OPTIMISATION OF A SPLIT PLATE POSITION MONITOR FOR THE ISIS PROTON SYNCHROTRON

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Abstract

A new beam position monitor (BPM) has been designed for the ISIS proton accelerator facility at the Rutherford Appleton Laboratory in the UK. The new monitor, which will be installed in the beam line of Target 1, is of a 'split plate' design which utilises two pairs of electrodes to allow the beam position to be measured simultaneously in the horizontal and vertical planes. Simulations carried out using the CST low frequency solver have highlighted the inaccuracies in the measured beam position caused by strong inter-electrode coupling in such a monitor. This coupling, along with imbalanced electrode capacitances, leads to reduced sensitivity to changes in beam position as well as producing a positional offset error. This paper describes how the problems associated with inter-electrode coupling have been removed with the addition of grounded rings placed between each of the four electrodes. The design and positioning of the rings also ensured that the four electrode capacitances were matched. The results are presented both as CST simulations of 'thin wire' beam position measurements and results from bench measurements of a prototype dual plane BPM.

INTRODUCTION

The BPM described in this paper will be installed in the beam line to Target Station 1 of ISIS. The standard position monitors installed at ISIS are 'split plate' designs, using a pair of cylindrical electrodes with a linear cut between them to measure the position of the beam in a single plane. The beam position is determined by measuring the electrical potential on each electrode and dividing the difference between the two by their sum [1]. This quantity is known as the difference over sum (DoS) and its use in the calculation of the beam's position is shown in equation (1).

This design has been expanded upon to measure the beam position in both planes using two pairs of linearly cut electrodes, with one pair rotated 90° around the longitudinal axis of the monitor. Though more mechanically complex, this requires less space than two single axis monitors and is more economical.

Test stand measurements taken from a prototype monitor showed that capacitive coupling between the two electrode pairs caused reduced position sensitivity and introduced a positional offset error, causing the electrical and geometrical centres of the monitor to differ. A large, earthed guard ring was added to the centre of the prototype to lessen these effects by minimising coupling between the two electrode pairs. Further measurements showed this to be a success although the sensitivity of the monitor was still lower than expected and the positional offset error was still relatively large.

To mitigate these issues, an extensive simulation programme was adopted using CST studio suite 2012 [2]. The main aims were the removal of the positional offset error and the adjustment of the position sensitivity to its ideal value.

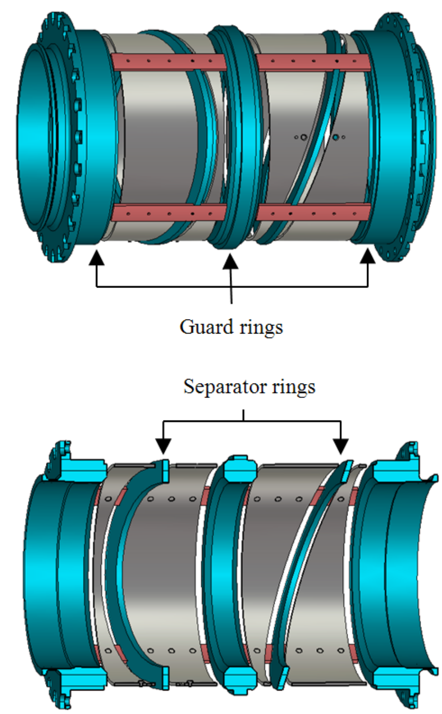

Figure 1: CST model of the optimised BPM with the outer casing removed. The second image shows a cross sectional view. Earthed components are shown in blue, electrodes in grey and ceramic spacers in red.

The sensitivity of split plate monitor is determined by the rate of change in the electrode signals as the beam position varies. The measured beam position along a single axis is given by the equation below: [3]

$$x = k\frac{\Delta U}{\Sigma U} + \delta x \qquad (1)$$

U represents the signals on each electrode in the pair, x is the measured displacement of the beam with respect to the centre of the monitor and δx is the positional offset error. The constant of proportionality (k) is often used as a measure of the monitor's response to changes in beam position [4] – the lower the value of k, the higher the sensitivity of the monitor.

The relatively long proton bunches in ISIS (30-60m) mean that a 2D electrostatic approximation can be used to

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calculate the ideal sensitivity of a cylindrical BPM. This is provided that earthed guard rings are installed at each end of the monitor to prevent external factors (such as transitions in beampipe size) from influencing the position measurement [5]. This theory shows that a monitor with ideal sensitivity should have a value of k equal to the inverse of the radius of its electrodes.

METHOD AND RESULTS

Throughout the design process CST EM Studio 2012 was used to model and simulate the behaviour of the monitor using both the low frequency (LF) and electrostatic solvers. The LF solver was used to measure the signals on each of the four electrodes while the electrostatic solver was used to calculate the capacitances between the different components.

Perfect electric conductor (PEC) was used as the modelling material for the electrodes, guard rings and the monitor body. A PEC cylinder with a radius of 1 mm was used as a 'thin wire' approximation for the beam. This had a Gaussian signal with a frequency of 2MHz applied to it to simulate the signal given off by a proton bunch travelling through the monitor. The amplitude of this signal was set to 1V although this was arbitrary as the DoS is a normalised quantity. The monitor body and earthed guard rings were assigned fixed potentials of 0V, whereas the electrodes were each given a "floating potential" so that they would be able to receive a signal from the beam.

Macor insulating strips were added to the design in the latter stages of development. These were modelled using alumina from the CST materials library, with the dielectric constant adjusted to 6.03 to equal that of Macor.

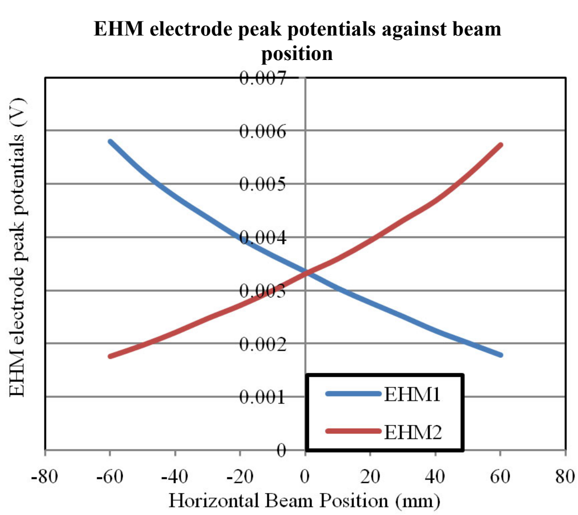

Figure 2: Peak electrode potentials in the horizontal monitor (EHM).

To calculate simulated position measurements, the peak electrical potentials on each electrode were measured during each LF solver run. These peak values were then used to calculate the DoS quantity for each of the two electrode pairs. The monitor's response to changes in the beam's position was observed by sweeping the beam along the axes of each electrode pair, with the peak potentials being recorded together with the beam locations. A plot showing the response of the optimised horizontal monitor is shown in Fig. 2.

The DoS values obtained in the sweeps for each electrode pair were plotted against the beam's positions. In split plate designs these graphs are linear while the beam is in the central region of the monitor (extending along approximately 60% of each transverse axis in this design) but become nonlinear as the beam nears the electrodes. The constant of proportionality (k, see Eq. 1) for a monitor is given by the inverse gradient of the linear region of this graph, which is shown in Fig. 3 for both the prototype and optimised designs.

The primary aim of the simulation programme was to reduce inter-electrode coupling, thereby increasing the monitor's positional sensitivity from the value observed in the prototype (k=179 mm) to that predicted by theory (k=1/R). The first modification was a reduction in the thickness of the electrodes from 12 mm to 3 mm. This reduced the coupling as much as possible without compromising the structural integrity of the cylindrical shape and increased the inner radius of the electrodes to 109 mm. The optimal value of constant of proportionality was therefore set to 109 mm for the rest of the design process.

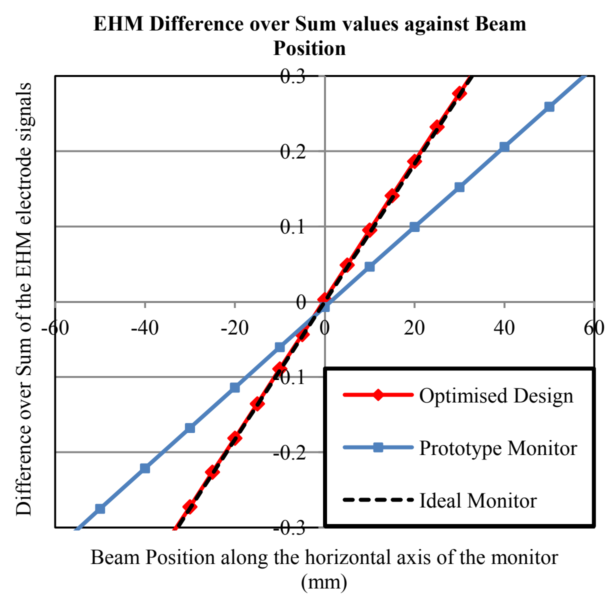

Figure 3: DoS graphs of simulated results from the prototype (k=179 mm) and optimised (k=109.2 mm) monitors. The dashed line shows the ideal sensitivity of k=109 mm.

In addition to the central and side guard rings that were present in the prototype a pair of thinner, grounded 'separator' rings were inserted in the linear cut between the electrodes of each pair (shown in Fig. 1). The inclusion of these rings provided the single largest gain in

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sensitivity of any step in the design process, decoupling the electrode pairs and providing approximately 63% of the desired sensitivity gain. Thick guard rings were also placed at each end of the monitor, providing symmetry by enclosing each electrode with a pair of earthed rings.

As well as the loss of positional sensitivity, bench measurements of the prototype BPM showed imbalanced capacitances between each of the four electrodes and the earthed monitor body. While small discrepancies can be controlled using tuning capacitors electrically connected in parallel to the electrodes, they represent varying sensitivities between the electrodes due to varying levels of coupling and so were addressed in the design. A consequence of closely matching these electrode-earth capacitances was that the positional offset error observed in the prototype would be minimised.

For studies of electrode-ground capacitances, the CST model was adjusted to run in the electrostatic solver of CST EM studio. The signal on the beam was replaced with a static potential of 1V and the potentials set on each of the electrodes were changed from floating to fixed values to allow the capacitance matrix to be calculated.

The inclusion of the separator rings was found to significantly reduce the discrepancies between the electrode capacitances (see Table 1). To further balance the four capacitances, a focus on symmetry in the design was adopted [6]. The aim of this approach was to ensure that the immediate surroundings of all four electrodes were geometrically identical. Each gap in the longitudinal plane between an electrode and an earthed component was set to a standard length of 7.5mm. Additionally the inner profile of each end guard ring was chamfered and resized to match that of the central ring (see Fig. 1).

Table 1: Electrode-earth capacitances for the horizontal monitoring pair along with the positional offset error of the monitor, calculated in CST at various stages of the design process.

	EHM1	EHM2	δx
Prototype	92 pF	107 pF	1.31 mm
Optimised Design	98 pF	98 pF	0.3 mm
Final Design	160 pF	160 pF	0.3 mm

These increases in symmetry were found to further reduce the positional offset error and so it was desirable to apply the same approach to the interior profiles of the separator rings. This required the thickness of these rings to be substantially increased. Although this further decoupled the electrodes in each pair, it also reduced the total strength of the signals measured. This meant that a compromise had to be found, and a separator ring thickness of 6.3 mm along the longitudinal axis was reached. This was enough to remove a large part of the offset error whilst still leaving a strong enough signal to be detected and measured accurately. However this thickness did not leave enough room to chamfer the interior edges of the separator rings to match the profile of the other guard rings.

To aid the ease of assembly of the monitor, it was decided that each electrode pair, along with its associated separator ring would be mounted on rails. These will maintain the required gaps between each component while allowing the electrode pairs to be slid into the monitor enclosure, one either side of the central guard ring. It was also required to increase the electrode-earth capacitances to 160 pF in order to match with existing electronics. To satisfy both of these requirements, four evenly spaced Macor strips (shown in Fig. 1) were placed around the outside of each electrode pair. These were shaped to fill the gap between the electrodes and the monitor enclosure, providing support for each electrode and holding it in position. The volume of these strips was chosen to increase the dielectric constant in this gap by the amount required to set the electrode-earth capacitances to 160 pF (shown in Table 1).

SUMMARY

Simulations carried out with CST EM Studio have shown that the inclusion of earthed guard rings, placed between each of the four electrodes, greatly reduces inter-electrode coupling and the associated loss of sensitivity in a split plate BPM. In particular the use of 'separator rings', placed inside the linear cuts of each electrode pair resulted in a substantial improvement in performance.

These rings, along with a focus on symmetry throughout the design process enabled all the electrode-earth capacitances to be matched, reducing the monitor's positional offset error and achieving the optimum positional sensitivity.

The next step will be to construct the monitor and collect readings using the test stand. These readings will be used to verify the results already obtained through simulations.

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