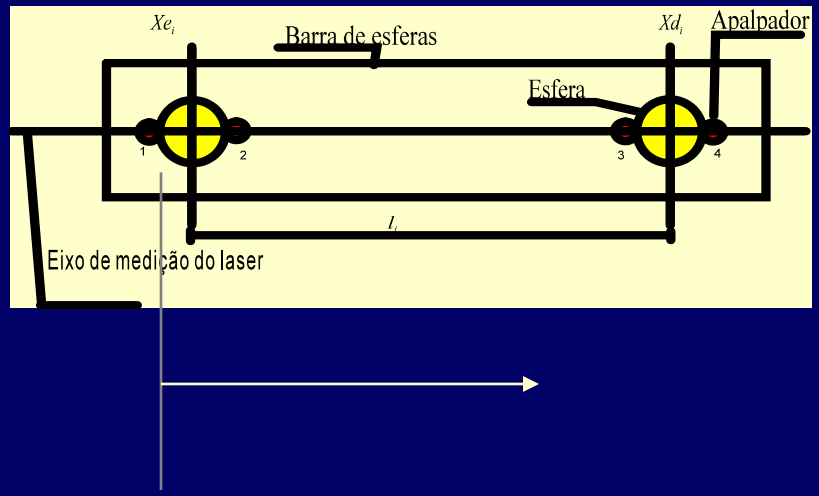
DATA-SHEET – LENGTH DEPENDENT PART

3 - Planilha de incerteza

Grandezas de Influência	Estimativa	Distribuição	Divisor	Incert. Padrão [μm]	Ci	Contrib. ui [μm])	ui^2 [μm]^2	vi
Temperatura do Ar	[ºC]							
Incerteza Certificado	0,0200000	Normal	2	0,010	-9,36E-07	-9,357E-09	8,756E-17	
Oscilação no tempo	0,0280000	Retangular	1,73205	0,016	-9,36E-07	-1,513E-08	2,288E-16	
Pressão Atmosférica	[Pa]							
Incerteza Certificado	52,5956743	Normal	2	26,298	2,69E-09	7,065E-08	4,991E-15	
Oscilação no tempo	8,2627871	Retangular	1,73205	4,771	2,69E-09	1,282E-08	1,642E-16	
Umidade do ar	[Pa]							
Incerteza Certificado	22,9063111	Normal	2	11,453	-3,70616E-10	-4,245E-09	1,802E-17	
Oscilação no tempo	8,2462720	Retangular	1,73205	4,761	-3,70616E-10	-1,764E-09	3,113E-18	
Comprimento de onda	[μm]							
	0,00000007	Normal	2	0,000	-2,19557E-06	-7,684E-14	5,905E-27	
						Total 2 =	5,493E-15	
Temperatura do Padrão	[ºC]							
Incerteza Certificado	0,0200000	Normal	2	0,010	1,15E-05	1,150E-07	1,323E-14	
Oscilação no tempo	0,0040000	Retangular	1,73205	0,002	1,15E-05	2,656E-08	7,053E-16	
Coef. de dilatação	[1 /ºC]							
	0,000001	Retangular	1,73205	0,000	-0,349	-2,015E-07	4,060E-14	
						Total 3 =	5,453E-14	

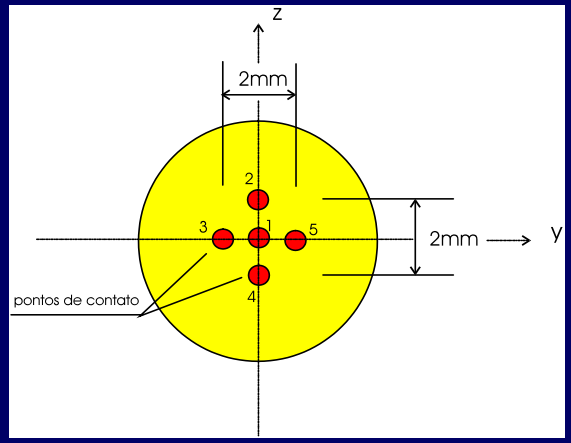

Comparison with BMC
Uncertainties (μm)
2,0
1,8
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
BMC
Calculated Uncertainty
Not good!!
Sum of two part
0,0
100,0
200,0
300,0
400,0
500,0
600,0
700,0
800,0
900,0
1000,0
Nominal values (mm)

BALL - BARS

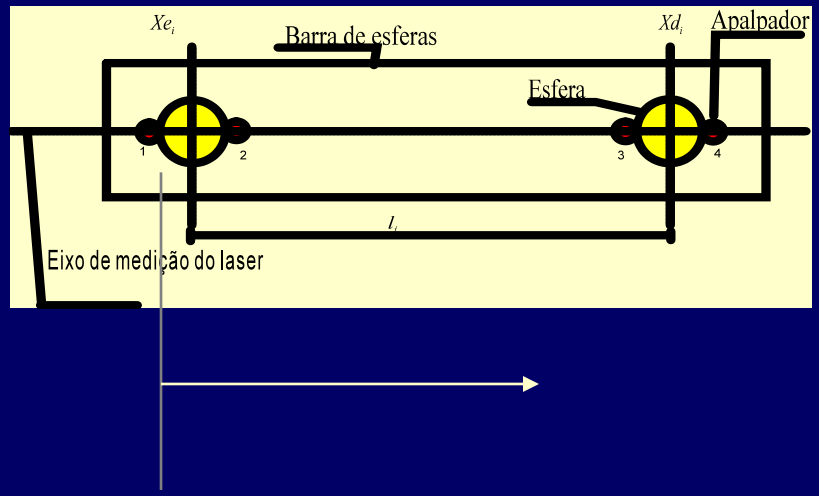


Beginning of the calibrated range

Probing the spheres

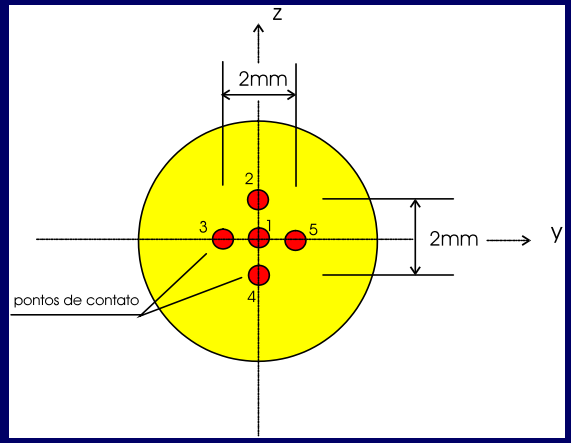


BALL - BARS



Beginning of the calibrated range

Probing the spheres



$$BMC - (0{,}2^2+(1{,}2*10^{-3}*L)\text{^}2)^{1/2} \text{ , } L \text{ in mm}$$

Rings, plugs and sphperes calibration

>Results of calibrated system not used

>Evaluation of the probing erros each calibration

>Differences between internal and external probing

>Measurements in the centre of the machine table (Range : 200mm)

BMC – Same as ball-bars

Trouble

Trouble : Only 4 gages

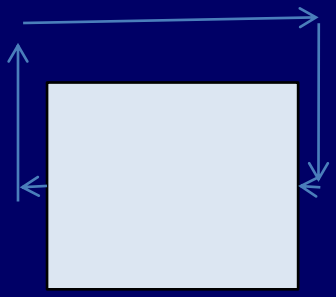
>11mm and 52mm rings

>One single 30mm sphere

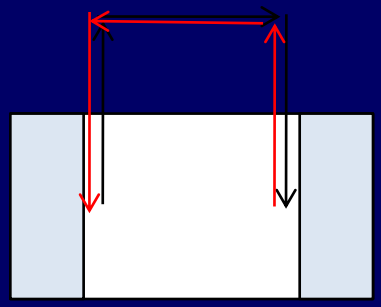
>One single 50mm plug

Solution: Gage blocks

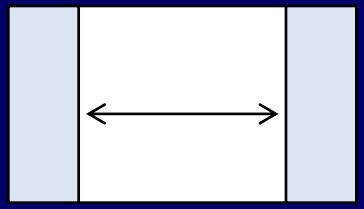
The right measurement strategy



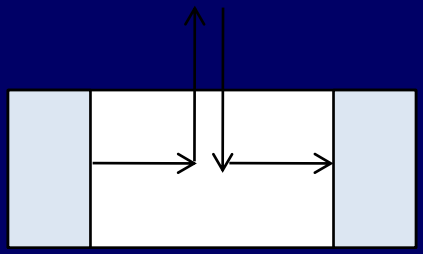
Gage-block - Strategy 1



Ring - gage - Strategy 2



Ring-gage - Strategy 3



Ring-gage - Strategy 4

Strategies 1 and 3 lead to same results

Some text results

Gage-blocks

Probing error (mm)	Date	Result for gage length (mm)	Difference from the certificate (mm)
4,99747	03/09/2009	49,99997	0,02
4,99747	04/09/2009	49,99995	0,00

Two spheres

Probing error (mm)	Date	Result for gage length (mm)	Difference from the certificated (mm)
4,99737	26/08/2009	19,98553	0,00
4,99727	26/08/2009	19,98560	0,07
4,99731	27/08/2009	19,98557	0,04
4,99731	27/08/2009	19,98555	0,02
4,99741	28/08/2009	19,98540	-0,13
4,99735	28/08/2009	19,98561	0,03

Gage-block and ring-gage

Probing error (mm)	Date	Result for gage length (mm)	Difference from the certificated (mm)
4,99747	03/09/2009	51,99930	-0,10
4,99752	04/09/2009	51,99940	0,00
4,99756	04/09/2009	51,99953	0,13
4,99754	04/09/2009	51,99944	0,04
4,99751	04/09/2009	51,99939	-0,01

Gage-block and plug

Probing error (mm)	Date	Result for gage length (mm)	Difference from the certificate (mm)
4,99764	26/08/2009	50,00073	-0,07
4,99769	27/08/2009	50,00045	-0,35
4,99765	27/08/2009	50,00059	-0,21
4,99763	28/08/2009	50,00058	-0,22

Some clients results

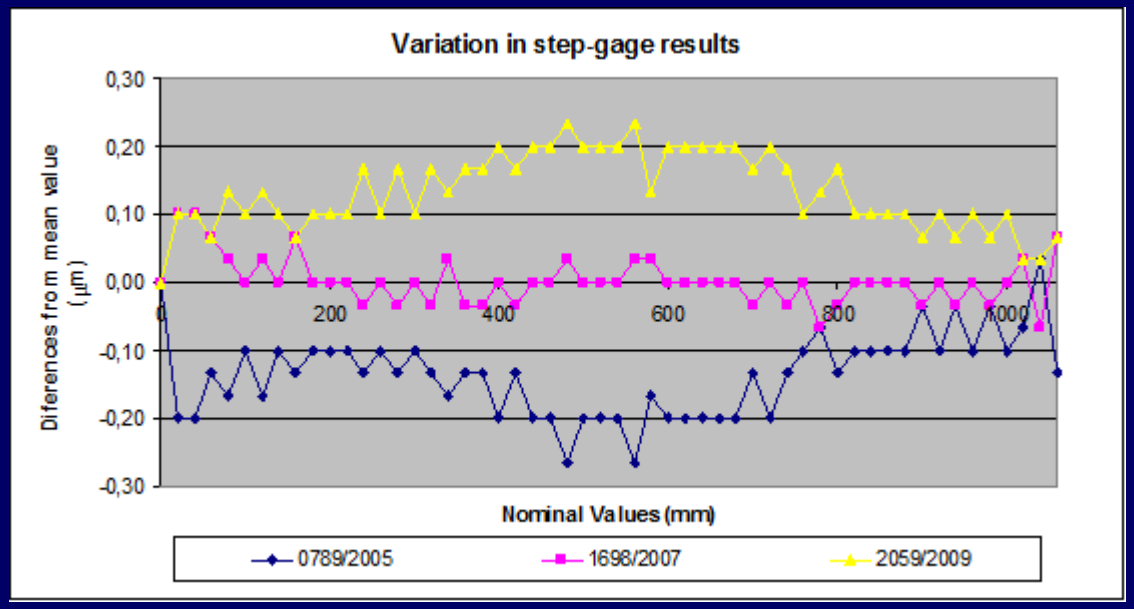
Ball-bar

Ball-bar - RC 1794				
Certificate	221mm	U_{221} (μm)	311mm	U_{311} (μm)
1343/2009	221,0047	0,5	311,0050	0,6
1959/2004	221,0048	0,5	311,0050	0,6

Ring-gage

Ring gage			
Serial Nbr		Identification	Model
1165		IMT - 023	Ident. Nbr.
Certificate			
0301/2003		0544/2005	
V.V.C (mm)	U (µm)	V.V.C (mm)	U (µm)
49,9996	0,2	49,99954	0,21
49,9995	0,2	49,99955	0,21
Certificate			
0963/2007		1286/2009	
V.V.C (mm)	U (µm)	V.V.C (mm)	U (µm)
49,9994	0,3	49,9994	0,3
49,9995	0,3	49,9995	0,3

Step-gage


Variation in step-gage results
Diferences from mean value (µm)
0,30
0,20
0,10
0,00
-0,10
-0,20
-0,30
0
200
400
600
800
1000
Nominal Values (mm)
0789/2005
1698/2007
2059/2009

Conclusions

System demonstrated good performance

Comparisons: EUROMET.L-K5.2004 – Step Gauge (420mm), EUROMET.L-K4.2005 – Diameter Standards, APMP.L-K5.2006 - Step Gauge (620mm).

But

Now under a re-evaluation.

Calibration with more points - 0mm to 200mm.

Ball-bar calibrations – client asks for better uncertainties.

Thank you!
Muchas gracias!

Questions and suggestions are welcome!