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DESIGN AND PROTOTYPING FOR DIAMOND-II STRIPLINE KICKERS

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Abstract

Diamond-II will require two types of stripline kickers during normal operation: the kicker actuators for the transverse multi bunch feedback system; and the injection stripline kickers which enable transparent injection. Both are very similar in design as they need to kick individual bunches without disturbing the following bunches. The main difference is the voltage requirements. The feedback kicker is expected to be driven with a maximum peak voltage of 100 V using a broadband power amplifier, whereas the injection stripline kicker is driven with a trapezoid voltage signal with a maximum peak voltage of 20 kV using a dedicated power supply with 1.6 ns rise and 1.2 ns fall times. This paper will describe the design and prototyping for both stripline kickers along with discussion of the required steps to get to final designs for each type.

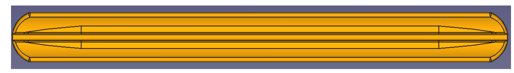
BASIC DESIGN CONSIDERATIONS

As with all Diamond-II [1] vacuum components, there is a desire to improve or at least match the performance and beam impedance of the design used in the current Diamond machine [2]. Higher impedance can reduce instability thresholds and generate localised heating as well as increasing the load on the RF system [3]. Reducing the beam impedance is particularly important as the injection kickers are additional components, and the existing feedback kickers are thought to be a significant contributor to the overall impedance budget of the existing Diamond machine.

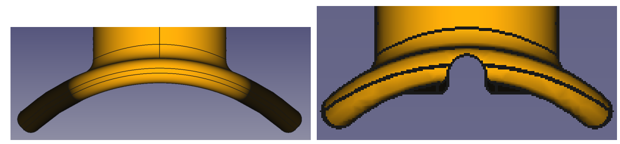
Both stripline designs are similar in that they comprise of two copper parallel plates running either side of the electron beam [4]. These are inside a steel vessel shaped to minimise the beam impedance and form a 50 Ω transmission line with the blades. Short counter-propagating pulses are sent along these plates as a single electron bunch passes between them and the field interactions have the effect of giving the electron beam a transverse kick [5–7]. In both cases simulations indicate the beam induces 300-900 V depending on operational mode so protection of the driving circuits needs to be considered.

All the electromagnetic (EM) design work was done using GdfidL [8]. For the initial theoretical designs, where considerations such as buildability are ignored, the main differences are the blade design. The starting point is to have the beam facing surface of the blades match the inner surface of the circular beam pipe which would be in place otherwise (see Fig. 1). This reduces the geometric impedance. The different locations of the striplines in the storage ring lattice define different beam stay clear and shadowing from synchrotron radiation. Therefore the injection stripline blades needed to have notches running down their length to remove the risk of heating due to direct impingement of synchrotron radiation.

(a) Feedback kicker: Beam facing surface.



(b) Injection kicker: Beam facing surface.



(c) Feedback kicker: end view. (d) Injection kicker: end view.

Figure 1: Geometry of the kicker blades.

For the injection kicker there was also a focus on the field flatness near the centre of the pipe aperture. This lead to the addition of a flat running down the length either side of the notch (shown in Figs. 1b and 1d). The high voltage of operation for the injection kicker required consideration of arcing thus care had to be taken that there were no sharp edges and that there was certain minimum distance between surfaces.

DEVELOPING BUILDABLE DESIGNS

Moving from theoretical designs to full mechanical designs meant we had to care about manufacturability, assembly, adding additional supports due to assembly forces or gravity. For most things the required changes were benign in terms of the impedance as one can see in Figs. 2 and 3 for the feedback and injection kickers respectively. The beam impedance has some changes between the simpler theoretical models and the more detailed mechanical models notably a reduction between 4 and 6 GHz and some frequency shifting in the 7-9 GHz region but is broadly the same.

Feedback Kicker

In the case of the feedback kicker a significant reduction in beam impedance over the existing Diamond design can be seen across the entire frequency range up to the waveguide cut off frequency of 10 GHz (see Fig. 2).

Supporting the stripline blades caused significant design challenges. The addition of flanges which are needed for assembly create a small cavity. The support design was prone to RF heating due to the support screws acting as antennae and coupling power from the main chamber into these small cavities. Over several design iterations we were able to bring this unwanted coupling down to 0.5 W which only generated a few degrees of temperature rise.

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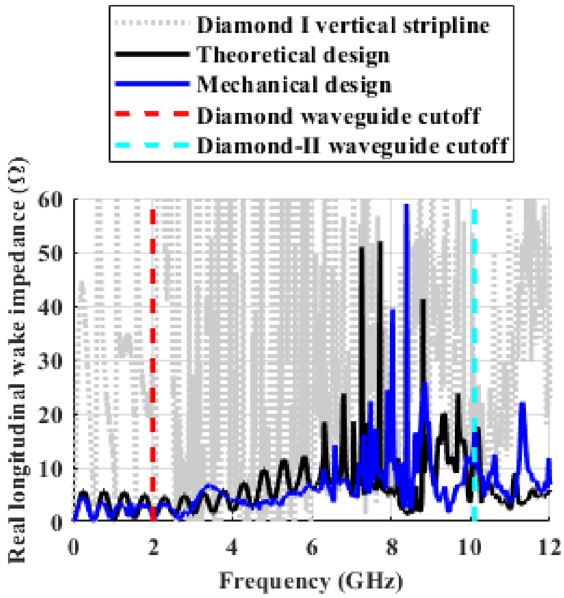

Figure 2: Impedance of the feedback stripline design from the original Diamond design to the full mechanical design of the prototype.

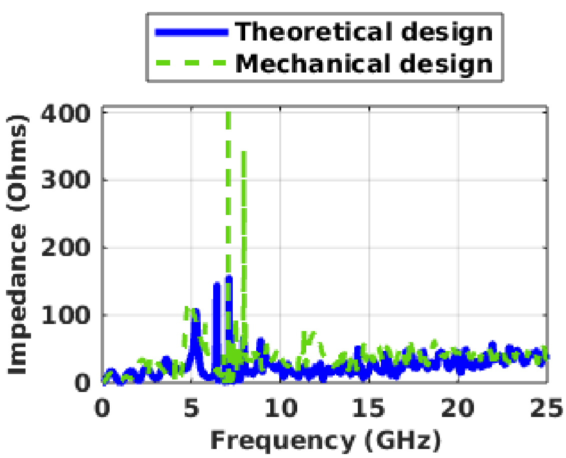

Figure 3: Wake impedance of the injection kicker.

The most significant impact of the move to a more realistic design was that the reflection at the signal ports was increased meaning it was less efficient to inject signals into the structure (see Fig. 4). However for the feedback striplines this means that the Diamond-II design will be very close to the existing Diamond design and so is still acceptable.

Injection Kicker

The mechanical design of the injection kicker is less advanced and there are more differences compared to the theoretical design. In particular there is a separation of functions for RF shielding and vacuum containment (Fig. 5). The main body will be a two skin design whereby the inner skin will define the RF environment that the beam sees, but then an outer chamber will define the vacuum interface. Also two set of blades will be in one chamber. This then leads

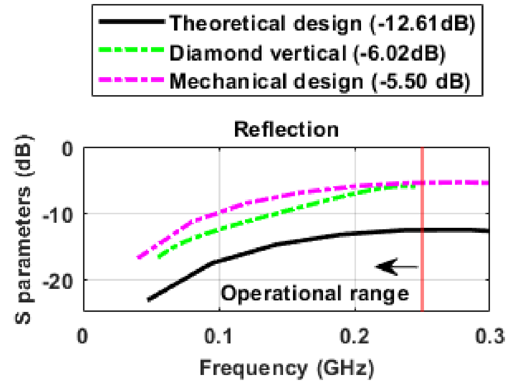

Figure 4: S-Parameter simulations of the expected reflection at the signal ports.

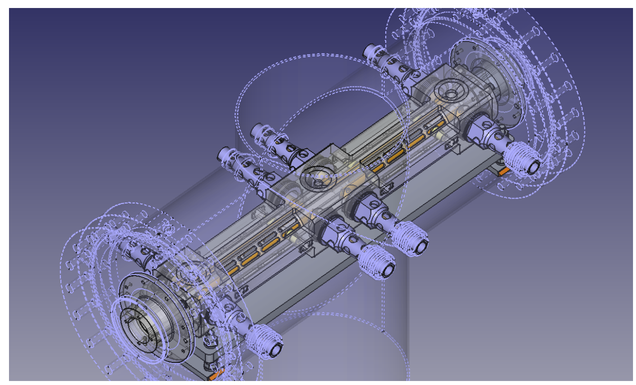

Figure 5: A single injection kicker module containing two sets of stripline blades.

Table 1: Longitudinal Wake Loss Factors (Simulated Bunch Length 16.7 ps)

	Design	Wake Impedance (mV/pC)
Feedback kicker	Diamond	827
	Theoretical Diamond-II	191
	Mechanical Diamond-II	187
Injection kicker	Theoretical Diamond-II	391 * 2
	Mechanical Diamond-II	960

to further considerations such as the longitudinal coupling between blade sets and the usual balance between RF shielding and vacuum pumping requirements. In this case the impedance for the mechanical design is currently significantly higher than the simpler theoretical design and further work is needed to reduce it (see Fig. 3 and Table 1).

PROTOTYPE TESTING

A prototype design was developed to allow testing in the existing Diamond machine. Due to space considerations the main vessel is very similar to the feedback kicker while the blade geometry is close to the injection kicker due to the

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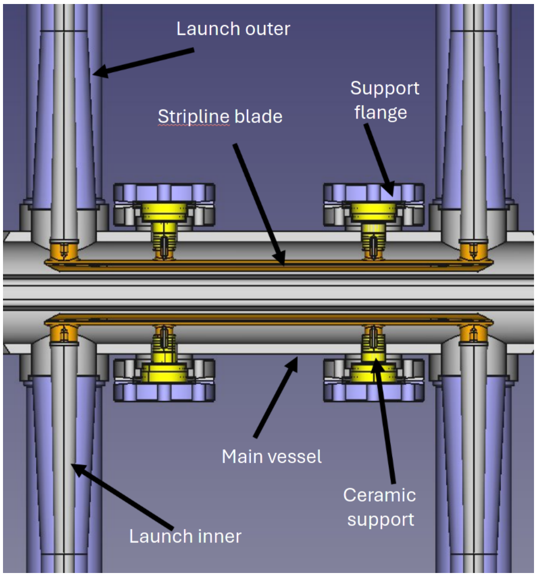

Figure 6: Geometry of the kicker prototype.

installation locations. Figure 6 shows a cut away view of the prototype kicker design.

The primary uses for this prototype were to validate the simulations, validate the kick performance and identify if there were any problematic heating issues.

Before installation S-parameter measurements were taken and these compared well to the simulations. This gives us confidence in the simulations for the final designs. The kick performance showed expected behaviour up to 5 kV and more detail can be found in [6].

Thermal Behaviour

From the EM simulations we can extract the energy deposited into each component and convert that into the expected power deposited for 300 mA operation. We can estimate the stable temperature by balancing the power deposited with the black body emission. Figure 7 shows the comparison of these simple models to measured data. For the geometrically simple cases e.g. the main vessel, the behaviour is very similar with an offset of a few °C. The more complicated case of the support flange shows the limitation of the simple model where we get a discrepancy of around 10 °C. More accurate thermal simulations have been done for some models particularly when working on the support heating issue, however this more basic approach allows for faster design iteration while having the more accurate simulations available for targeted studies.

From EM simulations of the beam induced signals we expect 13 W to be transmitted down the beam pipe in each direction, while 30 W is transmitted though each signal port, of which a fraction is deposited. Finally there is an expected 5 W of loss into the vacuum structure (see Table 2).

From measurements of the cooling circuit, 125 W is taken away from the main vessel body and signal feedthrough flanges. This implies that most of the energy passing through the feedthroughs is being deposited. This is not too surprising as the frequencies of the beam induced signals are much higher than 7 GHz which is the upper frequency the feedthroughs are specified for.

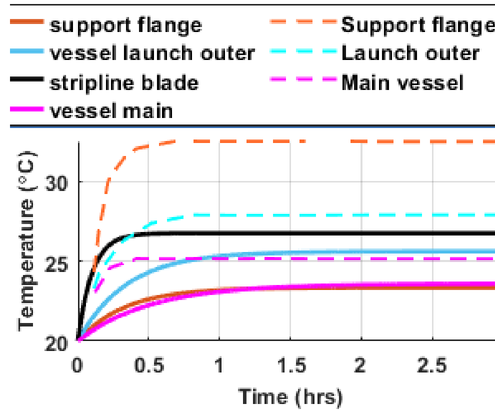

Figure 7: Comparison of measurements (dashed) to simulated thermal response using a simple balance of power deposition and black body emission (solid).

Table 2: Simulated Thermal Results for 16.7 ps Bunch Length

Component	Power Deposited (W)	Stable Temperature (°C)
Beam port	12.72	–
Signal port	30.51	–
Vessel	1.46	24
Launch outer	0.44	26
Stripline blade	0.25	27
Support flange	0.09	23
Launch	0.05	23

The thermal response to changes in beam current was assessed and showed a non linear dependence. This suggests it was due to RF fields rather than synchrotron radiation where a linear response would have been expected [3].

CONCLUSION

The kicker prototype has validated the blade support design which will be used in the feedback stripline. It has also validated performance of the blade design as an injection kicker (up to 5 kV). Thus, the feedback kicker design will look very similar to the injection kicker prototype but with the blade details for the feedback as described. The stripline blades of the prototype are very similar to the injection kicker and so this element of the design can be considered validated. However more work is needed to validate the full two set injection module.

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