EXPERIMENTAL STUDY OF THERMAL DEFORMATION OF THE MAGNET GIRDER AT SRRC STORAGE RING

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Abstract

It is observed that the thermal-induced deformation of the magnet girder induces height levelling changes of the magnet and the beam position monitor (BPM). The electron beam motions will also be influenced. The deformation mechanism is studied and a new improving approach is proposed in this paper. A prototype was tested in the laboratory and storage ring. The girder can be kept stable at about ± 0.1μm per shift after improvement. Some design considerations of the dynamic behaviour of girder are also discussed.

1 INTRODUCTION

In the previous paper [1], a systematic measurement of mechanical motion in micron level of key components in the storage ring was performed. One of the major sources of the deformation to influence the beam stability is the magnet girder. In order to stabilize the beam in the low frequency range (<1 Hz), the relation between the quadrupole magnet motion and orbit motion have been studied [1]. In general, a high-strength quadruple magnet with a motion of 1μm induces a maximum motion of 6μm on the beam along the circumference with feedback off. When the feedback is on, a quadrupole magnet motion of 1μm induces about a maximum motion of 2μm in beam orbit motion. When more than one magnet is in operation, the beam motion become more complex. Recently the air temperature fluctuation in the tunnel has been reduced to 0.2ºC p-p and deionizing cooling water temperature fluctuation has been down to 0.1ºC or 0.2ºC per shift. But some BPMs had long-term drift <5μm per shift. To meet the requirements from the users, the beam needs to be stabilized at around 1μm. Therefore the stability of mechanical components has to be improved to about 0.1 μm. The dynamic behaviour and deformation mechanism of the magnet girder are studied in this paper. A new approach of the girder design was tested in the ring. Some design considerations of the girder are also discussed.

2 MAGNET GIRDER ASSEMBLY

The effect of the deformation of the quadrupole magnet on the beam motion is relatively significant. Here we discuss the quadrupole magnet girder only. The girder is about 2.5 meter long and is supported by two steel- pedestals. Fig.1 shows the assembly of the girder. There are magnets and vacuum chamber located on the girder. BPMs are installed on the vacuum chamber and are used to monitor feedbacks. The supports of the BPM are rigidly designed to suppress the movement from other sources. Several aluminium formed bellows are used near to the BPM to eliminate effects from the expansion or shrinkage of the vacuum chamber. The gate valve seems a semifixed point on the vacuum chamber. As for precision mechanicals, it is difficult to control the massive structure to 0.1μm Factors including rigidity of the girder, thermal environment change (air or cooling water), chamber- induced deformation, internal stress condition and some other heat sources need to be considered. In addition, the static condition and the dynamic behaviour also needed to be considered. Because some factors are inter-related, therefore various tests were performed in the laboratory and the ring to further investigate the mechanism.

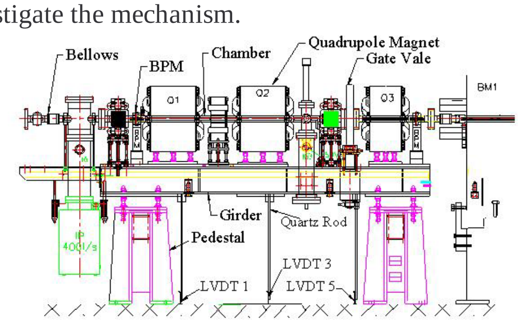

Figure 1: The girder assembly and layout of LVDT

3 THE MEASUREMENT METHOD

To measure the girder deformation we chose the ground as the reference. From the HLS data [2] of the ground levelling, the ground was kept stable at microns level for weeks. LVDT (linear variable differential transformer) was used as the measuring instrument of heigh levelling. This is a Tesa product with a resolution of 0.1μm and a repeatability of 0.01μm.To avoid the thermal effect in measurement, we selected the quartz rod as the measuring fixture (thermal coefficient < 0.5PPM). The LVDT was attached to the quartz rod to measure the change of the height levelling. Its layout is shown in Fig. 1. There were 6 LVDT for each girder.

When any external forces are applied on the girder and induced the deformation, the LVDT data will indicate the height and angle changes. All the data was PC-linked and archived.

The temperatures of the air and the girder were also monitored by the Pt 100. A force gauge with a resolution of 0.1 kg was used to measure the force in some tests.

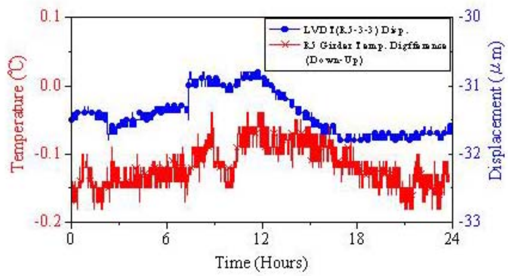

Figure 2: The temperature difference of the girder and LVDT data without insulation. (2001/8/22)

4 The dynamic behavior of the girder

The girder is the biggest mechanical structure in the storage ring. It seemed static during the user's time, but the beam current was decaying gradually. The heat loads from the electromagnet, air condition and cooling water may somehow change. The control of the deformation to a sub-micron order is important for the long-term drift of beam. The following approaches were used to investigate the mechanism.

4.1 The bending of the girder by temperature gradient

From the mechanics, a temperature difference between the upper and the lower surfaces in a long bar will cause a bending of the bar. For a 2m- long bar with a thickness of 30cm, a temperature gradient of 0.1°C will cause a bending and a sag in the middle point for about 1.6μm. Fig.2 shows the temperature differences of the girder in the upper and lower surfaces, as well as the heigh levelling change versus time. It can be seen that correlations exist between the temperature differences and the LVDT data. It was noted that a temperature difference of about 0.05 °C induced a girder sag of about 0.2μm. The LVDT reading presented here also includes other factors as follows.

4.2 The chamber induced deformation of the girder

If the girder is rigid enough, it will be persistent to the deformation induced by the thermal expansion of the vacuum chamber. To verify the stiffness of the girder, a 13kg lead block put near the centred point of the girder will induce a sag of around 0.5μm. When a longitudinal force of 5 kg is applied to the BPM of a straight chamber will induce a girder height change of 0.5μm. In PAC 99[3], C.C. Kuo found that the beam was perturbed by the cooling water of the vacuum chamber. A temperature fluctuation of 1°C will induce a change of the vertical beam orbit for about 2-3 μm. The horizontal orbit motion is about 4 times bigger. Comparing to the above girder deformation test, it maybe relate to the thermal expansion of vacuum chamber. At present the BPMs are fixed on the girder but there are not enough bellows to be installed on both sides of BPMs. There are also some constraint points such as the gate valve or the bending chamber on the straight chamber. When the chamber expands, a torque will be applied on the girder and the torque will induce a deformation of the girder. From the vacuum group internal report[4], the temperature of the straight chamber will change for about 0.6 °C as the beam current decays from 200 mA to 120 mA. For a 2-meter long vacuum chamber, a length of 27μm will decrease. If it was not absorbed complete by the formed bellows, the girder will sense the torque and the deformation will be possible. In our laboratory test, a temperature increase of 5°C in the chamber will induce a sag of about 5 μm in the middle point. In Fig. 3 there were two LVDT peaks at around 8:00 and 16:00, which occurred during the time at the reinjection of the beam and the cooling of the expanded chamber. The height of the girder was also influenced

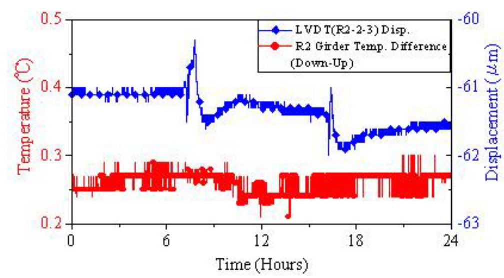

Figure 3: The temperature difference of the girder and LVDT data after insulation. (2001/8/28)

5 A NEW IMPROVED METHOD AND RESULT

5.1 Thermal property of the girder

To suppress the temperature gradient of the girder, a thermal insulation layer was put on the girder and pedestal. The temperature time constants of the girder increase from 7 hours to 18 hours after insulation. A temperature variation ΔT will be reduced by about 2.5 times for the girder after insulation. The LVDT data and temperature differences of the girder are shown in Fig. 3. It can be seen that the temperature difference of the girder can be controlled within 0.1 °C after insulation in a whole day period. I the mean time, the LVDT data was down to 0.5μm, exclude the injection effect. If the requirement is 0.1 μm per shift (10 hrs), then it means the girder temperature should be within 0.01 °C per shift (thermal expansion of steel is about 13ppm). From the time constant after insulation, the air temperature should be controlled within 0.025 ºC per shift. (The insulation can be further improved.) It provides the design rules for the air temperature control. Thermal insulation was applied in one of the superperiod of the ring. The results are shown in Fig. 4 and Fig. 5. It can be seen that after insulation the height levelling change is reduced from 2.0 µm to 0.6µm. Another point to be noted is that after each injection, the girder is exerted by a positive moment by the expansion of the nearby bending chamber and it is gradually released as the beam decays.

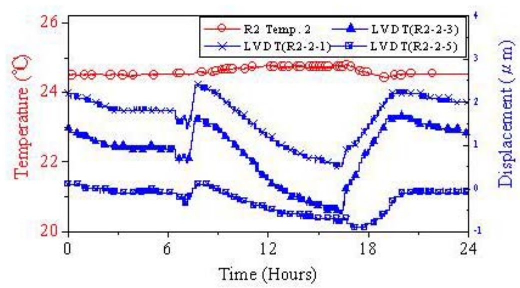

Figure 4: Height levelling change of the girder before the insulation. (2001/3/17)

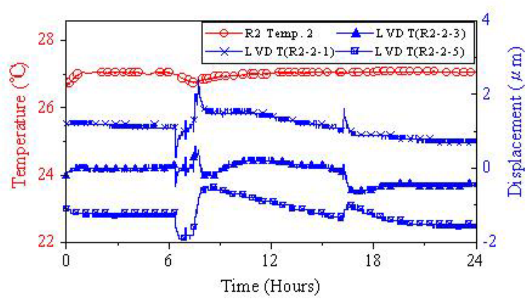

Figure 5: Height levelling change of the girder after the insulation. (2001/8/9)

5.2 The stiffness and constraint of the girder

From the test in section 4.2, the girder seems to be less rigid. Issues on enhancing the rigidity of the girder shall be addressed in the future.

Another issue is the constraint of girder. There are 4 straight vacuum chambers and 3 bending chambers in one section of the ring. 10 BPMs are distributed along a section and are fixed to the girder. 10 bellows are used to absorb the thermal expansion of the chamber. Some other fixed points are 2 gate valves and 2 big ion pumps. It seems that there are not sufficient bellows between each BPM and the fixed point. So the thermal expansion of the aluminium chamber will induce some moment on the girder as mentioned previously. Fig. 6 shows the results of the test with loosing the constraint of a BPM. A height change of ±0.1µm is obtained in the period of one shift. It is concluded that either increasing the bellows or improving the constraint is a reasonable approach. Another approach is to control the cooling water temperature in order to keep the temperature of the chamber constant. Ideally, BPM stand with an independent stand even with invar material is a good approach [5].

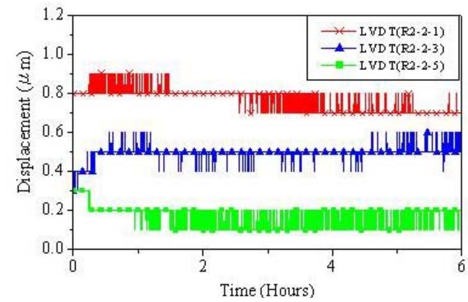

Figure 6: Minimize the girder height change by reducing the chamber expansion effect. (2001/8/21)

6 CONCLUSION

In this paper we presents the mechanism of the deformation of the magnet girder. One is the temperature gradient of upper and lower surface temperature of the girder. The other one is the constraint by the thermal expansion of the vacuum chamber. The former can be suppressed by thermal insulation. The later can be suppressed by increasing the numbers of bellows or by improving the constraint of the chamber. The stability of the girder reaches ±0.1µm per shift after improvement. Some design considerations for the dynamic behaviour of girder are also discussed .

7 ACKNOWLEDGEMENT

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