STRIP LINE MONITOR DESIGN FOR THE ISIS PROTON SYNCHROTRON USING THE FEA PROGRAM HFSS

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Abstract

This paper reports the development of a strip line monitor for the ISIS accelerator main ring. The strip line is still in the design phase and the work reported here is the results of the FEA programme HFSS. The strip line will eventually form part of a beam instability feedback system and will be used to control instabilities both in the current ISIS machine and for all future ISIS upgrades where higher intensities and energies could be realised. The strip line consists of two pairs of 550 mm by 160 mm broad flat electrodes configured to allow damping in both the horizontal and vertical planes. The paper describes the efforts to achieve a bandwidth of 280 MHz which will allow the feedback system deal with instabilities such as those caused by electron clouds. Design of the electrodes including matching of the feed throughs to the electrodes , concerns of materials for the electrode supports are considered. Also considered are methods used to improve inter-electrode decoupling (to better than -30db) . Results in the form of scattering parameters, time domain reflectivity and shunt impedances will be presented.

INTRODUCTION

The Rutherford Appleton Laboratory (RAL) is home to ISIS, the world's most productive spallation neutron source. ISIS has two neutron producing target stations (TS1 and TS2) driven at 40 Hz and 10 Hz respectively by a 50 Hz, 800 MeV proton beam from a rapid cycling synchrotron, which is fed by a 70 MeV H- drift tube Linac [1]. As a result of the current ISIS upgrade program [2] work has started on developing a beam feedback system as one measure against possible beam instabilities e.g. head-tail, electron clouds.

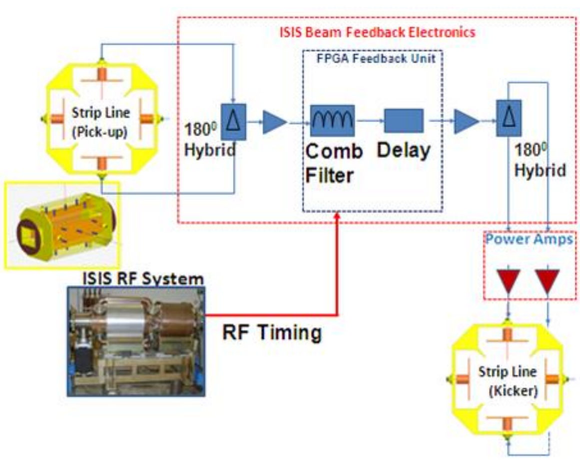

Figure 1: Proposed ISIS Feedback System.

The proposed ISIS feedback system is shown in figure 1. Two identical strip lines will be used, one as the pickup and one as the kicker. The strip line device has four electrodes to measure and correct for instabilities in both the horizontal and vertical planes. The electronics to provide the damping signal to the power amplifiers is still in development and will most likely use fast FPGA technology. The main complication that needs to be overcome is the fact that the strip line with be installed in an accelerating ring and thus the comb filter, which removes beam revolution signal, and the timing of the delay for the kicker will need to track the beam energy. For this reason the timing for the electronics will be taken from the accelerator RF system. So far only the strip line monitor design has been completed which is described here.

STRIP LINE DESIGN

The first stage in the design the ISIS strip line was carried out using FreeFEM [3], a 2-d FEA electromagnetic solver. This program provided a good starting model in terms of the electrode dimensions and position plus the internal structure of the strip line all of which could then be reconstructed within the 3-d FEA solver HFSS [4].

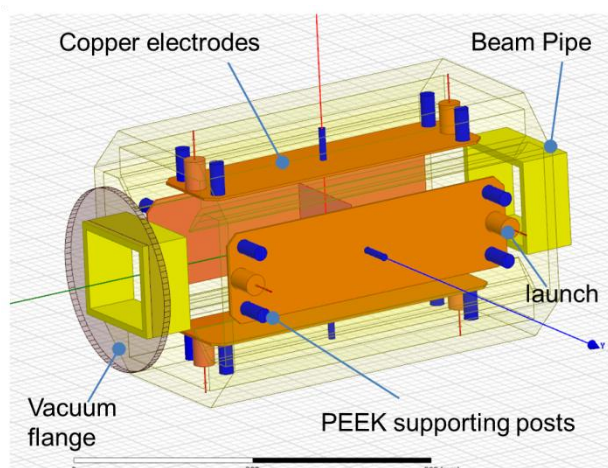

Figure 2: HFSS model of the ISIS strip line monitor showing the copper electrodes, the PEEK supports and the launches used to provide a matched RF path between the feed through and the electrode. The overall size of the monitor is 850 mm long by 425mm wide.

The strip line model is shown in figure 2. The copper electrodes are mounted to the stainless steel body using 25mm diameter PEEK posts. This material was chosen over ceramic because of the lower dielectric constant (3.2 against ~9 for ceramic) which preserves the high

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frequency performance of the strip line. There is also one thinner (12 mm diameter) post in the centre of the electrode for extra stability. The plate distance from the beam centre (120mm) is a compromise between achieving a low electrode coupling (-30db or better) and the highest possible shunt impedance for the kicker strip line (see HFSS Simulation). Minimal reflections at each port (better than -44db across full bandwidth) was also achieved by careful design of the electrodes launches (see electrode design).

HFSS SIMULATION

Electrode Design

The electrodes were made a long as possible to improve the low frequency performance. ISIS suffers from a 200kHz instability at around 2ms during the acceleration cycle and the idea is to have a system that could damp this frequency as well as take care of higher frequency instabilities, >100MHz, that might be expected with electron clouds [5].

The corners of the electrodes were tapered (see fig 2) to compensate for the increased capacitance in that region due to the PEEK supports. Figure 3 shows the S(1,1) scattering parameters with and without the corners tapered.

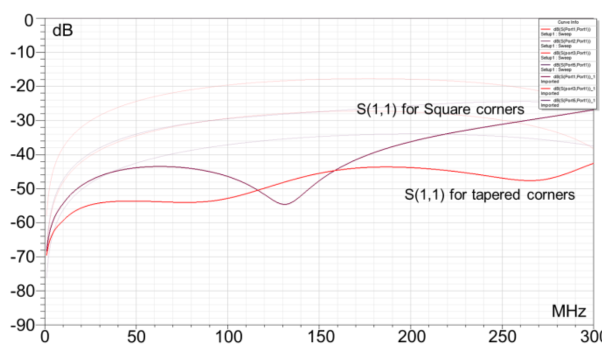

Figure 3: S(1,1) when removing corners of the electrodes to compensate for the capacitance of the PEEK supports.

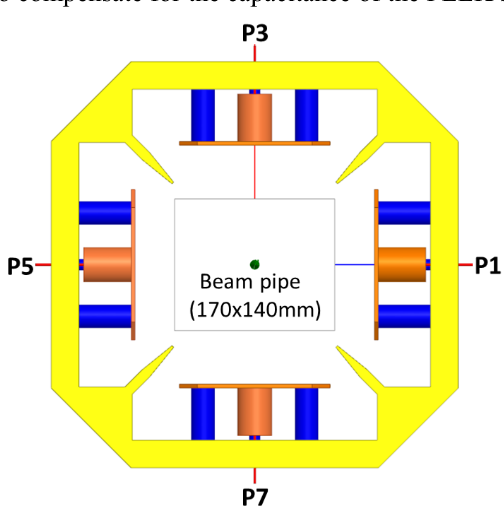

Figure 4: Cross section of the strip line monitor. Note the angled blades that reduce electrode coupling by -10db. The PEEK supports are shown in blue and the launches in orange. For reference to the scattering parameters the port numbers are P1, P3, P5, and P7.

Another consideration was signal coupling between electrodes. Figure 4 shows the cross section of the strip line monitor. The 45 degree blades are specifically designed to reduce such coupling. The effect of the blades are shown in figure 5

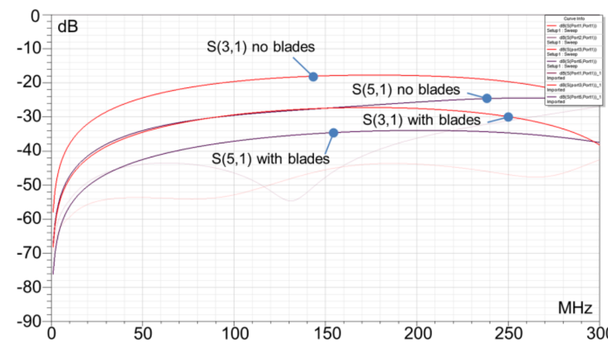

Figure 5: The blades give a -10db improvement in the decoupling of the electrodes. S(3,1) refers to the top electrode in fig 4 and S(5,1) to the left electrode.

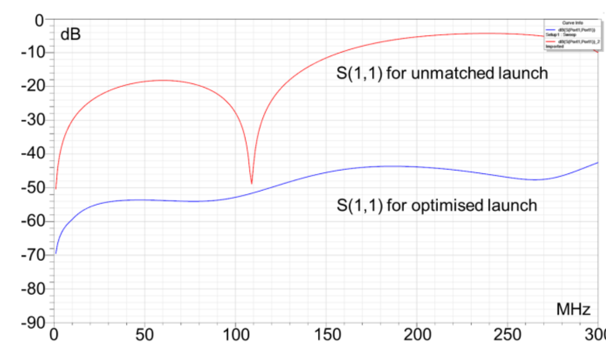

Figure 6: S(1,1) red trace is for a launch mechanically designed only to secure the feed through electrode. S(1,1) blue trace for the fully optimised launch.

Launches

The launches are copper cylinders mounted on each end of the electrodes. They provide a mechanical fixing point for the feed through electrodes (shown as red 'wires' at the ports in figure 4) as well as a RF matching path between the feed through and the electrodes. Figure 6 shows the effect of the launches on the S(1,1) scattering parameter. The (top) trace shows the S(1,1) for a copper cylinder of arbitrary dimensions (diameter 12mm, height 25mm) where only the mechanical aspects of securing the feed through electrode were considered. The (bottom) trace shows the S(1,1) for an optimised launch (diameter 37mm, height 50.5mm). To optimise the launch careful selection of the launch height and diameter must be made. Since both parameters are strongly coupled the approach taken was first selecting a 'sensible' height for the launch, and then finding the best value for the diameter. The

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height was chosen such that the top of the launch was 5mm from the wall of the vacuum vessel. This is a practical value that avoids potential electrical breakdown. Also if one makes the launch too short the diameter of the launch can get unacceptably large. Once the height is set then the diameter can be quickly found. To finish a final adjustment of the height can then be performed.

Figure 7 shows the final adjustment to the launch height for a diameter of 37mm. The graph shows the % power reflected from port 1 as a result of changing the launch height Similar plots can be produced for the diameter of the launch verse reflected power.

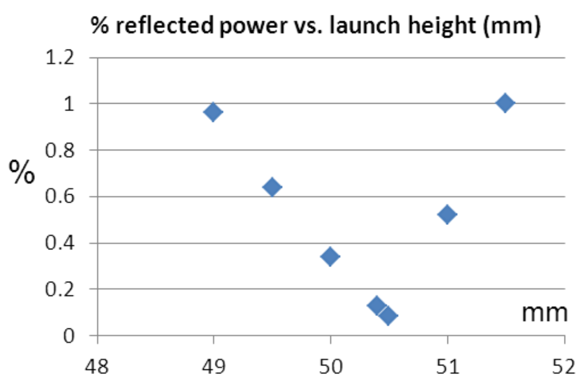

Figure 7: The final tuning of launch height. The y axis is % reflected power and the x axis the launch height in mm.

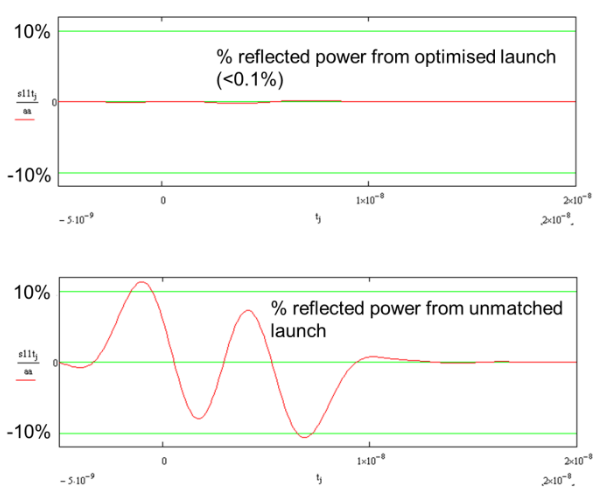

Figure 8: time domain reflections at port 1 showing optimised launch (top) against general launch (bottom) which although mechanically suitable gives a power reflection of 11%.

Shunt Impedance

The shunt impedance describes the ease at which the beam can be influenced by the kicker. The higher the impedance the more efficient the kicker is. Typical values range from 1kΩ to 5kΩ's even as higher a 10kΩ depending on the configuration of the strip line. Because of the relatively low value of this strip line shown in figure 9 we may need to compensate with larger power amplifiers. Figure 10 shows the bandwidth of the strip line (280 MHz) as achieved by modelling a thin wire through the monitor to form port 9.

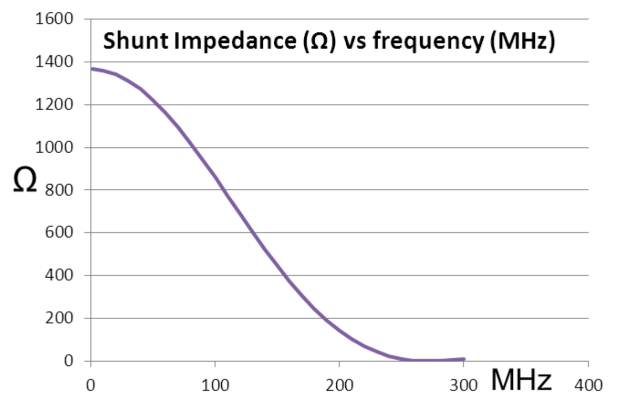

Figure 9: Shunt impedance verses frequency.

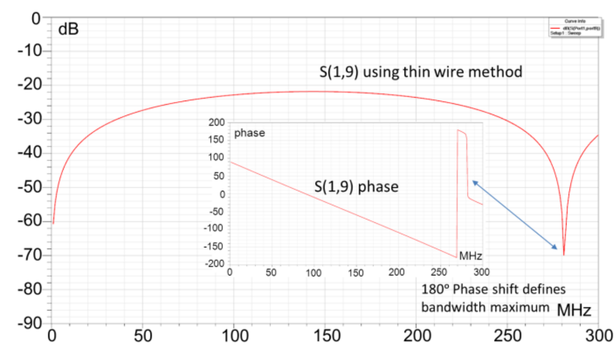

Figure 10: Thin wire measurement of bandwidth.

SUMMARY

The HFSS design of the strip line monitor has been completed. Results obtained from HFSS show the strip line to act as a low loss 50Ω loss transmission line over the required bandwidth. Properly designed launches are important to avoid loss of power to the kicker. Ensuring the coupling between electrodes is around -30db or better is desirable to ensure good sensitivity when used as a pickup. The use of blades worked well reducing coupling by -10db over the full bandwidth. The next stage is to build the strip line and compare the HFSS results directly to those obtained from a network analyser. Thin wire measurements of the strip line impedance will also be carried out.

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