A FAST QUADRUPOLE MAGNET FOR MACHINE STUDIES AT DIAMOND

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INTRODUCTION

Fast quadrupolar magnets (FQM) have been demonstrated in various schemes for increasing the coupled bunch instability thresholds [1] [3] [8], and for measuring the tune shift of transverse quadrupolar oscillation [5] [6], thus probing the transverse quadrupolar impedance [7]. Operationally they have been used to suppress quadrupole mode instabilities on injection at several machines [2] [4].

Due to machine upgrades, a ceramic vessel installed in the Diamond storage ring has become temporarily available for use. We decided to take advantage of this situation by designing and installing a simple air core quadrupole magnet which can operate at the fundamental quadrupolar frequencies for the horizontal (217kHz) and for the vertical plane (384kHz), as well as at the revolution frequency of the machine (533kHz).

Using this magnet we hope to be able to probe hitherto unexplored behaviours of the Diamond machine with the aim of improving our understanding of non centre of mass motions of the beam.

DESIGN AND REALISATION

After assessing several different coil geometries in a 2D EM simulation program a simple solution of two flat coils, on the top and on the bottom of the ceramic vessel was chosen. By driving the current in opposite directions in the two coils a quadrupolar field can be generated. Figure 1 shows the expected field distribution.

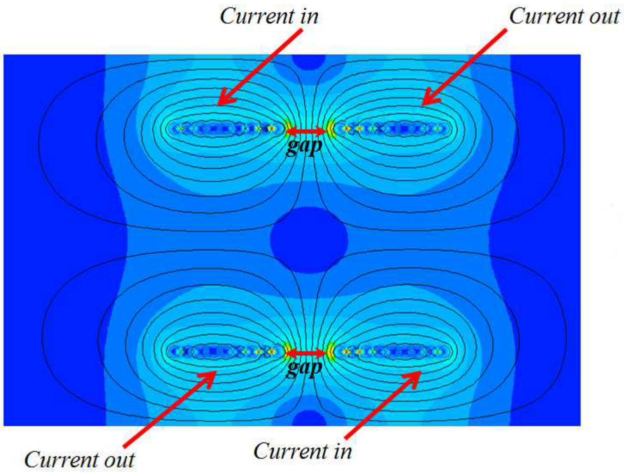

Figure 1: Simulated geometry of the magnet showing the expected quadrupolar field distribution.

The simulations showed that there should be as may turns as possible in order to increase the magnetic field, and also there should be as small a gap along the centre as possible in order to have a high field gradient. The number of turns on each coil was limited by the available space, and the wire radius set practical limits on the centre gap. The final magnet ended up being a pair of 14 turn coils with an 8mm centre gap, made of 2mm diameter enamelled copper wire.

Using these parameters to inform the model we calculated the horizontal and vertical field gradients as being 61mT/m and 64mT/m respectively (Fig.2). These field gradients are sufficient to drive growth and overcome radiation damping.

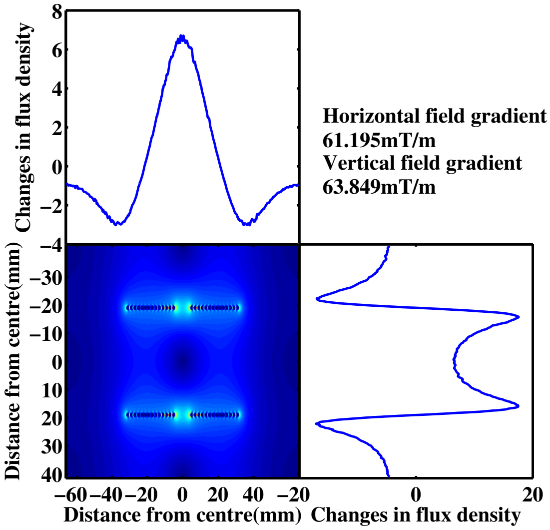

Figure 2: Simulated field gradients of the final magnet.

The coils were bonded in place on non-conductive boards. Using a simple frame, the boards were mounted around the ceramic vessel, as shown in Fig.3.

We planned to use an RF 50Ω amplifier as the power source. In order to match it well to the coils and so maximise the current flowing we decided to drive the coils as part of a resonator circuit. However this also has the effect that the system becomes narrow band and needs to be tuned to a frequency of interest. There are currently 3 operating modes, being tuned to either the vertical or horizontal quadrupole resonance frequencies to enable studies of tune shifts, or tuned to the revolution frequency in order to investigate transverse multibunch instability thresholds. In order to switch modes we change resonant circuits.

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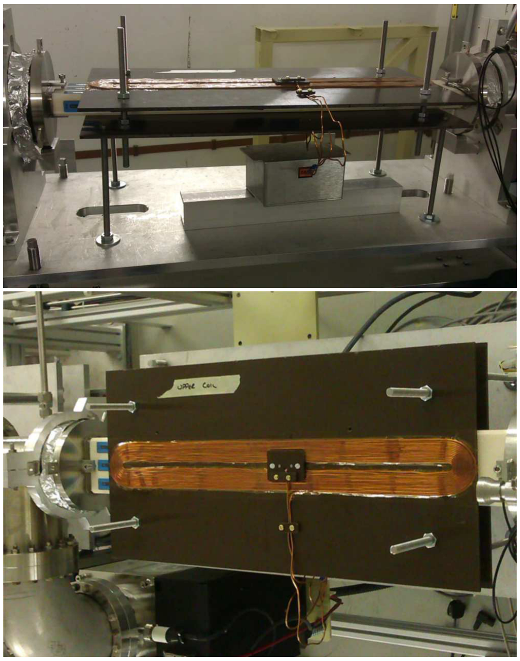

Figure 3: The fast quadrupole magnet in situ.

In order to go from simulation to a practical, tuned magnet, we followed the following procedure. First we simulated and build a test resonant circuit. The EM simulation gave an estimate of the resistance and inductance of the coils but did not include any effect from the ceramic vessel and the associated metallic coating. The circuit was assembled in situ around the ceramic vessel and the resonant frequency was measured. The circuit simulation was then adjusted to bring its predictions in line with the measured data. This allowed us to characterise the coil/ceramic subsystem as a set of resistance and inductance values.

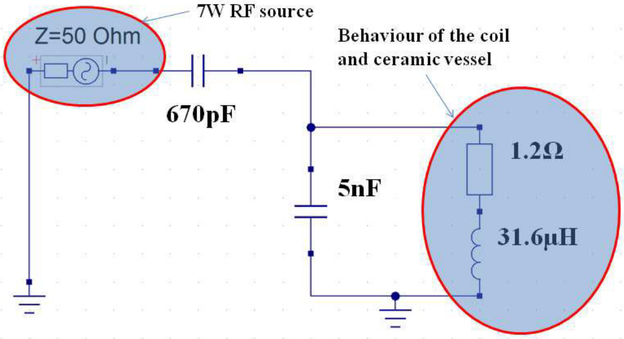

Figure 4: Circuit tuned for the vertical quadrupolar resonance.

Once the system had been characterised, the three desired resonant circuits were designed such that the system would resonate at the desired frequency in situ. An example circuit is shown in Fig.4, and a comparison of simulation and measurement is shown in Fig.5.

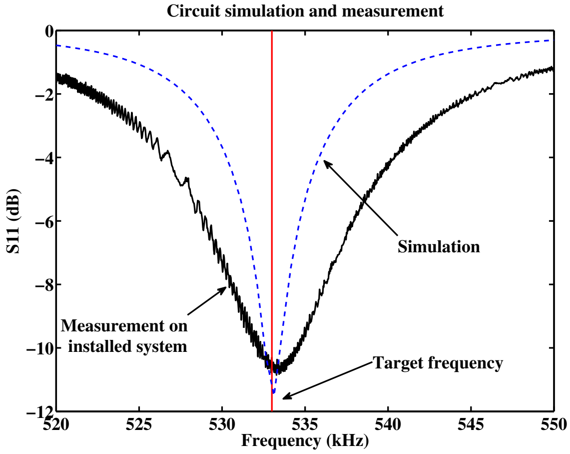

Figure 5: Simulation and measurement for the 533kHz resonator circuit.

INITIAL RESULTS

In order to test the system we tuned it to the vertical quadrupole resonance. The machine was set up with low current to reduce any detuning effects. The coupling was also lowered in order to achieve a reduced vertical beam size, which would make us more sensitive to any changes in beam size.

We measured the effect of the new magnet by recording the vertical beam size as reported by our two pinhole cameras and the results are shown in Fig.6.

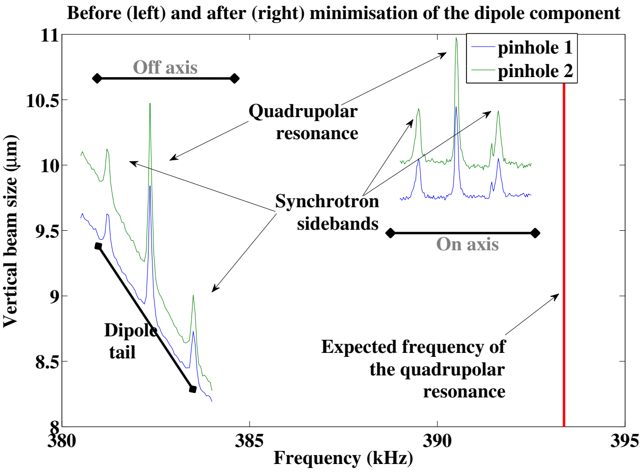

Figure 6: Initial results showing clear quadrupole resonances with associated synchrotron sidebands and how they relate to the expected quadrupolar resonance frequency.

We scanned the excitation frequency of the fast quadrupole magnet around twice the betatron frequency, which is the expected frequency for the quadrupole resonance. Initially we saw a quadrupolar resonance along with associated synchrotron sidebands superimposed on the tail of the dipole resonance.

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In order to reduce the dipolar component we changed the orbit through the fast quadrupole magnet to make the beam pass through its centre. This caused a tune shift which we corrected using our standard procedures. After this the quadrupole resonance was still at a different frequency. It did however show that the dipole component had been removed. The baseline beam size is higher probably due to slightly higher coupling which resulted from the orbit changes.

FUTURE PLANS

The quadrupolar tune shift with orbit change indicates that there is more to be understood. In the coming months, our planned investigations broadly fall into two categories. Firstly, determining how the quadrupolar tunes react to changes in various machine parameters, notably current, and also how this behaviour differs from the dipolar tune behaviour. Secondly, by using the system to apply a chirp to the beam so that each bunch has a slightly different resonant frequency to its neighbour, we hope to reduce the effect of coupled bunch instabilities and increase the instability thresholds.

More generally, work is needed to speed up the measurement such that the proposed parameter scans are practicable. By increasing the camera acquisition rate and more fully automating the measurement we expect to have a much more responsive measurement system, thus making our planned experiments more tractable.

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