VIBRATION DAMPING DEVICE DEVELOPMENT FOR THE ESRF STORAGE RING MAGNET GIRDER ASSEMBLY

L Zhang (zhang@esrf.fr), ESRF, BP220, F-38043 Grenoble Cedex

Abstract

To further improve the ESRF machine performance in terms of stability and emittance, the micron-order of magnitude vibrations of the accelerator magnets have to be attenuated using a damping device. Several passive damping devices have been studied to reduce the vibration of the ESRF Magnet-Girder Assembly (MGA) : ViscoElastic damping plates, tuned vibration absorbers, ViscoElastic damping links. Modelling and testing were closely used together in the various developments of damping devices. Damping plate and damping links have been tested on the MGAs in the ESRF storage ring. Both show excellent damping performances. Only damping links are compatible with the long-term stability of the machine and will be installed on the ESRF machine.

1 INTRODUCTION

Efforts have been constantly made to improve the ESRF machine performance since operation started. To increase the brilliance of the x-rays, for instance, lattice developments have been carried out in the axes of decreasing emittance coupling (from 10% to less than 1%) and optimising β functions. Local and global feedback systems are being implemented to improve electron beam stability, thus reducing the apparent beam size. To further improve the ESRF machine performance in terms of stability and emittance, the micron-order of magnitude vibrations of the accelerator magnets have to be attenuated by using a damping device. As the mechanical vibrations are amplified on the electron beam closed orbit more than 10 times by the quadrupole magnets [1], significant beam stability improvement can be expected using damping devices for the MGAs. Measurement results showed that the dominant frequency (7Hz) of the electron beam position fluctuation is due to the resonant rocking motion of the quadrupole girders in the lateral direction. Attenuating the resonant vibration of the magnets is the subject of this study.

2 ANALYSIS

2.1 Description of MGAs

Dynamic behaviours of the ESRF MGA have been intensively studied both by experimental testing and by finite element modelling (FEM) [2,3]. The first resonant frequencies and mode shapes are clearly identified as shown in Table 1. In the ESRF machine, there are 3 types of MGA : G10, G20, and G30. The G10 and G30 MGAs are mechanically symmetrical and have similar dynamic properties. The so-called prototype MGA was built up with the essential components of a G10 MGA. Vibration measurement results showed that the prototype has very similar dynamic behaviour to the G10 assembly in the storage ring for the 1st lateral rocking motion at about 8.7 Hz [2]. It should be pointed out that the first mode for G20 MGA is also a lateral rocking motion with a slightly lower resonant frequency of 7 Hz, since the mass in the G20 MGA is higher than on the G10 or G30 MGAs. Our objective is to attenuate this peak in the displacement spectrum by a factor of 5 at least.

Table 1 First 3 modes and natural frequencies (Hz) of the ESRF prototype MGA

No	Mode	*Test*	*FEM*
1	lateral rocking motion T_y	**8.68**	**8.64**
2	longitudinal rocking motion T_x	**11.74**	**11.75**
3	horizontal rotation θ_z	**13.63**	**13.69**

2.2 Damping devices and materials

Passive damping systems are most widely used to attenuate the vibration of structures, since they are known to be extremely effective for control of resonance response of structures [4, 5], and in general cheaper and simpler to implement than active damping systems. However, it is also known that passive damping countermeasures must be designed and configured to be application-specific, based on the structural dynamics at hand, the operating temperature range at the application site, the frequency content, part processing, cost, etc

Several passive damping systems have been studied to reduce the vibration of the ESRF MGAs:

- ViscoElastic Damping Plates (DP)
- Tuned Vibration Absorbers (TVA)
- ViscoElastic Damping Links DL)

In all these damping designs, ViscoElastic Material (VEM) is used. The properties of VEMs vary tremendously with certain environmental factors. Temperature, frequency, strain amplitude and static pre-strain are considered to be the most important effects. However, for the synchrotron applications, radiation exposure [6] is also an important environmental factor.

Appropriate selection of VEMs is essential for the successful damping design and applications.

2.3 Methodology

To set up an effective damping technique to such a complex system as the MGA, complete finite element analysis (static mechanical analysis, modal analysis, harmonic response analysis) and dynamic tests (modal testing, forcing response function measurement) have been performed. The testing and modelling of the prototype MGA were carried out in the following steps :

1. The FEM and testing were applied in parallel to the G10 MGA. Some simplification of FEM was made based on some test results. Correlation between modelling and testing was successfully obtained [2,3].
2. Correlated finite element model was then modified by adding different damping systems to simulate its effects and to optimise damping design [7]. FEM results were considered for manufacturing.
3. Dampers were installed and tested on the prototype MGA. Results were analysed and compared to those from FEM. Eventual modification on the dampers could be made. And steps 2 and 3 could be repeated.
4. Once the damping performance was satisfactory on the prototype MGA, damping devices were finally installed and tested on the 3 MGAs (G10, G20, and G30) in one cell of the storage ring. Damping performance and compatibility with the environment of the machine were analysed.

For the 3 mentioned damping systems, study on tuned damper was just stopped in the simulation step since the added mass on a quadrupole should be 450 kg, which is too high for real application. Studies on damping plates and damping links were carried on to the test stages.

3 DAMPING PLATES

Damping plate consists of a sandwich structure with steel and VEM layers alternately. These devices were positioned between the base of the girder jacks and the floor. The motivation for this design was to transfer the strain energy in the jacks to a weak ViscoElastic layer with high levels of damping. This design was firstly used at APS [8]. The APS damping plate is made of 3 steel sheets with 2 layers of VEM between them. We have tested samples supplied free by APS at ESRF. As the structural dynamics of the ESRF MGA is quite different from APS MGA, the APS damping plates are not significantly effective for the ESRF MGA. That is because we have stated (in section 2.2) that “damping countermeasures must be designed and configured to be application-specific”. Similar design has been optimised by use of FEM for the ESRF MGA. Damping plates with same VEM (AN217) but different thickness, or with different VEMs (AN190, FD220) and different thickness have been tested on the ESRF prototype MGA. Performance of specifically designed damping plates for ESRF MGA were better than APS samples. Nevertheless, two problems arose: (1) creep of VEM (2) performance degradation when damping plates and jacks were bolted to the floor because the bolts shunt damping plates

To reduce creep effects, thinner layer of VEM was used. Damping plates with 6-layers of VEM (FD220, t=0.18mm) were manufactured and tested. This 6-layers VEM damping plates has a similar stiffness and loss factor as the 2-layers VEM damping plates (FD220, t=0.25mm), but 3 times less creep than the latter. To avoid the use of bolts, adhesive film or VEM foil have been used to couple the damping plates to the floor and to the jack assemblies. This improves damping performance. All the test results are summarised in Table 2. Damping plates DTI-6L were installed and tested on 3 MGAs in the storage ring. Measurement results showed excellent damping performance with a damping ratio larger than 10 in the case of bonding with glue. However, the damping plates without bolts significantly reduce the horizontal stiffness of the MGA. Under the actions of electrical cables, cooling pipes and thermal deformation of vacuum vessels, an equivalent of 0.6 mm of lateral displacement was observed on these magnets during machine restarting. This incompatibility with the long-term stability of the machine conducted us to abandon the damping plate approach despite its damping performance.

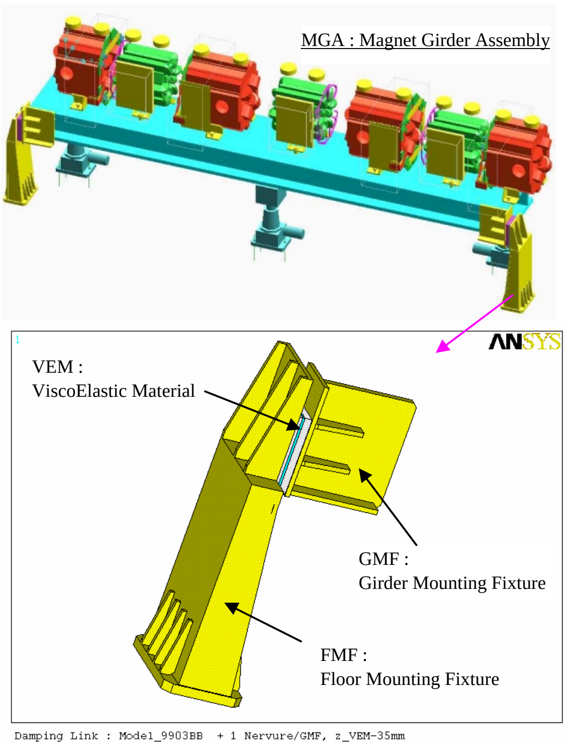
Table 2 Q factor, peak frequency and damping ratio for lateral displacement spectrum of a QF2 quadrupole on the ESRF prototype MGA with different damping plates and bonding modes

type of damping plate		**bonding mode**	***Q***	***f***	***ratio***
reference	*VEM*			*Hz*	
no plate		bolted	48.78	8.38	
APS-2L	AN217	bolted	34.55	8.38	1.4
		unbolted	31.87	8.13	1.5
AN190-2L	AN190	bolted	11.51	7.56	4.2
AN217-2L	AN217	bolted	9.36	7.56	5.2
		unbolted	9.35	7.47	5.2
DTI-2L	FD220	bolted	8.99	6.59	5.4
		unbolted	7.04	6.09	6.9
		glued	4.68	6.09	10.4
DTI-6L	FD220	bolted	14.16	6.81	3.4
		unbolted	6.00	5.59	8.1
		glued	4.96	4.97	9.8

4 DAMPING LINKS

The damping link design consists of adding a ViscoElastic link between the base of the girder and the floor. These links are installed in parallel to the existing jacks, therefore the required lateral stiffness is maintained. In parallel, the strain energy within the rocking motion of the girder can be dissipated in the damping links. Figure 1 shows the damping links installed on 3 MGAs (G10, G20, and G30) in the ESRF

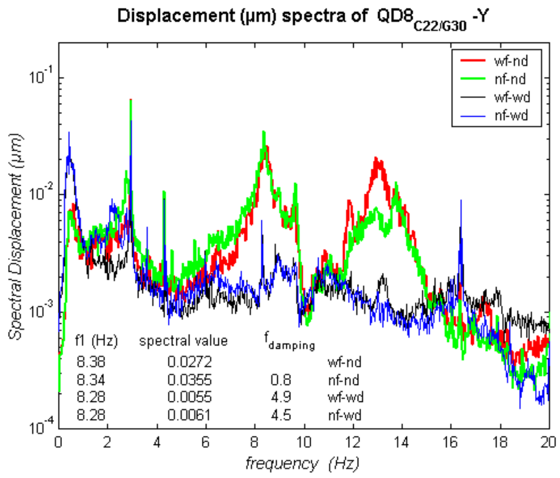
Fig.1 Damping link and installation on MGA



storage ring. The VEM sandwich was optimised to attenuate the 1st resonant vibration with an operation condition tolerating up to 2mm shear displacement in the vertical direction. These 2mm correspond to maximum possible accumulated stroke required by alignment for 2 years. The Girder Mounting Fixture (GMF) and Floor Mounting Fixture (FMF) are carefully designed both to accommodate the very limited space available for installation and to obtain a sufficiently high stiffness in flexion and torsion.

GMF is first bolted into the existing holes on the girder.

Fig.2 Spectral displacement of QD8 in lateral (Y) direction with (wd) and without (nd) damping links in the cases of cooling water flow on (wf) and off (nf).



The VEM sandwich is then fixed on the GMF. The FMF is placed on the floor on 3 adjustable screws and bolted with VEM sandwich part. Normally no stress is applied to VEM sandwich part. FMF is finally glued to the floor with an epoxy resin the polymerisation of which is achieved 7 days after application.

Measured spectral displacements (Fig.2) with damping links installed (wd) were compared to baseline (nd) in the case of cooling water flow *on* (wf) and off (nf). Results show excellent damping performance of the damping links. The 2 resonant peaks in the spectral displacement of QF7 and QF8 quadrupoles at 8.4 Hz for lateral rocking motion and around 13Hz for horizontal rotation are significantly attenuated.

The test results on the MGAs equipped with damping links in the storage ring were satisfactory for both damping performance and compatibility with alignment operations, it was decided to install damping links on all the ESRF MGAs. The installation of the damping links will be achieved by the end of this year.

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