Mechanical aspects of the design of third generation synchrotron Light source Storage ring girder system

Lluis Miralles , Liudmila Nkitina, Iouri Nikitine[1]

CELLS [2] *- Consorci per a la Construcció, Equipament i Explotació del Laboratori de Llum Sincrotró*

June 10, 2008

0.- Abstract

In storage rings of third generation synchrotron radiation facilities, the positioning tolerances of the elements of the machine are constantly challenged to achieve lower emittance and increased lifetime. This implies increasing positioning and alignment precision on the machine components. Especially critical in the case of ALBA, is the dynamical behavior in front of vibrations sources. The design of the Spanish Light Source (ALBA) storage ring support, positioning system, test done on the respective prototypes and results of the final design quality assurance tests are discussed.

1.- Introduction

The Consortium for the Construction, Equipping and Exploitation of the Synchrotron Light Laboratory (CELLS – www.cells.es), it is co-financed by the Spanish and the Catalan governaments and its aim is to be responsible of the first Synchrotron Light Source Facility to be built in Spain, which name is ALBA.

ALBA is a 3 GeV complex that will consist of a 100 MeV electron linear accelerator followed by a 3 GeV booster synchrotron and finally the 3 GeV storage ring where eventually a beam of 400 mA will circulate while at the beamlines the scientists will perform their experiments. ALBA will use the so-called top-up injection mode, in which the current is kept almost constant in the storage ring by injecting currents as small as 1 mA every few minutes. In this case all elements of the storage ring shall ensure proper stability of the beam.

[1] miralles@cells.es, lnikitina@cells.es , ynikitine@cells.es

[2] CELLS – ALBA · Edifici Ciències Nord · Mòdul C-3 central · Campus Universitari de Bellaterra · Universitat Autònoma de Barcelona · 08193 Bellaterra, Barcelona · Spain · http://www.cells.es

2.- ALBA storage ring girder system description

The storage ring lattice consists of 16 extended Double Bend Achromats (DBA), 8 matching cells and 8 unit cells. The ring is made of four identical periods with two long straight sections on each side. Each period consist of two matching and two unit cells in between. Each cell includes two bending magnets with adjacent quadrupoles and sextupoles.

The bending magnet with the surrounding quadrupoles and sextupoles should be, because of beam stability reasons, mounted on one girder driving to a total of 32 girders. There are 6 different types of girders, very similar between them.

Maximum vertical deformation under full load, 7150 Kg, should be below 50 µm. The girder should provide precision positioning for each magnetic or diagnostic element. The individual elements on the girder should be aligned to better than 30 µm. The precision fixation of the magnets and beam position monitors (BPM) on the girder is to be realised by precision holes (for pins) and grooves in the girder.

Figures 1 and 2 show the reference design of the ALBA girder with the location of the dummy magnets. The complete girder consists of the girder structure and the pedestals. In order to get high eigenfrequencies three pedestals with 6 fixations are foreseen, but only three of them will be used for the alignment.

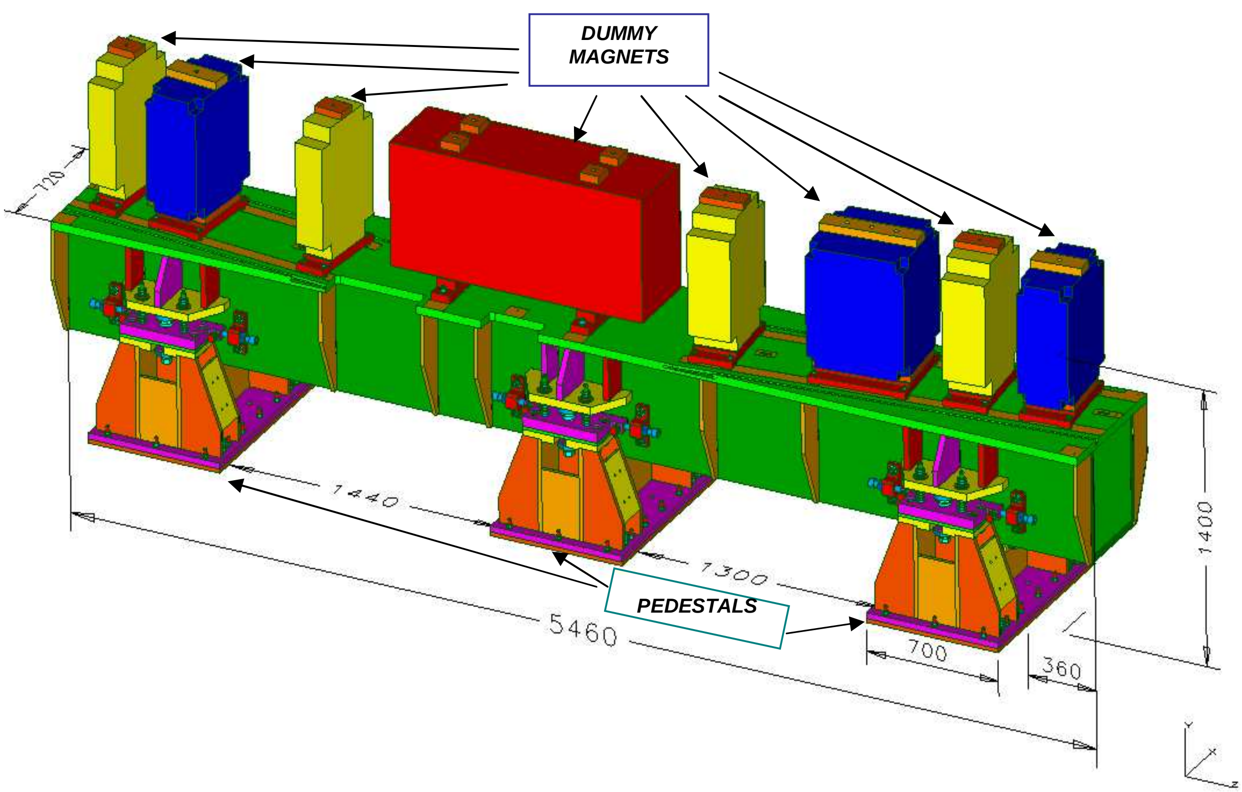


Figure1 3D-view of the girder with the dummy magnets on it and the pedestals

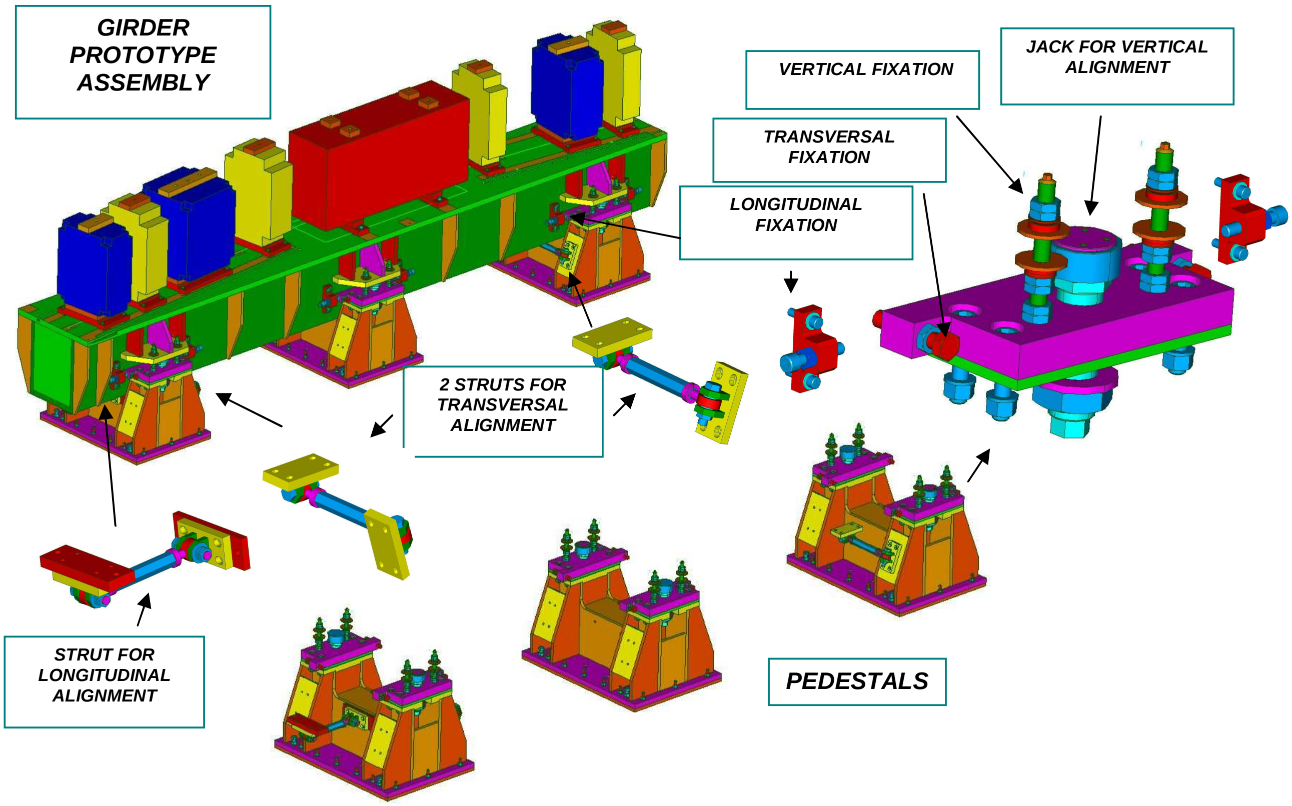


Figure 2 3D-view of the different components for alignment and fixation

Required flatness tolerance for the reference surface of the top plate of the girder is 30 µm.

Required position tolerances for the alignment holes and for the holes for pins are ± 15 µm.

The alignment range is ± 10 mm in vertical direction and ± 6 mm in longitudinal and transversal directions.

3.- Simulation

Several alternatives and solutions have been studied along the design process. Here the final solution is presented. An extensive program of simulations, including the study of a "long" girder case (Max II) has been conducted. The software being used for the simulations is ANSYS. Here the results for the final configuration are presented.

The results obtained are 17 µ for the maximum girder deformation. Maximum displacement on the magnets is 24 µ for 6 supports configuration and 50 µ for 3 supports configuration.

Figure 3 shows the results of the simulations.

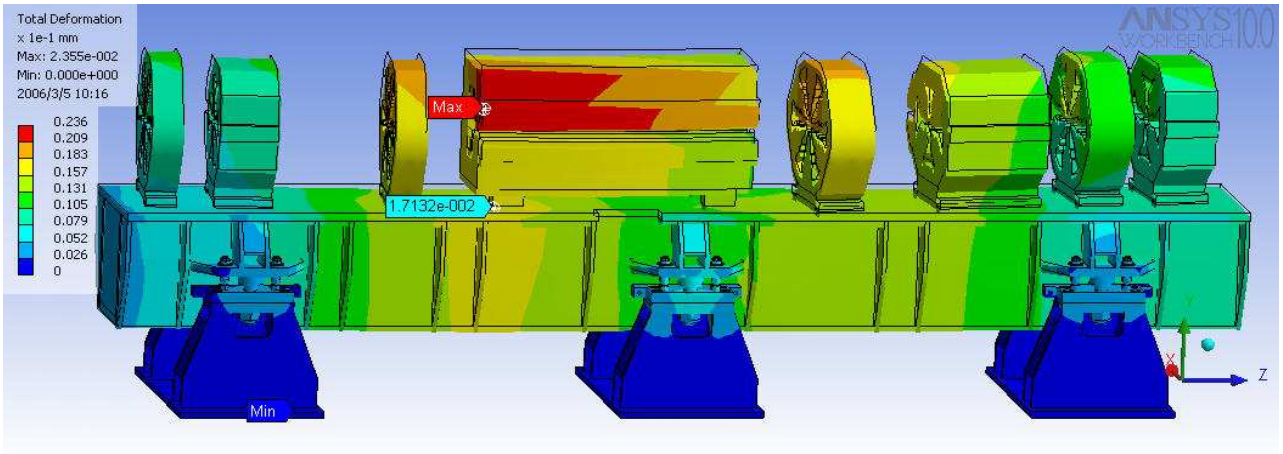


Figure 3 Deformation results, 6 supports configuration

The vibrations response of the girder structure is of special relevance in The ALBA case because the relative high levels of cultural noise expected at the site. The design has been pushed in order to get the first resonance frequency as high as possible. The results of those simulations are shown in the following table

Mode	Frequency (Hz)	Description
1	54	Rotation Z, girder bending
2	67	Twist
3	68	Magnet mode
4	71	Magnet mode
5	77	Magnet mode
6	79	Magnets and girder along z

4.- Tests results

4.1 Dimensional check

A prototype was ordered to industry in order to crosscheck the viability of the production and the simulations. Last but not least, to produce a 1:1 mock-up in order to develop techniques to align the system and to crosscheck overall design of the cell including the vacuum system.

The geometrical measurements were done by the CELLS survey and alignment group. The instrumentation used for the survey was a laser tracker FARO Xi V2 in conjunction with a 1.5” corner cube reflector. Configuration resolution 0,158 µ and accuracy is 2µ + 0,4 µ/m. The measurement configuration consisted in 4 measurements stations , 7 control points (± 5µ RMS), 196 measurements in the bundle adjustment.The results of the measurements showed a good result in flatness 12 µ RMS with 85 % of the points inside the tolerance range. See results in figure 4.

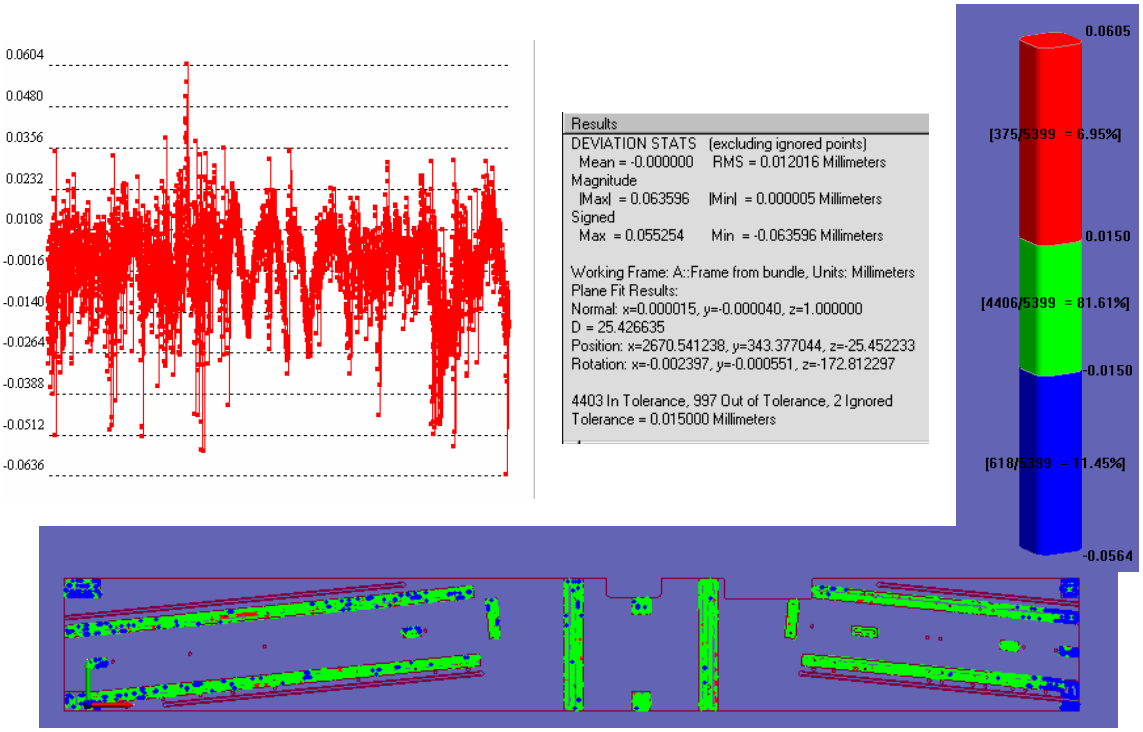


Figure 4 Flatness results

The results were not good regarding the position of the pin holes defining the positioning of the magnets. More than 50 % of the pin holes were out of tolerance range, being the typical tolerance 100 µ in front of the 30 µ specified. See results in figure 5.

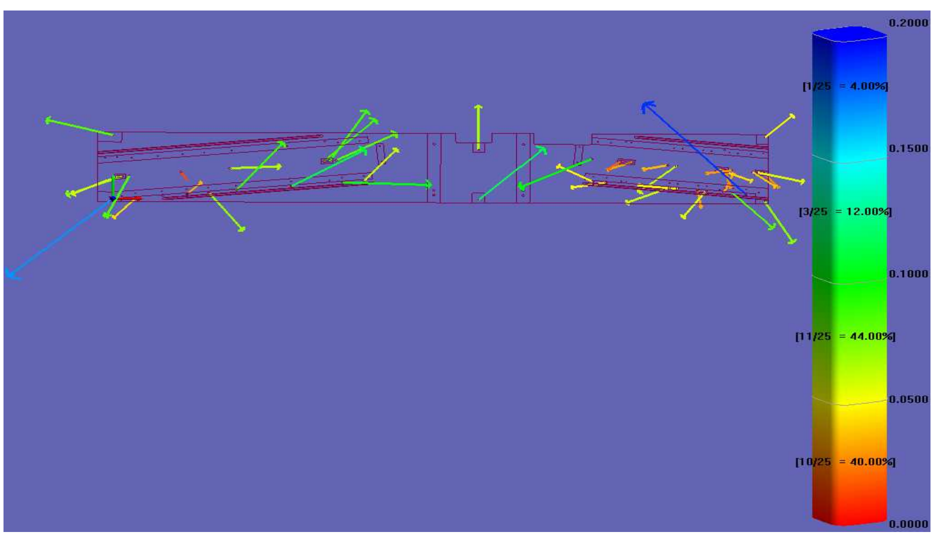


Figure 5 Pin holes position results

After discussion with the manufacturer several provision were taken in order to improve accuracy in the position machining of the pin holes:

- Refurnishing of the milling machine. Realignment and re-machining of the machine axis. Improvement of the machine base rigidity and planarity. Increase the working length to 6,5 m. Replacement and calibration of the CNC optical rules.
- Construction of a controlled temperature room around the machine. Machining temperature 23 ± 0,75 ºC.
- Strict control of the temperature on the machine and the pieces along the process.

After implementation and tuning of the process, the first series girder was produced. The results are presented in figures 6 and 7. Flatness RMS 10 μ, pinholes position RMS 25 μ.

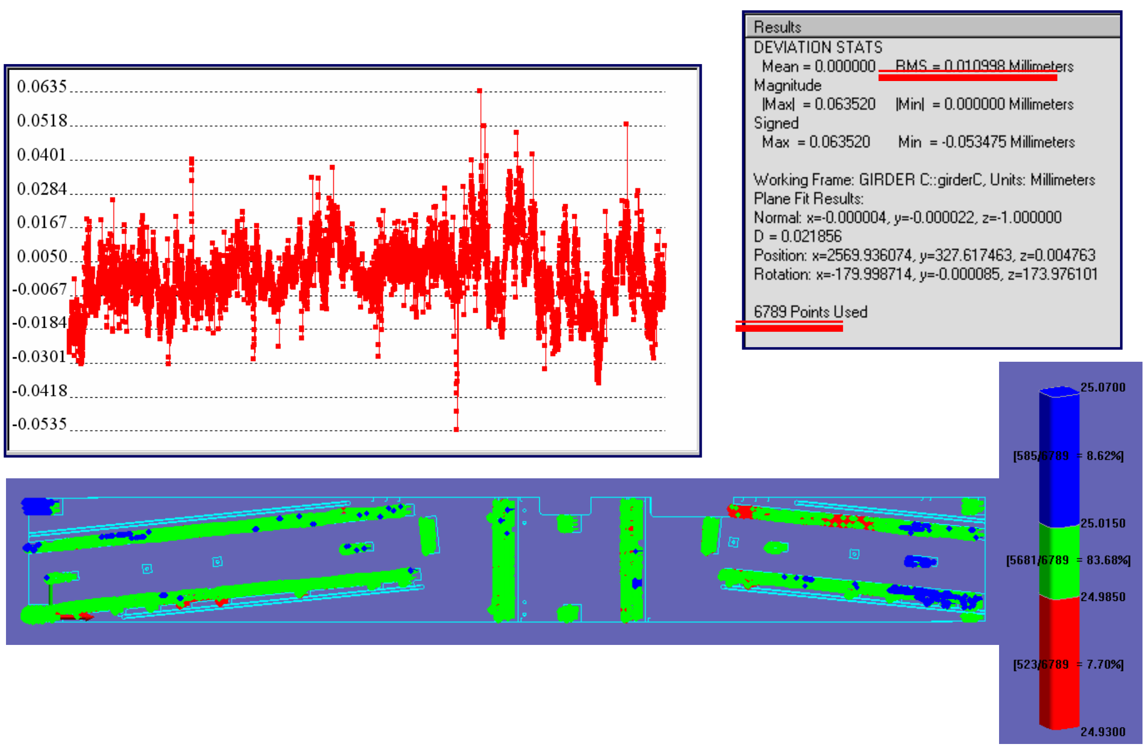
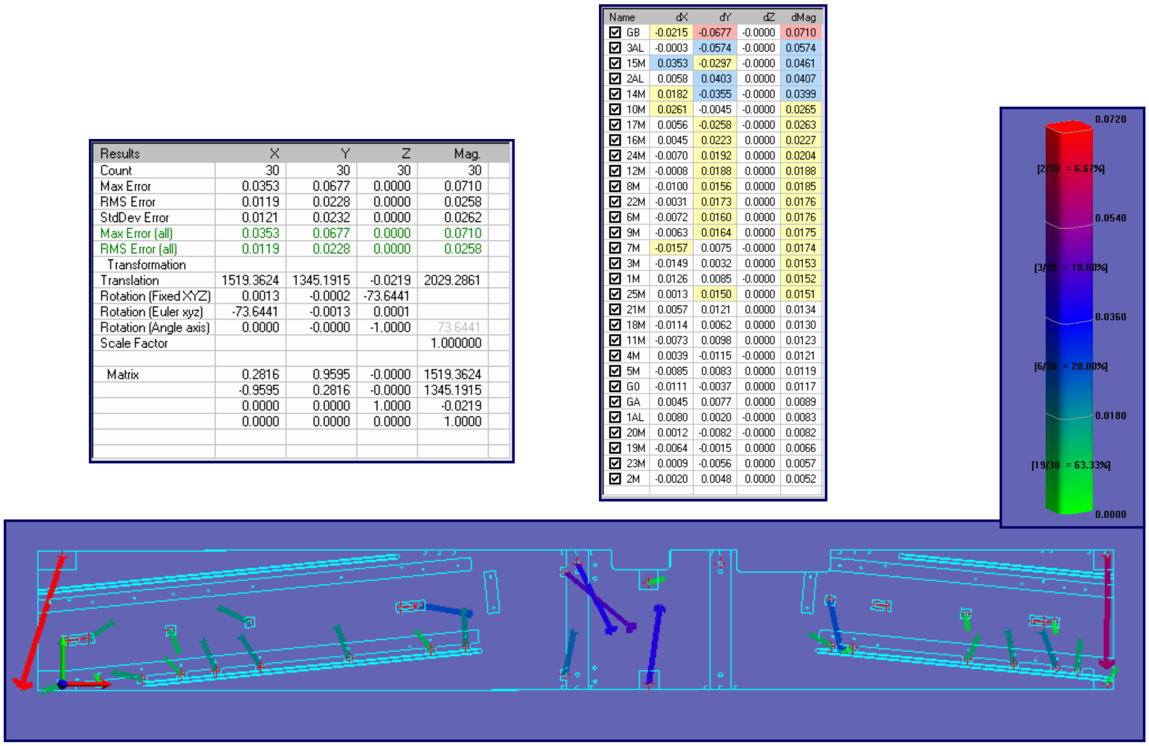


Figure 6 Flatness results



Results	X	Y	Z	Mag.
Count	30	30	30	30
Max Error	0.0353	0.0677	0.0000	0.0710
RMS Error	0.0119	0.0228	0.0000	0.0258
StdDev Error	0.0121	0.0232	0.0000	0.0262
Max Error (all)	0.0353	0.0677	0.0000	0.0710
RMS Error (all)	0.0119	0.0228	0.0000	0.0258
Transformation				
Translation	1519.3624	1345.1915	-0.0219	2029.2861
Rotation (Fixed XYZ)	0.0013	-0.0002	-73.6441	
Rotation (Euler xyz)	-73.6441	-0.0013	0.0001	
Rotation (Angle axis)	0.0000	-0.0000	-1.0000	73.6441
Scale Factor				1.000000
Matrix	0.2816	0.9595	-0.0000	1519.3624
	-0.9595	0.2816	-0.0000	1345.1915
	0.0000	0.0000	1.0000	-0.0219
	0.0000	0.0000	0.0000	1.0000

Name	dX	dY	dZ	dMag
GB	-0.0215	-0.0677	-0.0000	0.0710
3AL	-0.0003	-0.0574	-0.0000	0.0574
15M	0.0353	-0.0297	-0.0000	0.0461
2AL	0.0058	0.0403	0.0000	0.0407
14M	0.0182	-0.0355	-0.0000	0.0399
10M	0.0261	-0.0045	-0.0000	0.0265
17M	0.0056	-0.0258	-0.0000	0.0263
16M	0.0045	0.0223	0.0000	0.0227
24M	-0.0070	0.0192	0.0000	0.0204
12M	-0.0008	0.0188	0.0000	0.0188
8M	-0.0100	0.0156	0.0000	0.0185
22M	-0.0031	0.0173	0.0000	0.0176
6M	-0.0072	0.0160	0.0000	0.0176
9M	-0.0063	0.0164	0.0000	0.0175
7M	-0.0157	0.0075	-0.0000	0.0174
3M	-0.0149	0.0032	0.0000	0.0153
1M	0.0126	0.0085	-0.0000	0.0152
25M	0.0013	0.0150	0.0000	0.0151
21M	0.0057	0.0121	0.0000	0.0134
18M	-0.0114	0.0062	0.0000	0.0130
11M	-0.0073	0.0098	0.0000	0.0123
4M	0.0039	-0.0115	-0.0000	0.0121
5M	-0.0085	0.0083	0.0000	0.0119
G0	-0.0111	-0.0037	0.0000	0.0117
GA	0.0045	0.0077	0.0000	0.0089
1AL	0.0080	0.0020	-0.0000	0.0083
20M	0.0012	-0.0082	-0.0000	0.0082
19M	-0.0064	-0.0015	0.0000	0.0066
23M	0.0009	-0.0056	0.0000	0.0057
2M	-0.0020	0.0048	0.0000	0.0052

Figure 7 Position results

4.2 Vibrations tests

Two vibrations tests have been performed on the girder by two different institutes, Automotive research and DESY. Here the results of those tests are presented.

<u>Automotive research</u>

The following equipment was used during the test:
- PCB 339B01 accelerometers
- LMS PIMENTO acquisition system
- LMS CADA-X Modal Analysis software

The structure was impacted in three points/directions and vibrations were measured at 25 points (three axes at each point). Twenty points were on the girder structure and the other five points were on the magnets. See figure 4

Figure 4 Accelerometer positions and impact points

The acquisition was performed in three different conditions of the blocking system:

- With all movements blocked
- With vertical movements blocked only
- Without any movements blocked

The third condition was acquired at the magnet points only.

Table below shows the natural frequencies and a description of the corresponding mode shapes.

Mode	With all bolted joints		Only vertical bolted joints	
	Freq (Hz)	Description	Freq (Hz)	Description
1st	26	Bucking of the top plate + rotation around the longitudinal axis	25	Rotation around the longitudinal axis
2nd	37	Rotation around the transversal axis	36	Rotation around the transversal axis
3rd	39	Torsion of the assembly	37	Torsion of the assembly
4th	53	Flexion + rotation of magnets 21 and 22 (see Figure 4) in phase	47	Flexion + rotation of magnets 21 and 22 in phase (see Figure 4)
5th	61	Flexion + rotation of magnet 22 (see Figure 4)	61	Flexion + rotation of magnet 22 (see Figure 4)
6th	65	Longitudinal flexion + rotation of magnets 21 and 22 (see Figure 4) in opposition of phase	64	Longitudinal flexion + lateral flexion + rotation of magnets 21 and 22 (see Figure 4) in opposition of phase
7th	67	Longitudinal flexion of the beam + rotation of magnets 21 and 22 (see Figure 4) out of phase	66	Longitudinal flexion of the beam + lateral flexion of the beam + rotation of magnets 21 and 22 (see Figure 4) out of phase
8th	86	Rotation of magnets 21 and 25 (see Figure 4)	85	Rotation of magnets 21 and 25 (see Figure 4)
9th	95	Rotation of magnet 25 (see Figure 4)	95	Rotation of magnet 25 (see Figure 4)
10th	99	Flexion of the beam + circular movement of 24 and 25 magnet ends (see Figure 4)	99	Flexion of the beam + circular movement of 24 and 25 magnet ends (see Figure 4)

Table below compares de calculated and measured natural frequencies corresponding to equivalent mode shapes

Frequency (Hz)		With all bolted joints
Calculated	Measured	Description
54	26	Bucking of the top plate + rotation around the longitudinal axis
	37	Rotation around the transversal axis
65	39	Torsion of the assembly
68	53	Flexion + rotation of magnets 21 and 22 (see Figure 4) in phase
	61	Flexion + rotation of magnet 22 (see Figure 4)
	65	Longitudinal flexion + rotation of magnets 21 and 22 (see Figure 4) in opposition of phase
	67	Longitudinal flexion of the beam + rotation of magnets 21 and 22 (see Figure 4) out of phase
	86	Rotation of magnets 21 and 25 (see Figure 4)
	95	Rotation of magnet 25 (see Figure 4)
	99	Flexion of the beam + circular movement of 24 and 25 magnet ends (see Figure 4)

The main conclusions of the test are:

- The frequencies and mode shapes of the girder with all bolted joints and with vertical bolted joints only are very similar (except for the fourth mode). This tells us that the influence of the bolted joints has a little effect on the rigidity of the system.
- The calculated natural frequencies are much higher than the measured ones. The source of discrepancy is on the ground to base plate simulation assumptions.

DESY

The following equipment was used during the test:

- Two triaxial seismometers (Güralp, CMG-6TD, frequency range: 60s -80 Hz) one on the girder surface, one on the floor.

- Four single axis (two vertical and two horizontal) geophones (SENSOR SM-6), placed according to figure 5:

    - On the pedestal platform and the surface of the girder & on the floor and the pedestal platform to evaluate the transfer function of the girder structure.
    - On the surface of the girder and the magnet dummies to evaluate the transfer function between the girder and the magnet dummies.
    - On the left and right most corners of the girder surface to look for any twist modes predicted by FEA (ANSYS).

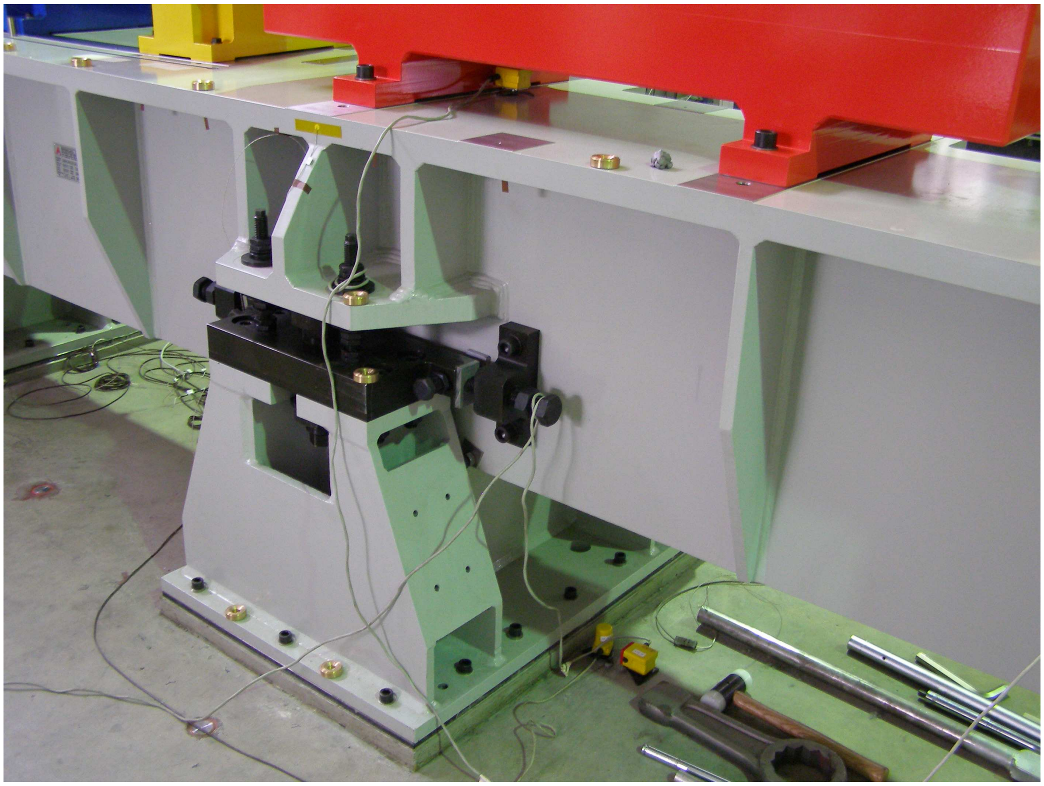
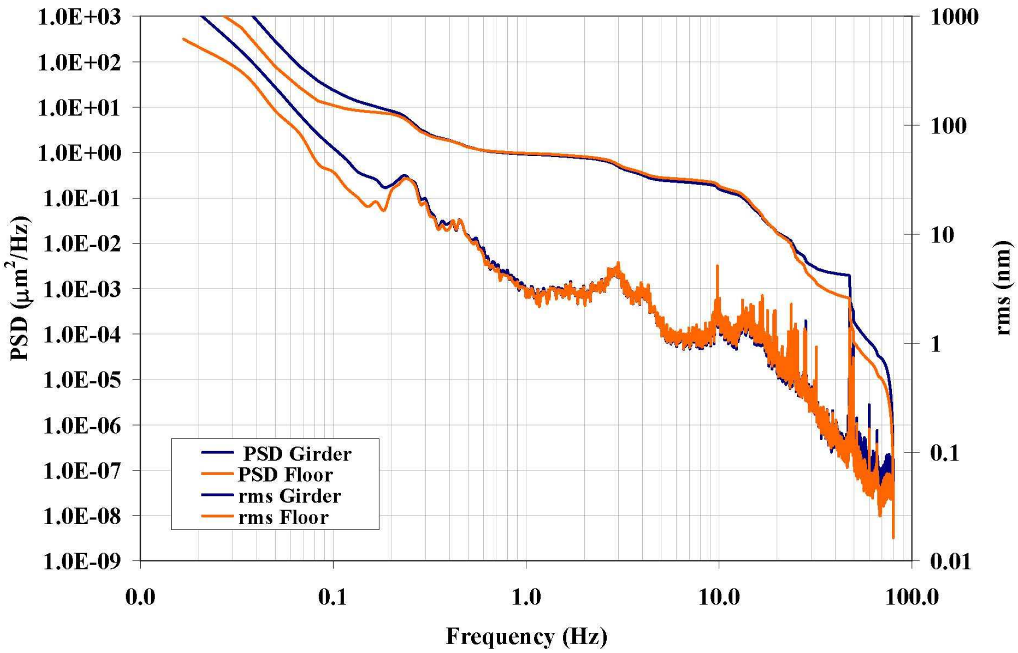


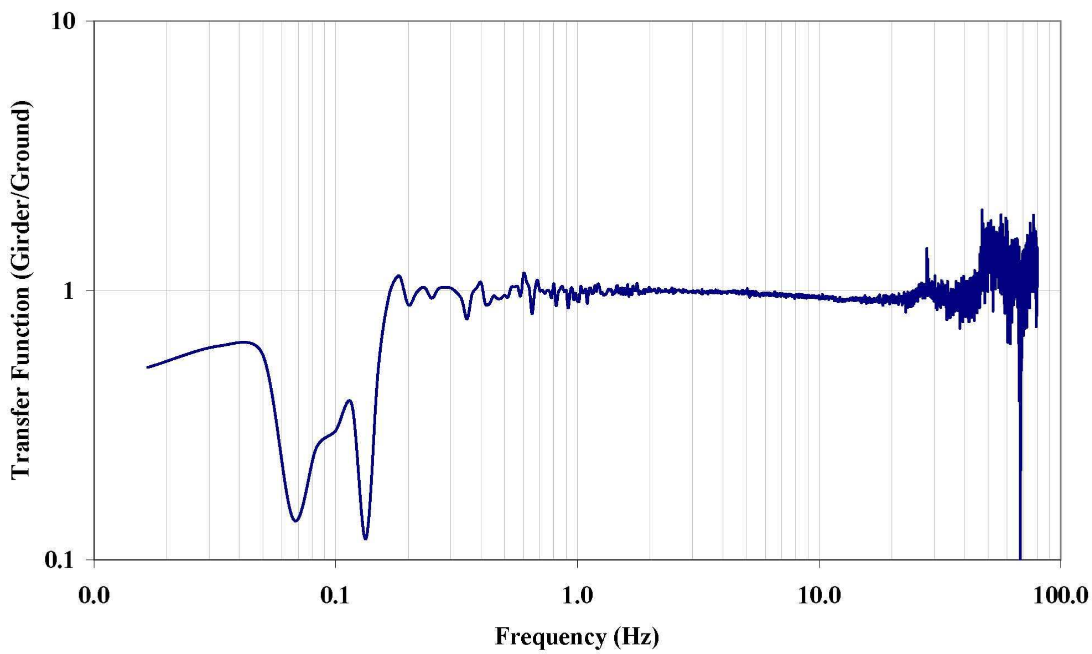
Figure 5 Geophones positions

The results are presented here

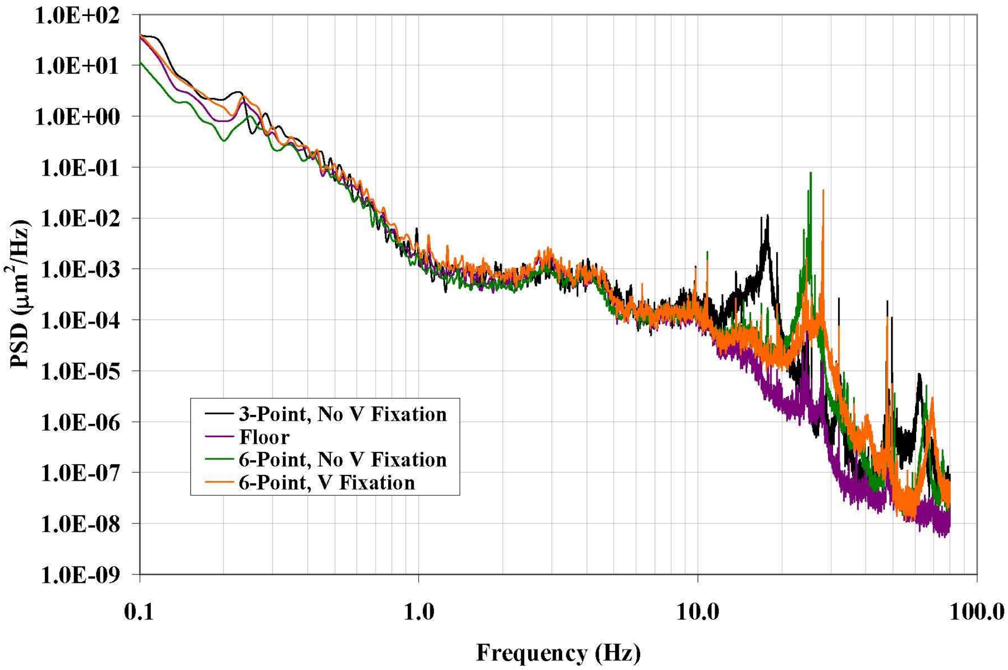


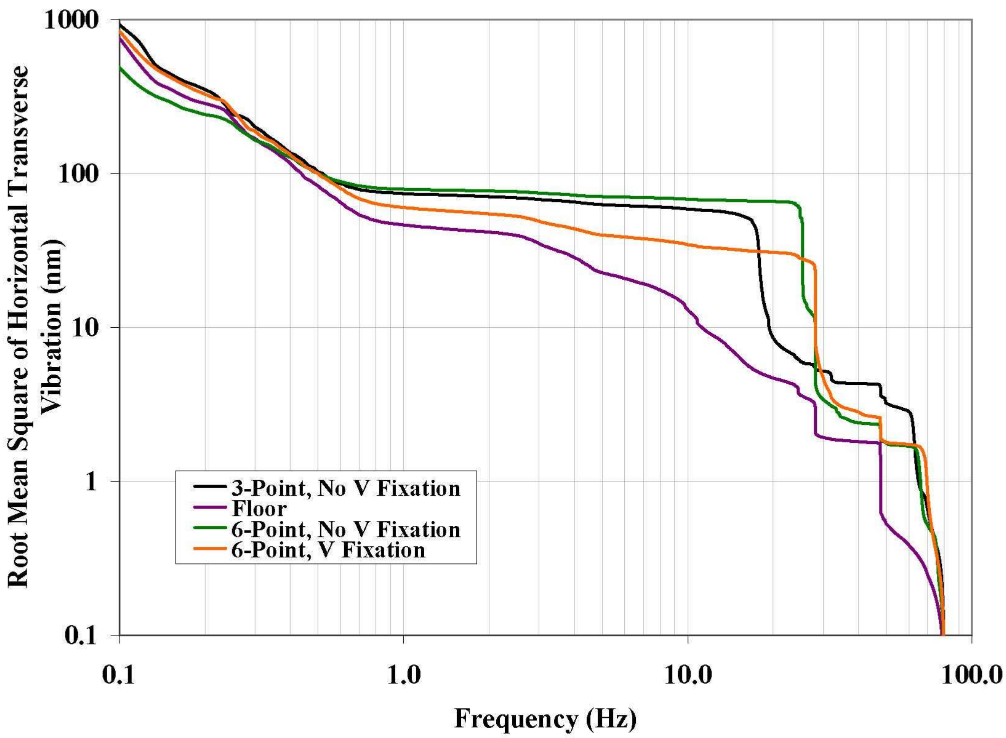
Average displacement PSD and the integrated PSD in vertical direction.

In the vertical direction the girder has exhibited a very good figure of merit with an almost one to one transferring of the ground motion, as shown in the seismometer measurement comparison between the girder and the ground.

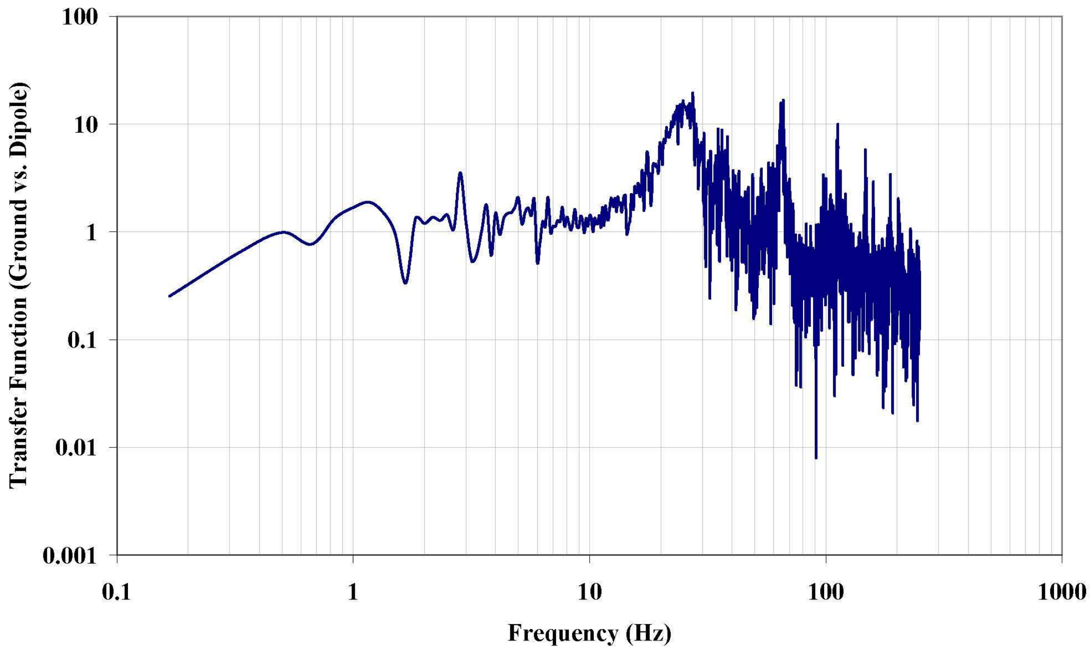


It clearly demonstrates that the girder is substantially rigid in the vertical direction, i.e., TF ~ 1 up to 40 Hz at least.



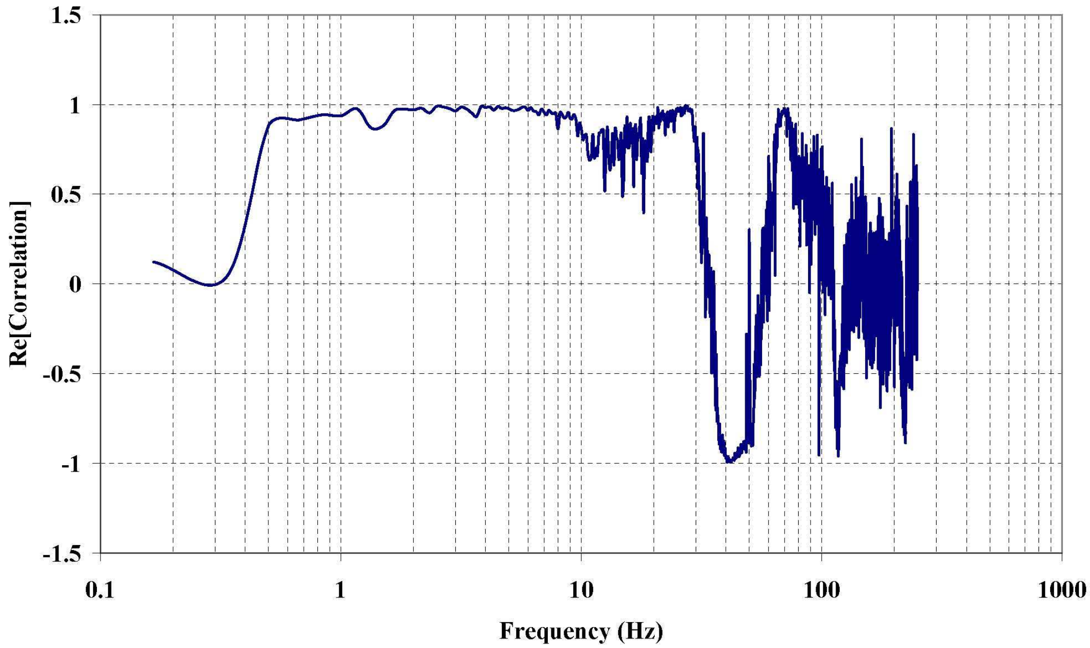


In its baseline design, the girder body is supported, on 6 points, on the pedestals. The effect of changing the number of the support points from 6 to 3 was investigated. Displacement PSD and displacement rms plots of these configurations are displayed in figures above. Results are compared to the measurements on the floor. In going from 6-point to 3-point setup, the frequencies seen on the surface of the girder are pushed backwards. The most dramatic effect is seen in the case of 3-points with no vertical fixation and can be directly compared with the case of 6-points with no vertical fixation. The 28 Hz mode is pushed down to 18 Hz, probably because of the re-distribution of the weight on the contact surface between the pedestals and the pedestal platforms. The 70 Hz eigen mode is pushed down to 63 Hz. The 24 Hz line visible in all the spectra is due to the vibrations produced of a rotary vacuum pump nearby. In the 6-point layout, the peak is much higher because it's next to the first mechanical resonance (the 28 Hz mode) of the system. The difference in the frequencies seen with/without vertical fixations, measured in the case of 6-point support, is less marked. The 70 Hz eigen mode is pushed down to 66 Hz and the 28 Hz to ~25 Hz. The resultant amplitude ~24 Hz is therefore high due to the existence of the peak from the vacuum pump as was mentioned above.



Transfer function on the magnets horizontal transverse

Transfer function of all the magnet dummies, from ground to the top of the magnet, was measured in both transverse and longitudinal directions in the case where the girder's vertical fixations were loosened. Figure above shows the transfer function measured for the dipole in the transverse direction. The two structures seen are in the ~25-28 Hz frequency range and ~66 Hz, the second being the first eigen mode of the girder. TF at 28 Hz is greater than 10 for the dipole. This rocking mode, due to girder pedestal-floor connection proves to be a dominant source for magnet displacement.



A twist mode mostly affecting the two ends of the girder was predicted by the ANSYS model to exist around 64 Hz. To validate this picture, two horizontal geophones were placed at the extreme corners on the girder surface and the correlation (coherence) between the signals was computed (Figure above). A girder twist-mode at ~40 Hz is clearly seen as a change in phase in the computed real component of the correlation versus frequency. The resonant frequency is much less than expected (~ 64 Hz in the model); a possible explanation is once again the effect of the pedestal-floor interaction.

5.- Conclusions

The ALBA storage ring girder system design has been crosschecked. The production issues have been solved and successfully implemented. The design geometrical tolerances have been achieved.

Considering the vibration response, the design shows good performance in vertical direction. The design shows worse performance in the transversal horizontal direction, being the first resonant frequency significantly lower than predicted by the calculations. The discrepancy is attributed to the base plate to ground interface.

Acknowledgement

We are very grateful to R. Amirika, A. Bertolini and W.Bialowons from DESY, for their interest supporting the mechanical engineering group at CELLS and to our colleagues from CELLS survey and alignment group, E. Pulido, F. Rey and A. Villalobos.

References

[1] EURO TeV-Report-2007-057. **Measurement of vibration characteristics of a magnet prototype girder for ALBA.** Ramila Amirikas, Alessandro Bertolini and Wilhelm Bialowons .Deutsches Elektronen-Synchrotron DESY, 22607 Hamburg, Germany

[2] AV070402/3. **Modal analysis of a girder of the synchrotron ALBA.** I. Fernandez, J. Garcia.

[3] Girder As-built report. 6/6/08. E. Pulido, A.Villalobos. CELLS.