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J. A. Mitchell

R. Apsimon

G. Burt

R. Calaga

A. Macpherson

See next page for additional authors

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LHC CRAB CAVITY COUPLER TEST BOXES*

J. A. Mitchell†, R. Apsimon, G. Burt, A. Tutte, Lancaster University, Lancaster, UK
R. Calaga, A. Macpherson, E. Montesinos, CERN, Geneva, Switzerland

Abstract

The LHC double quarter wave (DQW) crab cavities have two different types of Higher Order Mode (HOM) couplers in addition to a fundamental power coupler (FPC). The FPC requires conditioning, so to achieve this we have designed a radio-frequency (RF) quarter wave resonator to provide high transmission between two opposing FPCs. For the HOM couplers we must ensure that the stop-band filter is positioned at the cavity frequency and that peak transmission occurs at the same frequencies as the strongest HOMs. We have designed two test boxes which preserve the cavity spectral response in order to test the couplers.

INTRODUCTION

In order to increase the luminosity for the HiLumi LHC upgrade, bunch crabbing produced by crab cavities will be employed to increase the integrated luminosity [1]. Bunch crabbing is the process of rotating a bunch longitudinally by employing a transverse electric field. This process allows the increased crossing angle, a result of lowering β^* to increase the luminosity [2], to be accounted for and allows the bunches to collide head-on. The DQW crab cavity [3], shown in Fig. 1, is currently under construction and will be installed in the Super Proton Synchrotron (SPS) at CERN at the end of 2017 and tested throughout 2018. The FPC ensures power is correctly coupled into the cavity and the HOM couplers damp higher order modes excited in the cavity by the beam.

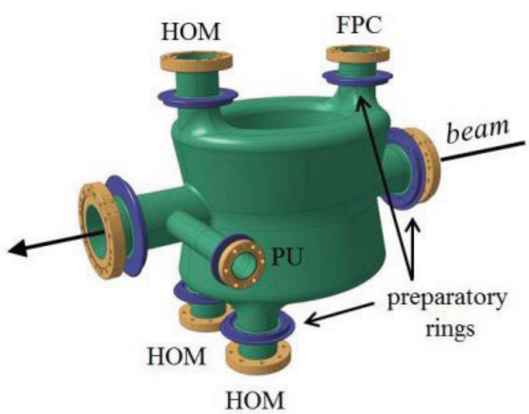

Figure 1: Labelled DQW crab cavity [4].

As the cavity is magnetically coupled, both the FPC and HOM couplers use hook shaped features to ensure good coupling with the magnetic field. For the FPCs, testing and conditioning at high power is necessary in order to ensure they will perform adequately under operating conditions.

Due to geometric complexities, along with the intricate welds needed on the structures, the DQW HOM couplers need to be characterised at low power to ensure any manufacturing inaccuracies have not led to a deviation from the desired operational characteristics.

FPC TEST BOX

The FPC, Fig. 2, is designed to couple power at the deflecting mode frequency of 400 MHz. In order to test the FPC at high power, a test box is required which can provide a high transmission between two FPCs, without inducing high peak surface electric fields. In addition to operational testing of the FPC, the test box is also a means of conditioning at ~ 100 kW; to allow the structures to support high power operation.

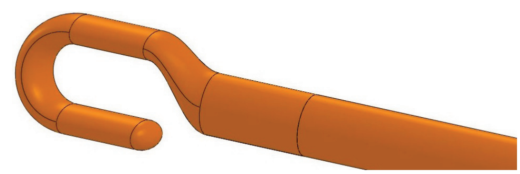

Figure 2: DQW FPC Hook.

The FPC test box, Fig. 3, is based on a quarter wave resonator (QWR). A standing wave is set up on the rod component of the QWR and the fields are such that the magnetic peak is located at the supported end of the rod and the electric peak at the open end [5]. The FPC hooks are therefore positioned closer to the supported end of the inner rod to ensure that the majority of the coupling is magnetic. By altering the length of the inner rod and varying the insertion depth of the FPCs, it was possible to generate a structure that operates at the correct frequency, with low peak fields and with a sufficiently large S_{11} bandwidth for conditioning. The structure has a peak electric field of 1.17 MV/m corresponding to an average input power of 100 kW. The S_{11} and S_{21} plots are displayed in Fig. 4.

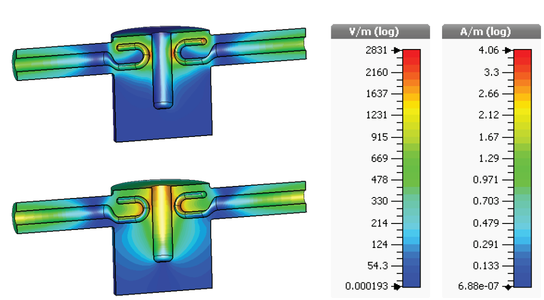

Figure 3: Log plots of the FPC test box electric fields in V/m (top) and magnetic fields in A/m (bottom) at 400 MHz.

* Work supported by Lancaster University and the Cockcroft core grant.
† j.a.mitchell@lancaster.ac.uk

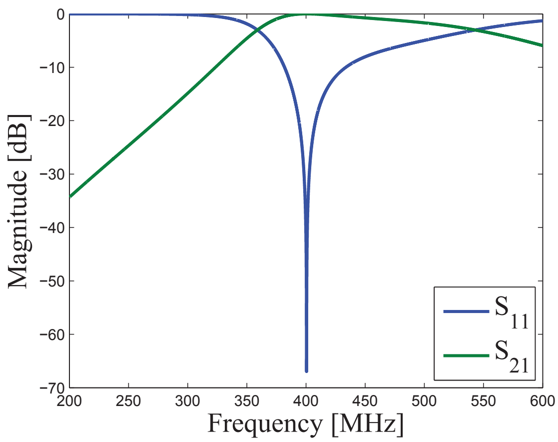

Figure 4: S_{11} and S_{21} plots for the DQW FPC test box.

HOM COUPLER TEST BOX

The HOM couplers are needed in order to damp the higher order modes to prevent beam instabilities and to reduce the power load transferred to the cryogenic system [6]. The structures are designed such that there is a stop-band filter at the 400 MHz deflecting mode to ensure rejection at the operating frequency. This filter is located just above the hook to reduce RF loss in the copper gasket used for connection with the cavity. Above this frequency, up to 2 GHz, the structure operates as a pass-band filter for a large transmission of the high impedance HOMs [7]. A schematic of the HOM coupler structure, with the two filters labelled, is shown in Fig. 5.

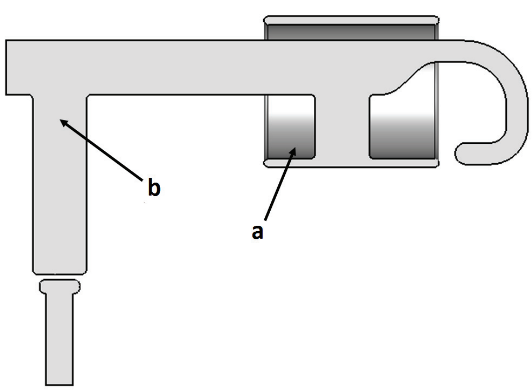

Figure 5: DQW HOM coupler hook cross section with LC stop-band structure (a) and an L-shaped pass-band filter (b).

Initially, characterisation of the HOM couplers will be done at low power. A normal testing procedure would consist of attaching a section of beampipe loaded with a lossy dielectric. However, in the case of the DQW crab cavity, this is unfeasible as the HOM couplers are connected directly to the cavity itself. Test boxes capable of analysing the frequency response of the couplers using transmission lines were thus investigated. Currently, two low power test boxes have been designed and are under construction in parallel.

L-bend Transmission Line

The test box is a symmetric four port system with two RF input ports and two ports for the HOM couplers. The ends of the L-shaped probes on the RF input ports are connected to the outer wall of the test box, allowing a current to flow and thus they couple magnetically to the HOM couplers. By measuring the S-parameters of the four ports, the frequency response of the HOM couplers can be determined. The model, constructed in CST MWS [8], is shown in Fig. 6 and the CAD design follows in Fig. 7.

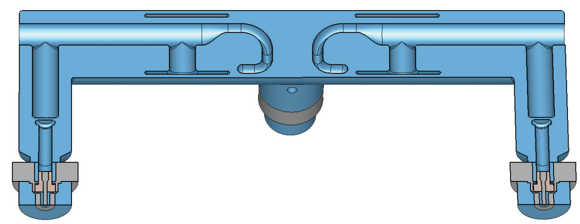

Figure 6: Cross section along symmetric plane for the L-bend transmission line test box simulation.

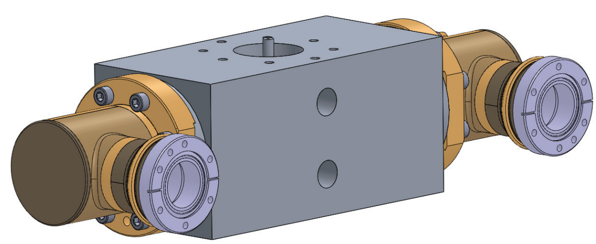

Figure 7: L-bend transmission line test box CAD render.

By quantifying the difference in the frequency and amplitude of the simulated test box response to that of the simulated HOM coupler, the transmission characteristics of the HOM coupler can be assessed. Following this, any errors in the response can be related to the geometries which strongly influence operation at that frequency.

Currently, the aluminum body and probes are being machined at Lancaster University engineering department.

Coaxial Chamber

In contrast to the L-bend transmission line structure, the coaxial chamber test box was designed using commercially available components rather than machined ones. The test box again uses a four port symmetrical design, but rather than transmission probes, the HOM couplers are inserted into a coaxial chamber where the inner conductor is terminated by conical 50 Ω EIA adapters. This allows the chamber to be reduced to N-type terminals for measurement using a Virtual Network Analyser (VNA).

Due to the use of commercially available components, only a discrete number of geometries are available. Apart from the addition of two coupler ports to the outer coax chamber, this test box allows a simple assembly using components with documented operational characteristics and associated

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tolerances. The coaxial chamber model is shown in Fig. 8. Procurement of the 6 1/8" EIA rigid line components necessary to construct this test box is currently underway.

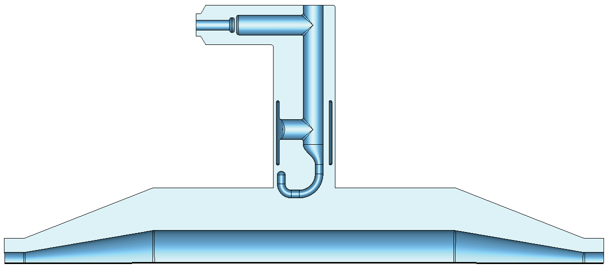

Figure 8: Cross section of the top half of the coaxial chamber test box (where the top and bottom halves are symmetric) at 50 Ω line impedance.

Comparison of Test Box Designs

Figure 9 shows the S_{21} parameter for the two test boxes detailed alongside the HOM coupler transmission response. Both test box designs are capable of accurately measuring the HOM coupler frequency response up to 2 GHz. The L-bend transmission design has been optimised to allow a more accurate analysis of the stop-band filter at 400 MHz. The higher frequency peaks however are more accurately defined by the coaxial chamber, which is also more robust to manufacturing tolerances.

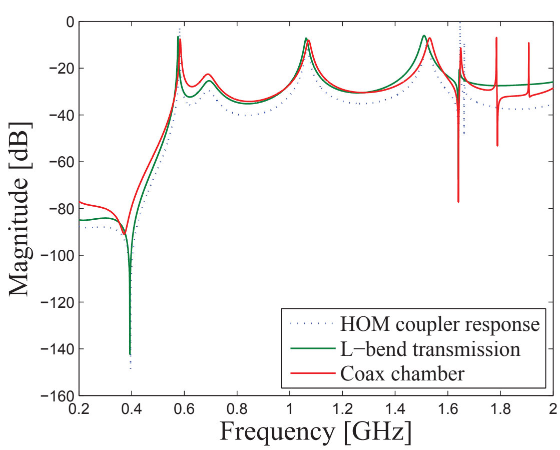

Figure 9: S_{21} for the L-bend transmission line (green), coaxial chamber (red) and HOM coupler (dotted blue).

Tolerance studies for both test box designs will allow associated error margins, imposed by the inaccuracies associated with manufacture, to be assigned to the measurement results from each test box.

FURTHER WORK

After testing, the need for tuning will be assessed. For the HOM couplers, the necessity of high power testing and conditioning will be evaluated; requiring a test box capable of operation at ~ 100 kW.

Test boxes for the FPC and HOM couplers for the Radio Frequency Dipole (RFD) crab cavity are also required. The feasibility of having a single FPC test box for both crab cavity types is currently being explored. The HOM coupler test boxes are being analysed for use with the RFD HOM couplers and, like for the FPCs, the feasibility of a single test structure is being investigated.

CONCLUSION

For the DQW FPCs, a test box capable of testing and high power conditioning has been designed. Currently, the mechanical construction of this test box is being assessed, with the testing and conditioning planned for late 2016.

For the DQW HOM couplers, two low power test boxes have been designed. Both designs enable the rejection frequency and the operation of the higher frequency high-pass filter to be analysed. Currently, the L-bend transmission line test box is being machined at Lancaster University engineering department and procurement of the components needed for the coaxial chamber set up is underway.

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