INVESTIGATION OF TRAPPED RESONANT MODES IN INSERTION DEVICES AT THE AUSTRALIAN SYNCHROTRON

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Abstract

The Australian Synchrotron light Source has 3 variable gap in-vacuum undulators (IVUs) in the storage ring. Since installation, these devices have been the source of strong beam instabilities. These instabilities seem to behave as trapped resonant modes of very high Q and high frequency, although a definite source has not been identified. The presence of these instabilities has necessitated operating at unusually high chromaticity for much of the light source's operations. More recently transverse feedback has been able to control the instabilities and recent developments in diagnostics have allowed some investigation of the frequency and mode response of these resonances. The results of this investigation will be presented in this paper.

IN VACUUM UNDULATORS

The Australian Synchrotron storage ring contains two 3-metre long In-Vacuum Undulators (IVUs) (IVU03 and IVU13) that close down to a 6.6 mm pole gap and one 2 metre undulator (IVU05) that closes to 6 mm, supplied in 2006 by NEOMAX Co., Ltd. The undulator period is 22mm in all devices, with 89 and 134 periods in the 2m and 3m devices respectively. The transition taper is a single piece of flexible copper sheet, fixed at each end so that it flexes as the pole gap is altered. Figure 1 shows the general geometry of the magnet array inside the vacuum chamber and Figure 2 is a photo of the transition taper at minimum gap on IVU05.

INSTABILITY SOURCES

The vacuum chamber of the Australian Synchrotron storage ring is stainless steel and therefore a major source of resistive wall impedance. The impedance effects have been measured previously [1] with the strongest effect in the vertical plane due to the aspect ratio of the vacuum chamber. The resistive wall effect is fairly easily damped by transverse bunch-by-bunch feedback systems.

A much more problematic source of instabilities have been the IVUs [2]. While these devices have copper wakefield shields with flexible transitions at either end, they have been the source of strong, high frequency resonances at particular gap positions that cause primarily vertical instabilities. The high frequency nature of these instabilities has posed a much stronger challenge to the transverse feedback system. An understanding of the source of these instabilities will be important in mitigating any future problems in new IVUs.

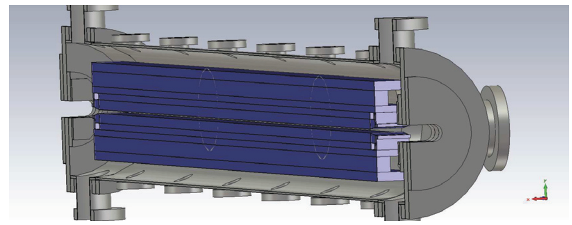

Figure 1: Geometry of the 2m IVU, in cutaway view. Transition tapers and feed-throughs are not shown.

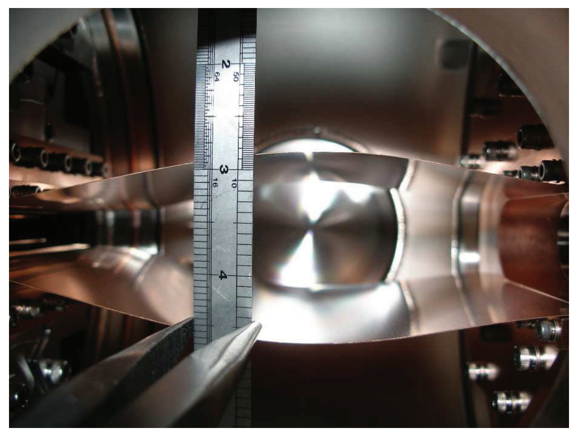

Figure 2: Transition taper view at 6mm gap on IVU5.

IVU Resonance Mapping

The onset of the observed high frequency instabilities is dependent on the undulator gap of each device. A number of resonances have been observed, typically separated by a gap width of 0.3mm, with each resonance only active over a span of tens of microns.

Attempts to map out these resonances in order to understand their source have been conducted. The procedure for mapping was to scan through undulator gaps with transverse feedback at low gain to allow instabilities to grow and then record the gap and instability mode number. The strength of these instabilities appears to drop with increasing gap, until eventually the resistive wall instability becomes dominant and further resonances become impossible to find via this technique. A more careful mapping using grow/damp and excite/damp techniques is required to fully map out the structure to larger gaps. This will be conducted at a later date after an upgrade of the transverse feedback system.

Tables 1 and 2 show the currently observed mode vs gap structures in each device. The gap values shown indicate the apparent midpoint of the resonance and there is typically a small range about these values that the resonance is present.

Table 1: IVU05 Gap Setting vs Peak Resonance Mode Number. Δ shows the gap difference between the current instability mode and the one preceding it.

IVU05 Pole Gap (mm)	Peak Instability Mode	Δ (mm)
9.27	215	
8.93	216	0.34
8.60	217	0.33
8.28	218	0.32
7.95	219	0.33
7.63	220	0.32
7.32	221	0.29
7.02	222	0.30
6.73	223	0.29
6.45	224	0.28
6.19	225	0.20
6.04	226	0.16

Table 2: IVU03 Gap Setting (mm) vs Peak Resonance Mode Number. Δ is difference in pole gap from the last instability mode.

IVU03 Gap	Mode	Δ	IVU13 Gap	Mode	Δ
7.62	195				
7.22	196	0.40			
6.77	197	0.45	6.66	197	
8.01	223		7.98	223	
7.64	224	0.37	7.61	224	0.37
7.31	225	0.33	7.27	225	0.34
6.95	226	0.36	6.95	226	0.32
6.61	227	0.34	6.60	227	0.35

The regular repetition of the instability at gaps of every 0.3 mm suggests a trapped mode resonance in the IVU chamber, with each 0.3 mm gap movement shifting the resonance frequency by 1 revolution harmonic (1.38 MHz). While IVU05 shows only one series of resonances, from mode number 226 to 215, IVU03 and IVU13 seem to also show a second series that begin with mode 197. These modes have a slightly greater distance between resonances and fall off in strength quicker.

The origin of the resonance is still not clear to us. The most obvious candidate would be the transition tapers, as they create a cavity-like shape, however the frequency change is very linear with gap which you would not expect from the distortion of the taper. Another possibility is a resonance between the magnet array which would be governed by the geometry of the vacuum chamber. It should be noted that IVU 3 and 13 (which are identical devices) show near identical mode-gap structure. This does suggest that the source has to do with the bulk geometry of the device. IVU05 exhibits a stronger set of resonances and the rest of the investigation concentrates on this device.

Transverse Feedback Mode Analysis

In September 2015 we had the opportunity to use the Dimtel bunch-by-bunch feedback system [3] for a night while it was under evaluation. It had had increased diagnostic capabilities over our current feedback system and this was used to conduct a mode growth rate scan across a range of gap values of IVU05. The pole gap was scanned in small (10-20 micron) steps and the bunch-by-bunch feedback system momentarily switched off to observe the growth of the unstable modes. An exponential fit is then made to the mode amplitude over time curve to extract the growth rate. Figure 3 shows an example of one such growth rate measurement.

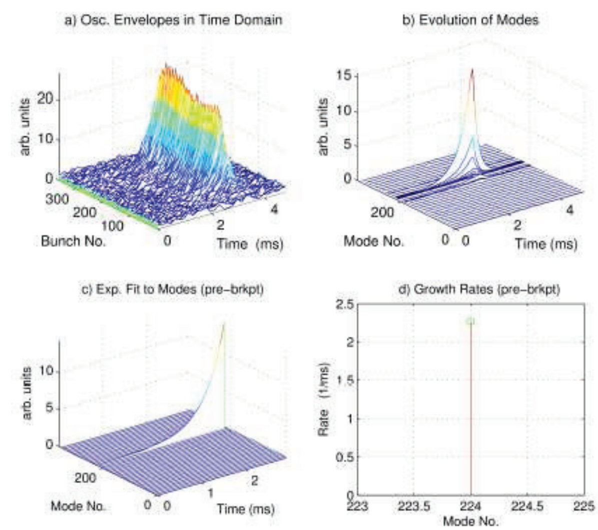

Figure 3: Grow/damp measurements using Dimtel transverse feedback system.

Putting together the results of the scan from a gap of 6.3 mm to 7.1 mm we see in Figure 4 the underlying resistive wall instability (mode 359) and 3 clear resonance peaks, of modes 222, 223 and 224.

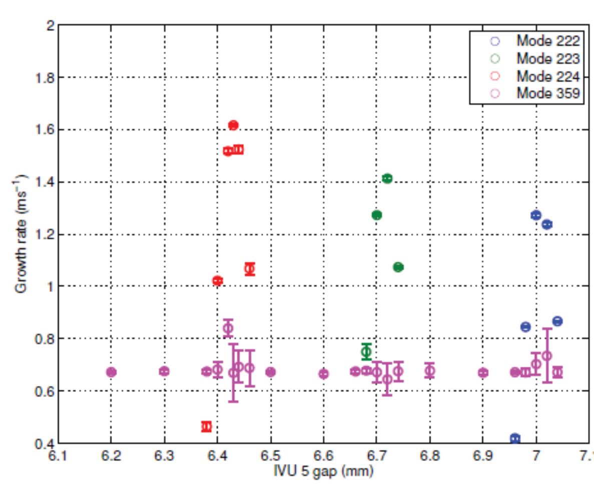

Figure 4: Instability mode growth rates for IVU05 vs gap.

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Fitting to these peaks we see in Figure 5 that the modes can be fit very accurately by second order resonances with bandwidth of 0.075 - 0.078 mm. The spacing between each mode is constant and we see that the modes get stronger at lower gaps, consistent with earlier observations. Assuming that each excited mode is separated by a revolution harmonic (1.38 MHz), we see a tuning sensitivity of 4.8 MHz/mm of gap movement, putting the bandwidth at 365 kHz.

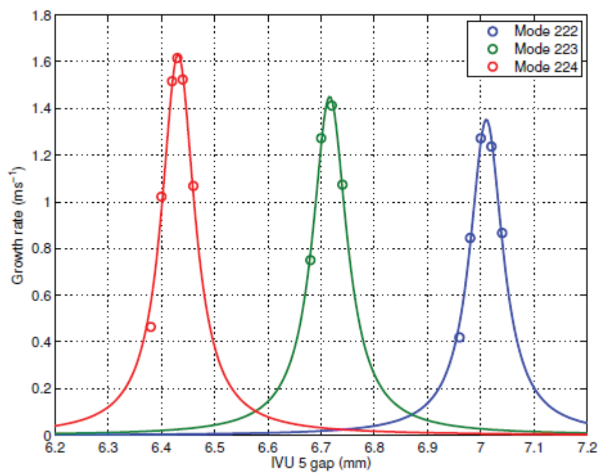

Figure 5: Second order resonance fits for modes 222 – 224.

To try and get an understanding of the fields in the IVU chamber we placed a crude coaxial cable stub antenna against a 35mm diameter glass viewing port that was present on IVU05 near the taper section of the vacuum chamber. The antenna was fed into a 8Ghz spectrum analyzer. We injected a single bunch into the ring to excite an even comb of revolution harmonics. For a given mode M, we scanned revolution harmonics located at $f_{RF} \times (N + M/h)$, where h is the harmonics number (360) and f_{RF} the ring RF frequency (500 MHz), up to 8 GHz. We then move the IVU off the mode resonance and scan again. A difference in the harmonic line amplitude should indicate that frequency was being excited and may be the source of the instability mode. Factors that complicate this measurement is that we are using missing many modes due to the beam pipe cut-off, and the relative coupling strengths and signal paths to the antenna are not known.

Figure 6 Shows the result of such a scan for mode 224 in IVU05. We can clearly see the cut-off of the viewing port window at around 2 GHz. We also see that the 7.3 GHz line has a clear increase in amplitude when the IVU gap is placed in the resonance position of 6.42 mm, which would indicate the resonance may be at this frequency. If that were true, then the previously measured bandwidth of 365 kHz would make the Q of this resonance 20,000, which seems extraordinarily high. Further measurement, involving an antenna placed inside the chamber will be made in the future to provide more information.

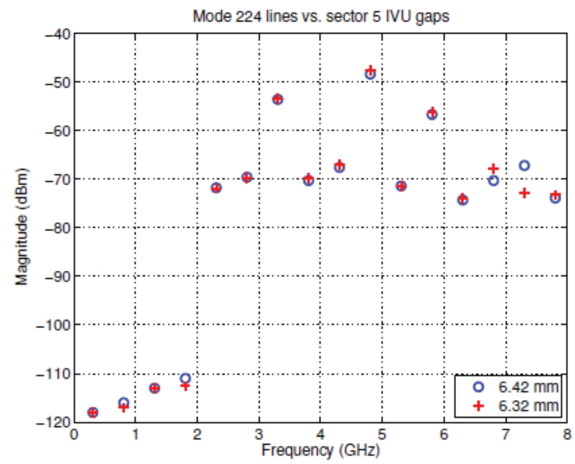

Figure 6: IVU 5 mode 224 resonance line strengths at different harmonics when on-resonance (blue dot) and off-resonance (red cross).

Field Simulations

Field simulations (using CST Studio Suite [4]) show many resonance modes with vertical fields in the beam path are possible. The frequency of these modes change with the length of the device and the gap. It may be possible that one such mode is responsible for the instabilities seen. The dependence of the frequency on the length of the device may explain the difference in resonance spectra between the 2m and 3m long devices. Computing resource constraints make a full simulation of the entire undulator device to high frequency beyond our capabilities at present, however partial simulations have shown information that will assist future investigations.

CONCLUSIONS AND FUTURE INVESTIGATION

We have observed instability modes in our IVUs that are sharp resonances. The pattern of resonances suggests it has something to do with the overall chamber geometry. Fiels simulations show possible resonances whose frequency is determined by the length and gap of the IVU magnet array. Investigations with a stub antenna and single bunch mode suggest the resonance is at very high frequency.

We are currently developing a set of directional RF antennas to be inserted into the IVU chamber and sample the fields inside during operation. we hope this will provide more information on the instability mode frequency and ways to mitigate it.

REFERENCES

[1] R. Dowd, M.J. Boland, G.S. LeBlanc, Y.-R. E. Tan, and D.J. Peake, "Impedance effects in the Australian Synchrotron Storage Ring", in *IPAC'10*, Kyoto, Japan, May 2010, paper TUPD026, pp. 1979–1981.

[2] D.J. Peake, R.P. Rassool, M.J. Boland, R.T. Dowd, and Y.-R. E. Tan, "Preliminary operational experiences of a bunch-

by-bunch transverse feedback system at the Australian Synchrotron", in *Proc. IPAC'10*, Kyoto, Japan, May 2010, paper WEPEB027, pp. 2473–2745.

[3] Dimtel, San Jose, USA, `http://www.dimtel.com`

[4] CST - Computer Simulation Technology, Darmstadt, Germany, `http://www.cst.com`

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