9th International Particle Accelerator Conference IPAC2018, Vancouver, BC, Canada JACoW Publishing
ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPMF021

INVESTIGATION OF OPTIONS FOR DAMPING TRAPPED IVU RESONANCES

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Abstract

Trapped resonances have been observed within the three In-Vacuum Undulators (IVUs) insertion devices at the Australian Synchrotron. These resonances can create vertical beam instability if not controlled through transverse feedback systems. Similar resonances have been observed at other synchrotron light sources around the world. Under certain conditions of undulator gap, these resonances can couple quite strongly to the beam, requiring high feedback gain. An investigation of the resonances has been carried out using 3D eigenmode and wakefield simulations to understand the resonances and determine the effectiveness of various schemes for modifying the damping the resonances.

INTRODUCTION

As shown in previous studies at the Australian Synchrotron [1], we have observed sharp vertical resonances within our in-vacuum undulators (IVUs) when set to specific gaps. These resonances cause beam instability unless damped. Other Light sources have also observed similar phenomena [2] [3].

Further investigation of the beam resonances in the undulators using grow-damp measurements at gap intervals of 0.005 mm is shown in figure 1. The progression of the instability mode number and the decreasing strength with increasing gap can be seen clearly, which indicates a loaded waveguide type resonance is present (with the resonant frequency determined by the undulator gap). The presence of more than one resonances is also indicated by the various gap intervals of different instability mode series'.

While we are currently using transverse feedback to damp the resonances, we will be installing more IVU devices in the future and it is not certain that the feedback would be able to stabilise multiple strong resonances simultaneously. We would therefore like to understand and, if possible, devise a way of eliminating these resonances from our current and future undulator devices.

RESONANCE STUDY

Previous attempts to model the IVUs ran into were hindered because we did not have the local computing resources to simulate the full device. We partnered with the local branch of Radio Frequency Systems (RFS), who have expertise in RF simulations and the computing resources necessary.

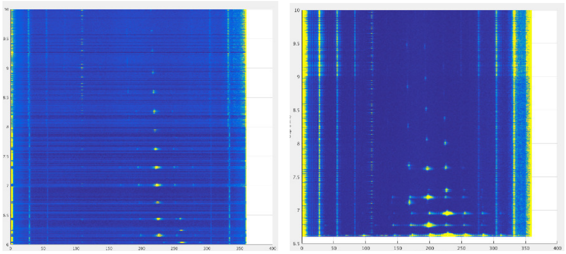

Figure 1: Instability mode growth rate vs IVU gap for the 2 metre IVU (left) and 3 metre IVU (right). Intensity scale has not been normalised.

IVU Model

An accurate 3D model of the IVU chamber for the 2 metre (IVU05) and 3 metre (IVU03, IVU13) devices was used in both the eigenmode and wakefield simulations in order to get the most accurate possible results. A cutaway view of the IVU05 model is shown in Figure 2. The only major approximation in the model is the curve of the taper transition pieces at each end, with straight line segments approximating the curve, based on photos taken of the taper in operation. The model allows for the magnet array gap to be moved between 6mm and 10mm so that we can study the effect of the changing gap.

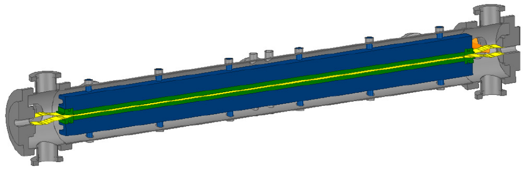

Figure 2: Geometry of the model for IVU05 used in simulations.

Observed Resonances

The results of the eigenmode simulations for each device are shown in table 1. The main problematic resonance in the 2 metre device has a tuning gradient of about 4.6 MHz/mm at 8mm gap, which corresponds well to simulated mode 3. For the 3 metre device, modes 4 and 5 correspond well to the tuning gradient of the two main observed instability modes.

The spacial field distributions of the resonances are quite similar, with both the E and H fields largely concentrated in the magnet array gap. Typical field distribution is shown in Fig. 3 and 4.

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Table 1: IVU Eigenmodes and Q Value

Mode	MHz	Q	MHz/mm @ 8mm
2m Device			
Mode 1	118.9	497	6.71
Mode 2	148.3	643	5.97
Mode 3	194.4	815	4.81
Mode 4	251.3	961	3.48
Mode 5	313.0	1094	2.67
3m Device			
Mode 1	121.0	751	7.68
Mode 2	135.9	852	6.30
Mode 3	160.9	960	5.38
Mode 4	193.5	1061	4.56
Mode 5	230.7	1166	3.64

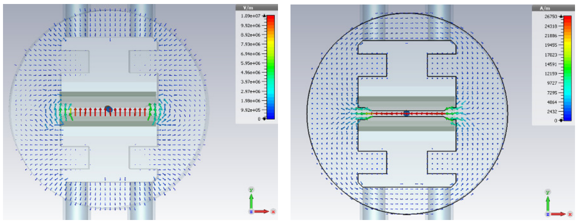

Figure 3: Transverse geometry of the E and H fields of the resonance

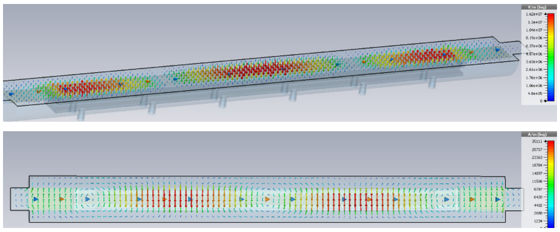

Figure 4: Longitudinal geometry of the E and H fields of the resonance

DAMPING STUDY

Now that we understand the spatial distribution of fields of these resonances, we can attempt to damp the resonance via insertion of some kind of lossy material, or use a conducting material to inhibit the formation of the resonance. The primary limitation is that we need a solution that we can easily incorporate into the existing devices as well as future ones. Several options were investigated in the following sections. For brevity in this paper we will show the results of the 2m IVU only, however the results are equally applicable to the 3m devices.

Baseline Wake Impedance

We used wakefield simulations in CST studio suite to look at the relative excitation of the resonances by the beam under various damping mechanisms. Due to the large structure being simulated we set our bunchlength to 70mm instead of 7mm for these calculations. This speeds up the calculation gteatly without loosing much accuracy at the relaticely low frequencies of these resonances. As a cross check, one simulation was conducted with the shorter bunch length, but the results were not significantly different. The baseline impedance of the 2 m device is shown in figure 5.

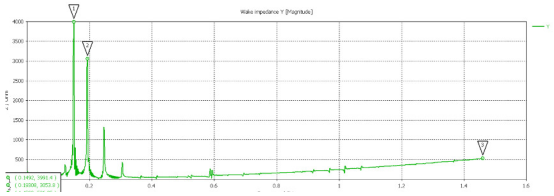

Figure 5: Baseline transverse wake impedance (Y) of the 2 m undulator at 6mm gap.

Antenna Dampers

Single or multi-turn antennas installed through the empty side flange ports of the IVU chamber designed to act as dampers (by drawing power into a load) were considered as a possible simple retrofitted solution. However on further investigation there were several issues that made them undesirable. The first was that the fields outside of the jaws of the magnet arrays was quite low, resulting in extremely low coupling to any antenna that could be placed in the device. This would necessitate multi-turn antennas to raise the coupling, however this then lowered the bandwidth of the antenna. The resonant frequency changes with the IVU gap, and so the antenna would not be able to damp well over all gap settings.

Conducting Shield

Placing a conducting shield alongside the walls of the magnet array should prevent field from leaking out and forming a resonance, however placement of this shield is limited by extend of upstream dipole radiation, such that it can only be place on one side and cannot be flush against the side of the array. Even though the engineering difficulty of installing such a shield would be very high, we modelled what a shield such as that in Fig. 6 might do. The resultant impedance spectrum, Fig. 7, shows that although the original resonant modes have all been suppressed, a new set of strong modes has appeared at higher frequency which does not make this an effective solution.

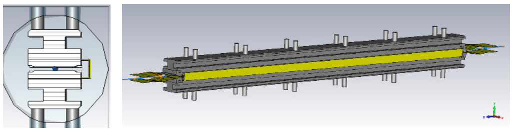

Figure 6: Geometry of conducting shield.

Ferrite Damper

If we look more closely at the H field distribution we can see that there are large concentrations around the magnet array support posts, shown in figure 8. Placement of an appro-

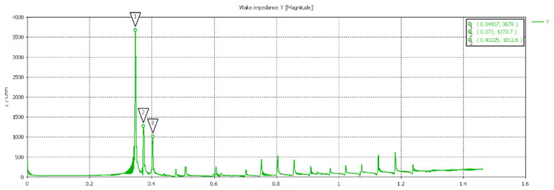

Figure 7: Impedance spectrum with a conducting shield along one side.

priate lossy ferrite ring around these posts could then effective damp the resonance. For our study we modelled ferrite rings of 10 mm height and 7 mm thickness placed around the top support posts. We selected only the top support posts so that the rings could sit on the structure by gravity, the bottom posts did not have ferrites on them. We considered two vacuum compatible ferrite materials, TT-2111R and 4S60. Ferrite material 4S60 was selected because even though it has a lower μ, it had a higher magnetic loss which made it more effective at suppressing the resonance.

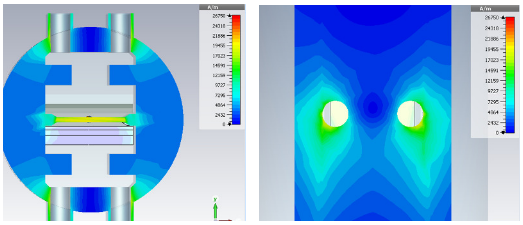

Figure 8: H field distribution near support posts.

Combinations of 2, 4, 8 and 12 ferrite rings were simulated, with the clear result that adding more rings give higher suppression of all modes. The impedance spectrum for 12 ferrite rings is shown in Fig. 9 and shows that 12 rings is sufficient to almost completely suppress the resonances. The eigenmode analysis reveals that the highest Q of the modes is now only 8.8, a factor of roughly 100 reduc-tion from baseline condition. Some further study is required to consider the expected heat load on the ferrites, although if they are fitted closely to the support posts than the IVU array can act as a large heat sink.

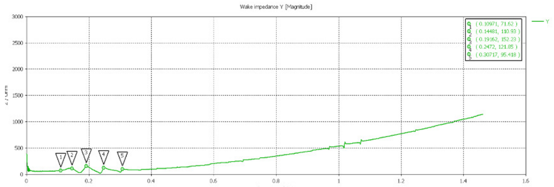

Figure 9: Impedance spectrum with damping ferrites along the top posts.

Ceramic Insulators

Another way of damping the surface currents near the support posts is by putting an insulating break in the stainless steel wall of the support post feed-through port. An insulating break will stop the surface currents flowing around the post by creating an open circuit. This could be achieved by adding a small ceramic section at the flange. The effect of adding an insulator was modelled and found to be of similar effectiveness to the ferrite rings for the problematic modes but could increase the impedance of other modes, therefore it is not an ideal solution.

Transition Taper

We also looked into redesigning the transition taper to see if the mode impedance could be reduced. We found that straightening the taper reduced the impedance of the resonances by a third. Further changes to the taper may also help, although the engineering required to achieve a perfectly flat taper may be problematic. This is an area that could use further study.

Summary

A summary of the different options is given in table 2.

Table 2: Summary of Damping Options

Solution	Sim. Effectiveness	Eng. Difficulty
Antenna	low	high
Shield	low	high
Ferrites	high	low
Insulators	medium	medium
New Taper	medium	high

CONCLUSIONS

The beam induced, transverse resonant modes inside our IVU chambers are now well understood. We have investigated the effectiveness of various methods for damping these modes and ferrite rings around the posts look to be the most promising and easiest to install. Only applying the rings to the top side of the device provides adequate damping and will make installation easier.

Future Work

Our next step is to look into producing ferrite rings that can be easily installed on our current device, We are considering 2 part split-rings that can be places around each post during a maintenance period. Thermal modelling will also need to be done to confirm that heat dissipation will not be an issue. We hope to test the design in the next year or two so that we can incorporate into future insertion device installations.

ACKNOWLEDGEMENTS

The Authors would like to thank Kai Tian (SLAC) for his valuable correspondence and suggestions regarding ferrite damping options.

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