STUDY OF 60 Hz BEAM ORBIT FLUCTUATIONS IN THE TAIWAN PHOTON SOURCE

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Abstract

The Taiwan Photon Source is a 3 GeV synchrotron light source at NSRRC. To achieve high quality experimental results, it is important to minimize beam motion. During the installation of insertion devices and front-ends, the beam motion around 60 Hz became significant. The response matrix together with singular value decomposition was used to identify the transmitter of the superconducting radio frequency system as the source for the 60 Hz perturbations. This was subsequently corrected by rerouting the grounding of the mains in the transmitters. Yet, the 60Hz orbit fluctuation became even more serious after the next shutdown. A serious of experiments are performed to dig out that the beam was disturbed by the magnetic field from newly installed fan motors. Shielding the fans with mu-metal and increasing the distance between fan and beam pipe drastically reduced the leakage field and greatly increased beam stability. These errors could be prevented at the design stage in the ideal case. However, these errors happened finally and need to be dug out and eliminated. The method and experiences are summarized in this report. These will benefit others who facing the similar problems.

INTRODUCTION

The Taiwan Photon Source (TPS) is a low emittance third-generation light source at NSRRC [1] with a circumference of 518.4 m and 24 double-bend achromat cells. There are 6 long-straight sections and 18 standard-straight sections to accommodate insertion devices. So far, ten insertion devices were installed in the storage ring producing synchrotron radiation for seven beam lines. The beam current at normal operation is now 300 mA.

During early beam commissioning, the main contribution to the vertical beam motion was around 29 Hz causing orbit motion of roughly 23 µm from running turbo molecular pumps [2, 3]. After turning them off during routine operation, the major beam motion left is caused by cooling water flow, which were greatly diminished after reducing the cooling water flow rate in the aluminium vacuum chambers from 10 to 6 liter/min. Serious efforts were made to eliminate more vibration sources in 2016 especially those related to the 60Hz mains frequency. To achieve submicron beam stability we must discover the sources and implement corrective measures.

While machine installation continued during the past year by implementation of insertion devices and front-ends, beam stability changed often, especially after the long shutdowns between December 2015 and March 2016 and between June and September, 2016. The 60Hz vertical beam motion became more significant after these activities. The identification of these 60Hz disturbances of the beam orbit and measures to eliminate their effects are discussed in this report.

ELECTRICAL NOISE CAUSED BY RADIO FREQUENCY SYSTEM

Before the shut-down in December, 2015, the power spectral density (PSD) [4] of the 60Hz beam motion was lower than 2 $\mu m/Hz^2$ and increased to 12 $\mu m/Hz^2$ after the long shut-down, as shown in Fig. 1 (a).

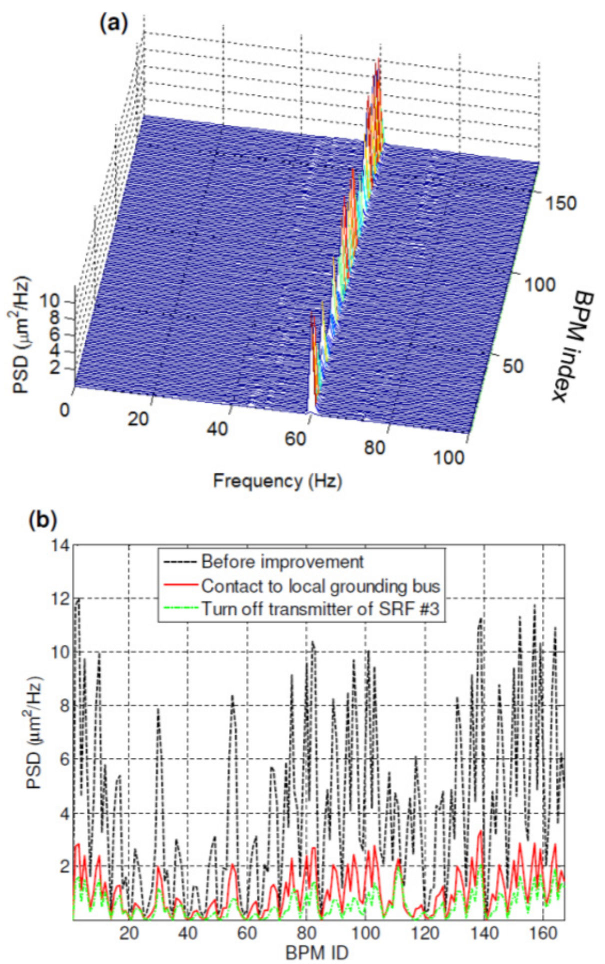

Figure 1: (a) The power spectral density (PSD) of beam motion at each beam position monitor (BPM) before improvement. (b) The comparison of PSD of beam motion at 60 Hz before improvement (black); after connecting the SRF transmitter ground to the local grounding bus (red) and after transmitter (SRF#3) turn-off (green).

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In order to identify the location of the vibration source, the 60Hz beam orbit (B, a column vector for all BPM locations) was extracted by Fourier transform from the beam position signals and is shown in Fig. 2(a). The response matrix (R) between BPMs and correctors can be expressed by singular value decomposition (SVD) [5, 6, 7] as $R = USV^T$ and the source contribution expressed in temrs of corrector currents would be $VS^{inv}U^TB$, where $S_{jj}^{inv} = 1/S_{jj}$. The results in Fig. 2 (b) show that the 60Hz beam motion mainly comes from a location nearby the 7th corrector in cell 17 (17-7) and 15 (15-7).

All power supplies at these two locations checked out to be working well and therefore the perturbations must come from other nearby devices. Because the superconducting radio frequency (SRF) cavities are located downstream of these two correctors, a test run with the transmitter of the SRF #3 system turned off resulted in the PSD of the 60Hz beam motion to have been reduced from 12 $\mu m/Hz^2$ to 2 $\mu m/Hz^2$ as the green line in Fig. 1(b). The perturbation comes mainly from the location of the SRF #2 cavity (corrector 15-7). Rerouting the grounding of the SRF transmitters reduced the PSD of the 60Hz beam motion down to 3 $\mu m/Hz^2$ as the red line in Fig. 1 (b).

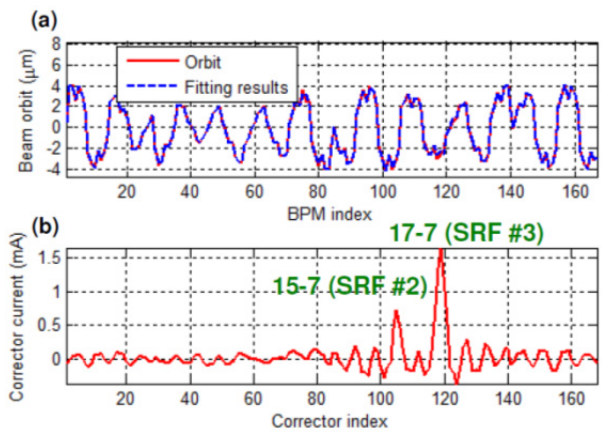

Figure 2: (a) The 60Hz beam orbit and fitting to the response matrix between beam position monitors and slow correctors. (b) The simulated output current of slow correctors.

COOLING FAN EFFECT

During the shutdown in the summer of 2016, 47 cooling fan stations were installed at the up- and down-stream of the straight sections to cool down the BPMs and nearby bellows as shown in Fig. 3 because the temperature at the bellows would be more than 50^0C without the fans. Each fan station is equipped with two fan assemblies. Before installing, the vibration of the fan to beam is evaluated and it is concluded that the vibration has less effect to the beam. However the effect of the leakage field to the beam is not considered to be an issue at that moment. The 60Hz orbit motion significantly increased after cooling fans were installed. At first, the vibration of the vacuum chamber caused by the fans was suspected again. However, the speed of the fan of type Centrifugal blower CY100B2P, is 3350 revolutions per minute for 60 Hz AC which corresponds to 56 Hz and such a vibration frequency is observed in the fan stations rather than 60 Hz thus excluding the vacuum chamber vibration as the culprit.

Next we suspected the magnetic field generated by the induction motor of the fans because they are located close to the vacuum chamber. A Lake Shore DSP Gauss-meter with a Hall probe HMMT-6J04-VR was used to measure the magnetic field, as shown in Fig. 4. The leakage field frequency, 10 cm away from the fan (Fig. 5), turned out to be 60 Hz similar with the beam motion.

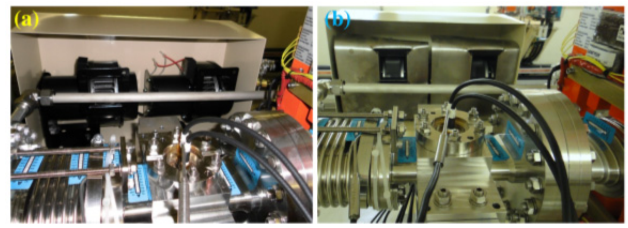

Figure 3: Fan stations installed on both ends of the straight section to cool down beam position monitors and bellows (a) before and (b) after shielding with mu-metal.

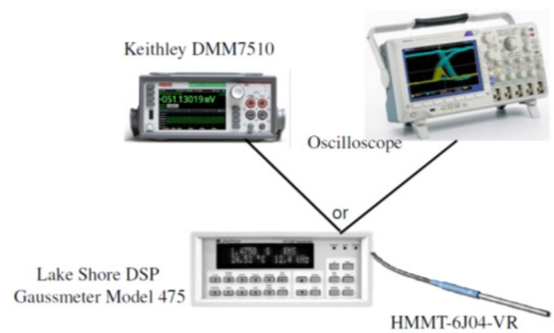

Figure 4: Setup of magnetic field measurement instruments.

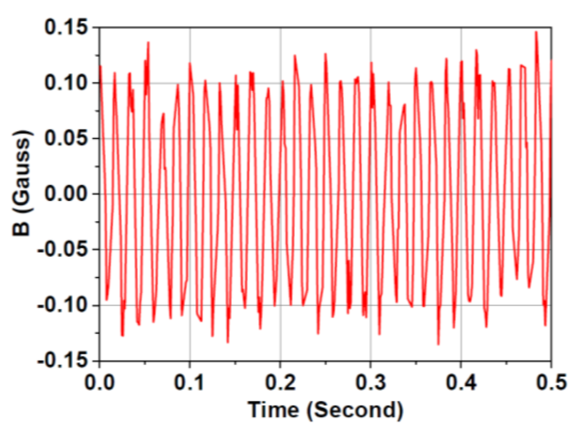

Figure 5: The magnetic field 20 cm away from the cooling fans.

To check that the beam perturbation really comes from the cooling fans, all fans in the tunnel were turned off except for one as reference. The amplitude of the 60Hz vertical beam motion dropped to one-third as shown in the Fig. 6. When checking the location of the 60Hz perturbation, it was found to come mainly from the RF-systems SRF #2 and SRF #3 and from the running fans.

To understand the leakage magnetic field for different fans types, it was measured along the air flow direction

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for the installed fans and three other types of fans. Figure 7 shows the leakage field along the X direction for these four fan types. The type #1 fan is installed in the tunnel of the storage ring. The magnetic field decays exponentially with distance from the fan and at a distance of more than 30 cm all fans show about the same leakage field. Because the air flow rate from the type#3 and type#4 fans are too small and the type#2 fan is difficult to install in the existing fan stations, we chose the type #1 fan as the best candidate to meet our needs.

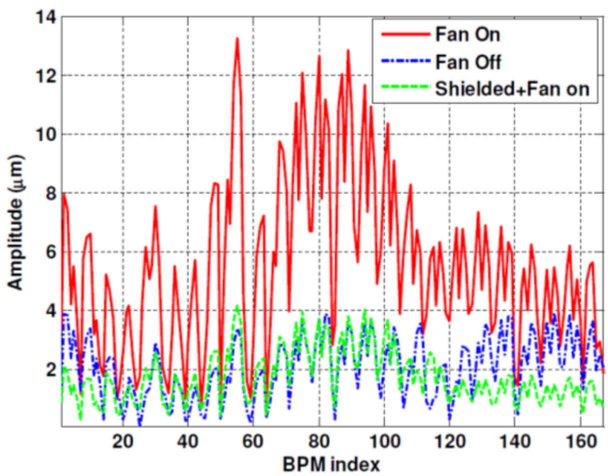

Figure 6: The vertical beam motion when the fans are turned on, turned off and shielded with mu-metal and removed from the vacuum chamber to more than 30 cm (fan on).

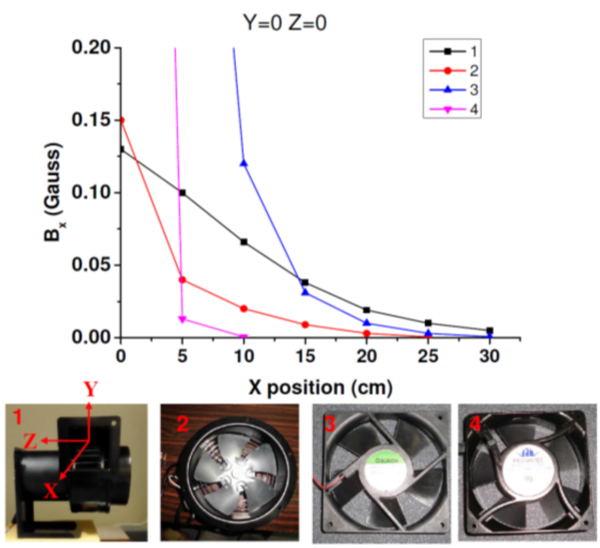

Figure 7: The leakage magnetic field of four fan types measured along the direction of air flow. These four fans were purchased from Centrifugal blower CY100B2P, Mini axial fan JAF-M6, Sunon KD2412PTB1-6A and Profantec P1123HST.

In the lab we experimented with mu-metal in various configurations to contain the magnetic field from the fan motor and show the shielding effectiveness in Fig. 8. Note that the measured magnetic field is much smaller than the Earth's magnetic field and ambient stray magnetic field. This 60Hz field is embedded in background noise, and it was extracted using sophisticated digital signal processing inside the gauss meter. The Hall probe is moved along the Z direction while the other coordinates are kept constant at X=20 cm and Y=0. The effect is better for the motor wrapped with mu-metal (case 2) than the fan assembly (case 1). The magnetic field becomes one-fifteenth when fan motor and whole fan assembly were wrapped by mu-metal (case 3). In the case 3, there are two layers of shielding on the fan motor area. Therefore, to wrap mu-metal on the motor and fan assembly were chosen to reduce the leakage magnetic field.

However, when fan assembly was installed at the accelerator with 24 cm away from the vacuum chamber, the magnetic field leakage can only attenuate to one-third at electron beam path between with and without the shielding. This unexpected result is due to material of the protection cover which is made of iron. Finally, increasing the distance between the fan assembly and electron beam path without scarifying cooling performance was decided. All fan assemblies were installed more than 30 cm away from the vacuum chamber, and leakage field become less than one-tenth of the original configuration. The amplitude of the beam motion at 60 Hz reduces to the level without the contribution of fan assemblies as shown in Fig. 6.

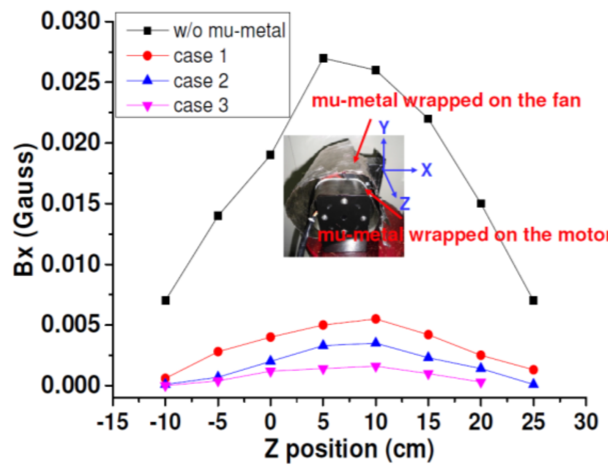

Figure 8: The magnetic field strength at 60 Hz with various shielding methods as the probe is moving along the Z direction and the other coordinates are kept constant at X = 20 cm and Y=0. Mu-metal is wrapped on fan assembly (case 1); on fan motor (case 2); both on fan assembly and on fan motor (case 3).

SUMMARY

For the beam motion at 60 Hz, the response matrix together with singular value decomposition is used to identify possible sources which cause of this beam motion. The effect comes from the transmitter of superconducting radio frequency systems are reduced by rerouting the grounding topology. The effect comes from the cooling fans is improved by shielding the fan with mu-metal and moved the fan away from the vacuum chamber. A way to identify the location of the sources is proposed and used in practical cases.

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