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DESIGN OF GIRDERS ON THE NEW UPGRADE LATTICE AT SOLEIL

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Abstract

The current girder set of SOLEIL features 4 girder types weighing from 1.85 t to 3 t, with a respective mass payload varying from 4.1 t to 8 t and lengths from 2.4 m to 4.8 m. The smaller size of magnets used for the present version of the SOLEIL upgrade allows a dramatic size and weight reduction of the magnet-girder assemblies (Fig. 1). On the other hand, the number of magnets has increased by a factor of 3, implying longer alignment and installation operations. Several setups involving 116 to 212 girders with various magnet layouts and binding systems have been studied. Dynamic and thermal performances have been evaluated by FEA analysis. This approach gives to accelerator physicists the performance of each solution, and thus a great versatility in the choice of the best setup in terms of dynamic and thermal stability.

DESIGN BASELINE

The design of the new magnet-girder assemblies con-siders experience gained from the existing installation, us-ing concepts with proven efficiency and good performance in terms of stability. However, some other features are not optimized for the new storage ring and had to be adapted or totally redesigned. The large number of girders and mag-nets in the new lattice leads to a need to reduce unit cost and alignment time.

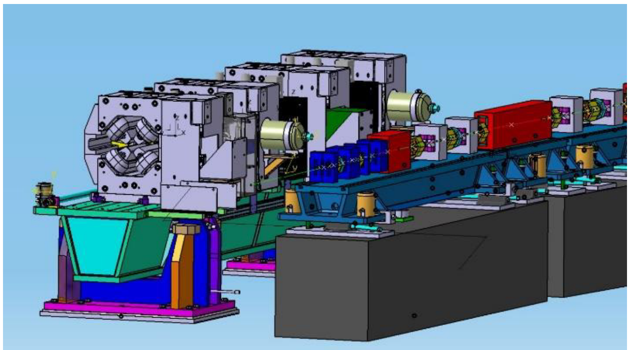

Figure 1 : SOLEIL vs Upgrade magnet girder assembly.

The small size of magnets makes possible to reduce the distance between beam axis and the upper face of girders to 240 mm, improving overall stability. However, the girder position is then higher with respect to the ground, imposing increased stability requirements on the girder support structures. Both granite and welded steel plinths have been considered as girder supports. These plinths are aligned, in all directions, with an accuracy of ±1 mm and grouted to the ground. The new lattice features 4 or 6 fixing point girders depending on the length. Due to the high long-term stability of the SOLEIL slab, motorization of the positioning system is not envisaged, particularly when considering its extra cost and complexity. In the same way, the current lock/release system is replaced by high stiffness wedges for vertical adjustment and push-pull screws for horizontal position. Stiffness is improved by applying a permanent vertical preload on wedges.

Girders are equipped with a HLS (Hydrostatic Levelling System) used during alignment operations. The new design implements a tooling referenced on the girder side face to set magnets on the beam axis with the requested accuracy.

MAIN SPECIFICATIONS

- Dynamic sensitivity of beam towards magnet position: lowest frequency > 70 Hz
- Sensitivity of beam towards magnet alignment:
  girder to girder 30 µm vertical and 50 µm horizontal
- 100 µm RMS in both planes for all girders
- Thermal stability based upon BPM specification:
  - 50 nm a couple of minutes
  - 500 nm on one day
  - ~ 1 µm on a week
- Ex-situ bake-out of vacuum chambers:
  C-shape dipoles and transverse motion mandatory

GENERAL LAYOUT

SOLEIL Upgrade features 2 basic cells: 7 BA* and 4 BA* 3 configurations have been studied:

- 212 girders with 1.80 m max length (Fig. 2).
- 116 girders with 3.60 m max length (Fig. 3).
- 176 girders with 3.20 m max length (Fig. 4).

In the 2 first layouts, long dipoles share the plinth with adjacent girders, the third layout features standalone dipole stands. Using a girder as a dipole support allows for fine setting and avoids the low resonance frequency of dipoles encountered on the present SOLEIL setup. Dipoles are fixed on an air bearing cradle which can be removed from beam axis for vacuum chamber installation (Fig. 5).

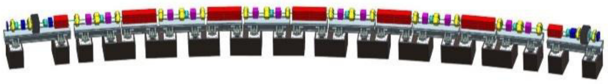

Figure 2: Configuration 1 (7BA segment).

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*BA: Bending Achromat

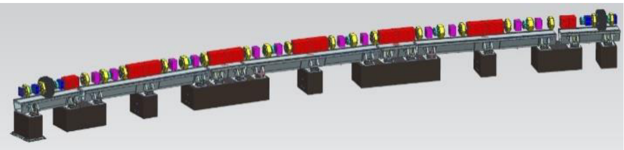

Figure 3: Configuration 2 (7BA segment).

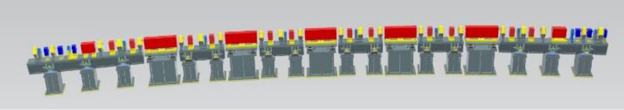

Figure 4: Configuration 3 (7BA segment).

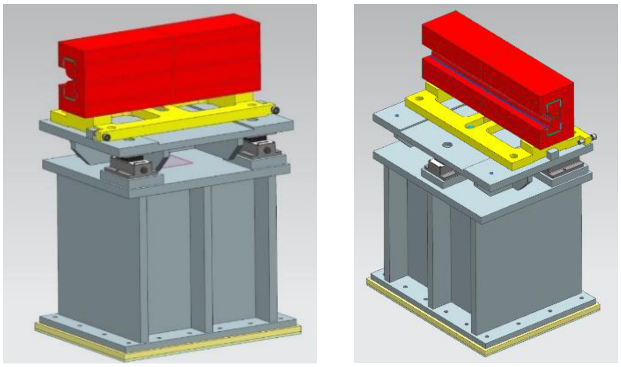

Figure 5: Dipole in operating and off beam position.

GIRDER CONSTRUCTION

The construction of the girders uses welded steel plates associated with cast steel parts common to all types. The length and fixation position are defined by the welded plates which are adapted to the different types (Figs. 6 and 7). The cast steel parts integrate fixation, setting, HLS sup-port and lifting points. In addition to cost reduction, casting allows realization of continuous internal stiffeners and lim-its stress caused by welding. Functional surfaces of girders are machined after welding and stress relief treatment.

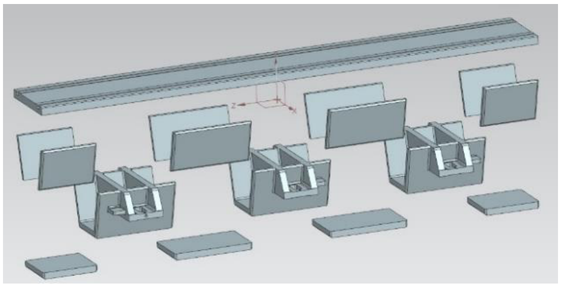

Figure 6: Configuration of 6 point girder.

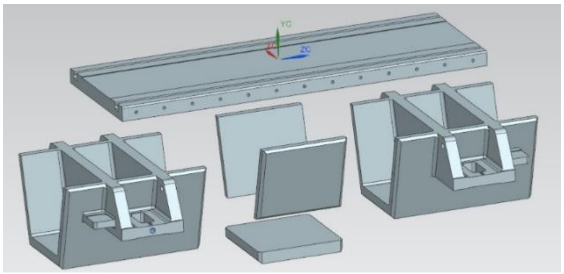

Figure 7: Configuration of 4 point girder.

FASTENING AND ADJUSTMENTS

The setting and fastening systems are located as high as possible with respect to the ground. Each girder is placed on commercial NIVELL® DK3 jacks (featuring 7 mm set-ting range and 25 t load capacity). Girder position along the beam axis is referenced by a spherical link aligned be-fore installing the girder. Horizontal adjustment is achieved using push-pull screws located on the inner side of girder (Fig. 8). A set of removable sensors monitor the position of the girder and controls the twist during align-ment. Fastening is achieved using vertical rods and a 5 t preload is applied at each point using a stack of elastic washers. Each girder is equipped with 3 HLS sensors used as reference during alignment operations.

Magnet alignment is achieved using a tooling refer-enced to the top and side surfaces of the girder machined with a ±15 µm flatness tolerance. Magnets are fastened us-ing the T-slots of the top plate.

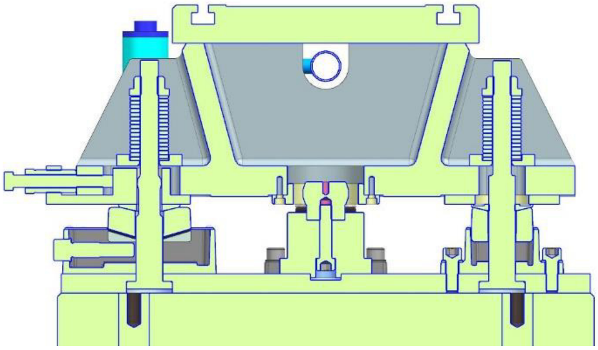

Figure 8: Section of girder setting system.

DYNAMIC SIMULATION

Simulation by Finite Element Analysis (FEA) has been carried out for the most critical magnet-girder types. Mag-nets are simulated by their 3D models, defined by a prelim-inary design. Jacks are modelled with their real shape and materials in order to accurately estimate stiffness. However non-linear effects are not yet been considered, so the effect of preload does not appear in the results. As an example, the calculated lowest resonance frequency (yaw mode) of the 3.60 m girder fixed on 6 points is 77 Hz (Fig. 9) which is higher than the current SOLEIL girders (47 Hz).

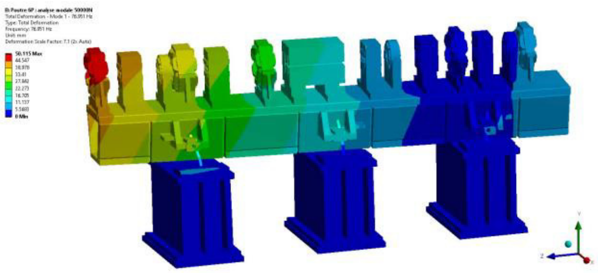

Figure 9: Dynamic simulation on a 3.60 m girder.

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THERMAL SIMULATION

Thermal stability specifications are critical for the Upgrade machine, in particular long-term drift. Granite and steel have been studied as a material for girder stands. Data for both materials are summarized in Table 1. Although volume heat capacity of granite is lower, stands are massive blocks and yield a better thermal inertia than welded steel plate stands. In the same way, considering stiffness, low Young modulus of granite is compensated by greater inertia of granite stands. Steel allows more complex shapes than natural granite, and the final cost depends on design and manufacturing process for both materials.

Table 1: Steel and Granite Characteristics

Material	Steel	Granite
CTE	$11\mathrm{x}10^{-6}$	$6.4\mathrm{x}10^{-6}$
Density	7.8 $\mathrm{Kg.m^{-3}}$	2.7 $\mathrm{Kg.m^{-3}}$
Thermal capacity	435 $\mathrm{J.Kg^{-1}.K^{-1}}$	837 $\mathrm{J.Kg^{-1}.K^{-1}}$
Volume thermal capacity	3393 $\mathrm{J.m^{-3}.K^{-1}}$	2260 $\mathrm{J.m^{-3}.K^{-1}}$
Young modulus	210 GPa	60 GPa

FEA simulations have been carried out to evaluate the thermal sensitivity of girders standing on two plinths (Figs. 10 and 11). Ground temperature is assumed to be 20°C and air temperature 23°C with a convection exchange factor of 10 $\mathrm{W.m^{-2}.°C^{-1}}$. Temperature effect in these conditions is a deflection along vertical axis of -7.2 and +4.2 µm on extreme points. If we consider that alignment is made in these steady conditions, stress will only result of air temperature variation in the tunnel, i.e ±0.1°C.

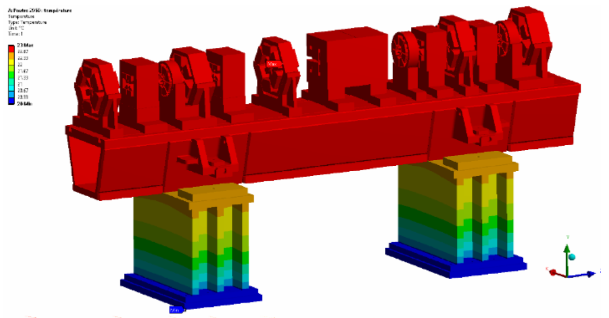

Figure 10: Temperature gradient.

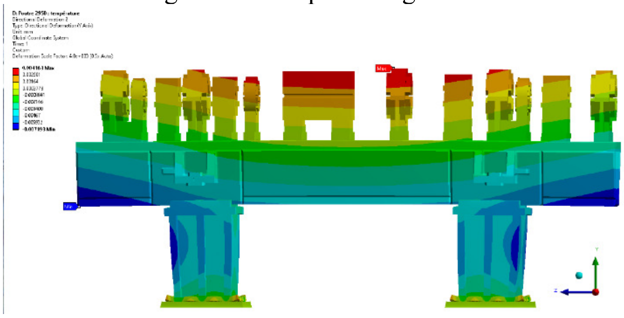

Figure 11: Thermal stress.

R&D PROGRAM

Vibration tests involving velocimeter sensors on the machine slab (Fig. 12) have been carried out in June 2021, and spectrum results will be used to evaluate vibrations on the FEA models. Measurements on NIVELL jacks using a test bench (Fig. 13) will give a real stiffness evaluation for preloads from 2 t to 5 t.

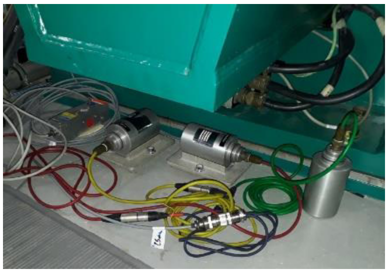

Figure 12: Velocimeters implementation on slab.

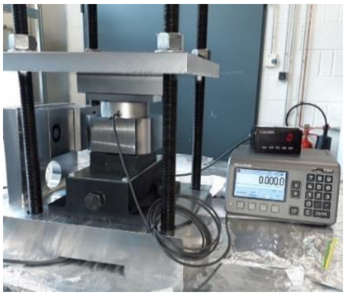

Figure 13: NIVELL jack on test bench.

Tests on prototypes will validate design features of the magnet-girder and FEA calculation. A steel plinth will be realized to perform thermal tests such as transient temperature measurements, and a long girder prototype loaded with dummy magnets will be used to carry out vibration response tests. If necessary, improvements will be made on the girder design. This prototype will also permit to validate alignment procedures for the girder itself and the magnets, and to improve the mounting process.

CONCLUSION

- Several setups have been evaluated, choice will be made considering stability, alignment and dark time reduction.
- Magnets are still in design phase, but the models of girders using modular elements can be easily changed to meet the final requirements.
- Further experimental measurements will be carried out to get realistic data for dynamic and thermal FEA simulation.
- The prototype of a complete girder is planned for 2022.