Procedure for placing PT-panels

in SFERA-III WP10 Task3

3D shape measurement round-robin

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1. Preamble

Scope of the round-robin (RR) organized by ENEA in the framework of SFERA-III WP10 Task3 is the comparison of the main geometrical parameters of 3D shape measurement of parabolic-trough (PT) reflective panels evaluated with the instruments adopted by each participants: ENEA, DLR, F-ISE, NREL and Sandia.

RR is based on the inter-laboratory circulation of 3 inner plus 3 outer PT panels; these panels were manufactured by Rioglass and kindly provided to ENEA in 2009.

Those old specimens are not representative of the actual Rioglass production and in any case, product ranking is out of the scope of this RR. The achieved results will be published ensuring anonymity of the manufacturer.

2. Supporting system and procedure

The Rioglass panels adopted in RR are designed for collector type LS3, with focal length 1710±1 mm. The panel width is 1700±1 mm. The chord of I*nner* and O*uter* types is 1641±1 and 1501±1 mm, respectively.

Each panel is labeled with its serial number printed on the back side (the painted surface), near the farthest rim from the ideal parabola vertex. In other words, panels must be installed so that the label faces outwards of parabola.

Each panel is hanged to the supporting structure by means of four ceramic pads, with a threaded metal nut inserted; these pads are glued on the back side in well defined positions. Along the flat direction, that is the width of the panel, the pads are distant 996±1 mm. Along the bending direction Tab. 2.1 lists the value of several parameters in the natural reference frame of the ideal parabola, i.e. where $\eta = \dfrac{1}{4f}\xi^2$; these parameters are:

- coordinates of the parabolic reflective surface, (ξ, η)
- slope in the above point, $\alpha = \arctan\left(\dfrac{1}{2f}\xi\right)$
- coordinates at the thread entrance, calculated by assuming the declared thickness of the pad, 12.4 mm (ξ_t, η_t)
- coordinates of the metallic-ball center(ξ_b, η_b), having diameter 20.0 mm, screwed in the pad and protruding from the pad for 18.5 mm (experimental mean value)

please note that all these points are aligned along the axis of the thread.

Table 2.2 reports the ball center distance between pairs of attacks for Inner and Outer panels.

Table 2.1: relevant parameters along the thread axis of the pad at the four reference positions for Inner and Outer panels

Type & #pad	ξ mm	η mm	α rad	ξ_t mm	η_t mm	ξ_b mm	η_b mm
Inner_inner	370.0	20.0	0.1078	371.3	7.7	372.2	-0.8
Inner_outer	1318.0	254.0	0.3678	1322.5	242.4	1325.5	234.5
Outer_inner	1918.0	537.8	0.5111	1924.1	527.0	1928.2	519.6
Outer_outer	2640.0	1018.9	0.6574	2647.6	1009.1	2652.8	1002.4

Table 2.2: ball center distance between pairs of attacks for Inner and Outer panels

Panel type	Outer-inner distance	Distance in flat direction
Inner	982	996
Outer	871	996

As general rule, the shape is generally affected on how the panel is hanged; on the other hand for the success of RR only the good reproducibility of the panel-placing is important, even if it is got by unusual manner, not representative of the normal usage. The supporting system for RR must be simple and effective.

We got very satisfactory results with the following method:

1. screw one metallic balls (see Fig. 2.1) at each one of the 4 ceramic pads
2. measure the distance between the top of the metallic ball and the top flat surface of the pad (top-pad)
3. conveniently to own experimental set-up, set the Lab reference with XY plane horizontal, Z axis vertical, and X axis oriented according to the bending direction of the panel, oriented oppositely to the parabola vertex
4. place 4 post-holders (see Fig. 2.1) in nominal position considering the ball center distance between pairs of attacks listed in Tab. 2.2
5. lock the position (x, y) of post #2 once and for all (see Fig. 2.2)
6. arrange a mechanical stop to block the x coordinate of the other inner post #1 at the same value of #2, letting free y
7. precisely adjust the height of the post-top on the same horizontal plane
8. gently place the panel on the posts, having cure of centering each ball on the respective post, that is letting to move the free posts to better fit the balls installed on the pads
9. gently block the position of all posts pay attention to not modify their position. If possible, after the completion of the shape measurement, remove the panel and measure the coordinate x, y, z of the top of any post in order to check their horizontally and annotate their final position

Please note that steps 8 and 9 are repeated for each specimens.

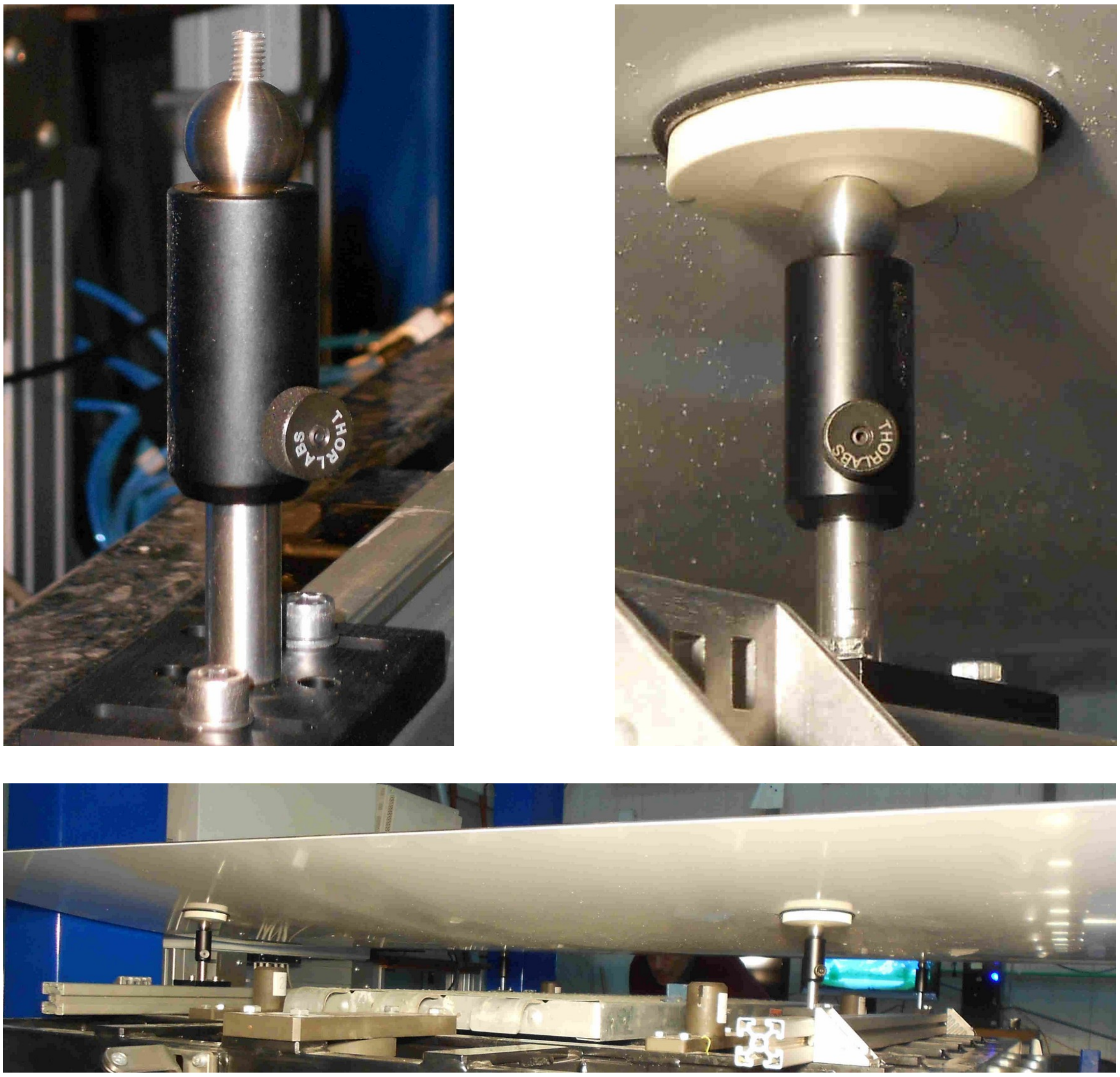

Fig. 2.1: threaded metallic ball placed on the top of a post holder (top left); metallic ball screwed to a ceramic pad and resting on a post holder (top right); overview of the panel placing on four post-holders (bottom).

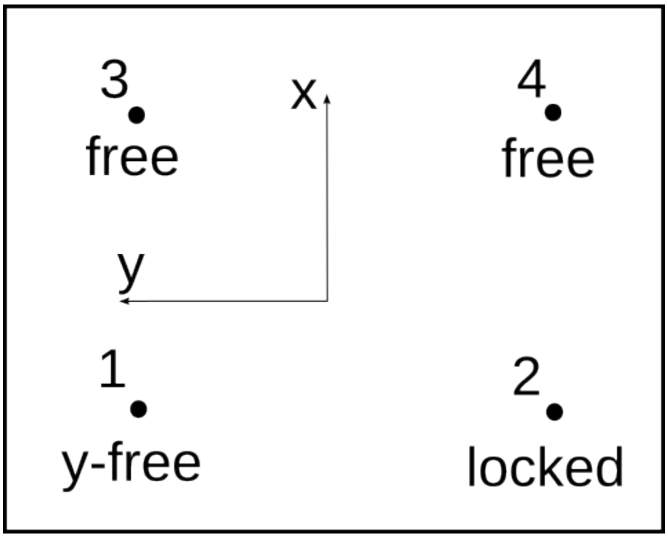

Fig. 2.2: numeration of the four attaching points and strategy to set their precise positioning in the XY plane.

3. Relationships between Lab and ideal parabola reference frames

Although RR could be limited to the comparison of high z and slopes $\mathrm{d}z/\mathrm{d}x$ and $\mathrm{d}z/\mathrm{d}y$ in the Lab frame, disregarding the *parabolicity* of the panels, the extension of the investigation to the *deviations* from the ideal parabola is another important scope of RR. At that purpose the knowledge of the relationships between the Lab reference frame and the natural parabola reference frame is fundamental.

Referring to Fig. 3.1, let XYZ the Lab reference frame already discussed in Section 2, and $\xi\eta$ the natural frame of the parabola, where $\eta = \frac{1}{4f}\xi^2$. The angle θ between Ξ and X axes is given by

$$\theta = \arctan \frac{\eta_{b_{out}} - \eta_{b_{inner}}}{\xi_{b_{out}} - \xi_{b_{inner}}} \tag{1}$$

obtaining 0.241990 and 0.587748 rad (13.865° and 33.675°) for Inner and Outer panels respectively on the basis of the values reported in Tab. 3.1.

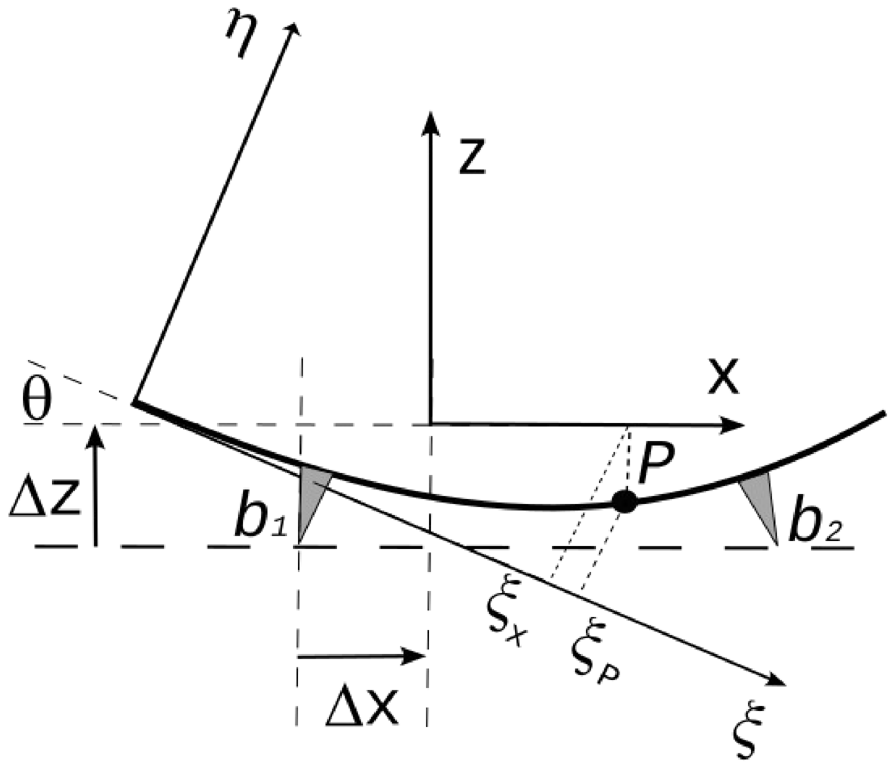

Fig. 3.1: parabola natural reference frame and Lab reference frame; the center of the metallic threaded balls lie in an horizontal plane parallel to XY plane of the Lab reference frame.

Let Δx and Δz the signed increment to reach the origin of the Lab reference from the center of the metallic ball placed on the attaching point closer to the parabola vertex b_1; in the parabola frame the Lab-reference has origin in

$$\begin{aligned} \xi_L &= \xi_{b1} + \Delta x \cos\theta - \Delta z \sin\theta \\ \eta_L &= \eta_{b1} + \Delta x \sin\theta + \Delta z \cos\theta \end{aligned} \tag{2}$$

Let (x, y, z) the coordinate of the measured point *P* of the panel surface. In order to compare z with the value expected for the ideal parabola, one needs to know the value of ξ_P i.e. the abscissa of P in the natural frame of the ideal parabola. Developing the reasoning in the plane $y = 0$, the point $(x, 0, 0)$ in the parabola frame has coordinates

$$\begin{aligned} \xi_x &= \xi_L + x\cos\theta \\ \eta_x &= \eta_L + x\sin\theta \end{aligned} \tag{3}$$

The coordinate of $P\,(\xi_P, \eta_P)$ are the solution of the equation system

$$\begin{cases} \eta = \frac{1}{4f}\xi^2 \\ \eta - \eta_x = -\frac{1}{\tan\theta}(\xi - \xi_x) \end{cases} \tag{4}$$

having solution

$$\xi_P = \frac{-b + \sqrt{b^2 - 4ac}}{2a} \tag{5}$$

where $a = \dfrac{1}{4f} \quad b = \dfrac{1}{\tan\theta} \quad c = -\eta_x - \dfrac{\xi_x}{\tan\theta}$

Finally, in the Lab frame

$$\begin{aligned} x_P =& (\xi_P - \xi_L)\cos\theta + (\eta_P - \eta_L) sin\theta = x \\ z_P =& -(\xi_P - \xi_L)\sin\theta + (\eta_P - \eta_L)\cos\theta \end{aligned} \tag{6}$$

where $\eta_P = \dfrac{1}{4f}\xi_P^2$

4. Experimental

4.1 Reproducibility of metallic-ball screwing

The metallic balls are identical one to each other.

The distance between ball-top and pad-top was measured as shown in Fig. 4.1 more times after complete removal and repositioning of a metallic ball on the same ceramic pad. The results are identical within the error ± 0.1 mm.

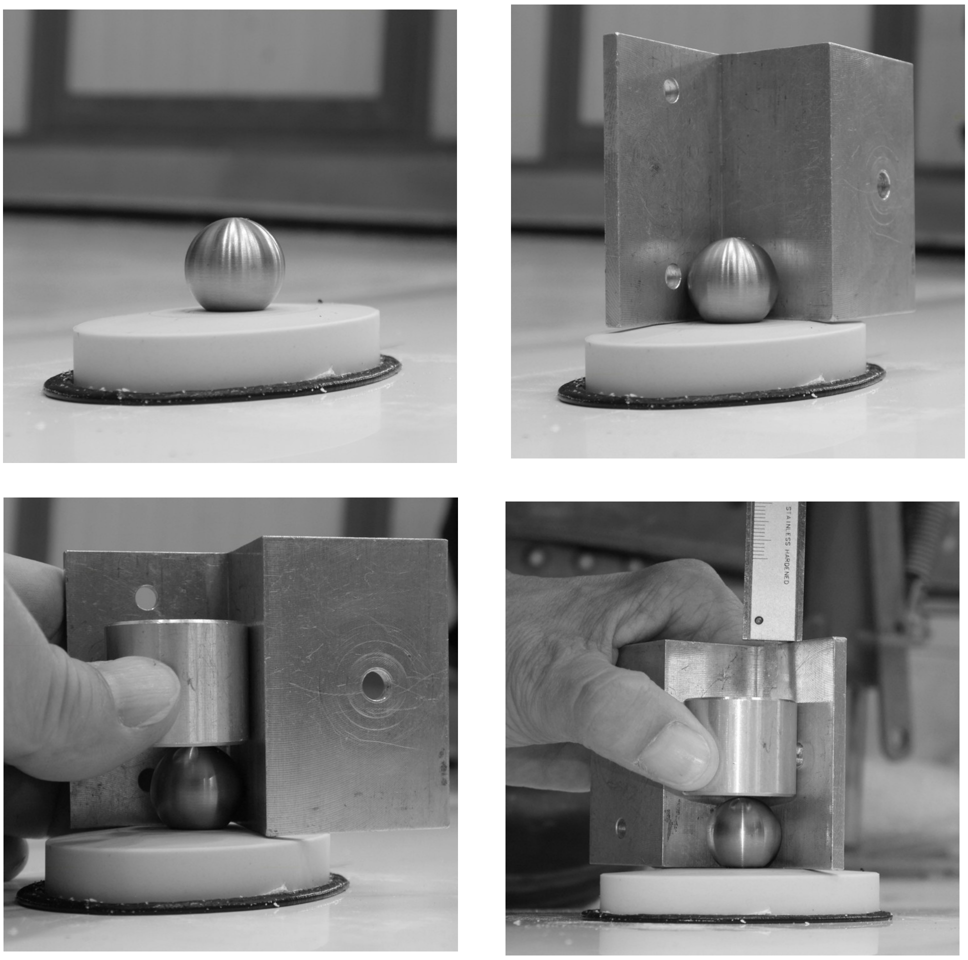

Fig. 4.1: measurement of the distance between ball-top and pad-top

4.2 Metallic balls on panels

After the 3D shape measurement, the distance between ball-top and pad-top was measured at each one of the four ceramic pad for each RR panels. The results are summarized in Tab. 4.1: the values are distributed in the range 18.1 – 19.0 mm; the mean value is 18.5 mm.

Table 4.1: distance (mm) between ball-top and pad-top; the error on the single measurement is ±0.1 mm

Panel		Ceramic pad			
Label (S/N)	Type	1	2	3	4
RS-B416405758	inner	18.6	18.6	18.7	18.7
RS-B416405759	inner	18.4	18.5	18.8	18.7
RS-B416405760	inner	18.5	18.5	18.7	18.5
RS-B416405761	inner	18.5	18.6	18.7	18.8
RS-B416405762	inner	18.6	18.3	18.7	18.8
RS-B077360493	outer	18.2	18.4	18.5	18.5
RS-B077360497	outer	**18.1**	18.6	18.2	18.5
RS-B077360499	outer	18.3	18.5	18.7	18.6
RS-B077360500	outer	18.4	18.5	18.8	18.4
RS-B077360501	outer	**19.0**	18.4	18.3	18.5

4.3 Measurement of post-holder position

Firstly we check the good reproducibility of the final position of the posts for the same panel; by means of a Total Station Leica TDA 5005 and its corner-cube-reflector accessory, the x,y,z coordinate of the post-top were measured after several placing of the same panel from scratch; the results are identical within the instrument error of 0.2 mm

Then, at the completion of each 3D shape measurement, we systematically measured the center position of each one of the four post-holder. Table 4.2 shows the displacement values from the ideal position computed according Tab 2.2 with respect to post #2 which is lock in the same position.

Mean and standard deviation of x and y displacement observed at a given post are shown in the last row of the table. The x-displacement for the couple of free attaching points is less than the expected value, likely as a consequence of the panel bending induced by gravity. In the other cases the displacement is null within the error or very small. In particular, the systematic positive value of the x-displacement of post#1 seems due to a sort of back-lash from the mechanical stop.

Table 3.2: displacement of post-center from nominal position

Panel		Post #1		Post #3		Post #4	
Label (S/N)	Type	Δx (mm)	Δy (mm)	Δx (mm)	Δy (mm)	Δx (mm)	Δy (mm)
RS-B416405758	inner	0.4	0.1	-0.7	-0.5	-1.1	-0.5
RS-B416405759	inner	0.2	1.1	-1.6	0.1	-1.5	0.1
RS-B416405760	inner	0.4	0.4	-1.4	0.2	-1.6	0.1
RS-B416405761	inner	0.3	0.1	-1.7	-0.2	-1.7	-0.1
RS-B416405762	inner	0.3	0.3	-1.0	-0.1	-1.2	0.0
RS-B077360493	outer	0.2	0.7	-1.1	-0.8	-1.7	-1.2
RS-B077360497	outer	0.2	1.1	-1.1	-0.2	-1.3	-0.4
RS-B077360499	outer	0.3	1.1	-1.4	-0.3	-1.9	-0.6
RS-B077360500	outer	0.3	1.2	-1.4	-0.6	-1.6	-0.3
RS-B077360501	outer	0.3	0.9	-1.7	0.2	-1.5	-0.1
$\mu \pm \sigma$		0.3±0.1	0.7±0.4	-1.3±0.3	-0.2±0.3	-1.5±0.2	-0.3±0.4