2nd International Workshop on Mechanical Engineering Design of Synchrotron Radiation Equipment and Instrumentation (MEDSI02)
September 5-6, 2002 – Advanced Photon Source, Argonne National Laboratory, Argonne, Illinois U.S.A.

# Thermal Deformation of the Magnet Girder and its Solution in the SRRC Storage Ring

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**Abstract**

The thermally-induced deformation of the magnet girder has been observed to cause positional changes of the magnet and the beam position monitor (BPM) in the order of microns. This work investigates the deformation mechanisms. Methods for reducing the deformation are also proposed and applied in the storage ring. The mechanical stability of the girder reached ±0.1 μm per shift after improvement. Photon BPM and intensity monitor in the beamline were enclosed to compare the influence of the mechanical stability of the girder.

**Keywords:** thermal deformation, magnet girder, storage ring

## 1. Introduction

Many beam related components such as beam position monitors (BPM), quadrupole magnets, sextrupole magnets are on a magnet girder. In general, BPMs are used in the feedback system; quadrupole magnets are orbit motion related components; sextupole magnets are energy dispersion related components. All this devices are sensitive to the position. Deformation of the magnet girder causes the above components to be dislocated, perturbing the orbit of the synchrotron beam. The users of the beamline will feel the effect of beam stability problem when they perform the high resolution and constant flux experiments. A feedback system was requested to improve the stability of the beam, but the position of the BPM had to be stabilized first. In experiment in SRRC, only one quadrupole magnet in motion some BPMs could sense the perturbation [1]. For example the motion of one quadrupole magnet through 1 μm induced a maximum motion of electron BPM about 2 μm. When more than one magnet are in motion, the beam motion is expected more complex than when only one magnet is moving. Another example is the height change of the girder versus the photon BPM reading as in Fig. 1. Notably, the stand of the photon BPM and the magnet girder were in the same tunnel and so were expected to experience the same thermal environment. Thermal deformation of the girder causes variation of the photon BPM reading. It implied the orbit amplification factor of quadrupole magnet due to change in height exceeded that due to the thermal expansion of the stand of photon BPM. Figure 2 plots the girder height versus the tracking center of beam intensity monitor in the beamline [2]. A change in the height of the girder induces a large position change in the centre of beam. Obtaining beam stability in the state of art the deformation of the girder is critical. The work investigates the dynamic behaviour and deformation mechanism of the magnet girder.

## 2. Magnet Assembly and Measurement Methods

Figure.3 shows the assembly of the girder. Magnets and vacuum chamber are on the girder. BPMs are installed on the vacuum chamber and their supports are rigidly fixed to the girder. Several aluminum formed bellows near the BPM are used to eliminate the effects from the expansion or shrinkage of the vacuum chamber. The gate valve is also a fixed point on the vacuum chamber. Controlling the massive structure to within 0.1 μm is difficult.

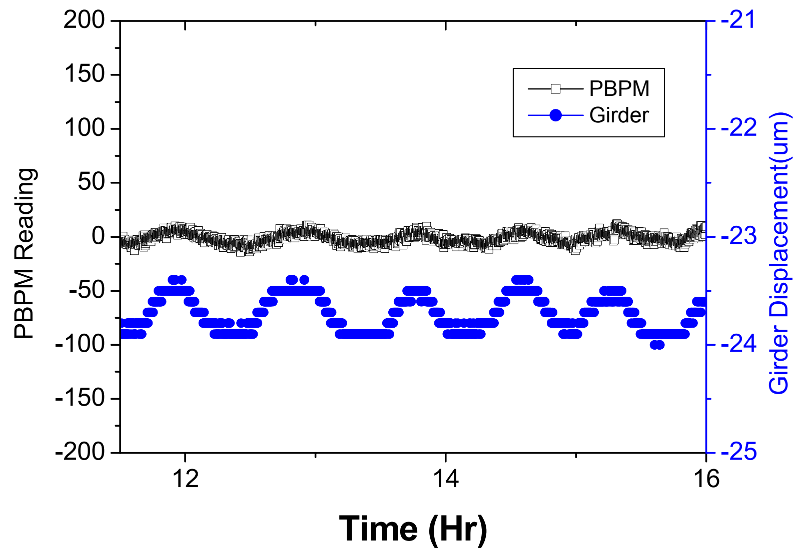


Fig. 1: Photon BPM reading versus girder height change. (2001/5/9).

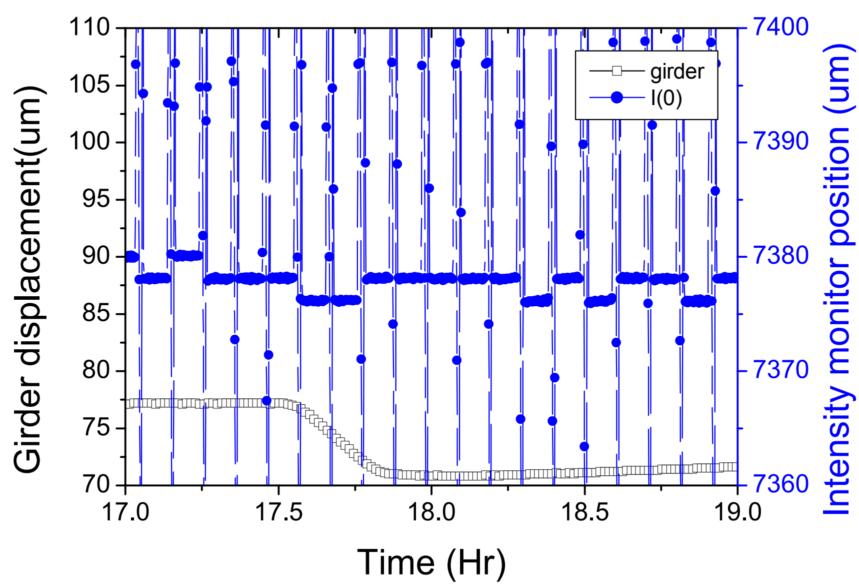


Fig. 2: Beam intensity center versus girder height change. (2002/8/7).

Factors including rigidity of the girder, thermal environment change (air or cooling water), chamber- induced deformation, internal stress and other heat sources must be considered. The static conditions and the dynamic behaviour must also be considered. Some of these factors are inter-related; therefore various tests were performed in the laboratory and the ring to further investigate the mechanism.

An LVDT (linear variable differential transformer) was used to measure the height of the girder. This is a Tesa product with a resolution of 0.1μm and a repeatability of 0.01 μm. A quartz rod was used as the measuring fixture (thermal coefficient $<$ 0.5 PPM) to prevent the measurements being affected by temperature. The LVDT was attached to the quartz rod to measure the change in the height. Figure 3 shows its layout. 6 LVDT were used for each girder. When any external forces were applied to the girder, inducing deformation, the LVDT data indicated the change in the height and angle. All the data were PC- linked and archived.

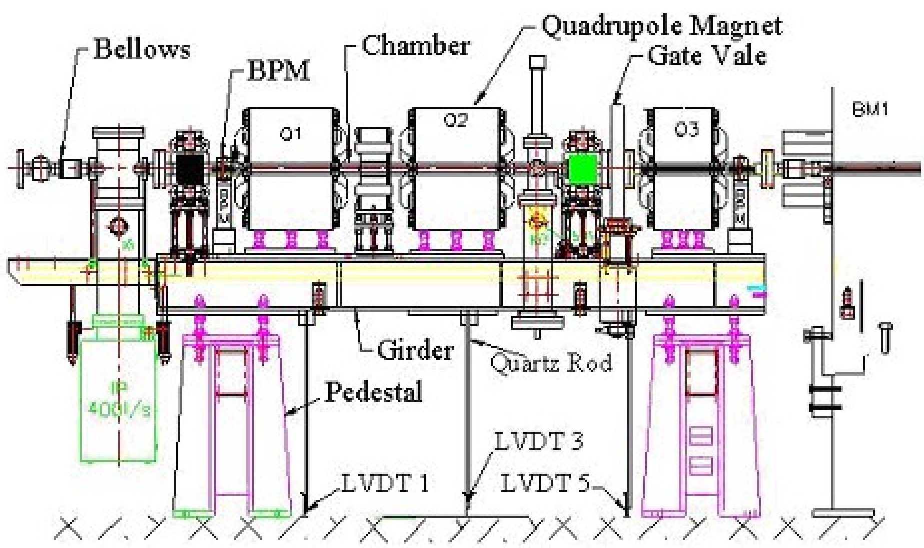


Fig. 3: The girder assembly and layout of LVDT.

## 3. Mechanism of Girder Deformation

### *3.1 Pedestal Height Change*

The pedestal height changes as the air temperature change. A variation of metal temperature in 1°C changes the pedestal height by around 10 μm for a thermal expansion coefficient of steel 11 ppm for steel. The height of the girder also changes with the pedestal height. Figure 4 shows the effect of the temperature variation of the air on the height of the girder. It is consistent with the prediction, but the 3 LVDTs gives different readings, implying deformation of the girder.

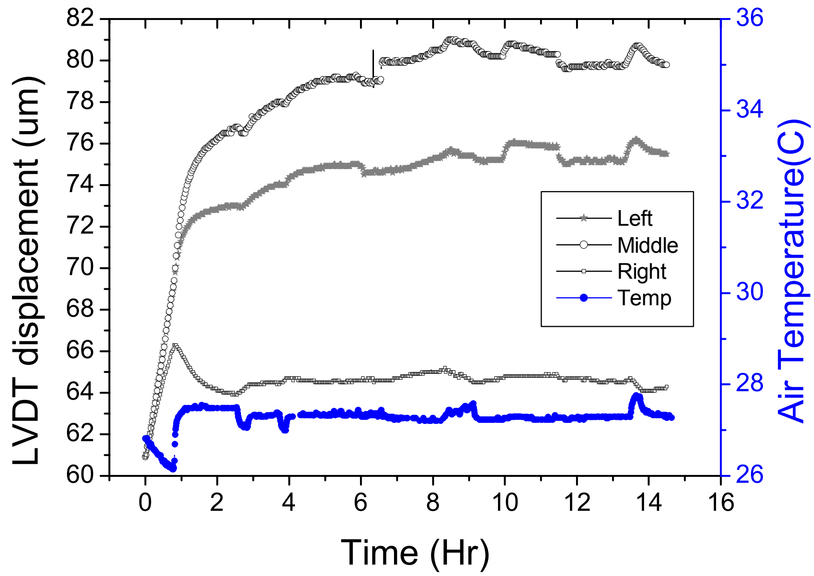


Fig. 4: The deformation of girder (left, middle, and right) versus air temperature (2001/5/7).

### *3.2 The Surface Temperature of the Girder*

Figure 5 shows the temperature differences of the girder in the upper and lower surfaces, as well as the height change versus time. The temperature differences are related to the LVDT data. The temperature of the upper surface of the girder is higher than that of the lower surface in this case by the heat source of magnet and chamber. Mechanically, a temperature difference between the upper and the lower surfaces of a long bar causes bending of the bar. For example, a 2 m-long bar with a thickness of 30 cm, and a temperature gradient of 0.1°C undergoes bending and the sag at the middle point is about 1.6 µm. The LVDT data in Fig. 4 also indicates that the middle point of girder is higher than both ends. The bending effect cannot be ignored.

### *3.3 Deformation of the Vacuum Chamber*

If the expansion of the chamber is not absorbed completely by the bellows then the thermal stress of the vacuum chamber induces the deformation of the girder because the straight vacuum chamber was firmly mounted on the girder. The chamber temperature is inevitably influenced by the temperature of cooling water and heating of the beam current. In Fig. 6, the air temperature variation was kept about 0.2°C, and the chamber temperature declined as the beam current decayed; an LVDT spike occurred and the chamber temperature changed abruptly at each injection. The LVDT reading was found to decrease more than 1µm as the temperature of the chamber decrease about 1°C. This phenomenon was also confirmed by a laboratory test in which the chamber was heated and the height of the girder observed to change. In SRRC, Kuo found that the beam was perturbed by the temperature variation of the cooling water of chamber. A change in the temperature of cooling water of 1°C induced a change of the vertical beam orbit of 2-3 μm. The change in horizontal beam orbit was four times greater [3]. A possible mechanism may have been the chamber- induced girder deformation.

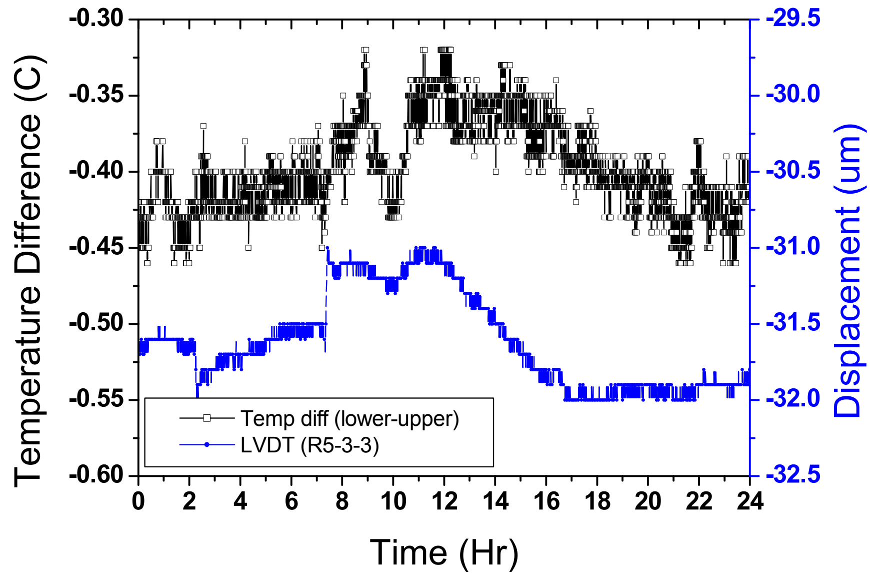


Fig. 5: The girder displacement versus the difference of surface temperature of girder without insulation (2001/8/22).

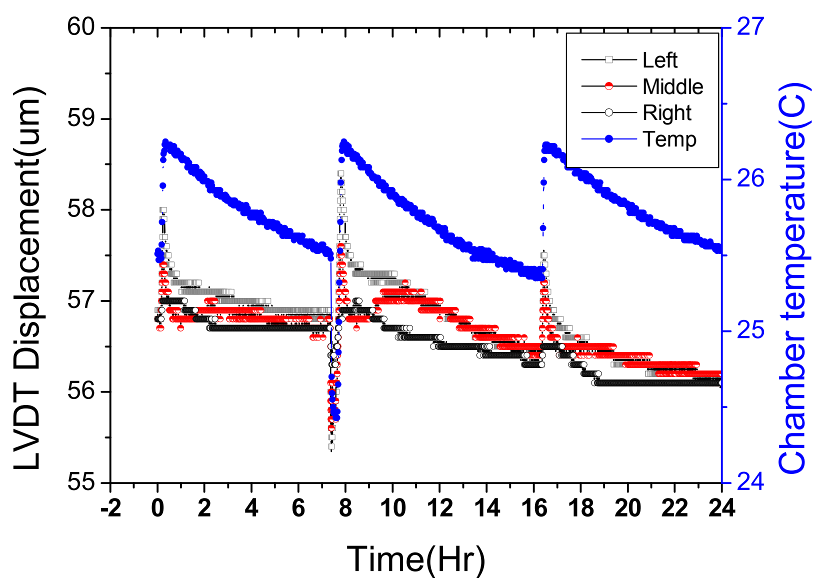


Fig. 6: The chamber temperature versus the deformation of girder (2002/6/5).

## 4. Solution of Girder Deformation

### *4.1 Insulation of the Girder*

The thermal environment can be improved or material with a lower thermal expansion coefficient can be used to reduce the thermal deformation. Much effort has been made to reduce the temperature variation to 0.2°C. However, the tunnel includes different kinds of dynamic heat sources (magnet and chamber), and maintaining the variation of the temperature of the girder to a very low value is not easy. Increasing the heat capacity of the girder by filling it with water is also a good approach [4], but engineering work is complex in this phase. The girder and pedestal were insulated. Figure 7 shows the LVDT data and the temperature difference of the girder. After insulation the temperature time constant of the girder increased from 7 hours to 18 hours. The temperature difference of the girder surface can be controlled to within 0.1°C. The LVDT data did not exceed 0.5 μm in the whole day, excluding the injection effect. The insulation method proposed here was to solve the deformation mechanism in last section 3.1, 3.2.

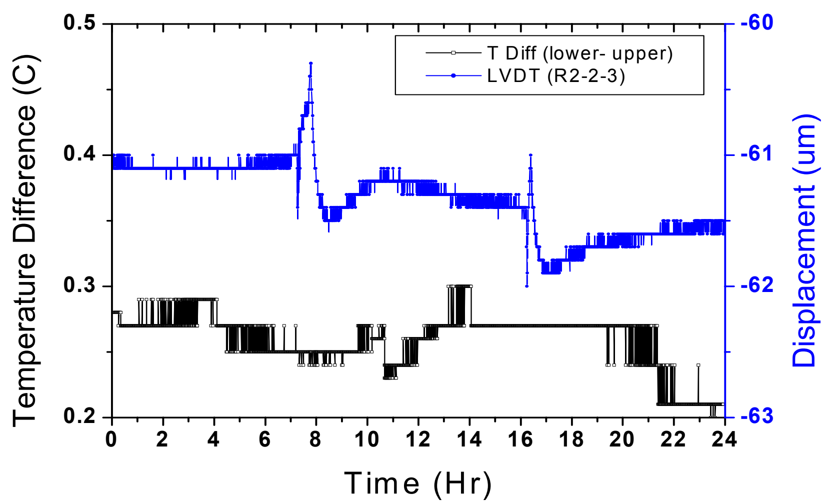


Fig. 7: The girder displacement versus the difference of surface temperature of girder after insulation (2001/8/28).

### *4.2 Active Bellows Compensation*

Aluminum formed bellows were designed to absorb the thermal deformation of the chamber. However, the stiffness of the bellows was such that they could not completely absorb the expansion of the chamber. An active bellows was designed to compensate for variation in chamber length by monitoring the chamber temperature, to reduce the deformation of the girder due to chamber deformation. Therefore, the total length of the chamber could keep nearly constant. One active bellows was installed in the ring. Figure 8 shows the performance of active bellows compensation. The injection spike of LVDT was halved. Under ideal condition, the mounting of the chamber must decoupled from the deformation of the girder.

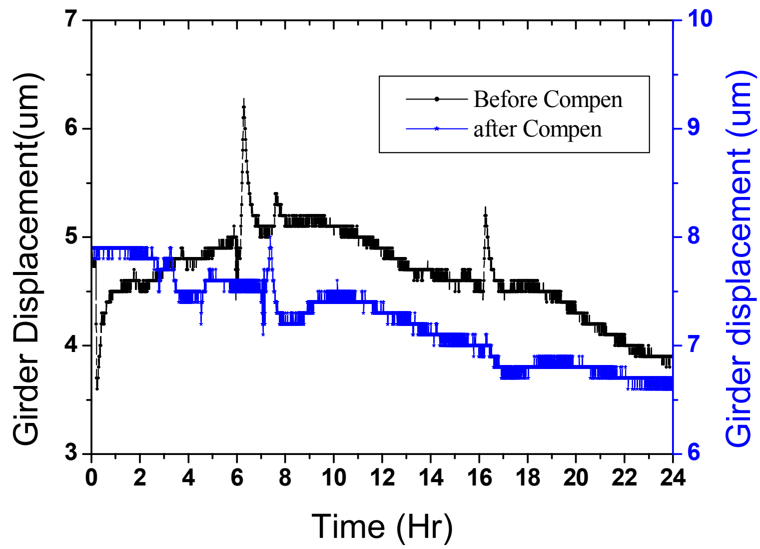


Fig. 8: Comparison the performance of active bellows compensation (2002, 6 /4 and 6/25).

## 5. Conclusion

Girder deformation closely related to the beam stability, according to data from photon BPM and beam intensity monitor. This study presents the mechanism of the deformation of the magnet girder, considering first the thermal expansion of the pedestal; second, the temperature gradient of upper and lower surface of the girder which causes girder bending, and third, and third, the constraint imposed by the thermal expansion of the vacuum chamber. The first two effects can be suppressed by thermal insulation. Increasing the compliance of the bellows or decoupling the deformation from the constraint of the chamber can improve the final effect. Active bellows compensation was tested to reduce the constraint of chamber. The mechanical stability of the girder reached ±0.1 μm per shift after improvement.

## 6. References

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