

VIBRATION OF MAGNET-GIRDER ASSEMBLY

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ABSTRACT

To improve the stability of the magnet-girder assemblies in the ESRF storage ring, vibration investigations have been carried out for in situ magnet-girder assemblies and a prototype. Characterisation tests were performed : operating response measurements, static stiffness measurements, modal testing. A finite element modelling (FEM) is being carried out for the prototype assembly. First results have correlated very well with the measurement results. This FEM will then be utilised to simulate and assess different vibration damping solutions.

1 INTRODUCTION

Mechanical stability of the magnet-girder assemblies in a storage ring is essential for the beam stability, since the mechanical vibrations are amplified on the electron beam closed orbit more than 10 times by the quadrupole magnets. Measurement results showed that the dominant frequency (7 Hz) of the electron beam position fluctuation is identical to the fundamental peak frequency in the lateral vibration spectrum of the magnet-girder assemblies. To further improve the ESRF machine in terms of brilliance, it's necessary to reduce the vibration of magnet-girder assemblies.

Generally there are three ways to reduce the vibrations of the magnet-girder assemblies : reduce the ground vibration in the site; increase the fundamental frequency of the assembly into the high frequency range since the ground vibration decreases sharply with the frequency[1]; set up a countermeasure by damping technique to reduce the vibration response of the assembly. The last option is most appropriate for the ESRF case. To set up an effective damping technique to such complex system like the magnet-girder assemblies, a FEM (finite element modelling) associated with testing applied to a prototype magnet-girder assembly should be used to simulate and optimise the various vibration damping solutions. The prototype was built up with the essential components of a G10 magnet-girder assembly : 3 jacks, a girder, 5 magnets, 3 horizontal adjustable or free guiding plates between the girder and the jacks (see Fig.1). The testing and modelling of the prototype were carried out by the way of bottom-to-top. Firstly, the girder with 3 jacks, the 5 magnets were tested and modelled separately. The advantage is to isolate difficulties in the FEM of the jacks and magnet fixation supports. Secondly, finite element models of different parts were integrated. Finally, testing and calculation were applied to the whole prototype assembly.

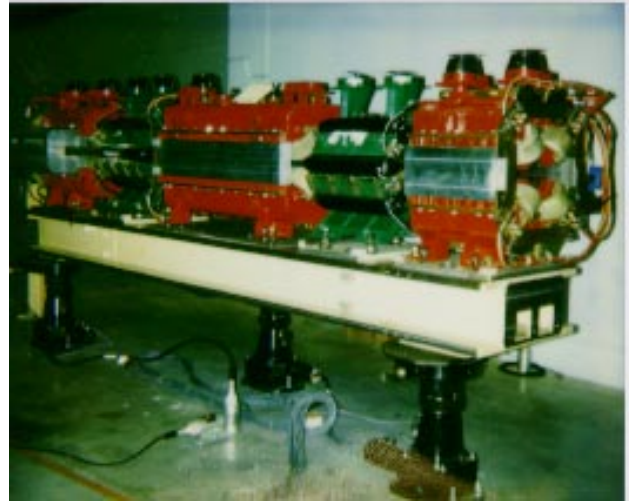


Fig.1 The prototype magnet-girder assembly

2 CHARACTERISATION TESTS

2.1 Operating response measurements

Operating response measurements were performed both for the in situ and the prototype magnet-girder assemblies. These measurements give out the essential dynamic information of the systems : vibration amplitude, peak frequencies, eventually mode shapes. Comparison between results of the two assemblies allows the reliability of the prototype to be evaluated.

Considering the characteristics of the ground vibration at the site [1] and the sensitivity of the electron beam to the vibration, we are interested mainly in the vibration in the frequency range of 1-100 Hz. The operating response measurements were made by using a 4-channel spectrum analyser with 4 geophones L-4C 1Hz [1]. For each measurement, the 4 geophones were placed respectively on the floor, girder and the central quadrupole magnet (Quad-c) and an end quadrupole magnet. Typical values of vibration amplitude are given in Table 1 as well as the

Table 1 Peak to peak displacements d_{pp} (μm) in 1-100 Hz, figures in brackets are the ratios related to the floor

d_{pp} (μm)		vertical	longitudinal	lateral
prototype	floor	1.41	0.54	0.53
	girder	1.48 (1.05)	0.71 (1.31)	1.57 (2.96)
	Quad-c	1.60 (1.13)	0.75 (1.39)	2.87 (5.42)
in situ	floor	1.05	0.48	0.57
	girder	1.11 (1.06)	1.38 (2.88)	1.62 (2.84)
	Quad-c	1.09 (1.04)	1.67 (3.48)	3.11 (5.46)

ratios related to the floor (given in the bracket). The vibration of the floor varies with time and with place. To go beyond this variation, the ratios should be compared. These ratios in the vertical and lateral directions agree within 10% between the prototype and the in situ assembly. The difference in the longitudinal direction is due to the increase in stiffness of the in situ girder by the vacuum chamber and cable rails attached to the magnets and the girder. However, the longitudinal vibration has much less influence on the electron beam than the vertical and lateral vibrations.

The largest vibration amplification by the Quad-c is in the lateral direction. The frequency responses of the Quad-c and an end Quad in the lateral direction are shown in Fig.2 for the prototype and the in situ G10 assembly. The fundamental peak at 9 Hz is observed in both assemblies. It's clear that the prototype has very similar dynamic behaviour to the in situ G10 assembly.

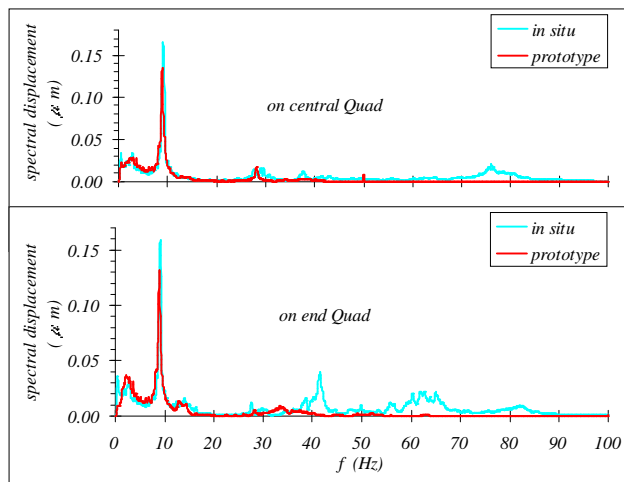


Fig.2 Frequency responses of Quads in the lateral direction

2.2 Static stiffness measurements

The motorised jacks are too complex for the FEM. As our concern is the motion of magnets, it's interesting to simplify the 3 jacks by a mechanical beam model. By

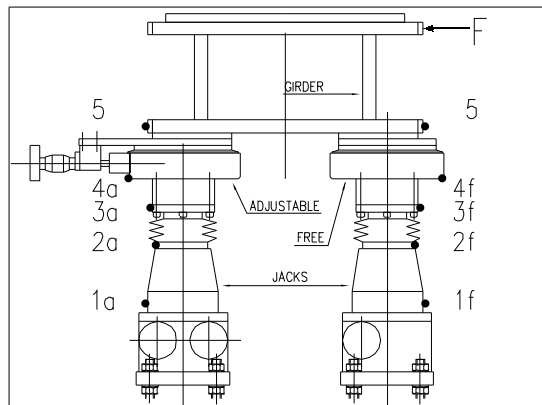


Fig.3 Cross section of girder-jack subassembly static stiffness measurement set-up

Table 2 Stiffness EI ($GPa \cdot m^4$) of beams used to simplify jacks.

No of beam	1	2	3	4a	4f
length (mm)	310	80	90	95	95
prototype subassembly	744	2.01	6.20	5.19	0.402
prototype	1170	2.90	18.7	5.69	1.91

measuring the static stiffness of the jacks, 4 beams per jack (Fig.3) have been characterised using the mechanical beam theory [2]. Results for the prototype and the prototype subassembly (without magnets) are given in Table 2. The values of the length and stiffness are then injected into the FEM.

2.3 Modal testing

Modal testing [3] has been made respectively for the girder-jacks subassembly, the prototype and in situ magnet-girder assemblies. This powerful experimental tool is frequently used to describe the dynamic behaviour of structures with natural frequency, damping ratio and mode shape. Excitation by a hammer at a point generates a Dirac pulse force F whose spectrum is approximately flat in the interesting band width (1-100 Hz). 3-D accelerometers measure the acceleration response a in 3 orthogonal directions at different points of a structure. These points form a mesh representing the structure. A set of frequency response functions (a/F) are then obtained. Related to the excitation force F , the frequency response functions at the measurement points are normalised and phase preserved. The mode shapes with natural frequencies and damping coefficients can be easily extracted from these frequency response functions. The mode damping coefficients are useful for the FEM to calculate the dynamic deformation, stress, and frequency response to the ground or force excitations.

3 FEM AND COMPARISON WITH TESTS

The bottom-to-top procedure was used in the FEM in order to model the jacks and magnets separately and validate the beam approach for the jacks.

3.1 Results for girder-jacks subassembly

The girder-jacks subassembly was firstly modelled. To approach the 3 jacks, the mechanic beams with characteristic parameters given in Table2 were introduced into the FEM. The girder structure was modelled by use of shell elements. Results of static deformation from the FEM are : $U_x=86.6\mu m$ for $F_x=2kN$, $U_y=130\mu m$ for $F_y=2kN$, compared to the measurement results : $U_x=85.5\mu m$, $U_y=90.8\mu m$. The difference is due to the backlash - non-linearity in the girder-jacks subassembly.

Modal analysis by the FEM [4] computes the natural frequencies and mode shapes of a structure from the definition of its geometry and material properties. For the girder-jacks subassembly, the first 5 modes calculated by the FEM are in excellent agreement with modal

testing results. The differences of the first 5 natural frequencies are less than 3% (see Table 3). The first 3 modes are the modes of deformation of the girder support : jacks, horizontal adjustable and free guiding plates.

Table 3 The first 5 modes with natural frequencies of the girder-jacks subassembly from the testing and modelling

No	modes	testing	FEM
1st	longitudinal translation (T_x)	11.26	11.12
2nd	lateral translation (T_y)	13.32	13.71
3rd	horizontal rotation (θ_z)	19.86	19.36
4th	vertical rotation (θ_x)	58.49	57.23
5th	girder deflection	71.05	71.50

A harmonic analysis by the FEM was carried out to calculate the frequency responses of the structure submitted to a harmonic force with the frequency varying in the specified frequency range (for instance 1-100 Hz by step of 0.1 Hz). The dynamic stress and deformation due to the application of the force can also be calculated. The data of mode damping ratio extracted from the modal testing were used in the harmonic analysis. Frequency response functions are compared to the results of the modal testing (Fig.4 for an upper corner point of the girder). In the lateral frequency response functions, the peaks near 13 and 20 Hz correspond respectively to the lateral and horizontal rotation modes. In the longitudinal ones, the peak near 11 Hz corresponds to the longitudinal mode. The peak of the rotation mode for this point is higher than that of the lateral mode because the force applied to the girder extremity excites particularly the rotation mode. However, in the operation case the peak of the lateral mode may be higher than one of the rotation mode.

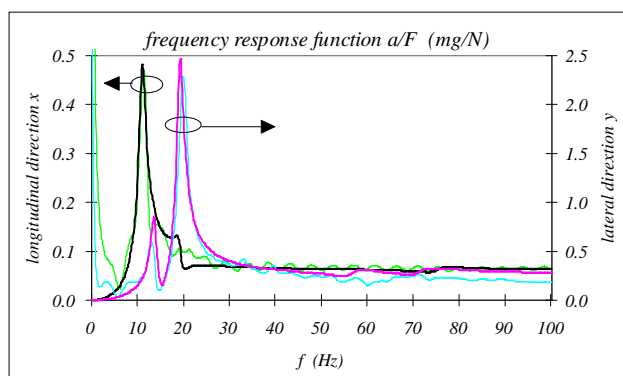


Fig.4 Frequency response functions from FEM (thick lines) and from modal testing (thin lines)

3.2 Results for the prototype and the in situ G10 assembly

The excellent agreements between the results of testing and modelling validate the simplification of the motor-

ised jacks by mechanical beams. The technique of static stiffness measurements is showed to be efficient to provide data for the dynamic modelling. The same methods are being applied to the whole prototype. Experimental studies (static stiffness measurements, modal testing) have also been carried out for the in situ G10 assembly. The FEM of the prototype is being finished. Results of principal modes with natural frequencies (Table 4) are very similar between the prototype and the in situ G10 assembly, between the testing and the FEM. The discrepancy of the frequency value for the longitudinal translation between the prototype and the in situ assembly is explained in section 2.1. The results of the modal testing confirms that the prototype has very similar dynamic behaviour to the in situ G10 assembly. Both the testing and the modelling show that the first mode of the whole prototype is lateral translation, and the second mode is the longitudinal translation. The order of these two modes are inverse for the girder-jacks subassembly.

Table 4 Principal modes with natural frequencies (Hz)

principal modes	in situ G10 testing	prototype testing	FEM
lateral translation (T_y)	8.77	8.71	9.07
longitudinal translation (T_x)	16.09	11.70	11.35
horizontal rotation (θ_z)	13.53	13.66	15.05
lateral motion of the Quad_c	29.65	27.82	29.27

CONCLUSION

The prototype has very similar dynamic behaviour as the in situ G10 assembly. The most influenced modes of the magnet-girder assembly are identified both by testing and modelling : lateral translation mode, horizontal rotation mode, lateral motion of the central quadrupole. The excellent agreements between the results of the testing and the finite element modelling validate the simplification of the motorised jacks by the model of mechanical beams. The technique of static stiffness measurements is showed to be efficient to provide data for the dynamic modelling. The finite element model of the magnet-girder prototype which is correlated with experiments will then be utilised to simulate and assess different vibration damping solutions in order to reduce the vibrations of the magnet-girder assemblies.

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