VIBRATION AT THE ESRF

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ABSTRACT

Third generation synchrotron light sources produce high brilliance x-Ray beams. Vibrations may degrade the electron beam centre of mass stability, hence dramatically reducing the brilliance. It is therefore necessary to carefully measure and survey the vibrations existing on site, to investigate the vibration responses of mechanical components of the accelerator machine and beamlines, and then to set up damping techniques for critical frequencies.

1. INTRODUCTION

The stability of the electron beam is extremely important to produce a high brilliance photon beam, because of small emittances as one of main target performances of the ESRF storage ring. Vibrations with an amplitude of 1 µm peak-to-peak applied to the quadrupole magnets would lead to an emittance growth of a few per cent, compared to the tolerance of 10%. The stability of both the photon beam and beamline components is crucial for the success of many experiments. Stability requirements of beamline components are typically : rms amplitude<1 µm.

To achieve this stability of the micron order of magnitude, not only vibration sources in the site should be identified and eventually controlled, but also mechanical components of the accelerator machine and beamlines should be carefully designed in order to minimise vibration amplification.

This paper presents the methods used to investigate vibration problems : testing and FEM (finite element modelling), vibration sources such as ground vibration and external vibration sources, vibration influences of various accelerator components and associated equipment.

2. TECHNIQUES OF INVESTIGATION

2.1 Instrumentation

Instruments for experimental studies of vibration mainly consist of sensors and digitalizer/recording systems. The criteria of selection of the instruments (sensors and digitalizer/recording systems) are : quantity to be measured, frequency range, resolution and dynamic range.

The sensors used at the ESRF are

- active geophones CMG-3ESP : 0.033-50 Hz
- passive geophones L-4C : 1-100 Hz
  L-22D : 2-100 Hz
- different piezo accelerometers
- laser vibrometer

From the discussion in the section on ground vibration, the interesting frequency range for the ESRF is

0.1-1000 Hz, and particularly 1-50 Hz

The geophones are adequate for measuring the ground vibration noise, the operating response of structures and mechanical components of the accelerator machine and beamlines. The displacement is computed by integration of the measured velocity. Piezo accelerometers are used for modal testing, and for noise and operating response measurements of small structures. Generally, piezo accelerometers are smaller and lighter but less sensitive than geophones. The non contact measurements by use of laser vibrometer have been also made for fine structure or places difficult to access with the accelerometer.

Three digitalizer/recording systems are available for different applications.

A seismic survey system (Lennartz OLM 5800, 120 dB) with 5 geophones L-4C was installed around the storage ring tunnel to continuously measure the vibration in the frequency range of 1-50 Hz. Vibration noise varying with time and vibration events such as earthquakes, explosions in the Grenoble area, impact of trucks on irregularities in the road near the ESRF site are recorded. Measurement data can be monitored from the machine control room. Spectra versus time for any one sensor can be visualised, as well as peak-to-peak displacement versus time for all sensors.

A four channels spectrum analyser is widely used to make operating response measurements at multipoints, to do modal testing which gives out natural frequencies and mode shapes of structures.

A high dynamic range portable digitalizer/recording system (6 channels, 24 bits) is adequate for long term site noise and operating response measurements.

2.2 Theoretical study

In the design phase, theoretical study is most adequate to take vibration in consideration. Analytic estimation of the fundamental frequency guides the design of simple mechanical structure by defining appropriate stiffness and mass. The FEM was applied to complex structures. Three types of dynamic analyses by the FEM can be performed : modal analysis, harmonic response analysis, spectrum analysis. The modal analysis computes the natural frequencies and mode shape of the structure from the definition of its geometry and material properties. The harmonic response analysis and the spectrum analysis compute the vibration response amplitude of the structure to an harmonic excitation and a random excitation respectively. The dynamic stress distribution can also be calculated from these last two analyses. For these ones, the damping coefficients of the structure needed can be extracted from modal testing.

2.3 Methodology

A typical vibration diagnostic of mechanical structures is initiated by an operating response measurement at multipoints. The vibration amplitude at a few key points is firstly evaluated, as well as the amplification factor, peak frequencies, and eventually the natural frequencies and the outline of the mode shape of the structure. If the vibration level is much smaller than the tolerance, or is comparable with ground vibration, the structure is then considered to be stable. Further investigation is generally not necessary. Otherwise, simple countermeasures will be tested, and if this is not sufficient, an advanced study will be followed. The advanced study including the modal testing and the FEM should lead to some effective countermeasures.
For the vibration investigation of an existing system, the theoretical and experimental studies are often combined, because these two methods are complementary. The FEM needs some data (such as damping coefficients), which can only be extracted from testing, and also needs to be correlated with measurement results. The validated FEM can be used to calculate the stress, the deformation, especially to simulate eventual modification of the structure in order to reduce the vibration by introducing damping. An example of vibration study by both experimental and theoretical methods is presented in another paper for EPAC96 [1].

3. VIBRATION SOURCES

The stability of mechanical components of the accelerator machine and beamlines directly depends on the floor stability, which is conditioned by various vibration sources. The ground vibration, external and internal vibration sources, have to be identified and minimised.

3.1 Ground vibration

The ground vibration is usually divided into 3 frequency ranges : low (f<1 Hz), intermediate (1-50 Hz) and high (f<50 Hz) frequency range. In the lower frequency range (f<1 Hz), vibration is essentially caused by ocean waves and micro earthquakes. This ambient seismic noise is centred around two peaks of 0.14 Hz and 0.07 Hz. With a typical wave propagation speed of 700 m/s in a sand-grave soil, the wave length is about 5 km and 10 km. The good spatial coherence of this microseismic noise within a couple of hundreds of meters results in a negligible differential vibration at any two points in a modern synchrotron radiation facility (diameter<500m). The intermediate frequency range (1-50 Hz) is the most interesting one for the synchrotron radiation facility, because the accelerator machine is sensitive in this frequency range. Main vibration sources are road and train traffic, the operation of heavy machines, the wind, and so on. In the higher frequency range (f>50 Hz), the ground vibration level is much smaller than in the intermediate frequency range because this vibration, mainly generated by smaller mechanical structure, is not powerful enough to induce significant ground vibration.

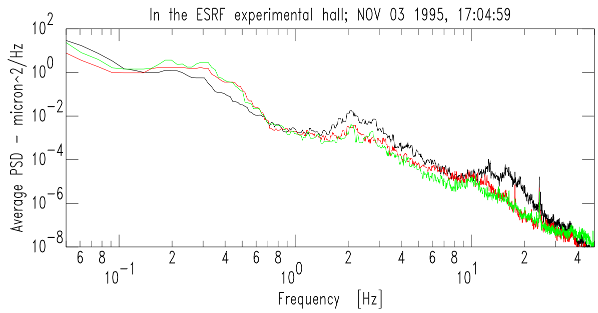

Fig.1 3D power spectral density displacement at the site (black line : vertical direction, red and green lines : horizontal directions)

The power spectral densities measured at the ESRF site are shown in **Fig.1** for vertical and 2 normal horizontal directions. The spectra in the three directions are quite similar. In the intermediate frequency range (1-50 Hz), the peak between 2 and 3 Hz is very characteristic for the ESRF site, the peak between 10 and 30 Hz (mainly for vertical direction) is due to traffic. A sharp peak at 16.5 Hz is caused by air-conditioning in the experimental hall and in the central office building. It is noticed that the ground vibration generally decreases sharply with frequency. That's why mechanical components were often designed with the first natural frequency > 30 Hz.
Figure 2 shows vertical displacements measured simultaneously in the ESRF experimental hall and in the basement of the ESRF02 building by means of two sets of identical sensors and digitizers. Excellent correlation of low frequency (0.05-1 Hz) vibration is observed between the two sites with a distance of about 500 meters. It's reasonable to neglect the low frequency differential vibration of two points in the ESRF storage ring or in the experimental hall.

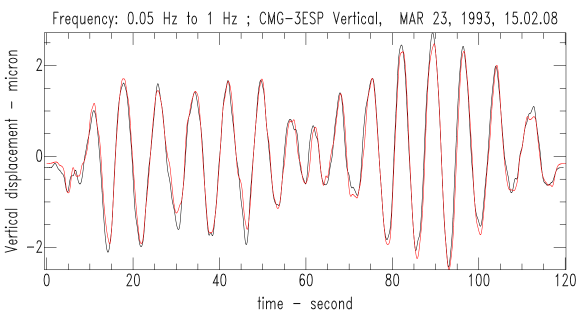

Fig.2 Vertical displacements measured simultaneously at 2 points distanced 500m in the site

2.3 External sources

From long periods of measurement observations, it is found that 95% of strong vibration events (peak-to-peak displacement >2 µm) in the site are induced by the passage of trucks over irregularities such as sewer covers on the Avenue des Martyrs, a local road. A technical proposal for road repaires was submitted to the relevant authority.

Vibration investigation has been made for various other bridges, roads, pumps, heavy machines near the site. The vibration influences can be globally seen in the ground vibration noise, which is correlated with working hours (see **Fig.3**).

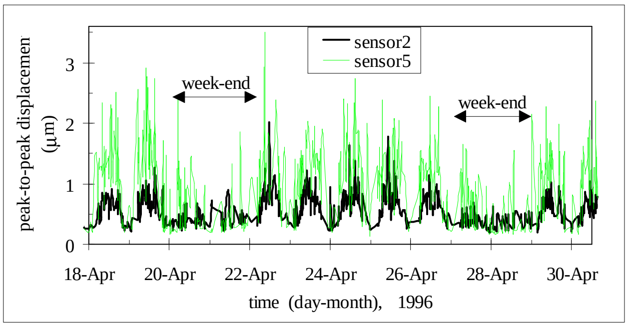

Fig.3 Peak-to-peak displacement versus time
The sensor5 is closest to the Av. des Martyrs

2.4 Internal sources

Vibration generated by various accelerator components has been intensively studied. The virtual internal sources are the HQPS (High Quality Power Supply), the cooling fluid of magnets and thermal absorbers, the operating of front end absorbers, air conditioning, the overhead crane.

The ten diesel engines of 1 MW each in the **HQPS** are occasionally used to generate self sufficient electricity to run the machine. The vibration introduced by the functioning of these powerful alternator-diesel engine units has been carefully controlled. The vibration amplitude at 30 m from the HQPS building is less than 1.3 µm peak-to-peak, compared to the 1.0 µm when all units are off. The vibration influence on the accelerator machine and beamlines which are at least 100 m from the HQPS building is negligible.

The **air conditioning units** in the experimental hall and in the central building generate a very sharp peak at 16.4 Hz. The contribution of this peak in the wide band (1-100 Hz) displacement is negligible.

The vibrations induced by a 6 ton **overhead crane** in movement are significant in the frequency range 30-80 Hz for both the storage ring and experimental hall slab. The amplitude in this frequency range is at maximum 10 times higher than the ambient noise. In addition, the quasi static deformation of the floor under the weight of the crane may affect some experiments on beamlines. The use of the overhead cranes are regularized.

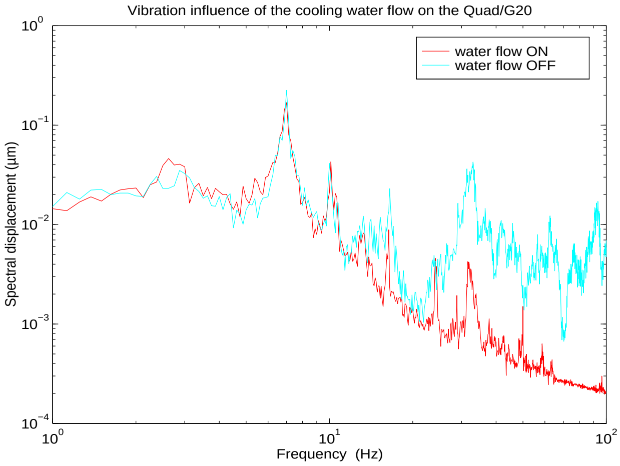

Fig.4 Lateral spectral displacements of a Quad : vibration influenees of the cooling fluids

Cooling fluid of magnets and thermal absorbers generates vibrations above 20 Hz. Fortunately, this is far from the first natural frequencies (7-13 Hz) of the magnet girder assembly. Although the vibration amplitude of magnets above 20 Hz is much higher than the ground vibration, it is still about 10 times lower than the peak at the first natural frequency (Fig.4).

The opening and closing of the movable absorber in the front-end by fast pneumatic valves induce very strong vibration on the magnets and on the girder. The peak-to-peak displacement of a quadrupole may be increased from 3.2 µm (noise) to 74 µm in the lateral direction, and from 0.9 µm (noise) to 21 µm in the vertical direction during the fast closing (50 msec). It is seen that the fast closing affects the e-beam stability, especially in the case of single bench mode. The slow closing (200 msec) generates a vibration amplitude on the quadrupole 6 times lower than the fast closing. This mode is being implemented. Analysis of the vibration response of the quadrupole G20 during the fast closing of the front-end movable absorber shows that the magnet-girder assembly is excited in the lateral direction at 7 Hz which is the first natural frequency, and the excitation lasts about 5 seconds. The modal damping ratio has been roughly estimated at 1.6%, which is very low. It is possible to increase this figure by using damping material adequately, and so to reduce vibration of the magnet-girder assembly. This subject is being studied.

It is certain that the efforts made on vibration reduction contribute to the outstanding achievement of the performance in terms of photon beam brilliance with the ESRF storage ring.

REFERENCES

[1] L. Zhang, "Vibration of magnet-girder assembly", EPAC96