OPTODYNE
Laser Metrology S.r.l.

Via Veneto, 5 20881 Bernareggio (MB) ITALY TEL + 39- 039 60 93 618
optodyne@optodyne.it www.optodyne.it

Measurement of the RAM inclination (SAG) and the column inclination due to RAM weight using a simple Single Beam Laser Interferometer and 2 set-up only.

Gianmarco Liotto Optodyne Laser Metrology optodyne@optodyne.it
Ivo Battaglin, RIMM Service rimmservice@alice.it

Abstract
This article describe the measure and calculation of the inclination, due to gravity of a protruding axis (RAM) with the use of a simple single beam interferometer and the linear position errors in simple and efficient way and without limit of range. Was also measured directly the error using tilting heads and tools that works far from the horizontal axis. Are also analyzed the linear positioning errors and calculated the angular errors (Pitch) and Straight errors, and evaluated the measurement uncertainty and the time spent for the measurement.

1. Introduction

In the machine tools with vertical column and horizontal RAM it is normal to face with the axes bended by the weight and that produces variable angular movement with consequent positioning error and posture of the tool when both axis length and tool length changes. Those errors are almost difficult to be measured with the traditional geometric methods and it is especially complicated to measure them for the whole travel extension in term of time and complication induced by the dimension of the reference artifacts. The proposed method utilizes a very compact laser interferometer that make possible perform , in very short time, measurements in different positions.
The method utilized is to measure the same Z axis movement in different position in respect to the vertical axis and calculate the Abbe error or sine error, or the difference of travel of two points of a rigid body that is subject to an angular movement during the linear motion. In the practical case, being the axis subject to the gravity force and not able to move in a perfect straight line, the point that is vertically distant D (or ΔY) from the reference axis will have a change of travel ΔZ proportional to the SAG angle and to the distance Δ Y from the reference axis.

$$\Delta Z = \tau \cdot \Delta Y \quad (1) \qquad\qquad \tau = \Delta Z / \Delta Y \quad (2)$$

where ΔZ is the error respect to the reference, τ is the angle expressed in radiant, and ΔY is the distance from the reference.

In the specific case we are measuring the same nominal travel of Z at two different height, in different Y position.

2. Measurement description

The measurement ids performed in 3 phases:

2.1 Measurement 1: The laser was positioned on a support in front to the machine and his beam aligned parallel to the Z by the beam bender. A small retroreflector positioned in the frontal part of the RAM, close to the spindle, is illuminated by the laser beam. the Z axis or RAM is positioned in a Y (Y1, vertical position) position that we call Position High, the exact position is read on the CNC panel an noted. Is than performed a linear position moving at sequential steps along all the Z axis travel. The layout of the measurement and the measurements results are represented in the picture and in the diagram shown below.

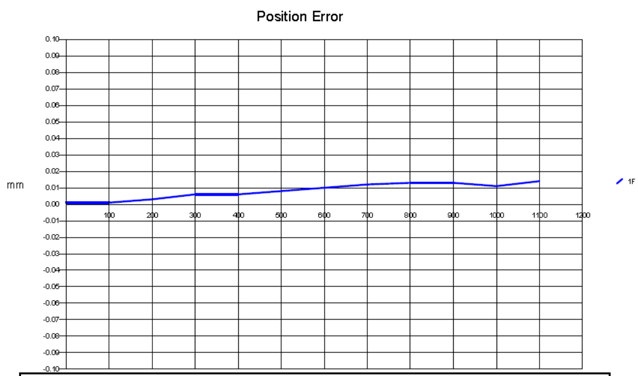


Fig.2 Linear positioning accuracy Diagram is the High position. Are measured 1100mm with 100mm steps.

Fig.1 Measurement of the position error in the Position High, both the laser than the axis are in the higher Y position.

The linear positioning error, normalized by the software at 20°C on a 1100mm travel is 0,014 mm at the point 1100mm.

2.2 Measurement 2:

The laser is repositioned at a lower Y high that we call Position Low in order that the laser beam illuminate the small retroreflector, that is not moved from his position on the RAM, and the beam aligned parallel to the Z axis movement. The exact Y position is read on the CNC panel and noted (Y2). Is repeated the linear position measurement exactly as before, same total elongation and same number of steps. The measurement layout are illustrated in the figure and in the diagram shown below.

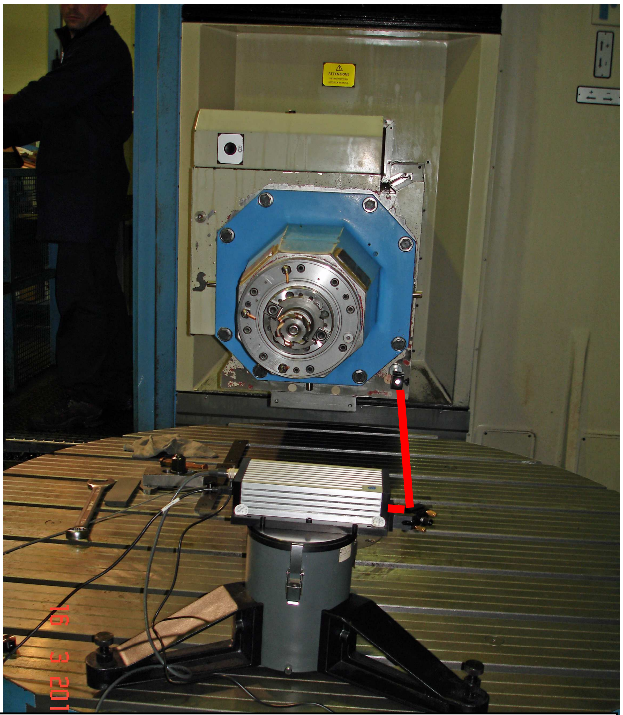


Fig. 4 Measurement of the position error in the Position Low, both the laser than the axis are in the Lower Y position.

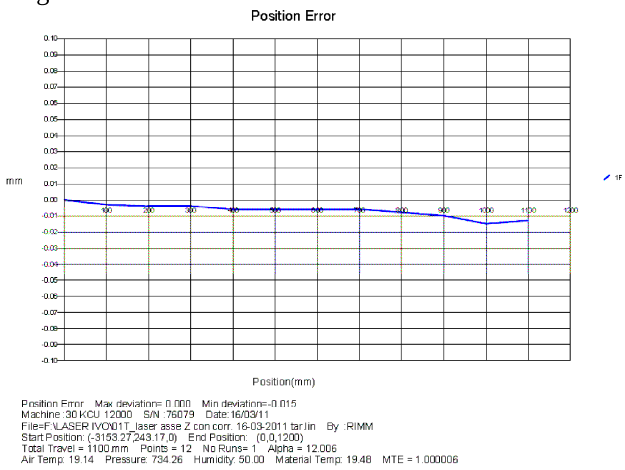


Fig.3 (Above) Linear positioning accuracy Diagram in the Position Low. Are measured 1100mm with 100mm steps

The measured position error at 1100mm is now – 0.012 mm with a variation of 0.026mm in respect to the measurement done 350mm above,

applying the formula (2) $\tau = \Delta Z / \Delta Y$ we can note an angular bending of the column of 74 micro radiant or 74 micrometer/meter at the end of travel (see par 4.2).

2.3 Measurement 3:

Fig.6 Measurement of positioning accuracy with retroreflector outreach. The laser his in the position Low, while the machine is in the position Hight. The retroreflector is connected with a spacer bar to the RAM.

The laser is kept in the same position of the second measurement and the RAM axis is moved high at the same High position for the first measurement. To the small retroreflector is connected to a spacer of a length equal to the distance (D) between the position high (Y1) and Position Low (Y2) of the RAM and illuminated by the laser light. The distance D is reached when the laser light reflected by the retroreflector re-enter in the laser aperture. The laser was not moved so it is already aligned parallel to the Z axis movement. The measurement of position error is again repeated exactly as for the measurement done before. The measurement layout are illustrated in the figure and in the diagram shown below.

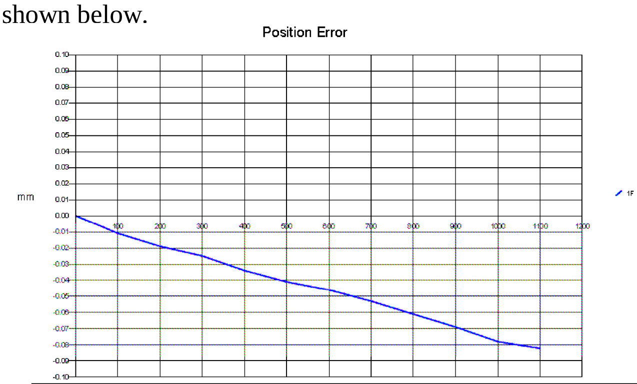


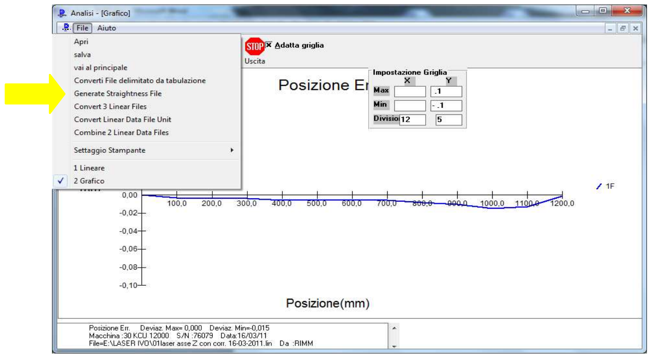
Fig.5 Diagram for linear positioning accuracy with retroreflector outreached

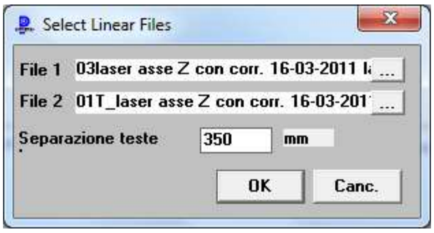
The measured position error with the retroreflector 350mm distant from the reference measurement is –0.082mm , the error measured with measuring 1 Pos High is 0.014mm the difference is 0.096 mm. Applying the formula (2) $\phi = \Delta Z / \square D$ we can note an angular bending of the RAM of 274 micro radiant or 274 micrometer/meter at the end of travel (see par 4.3).

4. Calculation and analysis of the collected data.

4.1 Analysis software

For the data collection and for the analysis of the results is utilized the powerful software of the laser, Optodyne LDDM that easily combine the data of two linear measurement done at a certain separation or distance, into a single linear and angular measurement like was collected from two laser system at the same time (Optodyne MCV-5000) or by a dual beam laser (Optodyne MCV2002). The procedure is as follow: is analyzed the first measurement file up to obtain the error plot, than select from the "File" menu: "generate straightness file" (fig8) and a dialog windows will shown (Fig7), insert the file of the reference measurement and the file of the shifted measurement, indicate the shift distance and click OK. The software will generate a file with extension ".str" that analyzed by the same analysis software allow to plot the angular error and calculate the straightness.

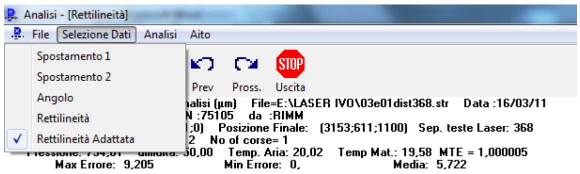




4.2 Sag of the column

Analysing the data collected with the first and second measurement, the positioning error inn the Position Low and in the Position High. First, the files are combined as seen before and the generated files analyzed calculating the pitch angle, that in this case is due mainly to the sag of the column, because of the weight combined with the outreach of the RAM.

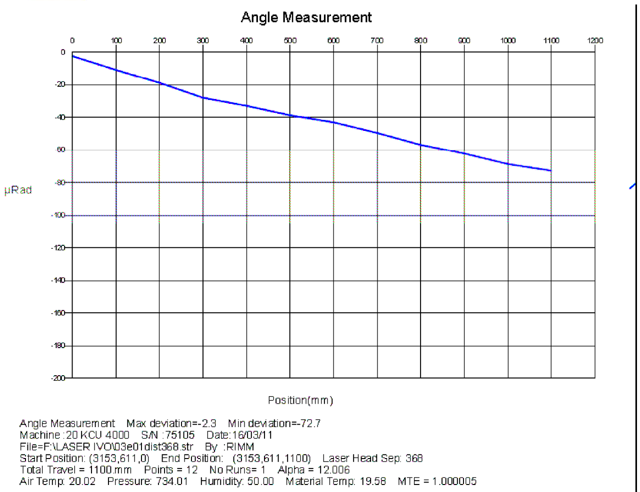
The measuring unit is micro Radians, that is equivalent to micrometer/m (or micro inch/inch) that allow easy error calculation.

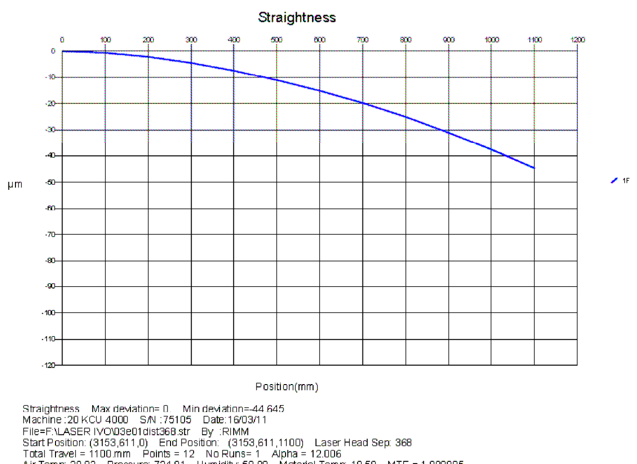


Posizione,m	Corsa #1 (µm)
0,0	0,
100,0	3,405
200,0	5,986
300,0	7,707
400,0	8,724
500,0	9,205
600,0	9,18
700,0	8,615
800,0	7,359
900,0	5,475
1000,0	3,002
1100,0	0,

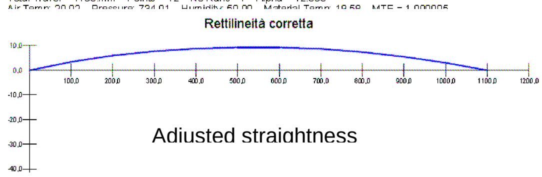
Second, is possible to select "Straightness" and the plot will shows the movement in the forward direction of the column due to weight.

The value of the movement hypothesized by the software model cannot be completely correct, because is not known the right pivot point.





The next selection will be "adjusted straightness" with end value shifted to zero.



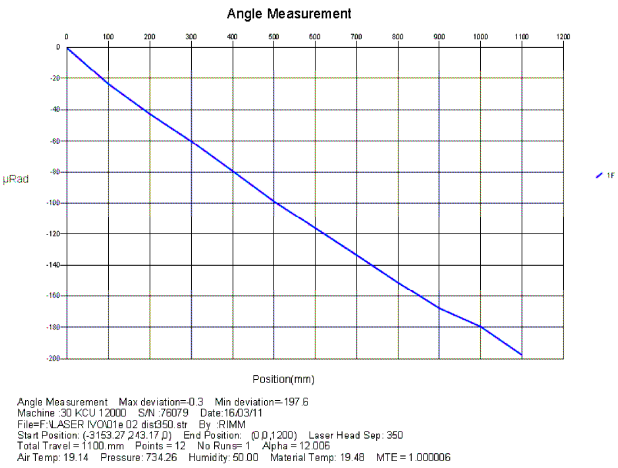
OPTODYNE
Laser Metrology S.r.l.
Via Veneto, 5 20881 Bernareggio (MB) ITALY TEL + 39- 039 60 93 618
optodyne@optodyne.it www.optodyne.it

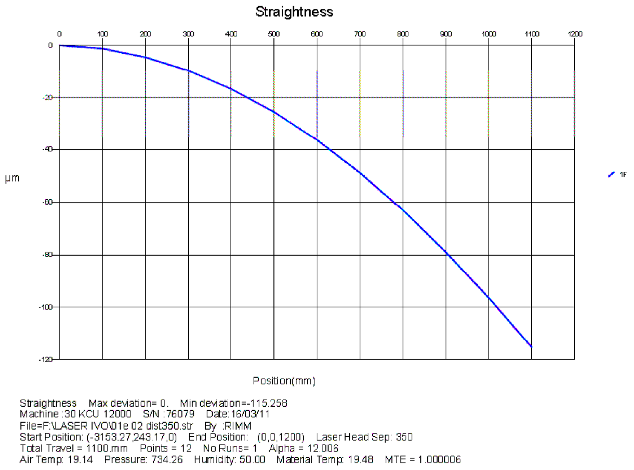
All those type of measurements are not sensible to cross axes electronic compensation that is not detected because obtained by an angular measurement.

4.3 RAM Sag

The sag of the RAM axis is evident with the combination of the first and third measurements, RAM and laser in Position High versus RAM in Position High with laser in Position Low (and a bar on the retroreflector. First is necessary to combine the measurement, than the pith angle and the straightness are analyzed.

Must be noted that the positioning error due to the column is common to the measurement done with the retroreflector positioned in the front face of the RAM and the measurement with the outreachhed retroreflector, than are automatically cancelled.





Above the plot of the sag angle of the RAM and the vertical sag movement as function of the Z axis movement anfd in the straightness plot. The adjusted straightness is not reported because the same as shown before.

As already noted an eventual electronically cross compensation is not shown because not detected, due to angular measurements. In case an electronic cross compensation is applied to measure sag and straightness it is necessary to use direct straightness measurement, like Quad detector, Wollaston prism or traditional dial gauge end straight reference. The angular measurement are still valid to put in evidence the effect of a long tool on a bending turret or on a large tool.

5. Practical use of the collected data

It easy to note that the deviation due to the column sag is much lower than the RAM sag. The effect of the two axes sag are summed at the tool. The effect of the sag respect to the gravity plane can be easily compensated by the cross compensation available on the more common modern CNC or can be compensated mechanically by non straight guideway end or by mechanical counterweight that change perpendicularity of the RAM, all the system try to keep the tool tip on an horizontal line. More difficult is to compensate the angular movement of the tip of the axis evidenced by the use of a 90 deg head and with the use of long tools. In this specific case a vertical tool with a length of 300 mm may have an error of 0.1mm drilling holes at 1m distance, while have no sensible error when the same tools is horizontal.

6. Error Budget

The measurement accuracy is limited by machine repeatability and accuracy in the evaluation of measurement separation (Abbe Offset). For instance in a machine with repeatability of 3 µm
and Abbe offset of 600mm the accuracy of the angular measurement is 0,003/600 =0,000005 rad (5 µm/m) or 1 arc Second that is good for the largest part of application.

7. Time spent for the measurement

1-	Laser Setup, optics alignment and warm up, PC start up, cable connection and program initialization, write the measurement part program, transfer it on the CNC and test the Part Program.	20 minutes
2-	Run the fist measurement , 11 steps well time 5 sec	1 minute

3- Reposition the Laser in the Lower position, move the axis in the lower position, laser realignment		3 minutes
4- Perform the second measurement		1 minute
5- Move the axis in the upper position and position the retro reflector with extension.		2 minutes
6- Data Analysis and generation of angular files		10 minutes
7-Various not calculated		15 minutes
	Total	42 minutes

The total time used for the set of 3 linear measurement that have generated the Positioning error, Column SAG angle, RAM SAG angle, RAM straightness is less than one hour

8. Utilized instrument

a- Optodyne LICS-100A Very compact interferometer using LDDM technology.
b- LDDM Software for collecting data, analysis, and generation of angular files

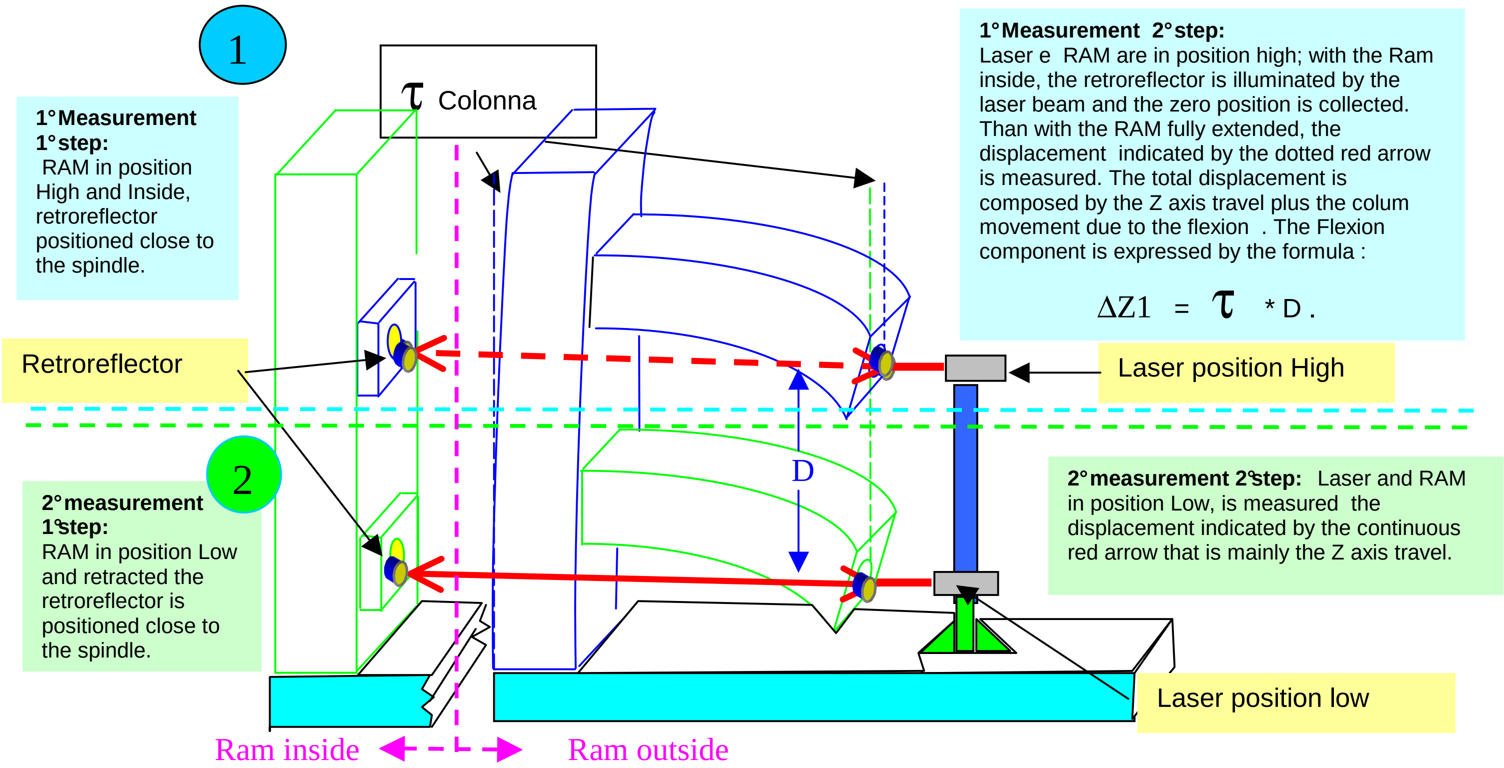
9. References

1. C.P. Wang, "Laser Doppler Displacement Meter" Lasers and Optronics, 6 (No.9), pp. 69-71, September 1987.
2. C.P. Wang, "Abbe Error and its Effect on Position Accuracy of an X/Y Table" Motion, 5 (No. 6). Pp. 19-22, November/December 1989.
3. Charles Wang and Gianmarco Liotto, "Measurement of 18 positioning errors Using a simple laser Doppler displacement meter", International Symposium on Precision Mechanical Measurements.(ISPMM'2004) Aug. 24~28, 2004,Beijing. China
4. Optodyne, application notes AP1109

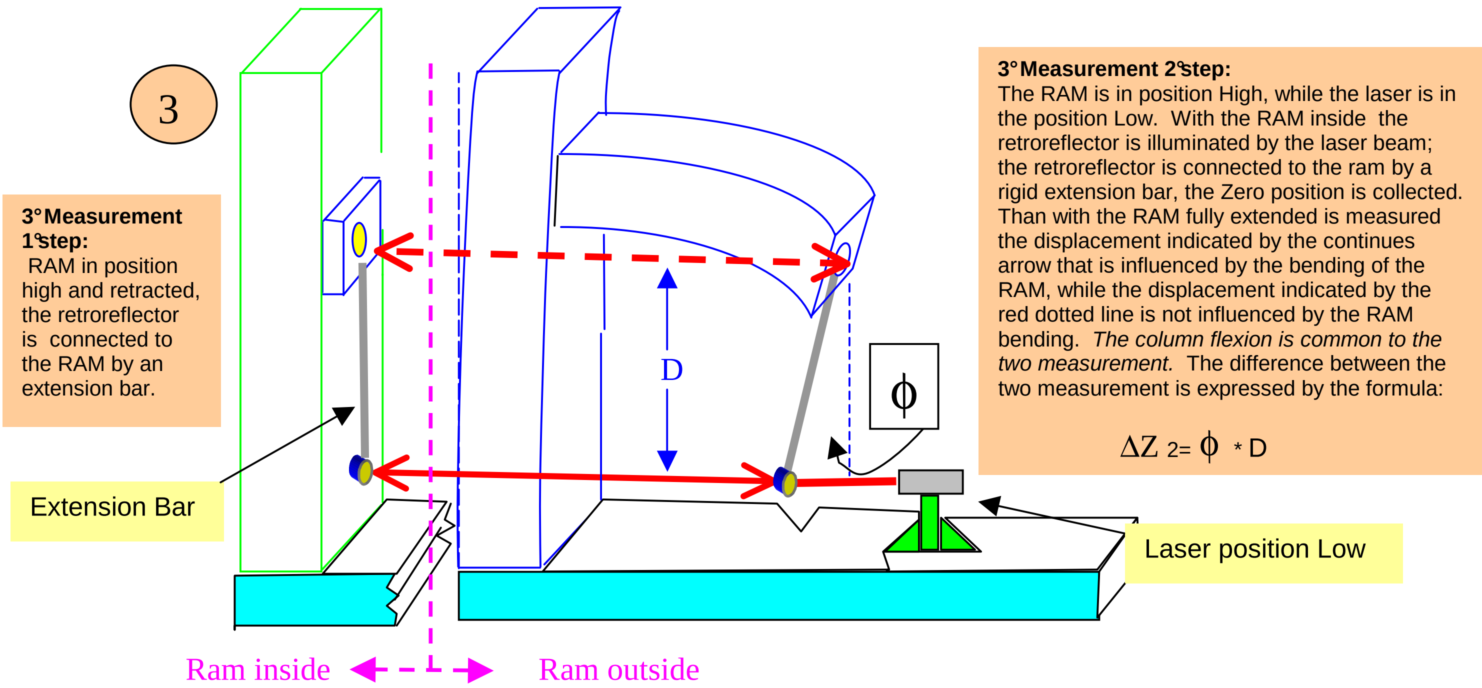
OPTODYNE
Laser Metrology S.r.l.
Via Veneto, 5 20881 Bernareggio (MB) ITALY TEL + 39- 039 60 93 618
optodyne@optodyne.it www.optodyne.it

10 . RAM and COLUMN GRAVITY SAG -

sketch of 3 positioning measurement performed at two different heights



The above figure show the 4 phases of the positioning measurement of the Z axis at 2 different hights



The above figure show the two phases for the position measurement of the Z axis with extension and in axes collected the measure with extension previously measured with Laser and RAM in position High.