INITIAL WORK ON THE DESIGN OF A LONGITUDINAL BUNCH-BY-BUNCH FEEDBACK KICKER AT DIAMOND

A. F. D. Morgan, G. Rehm
Diamond Light Source, Oxfordshire, UK

Abstract

In 2017 it is planned to install some additional normal conducting cavities into the Diamond storage ring. There is some concern that higher order modes in these devices could cause longitudinal instabilities in the beam. In order to deal with this potential problem we have started work on designing a longitudinal bunch-by-bunch feedback system. This paper will concentrate on the design and simulation of the kicker cavity, which is of the overloaded cavity type.

We chose the overloaded cavity type due to its lack of HOMs, and the wide bandwidth.

INITIAL SYSTEM TESTS

In order to investigate the type of instability we would expect to dominate on the Diamond machine, and to test the capability of our existing sampling electronics, we decided to use the already installed stripline kickers which are used for the transverse feedback system. By operating them in common mode rather than the usual differential mode it is possible to make them act as a weak longitudinal kicker. In order to achieve this, we replaced the existing RF output chain of the transverse multibunch feedback system (TMBF) with the arrangement shown in Fig. 1. Also the striplines were driven in the range 1.5-1.75 GHz rather than the 0-250 MHz they were originally designed for.

For this setup we are only using a mixer as a modulator, thus we are exciting both the upper and lower sidebands. In normal operation, due to our momentum compaction factor (α) of 1.7×10^{-4} and our relativistic gamma factor (γ) of 5870, we are operating above transition ($\eta > 0$) in terms of the Robinson criterion, as shown in Eq. (1).

$$\eta = \alpha - \frac{1}{\gamma^2} \tag{1}$$

This means that only the upper sidebands are potentially unstable [1,2]. Correcting the lower sidebandes is unnecessary, however, for these tests the trade off against simplicity was deemed worth it. In the final system we envisage using IQ mixing to drive single sideband only, which is more efficient and means we are only affecting the modes which the machine is driving towards instability.

For the data capture part of the system, we used our existing frontend and our spare transverse data capture system [3]. The frontend timing was adjusted to sample the zero crossing of the bunch signal in order to maximise the phase sensitivity (and thus the longitudinal position) for each bunch.

With this modified setup we proceeded to run grow/damp studies similar to ones we have done previously for transverse measurements [4], where we excited each mode of oscillation of the bunch train individually, turned off the excitation and recorded the decay. By fitting this to an exponential decay we were able to obtain damping rates on a mode by mode basis.

Our results (Figs. 2 and 3) showed that, unsurprisingly, we are currently comfortably far from a longitudinal instability threshold for normal operating conditions. The most unstable mode would require a beam current of ~ 550 mA to move into an unstable regime. There is a large increase in the noise around mode zero. this is due to the fact that our striplines become particularly weak at those frequencies

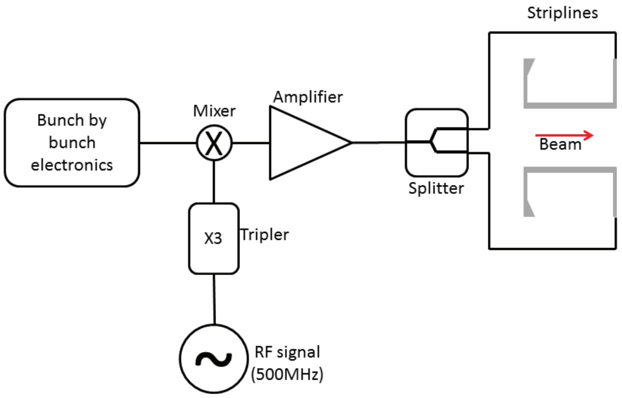

Figure 1: Basic schematic of the modified RF output chain of the TMBF.

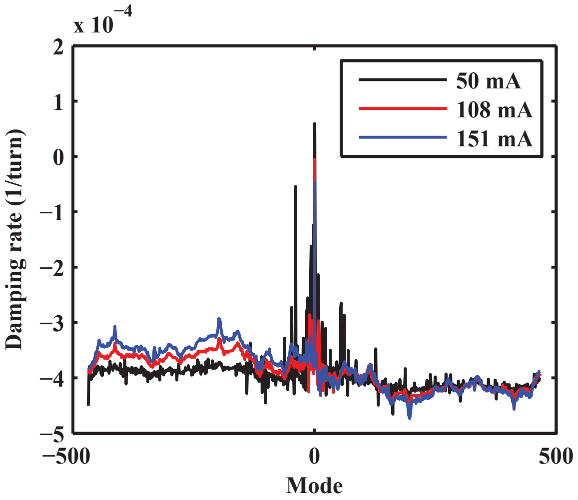

Figure 2: Damping rates for all modes at a range of stored beam currents.

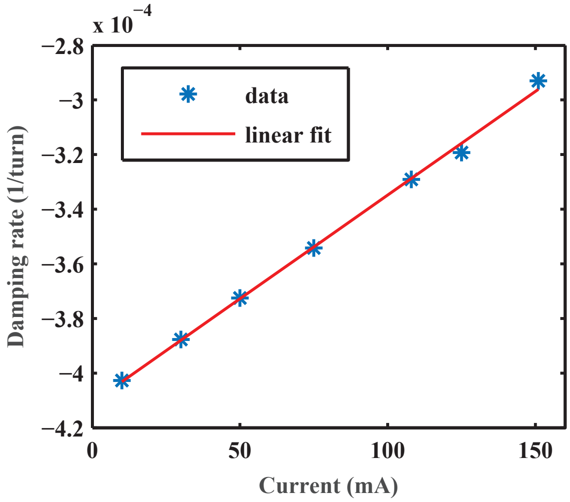

Figure 3: Damping rate against stored beam current for the least damped mode.

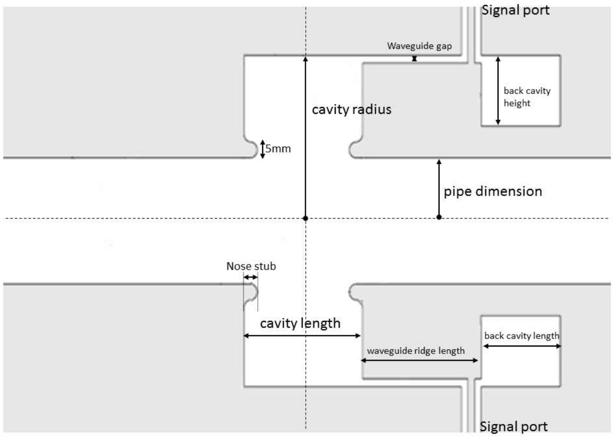

Figure 4: Longitudinal cut of the cavity geometry.

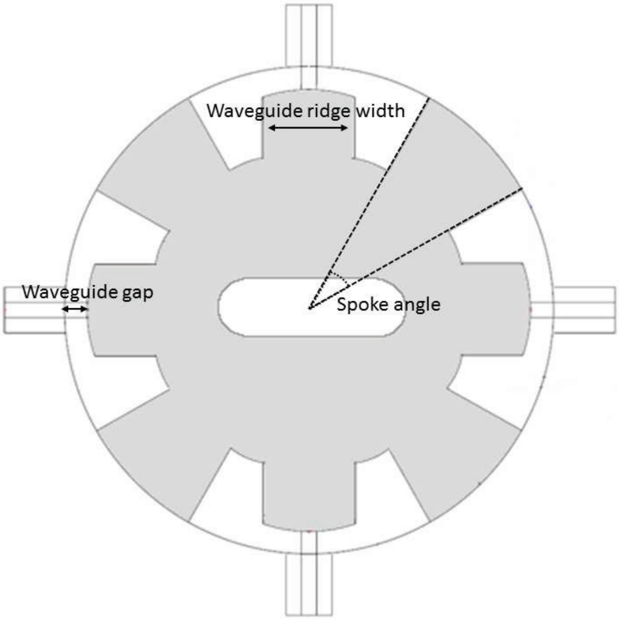

Figure 5: Transverse cut of the cavity geometry.

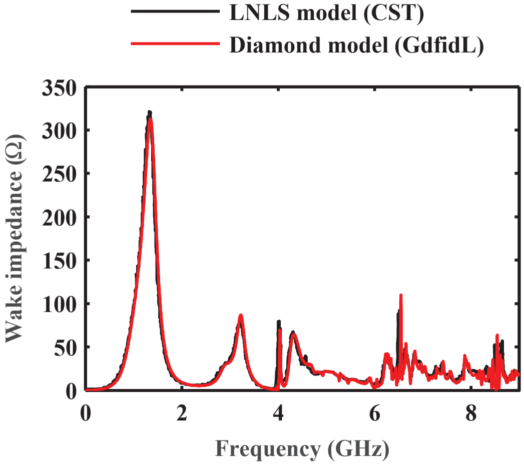

Figure 6: Comparison with the LNLS data.

More studies are planned to investigate the instability thresholds under different operating conditions.

In this benign environment, the stripline kickers would suffice as we are only measuring and need just a small perturbation to the beam. However, this small kick would be insufficient to provide any significant damping of instabilities.

Thus, having tested the basic system, we need to design a longitudinal kicker which is better suited to the expected requirements.

SIMULATION OF THE KICKER

The base design was an overloaded cavity, as used in DAΦNE [5], LNLS [6] and many others [7–9]. An example of which is shown in Figs. 4 and 5.

In order to determine the most suitable parameters, several criteria have to be considered. Firstly, the resonance frequency needs to be correct, in our case the upper sideband of the third RF harmonic is our target, giving a centre frequency of 1.64 GHz. Additionally, the power loss into the structure has to be as low as possible. Sharp resonances in the wake impedance want to be minimised otherwise large variations in heating for different operating conditions may be seen. There also have to be no hot spots, and, to reduce the requirements on the drive amplifiers, the shunt impedance needs to be a high as possible.

We based our initial design on the LNLS version of the cavity [6]. Initially we replicated the design, which gave a useful check as well as an interesting comparison of the CST code used by LNLS, and the GdfidL code used by us. Figure 6 shows the comparison of the wake impedance.

Once we had a suitable initial model, we had to consider how this structure would work installed in the Diamond ring. Being as our pipe dimensions are not the same as the initial model we have to either add tapers to match the

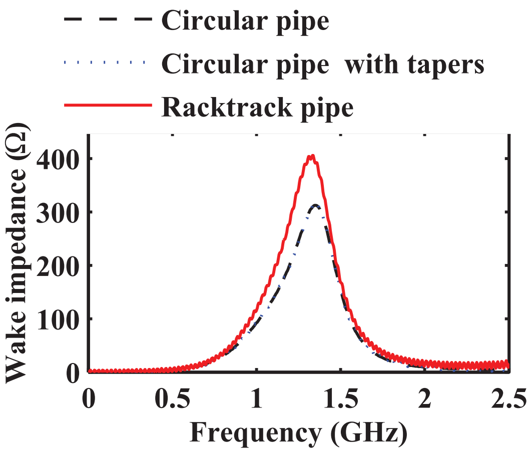

Figure 7: Change in the wake impedance due to pipe cross section changes.

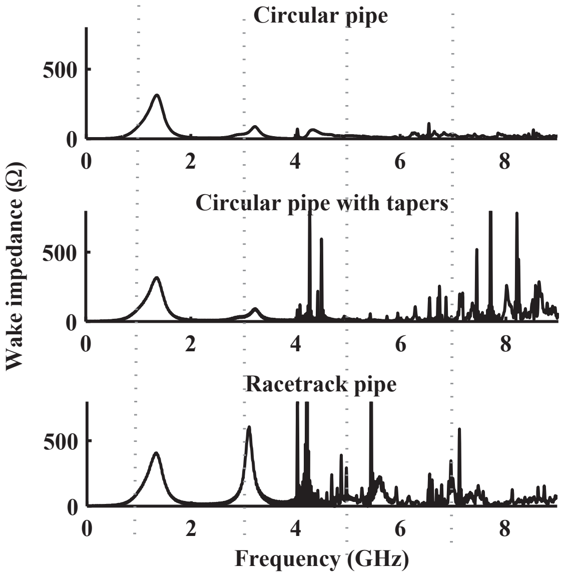

Figure 8: Real part of the wake impedances for different pipe shapes.

external beam pipe shape, or use the racetrack beam pipe cross section throughout the structure. The first case has the advantage of maintaining the rotational symmetry of the cavity, but at the cost that it introduces an additional shallow cavity which would negatively impact the wake loss factor. Conversely, maintaining the racetrack cross section throughout the structure would probably have a reduced wake loss factor but may introduce unwanted features in the wake impedance.

Changing the pipe to a racetrack has only small effects below 2 GHz which can be compensated for with other adjustments to cavity geometry (Fig. 7).

When we look at the wake impedance data we need to consider a much broader frequency range, as the beam can excite up to frequencies of around 20 GHz.

As Fig. 8 shows, although the main operating band below 2 GHz is largely unaffected by the changes in pipe cross section. Both the addition of the taper or the change to a racetrack pipe add new unwanted resonances. The resonances in the taper model are broadly what would be expected from a simple pipe tapering down, as illustrated in Fig. 9, thus the details of the cavity are not dominant.

However, in the racetrack pipe model all the resonance are due to the cavity itself. The new resonances appear as the new beam pipe is smaller and so resonating modes which were well coupled to the larger circular pipe, with its lower cutoff frequency, are unable to couple out of the structure with the smaller pipe in place. This also explains why the resonances stop just above 7 GHz. This is the cutoff frequency of the racetrack pipe for the modes present in the structure.

Using the wake loss factor as a metric, the taper causes a rise from 520 mV/pC from the initial model, to 806 mV/pC. The racetrack model by comparison causes a rise to 1250 mV/pC. Thus in this form, the taper solution would be preferable. However some effort was spent identifying and understanding the structural causes of the racetrack model resonances, as these may be able to be reduced or eliminated with small design changes to the cavity.

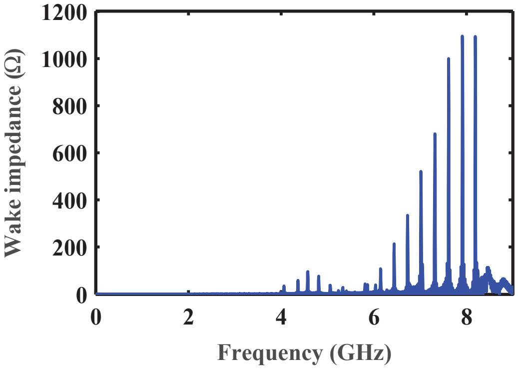

Figure 9: Real part of the wake impedance for the shallow cavity made by the tapers.

In order to understand the behaviour of the main cavity a model containing just the pipe and cavity was constructed. The results are shown in Fig. 10.

The line of the third harmonic of the cavity is one of the largest of the newly introduced resonances. In order to deal with this the waveguide structure needed to couple out lower frequencies. Ideally we want to couple out all frequencies above the bandwidth around the fundamental cavity resonance. As this coupling structure from the cavity to the signal port is fundamentally a ridged waveguide, one would expect that the ridge height would have the most impact on the cutoff frequency. A simulation was run where the ridge height was increased such that the gap between the ridge and cavity wall was reduced from 5 mm to 1 mm.

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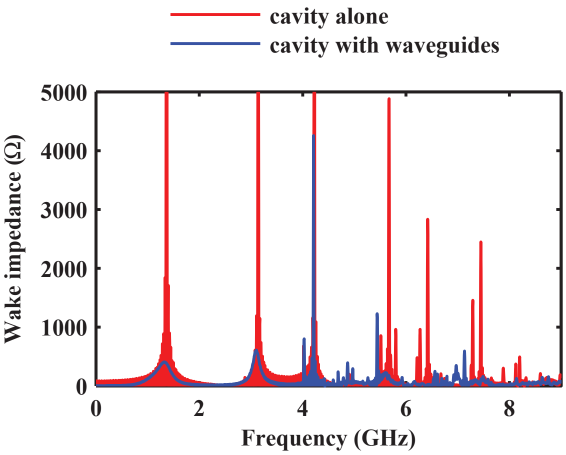

Figure 10: Comparison with and without waveguides.

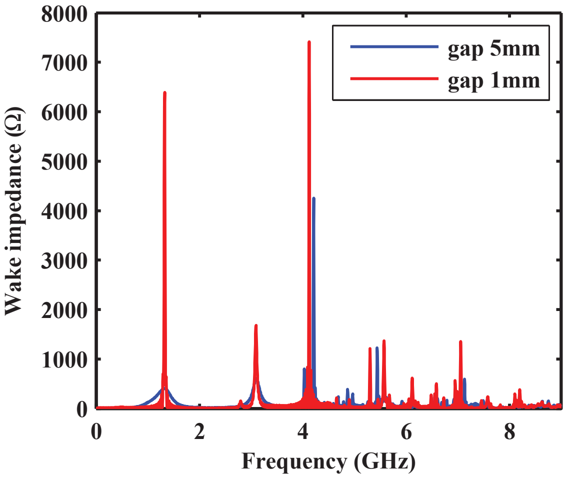

Figure 11: Comparison of the original racetrack model, and one with a reduced gap.

The wake impedance of that simulation is shown in Fig. 11. The resonance at 4.2 GHz is still strongly present which indicates that the cutoff was not lowered enough. It also has the unwanted effect of reducing the bandwidth of the cavity. A more thorough investigation was required.

To that end, a series of simulations was run sweeping various dimensions of the waveguide structure (Figs. 4 and 5). Initially we just looked at how the main design resonance reacted to these changes. For most parameters the design frequency was largely insensitive to changes, with 5 mm changes leading to a few GHz frequency shift. The exceptions were the length of the nose stub, and the waveguide ridge width and height.

Looking more broadly at the higher frequency resonances, the dimensions of the back cavity has quite some impact in the range 4 GHz to 5.8 GHz, as does the nose stub length. A new model with a longer nose stub and a smaller back cavity was tried in an effort to reduce the amplitude of the resonances generally and so bring down the overall wake loss factor.

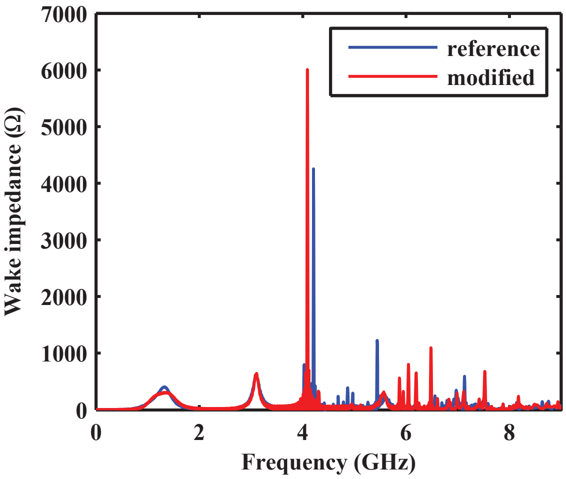

Figure 12: Comparison of the original racetrack model, and new design.

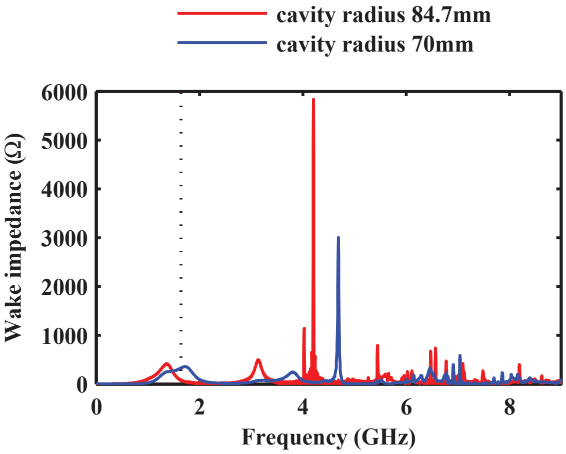

Figure 13: Comparison of the original racetrack model, with a smaller cavity design.

As Fig. 12 shows, the family of resonances around 5 GHz have been moved to be around 6 GHz. Unfortunately there is also an increase in the amplitude of the third harmonic cavity resonance at 4.2 GHz, which means that the wake loss factor is largely unchanged.

The next step was to modify the cavity radius in order to move the main resonance frequency from 1.35 GHz to 1.64 GHz. By moving the fundamental to a higher frequency we aimed to move the 3rd harmonic above the cutoff for the extraction waveguides.

As Fig. 13 shows, modifying the cavity radius alone is not sufficient. There is a shift of the main peak to 1.64 GHz (as shown by the dotted vertical line) however the bandwidth needs to be optimised. The strong third harmonic line has shifted to higher frequency. Unfortunately it is still below the cutoff of the ridged waveguide structures. Clearly further work is needed to optimise the design. One option is to change the resonant frequency to work around a higher RF harmonic.

CONCLUSION

We have demonstrated a longitudinal analysis system using our existing installed striplines. The development of a longitudinal kicker to enable the operation of a multibunch feedback system is progressing. Initial studies have shown that the modifications required from the circular symmetric model to enable installation of such a cavity into the Diamond ring all introduce unwanted sharp resonance lines. Although small modifications to the existing design can impact the behaviour above 4.5 GHz, the third harmonic line of the cavity is trapped in the structure. Further work is needed to improve the coupling out of this cavity harmonic.

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