MECHANICAL IMPROVEMENT IN BEAM STABILITY AT NSRRC

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Abstract

For the beam stability we have made some mechanical improvements at NSRRC. It included the improvement of monitoring system, deformation of girder and chamber deformation. The mechanical stability was pushed to about 0.1µm order. In this paper we present the experimental study, measurement set up and improvement methods in improving mechanical stability.

INTRODUCTION

Stability is one of critical parameters for the users experiment. For accelerator people the related issues were electron orbit or beam size fluctuation. Mechanical induced beam motion has been reported in NSRRC [1,2]. According to beam physics, a single point kick of strength along the circumference of a storage ring gives rise to a closed orbit displacement at specific position [3]. Kicks can arise mostly from quadrupole magnet displacement. Among the magnets quadrupole magnet was the most p osition sensitive device to the beam orbit. Another position sensitive devices were beam diagnostic components such as beam position monitor (BPM), photon beam position monitor (PBPM) and other. One often used the above diagnostic devices to control the beam orbit or show the stability index. When their structure was not stable it would be confused to get the right information for the beam. In the storage ring vacuum chamber, BPM and magnets were all seated on the girder. Interplay of above devices would make the beam stability issue mix together. A systematic study of related problems were preceded at NSRRC. In the following section we will introduce the experimental study, measurement set up, and improvement methods at NSRRC. After improvements the beam intensity fluctuation was down to below 0.1% for most of user's time.

IMPROVEMENT ON MONITORING SYSTEM.

One monitoring system simulated the intensity variation on the entrance slit of the beamline. It consisted of a focusing mirror, a pinhole and a photo-detector. A schematic drawing is shown in Fig.1. Pinhole with 50µm diameter was on a PZT tracking actuator to let the maximum intensity go through. A photo-detector behind the pinhole recorded the photocurrent and told the intensity fluctuation. After the actuator tracked the intensity maximum and stayed there for 256 second to record the photocurrent variation. It also offered the information of beam position variation. The position of the pinhole after each scan was an indication of electron beam position. According to beamline layout 3µm of vertical beam position change would induce 1 µm change in image plane. Mirror tilted $\Delta\theta$ would deviate the beam $2\Delta\theta$ from original direction. From the calibration data 1 µm pinhole position change was equivalent to the Δ I/I reading 0.1%. The resolution of the Δ I/I was below 0.01%. So we could observe the orbit fluctuation below 0.3µm rms.

In the above discussion the mechanical stability of this system was required to about 0.3 µm. Before the improvement the mirror was mounted on the chamber and the pinhole position reading was about 100 µm drift for one shift. We also observed tens of micro-radian tilting angle change on the mirror and chamber. The temperature of the chamber changed as the beam current decayed. After these measurements we replaced the mirror mount with an independent stand as Fig. 2. The pinhole position drift was down to µm range. The mirror manipulator used bellows to decouple the chamber deformation with the mirror.

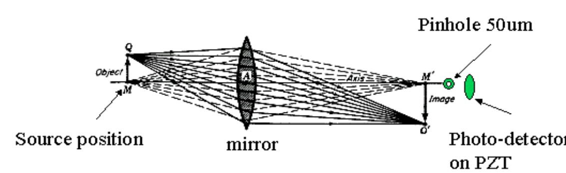

Figure 1: Schematic layout of monitoring system.

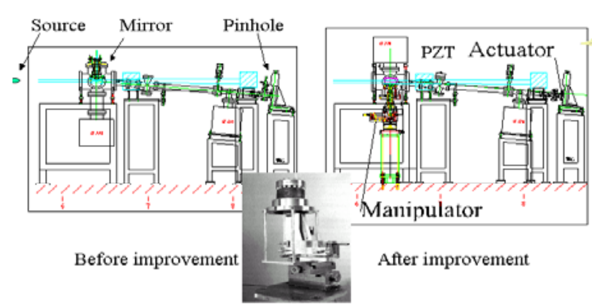

Figure 2: Add an independent mirror manipulator to the monitoring system

This experience told us the long-term drift of the chamber has to take into consideration in precision monitoring system. In the beam decay mode operation the thermal stress changed all the time. Decoupling the chamber deformation with key components is a reasonable approach.

IMPROVEMENT ON RING COMPONENTS.

To study the related factor on beam stability, a vibration shaker was applied on the quadrupole magnet in micron range and observed the response of BPM and PBPM. The response of BPM was quite as predicted without feedback system. When the feedback system turned on the motion of some BPM was locked while unlocked ones showed the perturbed response [4]. To collect more data for analysis an on-line measurement system was set-up. The measurement precision was set 0.1 μm and 0.1 °C. Some displacement and temperature sensors were attached to magnet, girder, and chamber etc. We used potential meter and liner variable differential transformer (LVDT) with resolution 0.2 and 0.1 μm as displacement sensors. They were mounted on quarts rod fixture to avoid thermal effect for its low thermal expansion coefficient. There were six LVDT for one girder to measure the height change of the girder. A stable granite stand was designed to measure the relative motion of magnet. A quartz rod with sensor also monitored the motion of the stand. Pt100 monitored the temperature of air, cooling water, and girder.

Girder deformation.

Girder is the common support for the magnet, BPM, chamber and pump. Once it deformed all the components on it would also move. It is straight forward that the pedestal height would change with the air temperature. The thermal expansion coefficient of the steel is about 11ppm. One degree C would change the height about 10 μm. It was quite match with our observation. We observed the temperature variation of air temperature correlate well with the PBPM reading [5]. When we put insulation on the pedestal the temperature time constant increased from 7 hours to 18 hours. It could smooth out the temperature variation to some extent. Increasing the heat capacity of the girder by filling it with water is also a good approach.

Another point of the girder deformation was the temperature gradient of the girder. We installed temperature sensors to measure the upper and lower surface of the girder. From mechanics, a temperature difference between the upper and lower surface of a long bar causes it bending. For example, a 2-m long bar with a thickness of 30cm, and a temperature gradient of 0.1 °C undergoes bending, the sag at the middle point is about 1.6 μm. We often found the LVDT data in the middle of girder were bigger than both ends. The temperature of the upper surface was always higher than the lower surface except in the injection.This implied the heat radiation from the magnet or chamber would cause the upper surface of girder higher. To eliminate this effect we put the insulation on the girder. The result is shown in Fig. 3. The deformation of girder could reduce five times to 0.2 μm.

Chamber Deformation

Generally, chambers were always fixed on the magnet girder. It provided a stress transfer route to affect the magnet position. For a normal quadrupole magnet girder the transverse stiffness was lower than vertical direction. Therefore thermal expansion of chamber was easy inducing transverse impact on girder. Once the girder was pushed transversely the coupling to vertical direction sometimes happened. In the beam decay mode operation the thermal load on the chamber changed, the thermal stress would be time dependent. Although bellows was used to absorb the thermal expansion but it could not eliminate it completely.

Another issue for the chamber deformation is the BPM position. BPM was welded on vacuum chamber and usually fixed rigidly on the girder. Once the chamber expanded the girder maybe not strong enough to resist the thermal stress. So the better solution is to relieve the stress in guided direction. We relieved the constraint of a specific BPM then the girder deformation was reduced to a least value. Fig. 4 shows the data. So we proposed a new BPM fixture with low stiffness in longitudinal direction but high stiffness in vertical and transverse direction. The drawing is shown in Fig. 5.

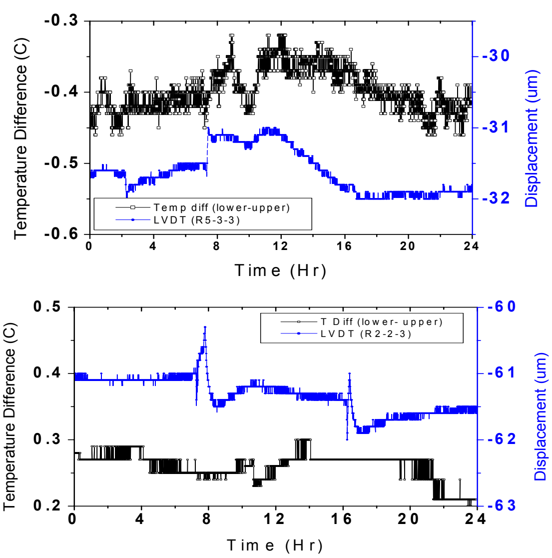

Figure 3: Compare the deformation of girder before insulation (upper) and after insulation (lower fig).

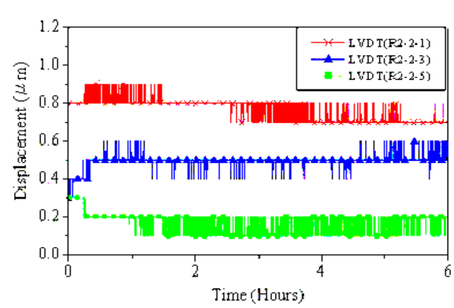

Figure 4: High stable girder by reducing the chamber deformation

The most impacting factor of the chamber deformation is water-cooling temperature. At NSRRC Kuo found variation of cooling water temperature in the chamber correlated well with the beam variation [6]. The horizontal BPM sensed stronger than vertical BPM. The transfer mechanism was the low stiffness of the girder. From the above discussion we can find temperature of cooling water in chamber is essential to control the deformation of chamber. The easiest way is to keep inlet-water temperature nearly constant. But in the decay mode operation the thermal load on the chamber was decreased, so it was not the best way to keep the temperature of chamber constant. Generally the heat load on the bending chamber was higher than the straight chamber. So the fixed point of bending chamber had better carefully design to guide the deformation of chamber. This problem would be reduced by the top-up mode operation with constant heat load in the future.

Vibration

Girder assembly is an vibration sensitive structure in beam stability. Different kinds of vibration suppression schemes have been proposed in other facility. In APS they used the damping pads [7], in ESRF damping link was adopted successful to suppress the girder vibration [8]. For old ring it may be difficult to replaced all girders so adding extra damping is a good approach to solve the vibration. In the new ring such as SLS and Diamond they designed the high eignfrequency of girder to reduce the amplitude of vibration. Recently we designed and fabricated a new girder with high eignfrequency and high damping [9]. The frequency response function is shown in Fig. 6. It shows the eignfrequency increasing to 35 Hz, the damping is also good enough. We used the composite material to stiffen the joints between the girder and pedestal, pedestal and ground. The composite material was a mixing of epoxy and sand similar to polymer concrete [10]. It has high strength and enough damping. It also has potential as an add-on damping without discard the original structure.

In the reducing vibration from utility such as water and air, we improved the vibration of air handling unit by using two stages spring isolator. The water flow induced vibration needs further study in the future.

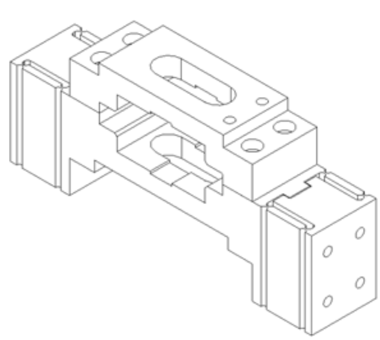

Figure 5: Design of new BPM fixture.

SUMMARY

The mechanical improvement in beam stability at NSRRC had proceeded. The girder deformation was from the temperature variation, temperature gradient of girder, and chamber expansion force. Different actions were proposed to eliminate it. The mechanical stability of the girder reaches 0.1μm order after improvement. For the intensity monitor we adopted an independent stand for mirror to decouple the thermal effect of chamber. The stability kept about 0.1μrad. In the vibration, composite material was tested on a girder prototype. It has high stiffness, enough damping, and has high potential to replace old structure.

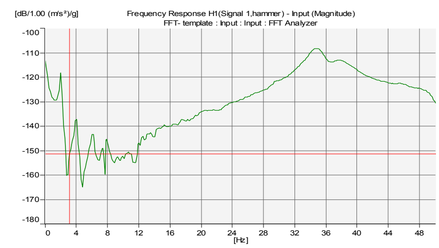

Figure 6: Frequency response function of quadrupole magnet on the new girder.

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