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BEAM-BASED MEASUREMENT ON THE PERFORMANCE OF FERRITE DAMPERS IN AN IN-VACUUM UNDULATOR*

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Abstract

We have previously reported our design of passive dampers to suppress the trapped RF modes in an in-vacuum undulator (IVU) at SPEAR3. These ferrite dampers were installed in SPEAR3 ID 17, which has recently been commissioned with beam. In this paper we report the results from the beam commissioning to show that the dampers function as expected. Further, beam-based characterization indicates that the installation of the ferrite dampers have made negligible the once problematic effects of the modes in this device on the beam dynamics.

INTRODUCTION

In vacuum insertion devices have gained some popularity in recent years in synchrotron radiation light sources worldwide. The focus of new beam line development in SPEAR3 has also been on IVUs. In 2018, the fourth IVU, BL17 ID, was installed in SPEAR3. Because the IVU can operate with a variable gap and introduce a small physical aperture in the storage ring, it can impact the beam dynamics and machine protection in many different ways. For the BL17 ID, the main concern is related to beam dynamics. This ID was based on the same design as the previously installed BL15 ID, which was observed to cause coupled-bunch instabilities (CBIs) in SPEAR3 when the active coupled-bunch feedback system is off [1]. In an attempt to eliminate this problem without feedback, extensive numerical studies were carried out and a passive solution using ferrite dampers was chosen for its simplicity and effectiveness [2, 3]. Because of the simplicity of the damper design, it was possible for the vendor to integrate the installation of ferrite dampers into the manufacturing process with short notice. Therefore, it has become an important task to characterize the damping performance of these ferrite dampers.

DAMPER INSTALLATION

The ferrite pieces are made from commercially available stock TT2-111R [4] material. The ferrite pairs consist of two identical pieces, each 30 x 40 x 5 mm, with a half circle relief to permit assembly around the supporting rod. A gap of 25-50 μm is left between the pieces to provide for thermal expansion. The details about the structure design of the dampers can be found in our previous publication [3]. The installation of ferrite dampers in BL17 ID was sent to the vendor as an additional request during the undulator production process. The original plan was to install 24 pairs of ferrite brackets around the 24 supporting rods in the upper and lower rows, however, only 20 pairs were actually installed because of some technical constraints. Even with the missing dampers, we still expected the remaining dampers would be sufficient to keep the beam passively stable. In order to monitor the operational temperature of these tiles, two thermocouples (TCs) were attached to two of the ferrite tiles near the end of the ID.

Before installing the device into the accelerator tunnel, we conducted cold RF measurements to identify the trapped RF modes. For this measurement, we duplicated the experimental setup of the RF measurements for the BL15 ID with an HP8753ES network analyzer and two loop antennas installed in the IVU chamber. We knew which higher order modes (HOMs) existed in the mechanical structure from our previous studies on the BL15 IVU and identified them in the BL17 IVU. In the BL15 ID, the HOM #3 has the highest loaded Q of about 390. However, in the new device, all three modes have relatively low loaded Q's. Particularly, at a 6.79 mm ID gap, where the BL17 ID HOM was strongest, the loaded Q of HOM #3 is measured as low as 24.8, which suggests over an order of magnitude damping effects from the ferrites.

Though being heavily damped, the HOM #3 still has a slightly higher Q than the other two modes we measured. Therefore, one goal for our beam-based characterization is to study the interaction between HOM #3 and the beam dynamics. In Fig. 1, we plotted the measured resonant frequency of mode #3 in the BL17 ID at different gaps with the lower side band (LSB) frequency of different CBI modes. The minimum operational gap for BL17 ID is 7.3 mm; therefore, when varying the ID gap from 7.3 mm to 9 mm, the resonant peak of mode #3 overlaps with the CBI mode #168 to #173 at different gap settings. It appeared that, at around a 7.36 mm gap for BL17 ID, the measured trapped mode

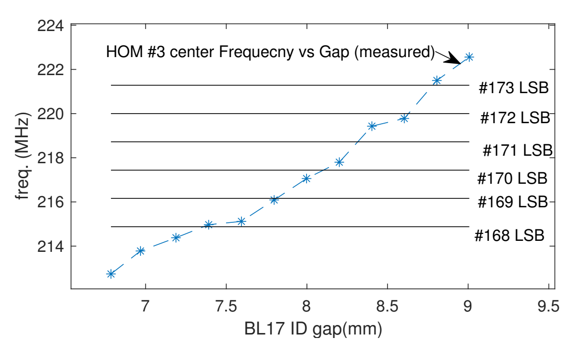

Figure 1: The resonant frequency of the measured HOM #3 crosses different CBI modes with ID gap change.

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frequency from the cold test overlaps with the CBI mode #168. From earlier simulation studies, we learned that the transverse beam coupling impedances of the trapped HOMs were larger at smaller gap.

BEAM COMMISSIONING

The first beam commissioning of the BL17 ID was conducted on June 4th, 2019. We increased the SPEAR3 stored beam current slowly to 500 mA in multiple steps within a period of less than 2 hours. As a precaution, the BL17 ID gap was fully open during injection and only closed to its minimum 7.2 mm gap after each fill. The readings of two TCs on the ferrite dampers, the local and global ring vacuum, and ring radiation monitors were closely monitored. The coupled bunch-by-bunch (BxB) feedback system was active during the entire process. The history of the TC temperatures and ring vacuum is shown in Fig. 2. The temperature readings of the two TCs increased slightly by about 1 °C and 2 °C respectively. The vacuum pressure, both locally and globally, was independent of the BL17 ID gap size.

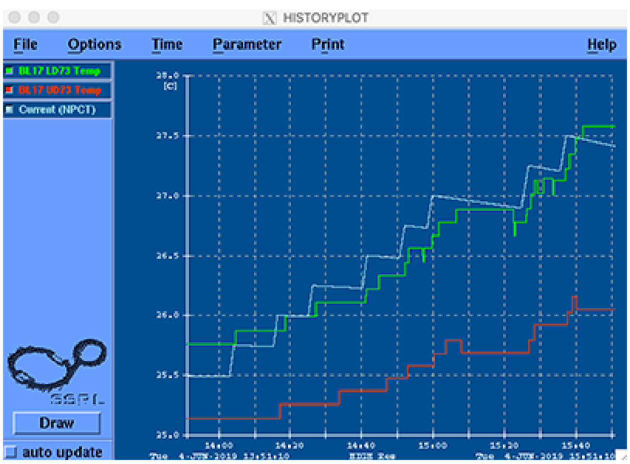

Figure 2: SPEAR3 history plot during BL17 ID beam commission shows readings of the TCs on the ferrite dampers.

Following the first beam commissioning experiment, a series of beam-based measurements were performed to investigate the damping performance of the ferrites. The goals of the experiment were twofold: first we wanted to confirm the beam is stable passively at any ID gap settings; second, we want to characterize the damping performance of the ferrite dampers. After a thorough scan of the gap size with the BxB feedback on or off, we could find no indications of beam instabilities in either case. Therefore, we concluded that the beam was passively stable with the BL17 ID at any operational gap and the ferrite dampers installed in the BL17 ID were effective to suppress the trapped HOMs with no significant thermal effects at our full operational current of 500 mA stored beam.

DRIVE-DAMP MEASUREMENT

Though the ID 17 is passively stable for the stored beam, using the drive-damp technique of the BxB system [5], it is still possible to evaluate the damping performance of the ferrites by measuring the damping time of the driven coupled bunch instability mode. Similar measurements, with other similar IVUs, were previously carried out in the Diamond Light Source [6]. Researchers there had also observed beam resonances caused by HOMs at intermittent gap settings. An example of the drive-damp measurement is shown in Fig. 3. With 320 mA of stored beam, the BxB feedback system was first set to drive the instability mode for 3ms. The drive was then switched off and, depending on the experiment, the feedback was either on or off. When the BxB feedback remains on after the drive, the decay rate of the driven instability is nearly instantaneous. When the BxB feedback is off, the driven instability damps down slower, as expected, with an exponential decay. By fitting this decay, we can derive the damping time τ_D, which depends on many factors such as radiation damping, decoherence, Landau damping, and the shift of the bunch spectrum due to the non-zero chromaticity of the beam. If the predominant HOM mode, in this case the mode #3, is sufficiently strong, the damping time for the relevant CBI mode should be longer when the HOM mode frequency is overlapping with the CBI mode frequency, which is the lower betatron sideband of the corresponding harmonics. However, if the HOM mode is too weak, the damping effects of the driven CBI mode will be dominated by radiation damping and other nonlinear effects. As a result, no resonant effects can be observed. We have conducted a series of measurements with different vertical chromaticity ξ_y and beam conditions in search of such type of resonant behaviors.

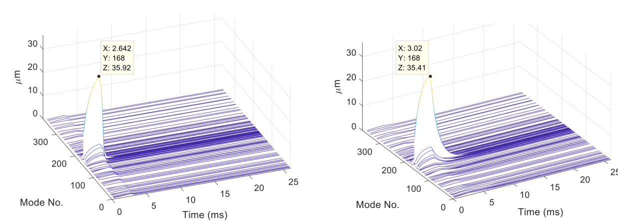

Figure 3: Drive-damp measurements at 7.36 mm gap with the BxB feedback on (left) or off (right) after the drive.

As previously mentioned, the RF cold measurement indicates that CBI mode #168 could be the one impacted most by the trapped HOM #3. Therefore, we first focused on this instability mode. In Fig. 4, we show the variation of the damping time for mode #168 with BL17 ID gap, from 7.2 mm to 7.9 mm while using the BxB feedback system to drive mode #168. Each data point is an average of three consecutive measurements. The vertical chromaticity ξ_y was set at the operational value of +2. There is no resonant pattern within the scanned gap range. However, the results show that τ_D is smaller for 500 mA of stored beam than with 300 mA of stored beam. This is unexpected, because radiation damping is independent on beam current and the growth rate of the instability mode due to the trapped HOMs increases with beam current. It likely implies that nonlinear

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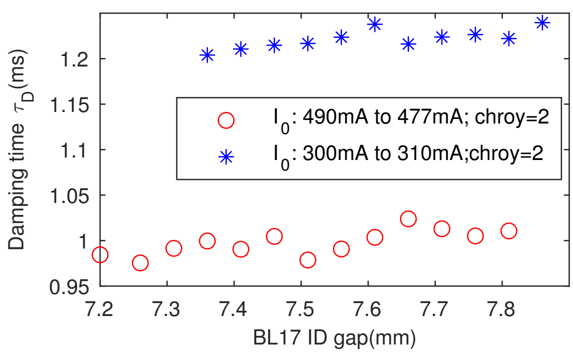

Figure 4: Damping time for CBI mode #168 at different BL17 ID gaps with different stored beam currents.

effects contribute more to τ_D than the trapped HOMs at higher beam current. To compare the results for different ξ_y, we reduced the chromaticity first from +2 to +1, and then further to +0.75. As shown in Fig. 5, with reduced chromaticity and roughly similar stored beam current, the damping time increased. We could not conducted grow-damp measurement with zero chromaticity due to strong resistive wall instabilities that can be damped with BxB feedback on or ID gap open beyond 15mm.

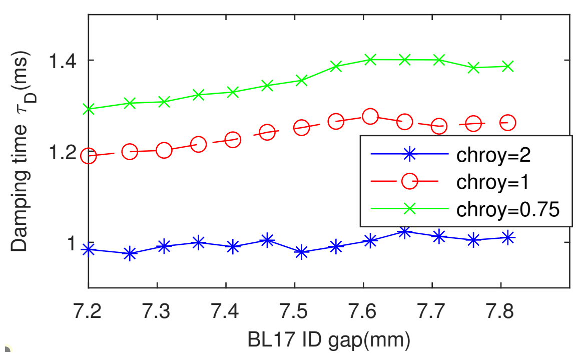

Figure 5: Damping time for CBI mode #168 at different BL17 ID gaps with different ξ_y.

With stored beam, the spectrum of the trapped HOMs could shift due to small IVU structure variations caused by the heat from beam loading and synchrotron radiation. For further investigation of this possibility, we conducted another measurement to fix the gap of ID at 7.36 mm while driving different CBI modes, from mode#154 to 180, using the BxB feedback system. The results, shown in Fig. 6 for both the lattice with ξ_y=2 and ξ_y=1, indicate that the damping time of mode #168 is not the longest at all. Instead, it appears that there is a peak at mode #158. To confirm that this peak is due to the trapped RF modes, we further conducted drive-damp measurements for mode #158 at different ID gap settings. The results, plotted in Fig. 7, show that the damping time of this mode is not sensitive to gap movement. All these measurement results convince us the installation of the ferrite dampers have made the driving terms from the HOMs in the IVU insignificant.

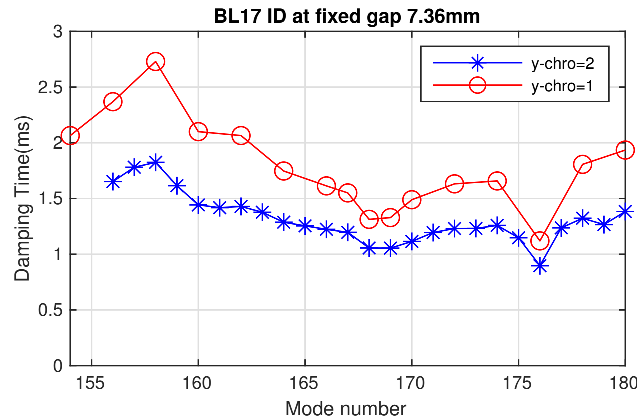

Figure 6: Damping time for different CBI modes while keeping the BL17 gap at 7.36 mm.

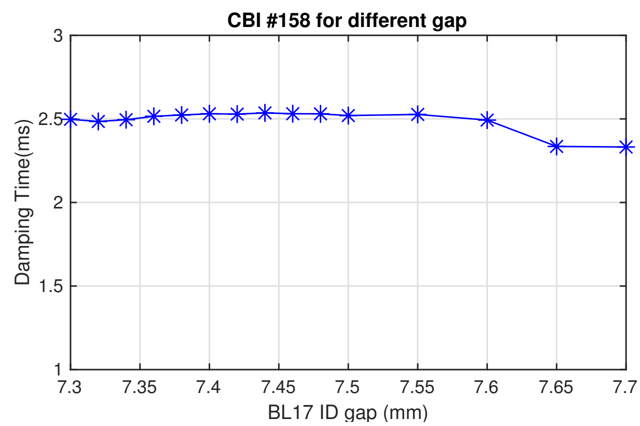

Figure 7: Damping time for CBI mode #158 at different BL17 ID gaps.

CONCLUSION

BL17 ID is the first IVU with ferrite dampers for HOMs to have been installed in a synchrotron radiation light source. The first beam commissioning of the ID went smoothly with the active feedback system on. Later, with careful measurements using the drive-damp techniques and monitoring the machine status with different beam conditions and ID gap settings, we concluded that the ferrites dampers work as expected and the beam was passively stable for the operating lattice at any gap settings.

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