MEASUREMENT OF RF RESONANCES AND MEASURED IMPACT ON TRANSVERSE MULTIBUNCH INSTABILITIES FROM IN-VACUUM INSERTIONS DEVICES

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Abstract

Diamond Light Source has currently 15 in-vacuum insertion devices (ID) installed, mostly built in-house. Their measured impact on multi-bunch mode damping as a result of varying magnet gap was shown before, now we augment these with measurements of broadband frequency spectra with stored beam obtained using an antenna placed in the ID vacuum. Finally, we present off-line measurements of resonances in the ID vessel acquired using a vector network analyser and two antennae installed in-vacuum.

INTRODUCTION

With 15 in-vacuum insertion devices (ID) currently installed at Diamond Light Source (DLS) there has been a strong interest in the interaction between these devices and the stored beam, either in terms of beam dynamics or by RF heating of the structure. Some impact on beam dynamics has previously been observed at DLS and reported in changes to transverse multi-bunch damping behaviour [1, 2], but these do not provide a complete picture on potential RF resonances in general which could still be a source of heating. Other light sources have reported transverse multi-bunch instabilities [3, 4].

Following the initial observation, further experiments were performed using one particular ID which was fitted with a set of three short dipole antennae, which were installed in the same vacuum vessel as the magnet beams. Firstly, the impact of ID gap changes over the full range of 5-29 mm was recorded in terms of multi bunch mode damping times. Secondly, the spectrum received by the three antennae was recorded both with single bunch and multi-bunch fill, again for the same gap range. Finally, the S-parameters between pairs of the three antennae were measured without beam for the same gap range to indicate potential resonant modes in the structure.

DAMPING TIME MEASUREMENTS

The ability to measure damping times of multi-bunch modes is provided by the Transverse Multi-Bunch Feedback system, using functionality provided within the field programmable gate array used in the electronic feedback processor [5]. Thanks to pre-processing we are able to record, extract and store a full damping spectrum of all 936 modes in one plane within a few seconds. This short time has allowed many repeated measurements while changing the ID gap by small amounts of 20 µm at a time.

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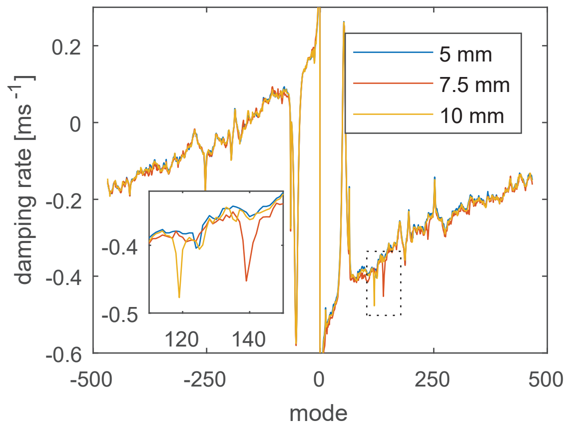

Figure 1: Damping rates for all vertical multi-bunch modes measured at 0 chromaticity and 150 mA full fill stored beam. The inset shows a magnified view of the changes related to ID gap.

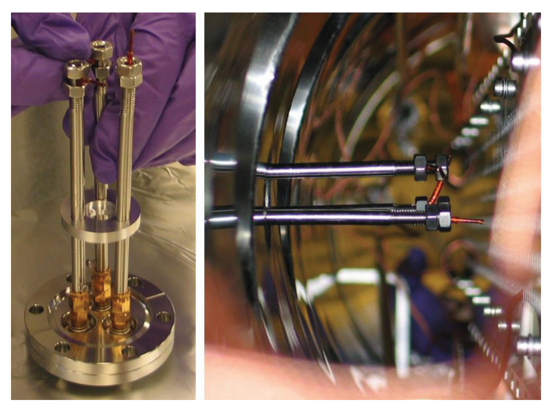

Figure 2: Left: View of the three in vacuum antennae during assembly. Right: View of the antennae installed in the ID, of which the shielding plates are visible on the right.

It should be noted that while there is evidence of some frequency changes of resonant modes (see Fig. 1), the overall effect remains small in terms of impact on damping time. Also for reasons currently not understood, only changes on the positive modes are observed while no impact on negative modes is seen [1].

ANTENNAE ASSEMBLY

These antennae had been added into the vacuum tank of the ID purposefully during its manufacturing, and feature three roughly perpendicular short dipole antennae. The antennae are manufactured from polyimide dielectric

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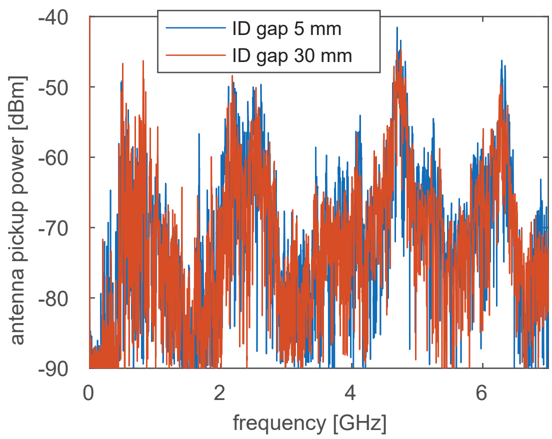

Figure 3: Spectra from one of the antennae for extremes of ID gap acquired with 2 mA single bunch stored beam.

in-vacuum coaxial cable, and have a 10 mm long section of the outer conductor removed, with the inner conductor and dielectric exposed (see Fig. 2). Short dipoles like this should provide bandwidth up to several GHz. The perpendicular arrangement of the three antennae serves two purposes: firstly as pick-ups any orientation of the electric field of resonant modes will couple to at least one of the three antennae, secondly for S-parameter measurements natural cross talk between any two antennae is minimised in this orientation.

SPECTRUM ANALYSER MEASUREMENTS

To augment the damping time measurements, a broadband Spectrum Analyser (SA) was connected to one of the three in vacuum antennae. A single bunch with 2 mA was then stored which created a comb excitation every f_{rev} = 533 kHz and the ID gap changed in steps while recording spectra. In total, 251 spectra of 30001 points were recorded at a spacing of 100 µm covering the whole 5-30 mm ID gap range. Spectra of the two extreme gap settings are shown in Fig. 3. It is evident that a rich spectrum of thousands of resonances (both narrowband and broadband) exists inside these complicated structures. At frequencies >7 GHz there was no power >-65 dBm detected. It should also be noted that no correction for attenuation in the cable was applied, which is estimated in the order of 11 dB at 7 GHz.

In user operation, DLS normally operates with 900 out of 936 bunches filled, creating an excitation spectrum dominated by the harmonics of $f_{\mathrm{RF}} \approx 500$ MHz. Consequently these frequencies stand out in the spectra in Fig. 4. The behaviour at individual harmonics is hugely varied, with dynamic changes over the ID gap range sometimes spanning 20 dB. Also there is no particular relationship of the detected power to the ID gap.

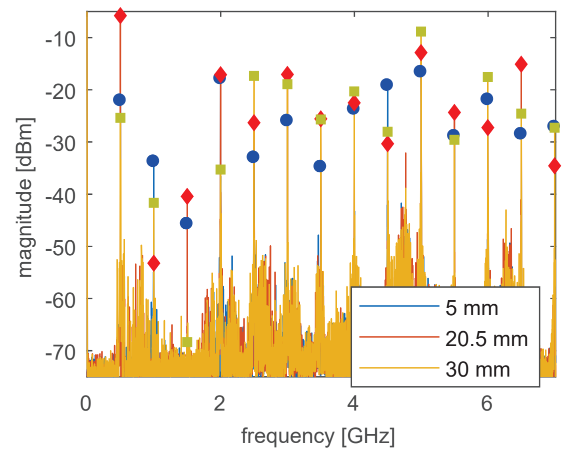

Figure 4: Spectra acquired from one of the antennae for 3 different ID gaps acquired with 300 mA stored beam in 900/936 bunches ‘user mode’.

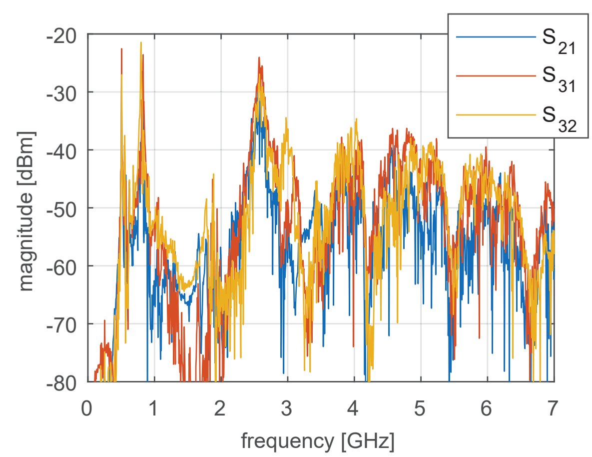

Figure 5: S-parameters acquired at the maximum ID gap with no stored beam.

VECTOR NETWORK ANALYSER MEASUREMENTS

While the spectra measurements with single bunch excitation provide a rich characterisation of an ID, they might be complicated by the changes in coupling from the beam to the structure, in particular since perforated shielding plates are mounted on the left and right of the magnet beams. The perforated plates will change their overlap as the ID gap is adjusted.

As an alternative approach, we thus measured the S-parameters between the three antennae of a fully assembled ID including shielding plates using a Vector Network Analyser (VNA) as used in [4]. These tests were performed without stored beam, so they show only the RF resonances of the structure (see Fig. 5), but give no indication of the coupling of these to the beam. Note that the cables were corrected for using an estimated length and data sheet attenuation function.

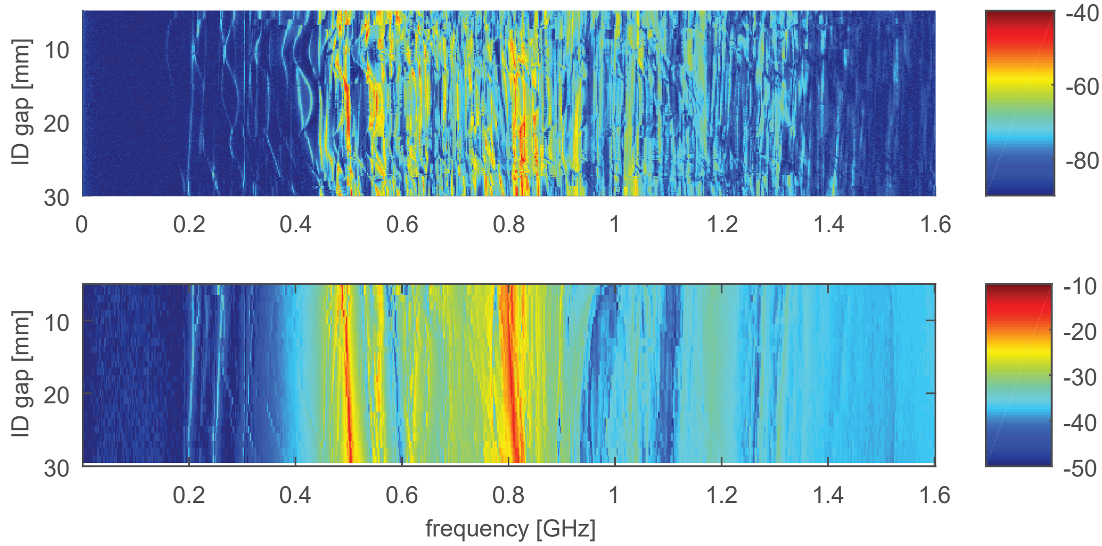

Figure 6: Comparison of single bunch spectra (colour-map in dBm) and S21 (colour-map in dB) over the same gap and frequency range.

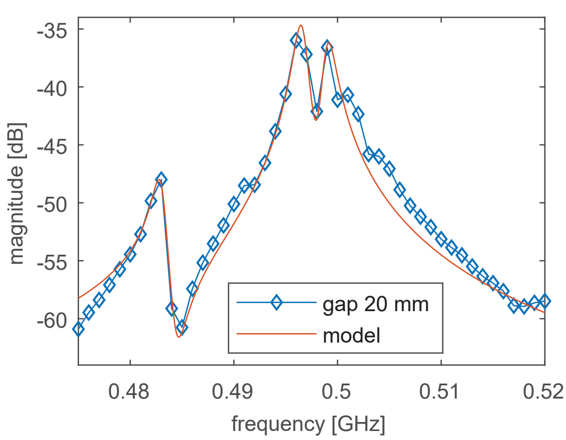

Figure 7: Measured S_{21} fitted over a small frequency range with a model of three second order resonators of f_0=483 MHz, 496.56 MHz and 499 MHz with suitably chosen amplitudes and phases.

COMPARISON OF SA AND VNA MEASUREMENTS

Figure 6 shows a like for like comparison of single bunch spectra and S_{21} over the ranges of 5-30 mm ID gap range and 0-1.6 GHz, which was chosen to give good resolution on the VNA. From this it is evident that the resonant features move in frequency as the ID gap is changed. On the other hand, the single bunch spectra show the influence of coupling changes on these moving resonances, making the picture even more complicated to interpret.

For instance, the S_{21} measurement shows a resonance near 500 MHz precisely aligning with f_{RF} near the 20 mm ID gap. As this is far from the typical operating range of 5-8 mm no adverse side effects are known of this coincidence so far.

It is also possible to fit S_{21} at 20 mm ID gap over a narrow range of frequency with a model consisting of several second order resonators with suitably chosen amplitude and phase, as done in Fig. 7. Notably, all three resonators in this model are of reasonable quality factor $Q_0 = 350$.

This kind of 'mode factoring' could be generalised to some degree and be based on higher resolution S-parameter data. Such a measurement approach would deliver at least some insight into built ID structures, at the small cost of an SMA vacuum feed-through and some short pieces of in-vacuum coax wire. It would seem this is a much easier to realise approach than attempts to model a full ID in its entirety in wake field analysis codes, which would require memory sizes still at the limit of availability while still suffering from absence of details not captured in the manufacturing drawings.

CONCLUSION

These measurements show that there is a much richer ensemble of RF resonances inside an ID vacuum vessel, certainly richer than we previously assumed [6], and in line with what should be expected from such a complicated structure. There are some low frequency resonances (the lowest near 200 MHz) with $Q_0 \approx 350$, and a significant resonance near 500 MHz which in our particular example just misses the f_{RF} at operational gaps, followed by an uncountable number of higher resonances.

ACKNOWLEDGEMENTS

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