# THE GIRDER SYSTEM FOR THE NEW ESRF STORAGE RING

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*Abstract*

The ESRF is proceeding with the design and procurement of its new low emittance storage ring (Extremely Brilliant Source project).

This completely new storage ring requires a high performance support system, providing high stability (first resonance frequency about 50Hz) and a precise alignment capability (50µm, manual in transverse direction and motorized in the vertical one).

In order to meet these requirements we decided to support the magnets of each of the 32 cells of the synchrotron with four identical girders that was considered the best compromise between cost, complexity and performances. Each of the resulting 128 girders is 5.1m long, carries about seven tons of magnets, and its weight including fixed basement and adjusting system is six tons.

The adjustment system relies on modified commercial wedges; their stiffness was evaluated through laboratory tests. The FEA calculations carried out to optimize the design will be presented, together with the results obtained on a complete prototype girder system which was built and extensively tested and confirmed the modal calculations..

## THE NEW LAYOUT

The present machine presents the lattice called Double Bend Achromat, with two bending magnets and 3 groups of optical magnets in each of its 32 cells. Only the groups of optical magnets are supported by adjustable girders. The dipole, less demanding in term of positiong precision, are placed on fixed supports. The lattice of the new machine is a Hybrid Seven Bends Achromat, constituted by 4 dipoles, 3 dipoles-quadrupoles and 24 optical magnets (Figure 1).

This complexity make unpractical the choice of different support for the different magnets, especially considering that the dipoles are relatively small and light. The solution of supporting all the machine on adjustable girders has been taken. The disposition of the magnets in the lattice led us to divide each of the 32 cells in 4 groups of magnets with almost the same weight (6 Tons) and length (5.1m), and support each of them with an adjustable girder.

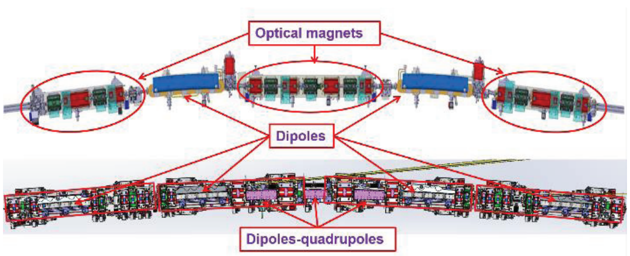



Figure 1: Lattice.

## SPECIFICATIONS

The requirement of the girder are summarized in Table *1*.

The positioning precision is due to the physics of the machine and it will not be discussed here.

The re-alignment frequency is linked to the long-term movements and deformations of the ESRF site. During the last years movements of several mm were registered especially in the vertical direction, therefore a fast and convenient alignment method of the machine is required.

The choice of the target value of the first resonance frequency was based upon practical considerations about the behaviour of existing structures and the amplitude of the vibrations present on the site. In theory the important value is the amplification factor of the ground movement as a function of the frequency, but this is nearly impossible to calculate. However this amplification is usually very low for frequency below the 1$^{st}$ resonance. As the amplitude of the ground vibrations is significant mainly for frequency below 30Hz a value of 35Hz was specified for the 1$^{st}$ one.

Table 1: Specifications

| Aspect | Value |
|---|---|
| Length | 5.1m |
| Payload | 6-7 Ton |
| Positioning precision | 50µm (Vertical-transv.) |
| Positioning precision | 1mm (Longitudinal) |
| Alignment freq. | 2 times/year |
| Alignment method | Motorized (Vertical) |
| Alignment method | Manual (Transv.-long.) |
| First resonance frequency | 35 Hz (minimum) |
| Planarity of top surface | +/-50 µm |

## GIRDER DESIGN

Several configurations were considered, with 3 and 4 supports. Three supports permit to not over define statically the girder, but as this solution does not permit to obtain the requested first resonance frequency, we decided to adopt a 4 supports system for this reason. The four supports version hallow holding the load in the vertical direction but not blocking the movements in the horizontal one. Two jacks are used to adjust the transversal position of the girder, while simple pushing screws set the longitudinal one. Figure 2 shows the design of the machine.

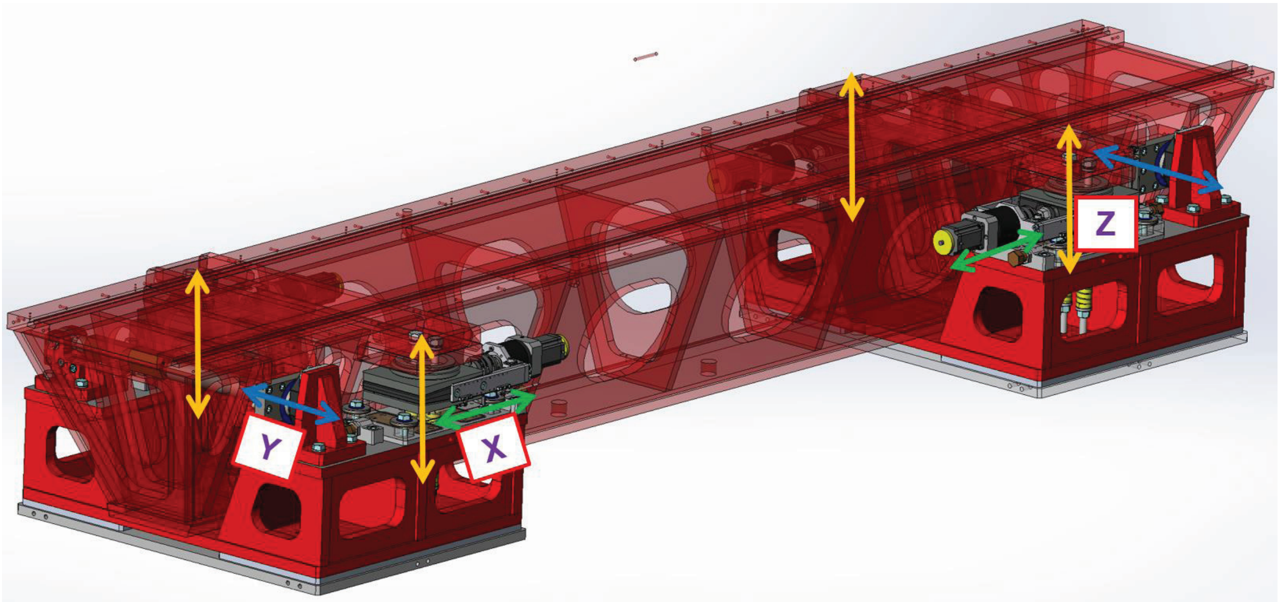



Figure 2: Girder design.

### *Vertical Supports*

The vertical supports are based on the use of commercial wedges produced by Airloc and modified to accept the motorization and the related stress (Figure 3). The nut and some internal washer acting as axial bearing were made in aluminium bronze, the driving shaft for motorization reference and fixation holes added. Two spring were added to add a preload of about 1.4 Tons. Under this component a sliding surface based on Fibro sleds was added to ensure the horizontal motion.

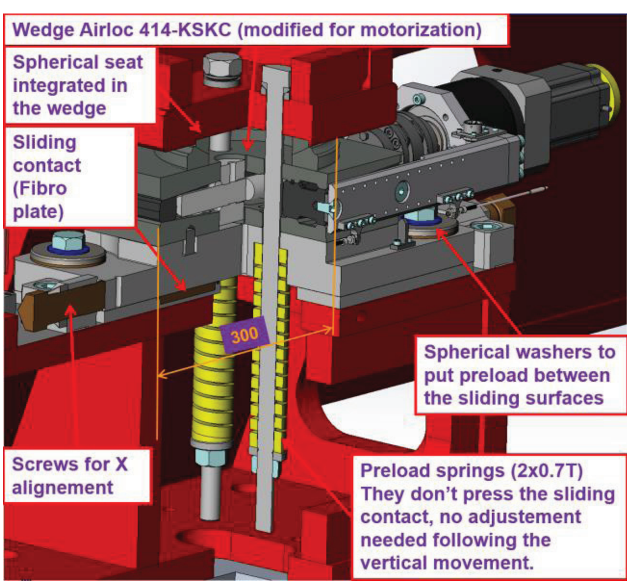



Figure 3: Vertical supports.

### *Horizontal Jacks*

The motion in the transversal direction is ensured by two commercial wedges mounted vertically (Nivell DK2). As these component can only push forward a spring was placed in the other side to permit the reverse movement. These components, as they avoid any translation of the girder in the transversal direction, also ensure the absence of parasitic lateral movement of the girder during the vertical motion (Figure 4).

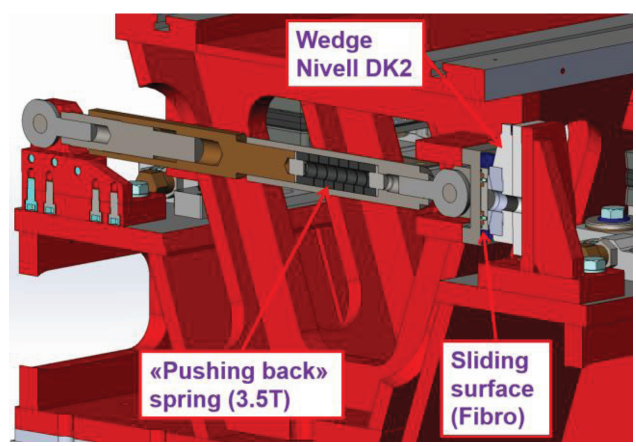



Figure 4: Vertical supports.

## STATIC ANALYSIS

### *Gravity Deformation*

To respect the planarity tolerances the deformation due to the own weight of the girder and the one of the magnets has to be taken in consideration, adding it to the machining tolerances. A static FEM analysis using the software Simulation was performed for this purpose. The result shows that the maximum deviation with respect to the medium plane of the upper surface is +/-18µm (36µm height difference between highest and lowest point). The analysis was performed on only ¼ of the structure using the symmetry with respect to the two vertical planes (Figure 5).

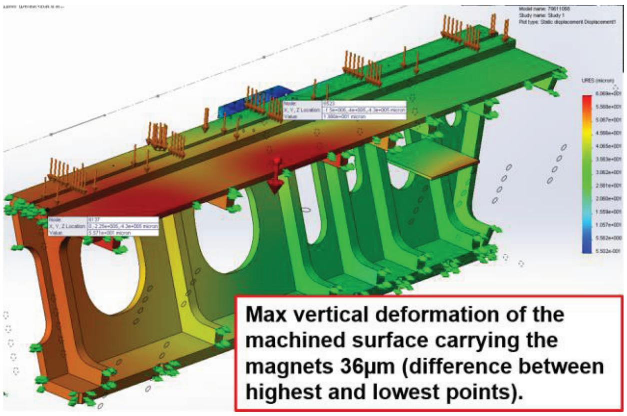



Figure 5: Vertical supports.

### *Hyperstatic Efforts*

As the girder is supported on 4 points it is one time over defined in the vertical direction. This means that if the supports are not in the same plane above a critical value one of them can lose the contact and leave the girder on 3 supports. This condition (like a table on rough floor) is extremely dangerous because then the position of the girder would not be defined anymore and the stability would be compromised. Errors lower than the critical value generate a torsional deformation enabling to keep contact on the four supports. The FEM analysis (Figure 6) made with Simulation indicates that the girder follow a support out of position, twisting, up to about 400µm, which is largely sufficient considering that the motion precision is around 10 µm (see below). Even in this case it was possible to make the analysis only on ½ of the model thanks to a diagonal symmetry plane.

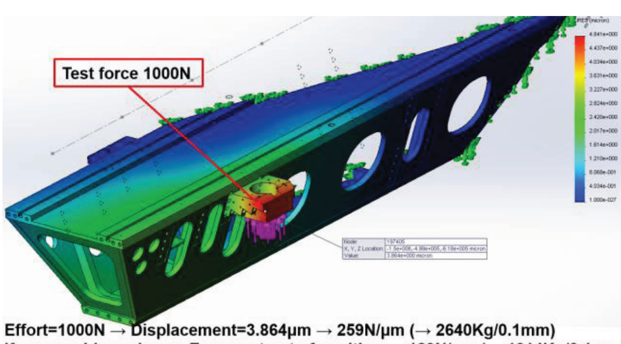
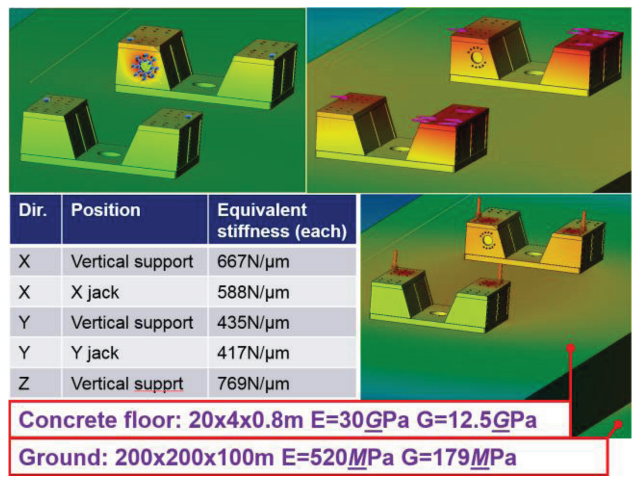



Figure 6: FEM analysis hyperstatic effort.

## MODAL ANALYSIS

### *Boundary Conditions*

As the girder system is very stiff the influence of the stiffness of the slab and the ground can't be neglected. A 3D model of these parts including the steel bases of the girder was made (Figure 7) and an elastic analysis was performed to calculate the equivalent stiffness of the supports integrating the floor to be used in the analysis as a virtual "elastic foundation". The stiffness for an optional jack for longitudinal adjustment was also calculated, even if this component was finally suppressed and replaced by simpler pushing screws.




| Dir. | Position | Equivalent stiffness (each) |
|---|---|---|
| X | Vertical support | 667N/µm |
| X | X jack | 588N/µm |
| Y | Vertical support | 435N/µm |
| Y | Y jack | 417N/µm |
| Z | Vertical supprt | 769N/µm |

Figure 7: Ground and bases.

### *Wedges Stiffness*

The stiffness of two models of wedges produced by different supplier were tested in our laboratory, using a hydraulic press to apply the real load in the vertical direction and a spring to apply the probing load in the horizontal plane (Figure 8). The one that was retained is the Airloc 414KSKC. This massive component is designed for charges up to 40 Tons, but we chose it for its high rigidity. As the amplitude of the ground vibration is extremely small even the efforts induced in the structure are mini- mal. Hence there is no slipping motion of the sliding surfaces used for the horizontal adjustment. In this way the stiffness of the wedges used for the vertical movement is crucial to avoid vibration in the horizontal direction too.

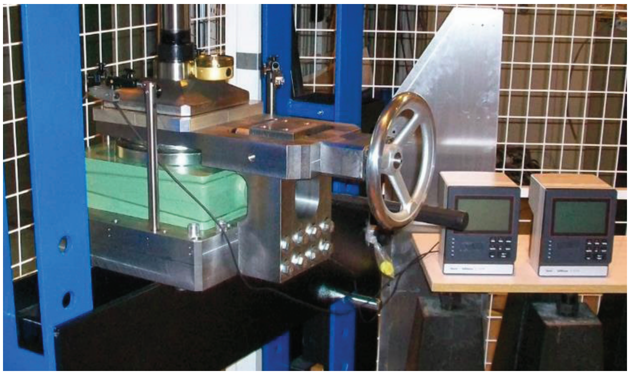


Figure 8: Wedges test.

### *Complete Analysis*

Combining the stiffness of the "ground+slab+bases" and the one of the wedges in the three axis we obtain the values of the equivalent elastic foundation to be used in the girder analysis (Table 2). The Figure 9 shows the first modal shape with the calculated foundation values and an equivalent payload.

Table 2: Equivalent Stiffness for Modal Analysis

| **Dir.** | **Position** | **Ground+ Slab+ bases** | **Adj. wedge** | **Global equivalent stiffness** |
|---|---|---|---|---|
| X | Vertical supports | 667N/µm | 1200N/µm | 429N/µm |
| Y | Vertical supports | 435N/µm | 1100N/µm | 311N/µm |
| Y | Y jacks | 417N/µm | 500N/µm | 227N/µm |
| Z | Vertical supports | 769N/µm | 1600N/µm | 519N/µm |

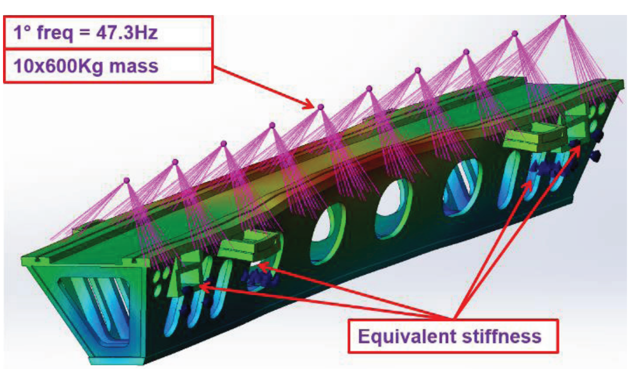



Figure 9: Final Analysis.

## PROTOTYPE

### *Prototype Configuration*

A prototype of the whole girder system was made to make a real scale test about the girder's performances, especially regarding vibrations modes and alignment precision. Other purposes of the installation were to check the feasibility of the installation and the interfaces with others sub-system in the limited space of the ESRF storage ring tunnel (Figure 10). The mechanical design of the prototype was more complex than the series, the supports interfaces were screwed and not integrated in the structure in order to have the possibility to make modifications in case of unsatisfactory results.

Figure 10: Prototype installation.

### *Motion Test*

Motion analysis was made to ensure the requested alignment precision, especially in the vertical direction that needs frequent adjustments. Table 3 shows the main results.

Table 3: Motion Test

| **Performances in +/-2mm motion** | **Value** |
|---|---|
| Z motion accuracy | 10.8 µm |
| Z motion repeatability | 3.3 µm |
| Z motion increment | 0.3 µm |
| X parasitic movement | 11.3 µm |
| Y parasitic movement | 7.8 µm |

### *Vibration Test*

Vibration test was performed by Marc Lesourd on the prototype. Dummies magnets with the same shape and weight as the real ones were installed to have a realistic payload. The response of the system to the ground vibration noise is very good, we registered a maximum amplitude of the vertical vibration on the critical magnet (QF6) only marginally bigger than the one of the ground (Figure

11). The frequency response of the girder system is in good agreement with the calculated values. The graph of Figure 12 shows that the girder follow perfectly the ground movements up to a frequency around 50Hz. The response to an excitation with hammer indicated that the first vibration mode involving the girder is 51Hz, some lower frequency around 40Hz could interest QF6 only.

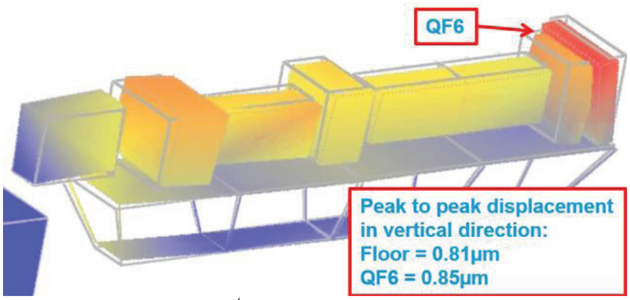



Figure 11: 1st Measured Vibration Mode.

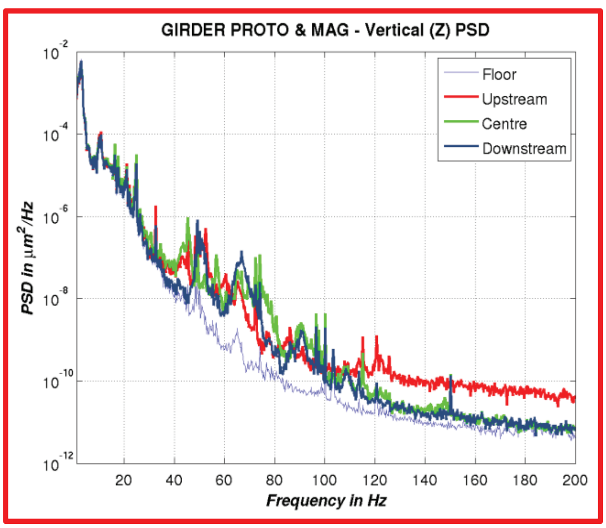



Figure 12: Ground Vibration Response.

## CONCLUSION

The results of the test made on the prototype gave the expected results for all the main aspects (both movement precision and modal frequency).

We already started the production of the 128 girders necessary for the new storage ring, two suppliers were selected and they will complete the 2 pre-series before the end of 2016. The delivery of the series ones id foreseen during 2017 and beginning 2018, in order to start the mounting of the components on the girders in 2018 and to do the installation in the tunnel in 2019.

## NOTE

This paper is a brief report of a work made internally at ESRF for a specific purpose. The aim of this paper is only to inform about the obtained results. Any reference to existing similar work is not included for mere lack of time before the MEDSI 2016 conference.