MECHANICAL DESIGN AND RF MEASUREMENT ON RFQ FOR FRONT-END TEST STAND AT RAL

A. Letchford, Rutherford Appleton Laboratory, Oxford, United Kingdom
P. Savage, J. Pozimski, Y. A. Cheng, Imperial College, London, United Kingdom.

Abstract

This paper will present the mechanical design and preliminary results of a RF measurement system for the cold model of a 324MHz 4-vane RFQ, which is part of the development of a proton driver front end test stand at the Rutherford Appleton Laboratory (RAL) in the UK. The design concepts will be discussed and some issues in manufacturing of the RFQ will be pointed out, and specific modifications will be explained. Furthermore, results of thermal simulations of the RFQ will be presented together with RF simulations of the resonant frequency, the Q-value and the longitudinal field distribution.

INTRODUCTION

High power proton accelerators (HPPAs), have many applications, including drivers for spallation neutron sources, neutrino factories, transmuters (for transmuting long-lived nuclear waste products), energy amplifiers and tritium production facilities. For the short pulse operation necessary for spallation neutron sources and neutrino factory drivers, only much lower beam powers have been used so far (0.08MW for PSR and 0.16MW for ISIS) [1]. Both machines use H^--injection to accumulate intense short bunches and need an increase of at least a factor of 30 to reach the goal of MW for future HPPAs. In order to contribute to the development of HPPAs, to prepare the way for ISIS upgrades and to contribute to the UK design effort on neutrino factories [2], a front end test stand (FETS) is being constructed at RAL in the UK. The aim of the RAL FETS is to demonstrate the production of a 60 mA, 2 ms, 50 pps chopped beam. A detailed description of the project and the current status is given in [3]. A RFQ for bunching the beam and accelerating it from 65 keV to 3 MeV will be used as the first accelerator element. The resonant frequency of the RFQ was chosen to be 324 MHz to have a sufficient high frequency for a serious test of the chopper and because of the availability of a klystron from Toshiba. Simulations of the particle dynamics as well as the modelling of the electromagnetic properties of a 4-vane and a 4-rod structure have been performed. The design of the 4-vane type cold model is finished, a first analysis of the heat distribution has been performed and a copper cold model is in production. A bead pull measurement system has been set up and tested using a pillbox cavity and first investigations of the RF properties of the cold model will start soon after this conference.

MECHANICAL DESIGN AND THERMAL MODELING OF RFQ

The development of the mechanical design was an iterative process that started with a 2D profile of the vane type RFQ. The 2D profile represented an ideal Physics model and was created using the CST MWS software suite. The goal was to adapt this profile to produce a 3D engineering model that could be manufactured by the Imperial College HEP group workshop. Working in Autodesk Inventor 10 a parametric model was designed that was producible and that contained ports for RF coupling; vacuum pumps and cavity tuners and had sufficient stiffness. These engineering constraints were then remodelled to assess the Physics performance and this cycle was repeated until a design was produced that satisfied both the Physics and the Engineering requirements.

Mechanical Design

The first cold model design consisted of 4 identical sections which, when joined, would form the complete model. The join interface was at 45 degrees to the plane of the vanes. To test the manufacturing process of the design one quarter was manufactured from aluminium (see Figure 1). In parallel, a simple copper model without vanes was produced to study the brazing process. Lessons learned from the brazing process were fed back into the design and the brazed model was sliced and inspected. While the production of the inner surfaces, the undercuts and the coupling in ports went satisfactorily, problems were encountered during manufacture with producing an angled interface. Additional difficulties concerning the final brazing process on the angled surfaces to join the quadrants, and the need for further ports on this surface for tuning and pumping led to a design change.

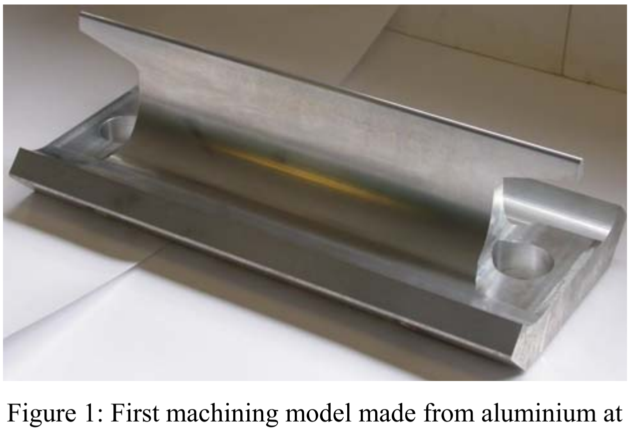

Figure 1: First machining model made from aluminium at Imperial College London.

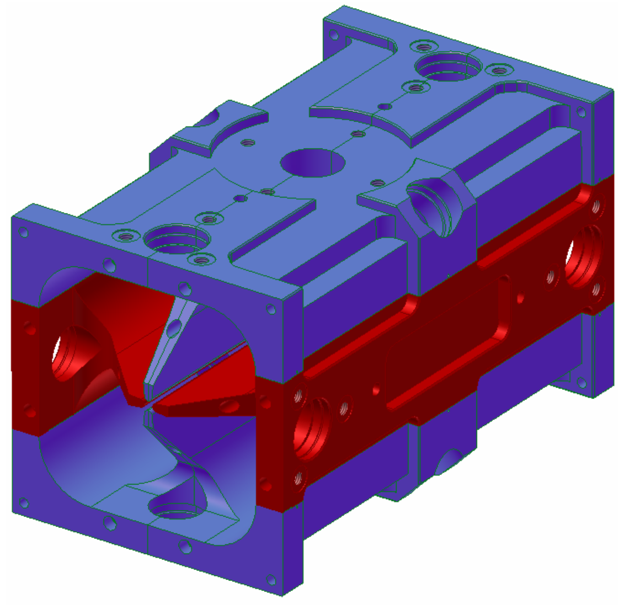

Figure 2: CAD drawing of the design used for fabrication of the 4-vane cold model.

The final form of the design for the cold model now consists of 2 small quarters and 2 large quarters with joint interfaces in the horizontal plane (see Figure 2). These changes aid the production accuracy of the joint interface, which determines the accuracy of the complete model. We require of the order of a +/- 10 micron vane tip to tip tolerance once assembled. The flow and assembly for the brazing process is also aided through the use of horizontal interfaces.

Features of the cold model include 8 Ports for RF coupling at both ends of each section, one port for a tuner for each quadrant and two ports for vacuum pumping allowing direct access to all 4 quadrants for optimum pumping speed. The cold model does not have vane tip modulations as per the final design. After a delay of about 6 weeks due to a breakdown of the CNC machine in the workshop, the model was manufactured from grade C101 Oxygen-free copper which was chosen for it's high conductivity and excellent brazing properties. The four quadrants are finished and the brazing will take place immediately after this conference.

Thermal Modelling

Some preliminary Finite Element Analysis (FEA) calculations have been made to assess the performance of the proposed cooling system. The goal is to accurately map the heat input into the RFQ from the RF power distribution and to produce a cooling circuit design that maintains thermal expansion to within the prescribed tolerances. Simulations of the RF properties and the wall losses of the 4 vane model using MWS show a very homogeneous distribution of the losses and therefore heating over the inner surface. The completed cold model will be used to perform cooling tests, the results from which will be used to benchmark the FEA model. The situation is somewhat different in the preliminary studies of the 4 rod model, as the losses and therefore the heating are concentrated on the joints between the stems and the rods. Figure 3 shows a result of these preliminary studies of the heat distribution in the stems for the 4 rod model.

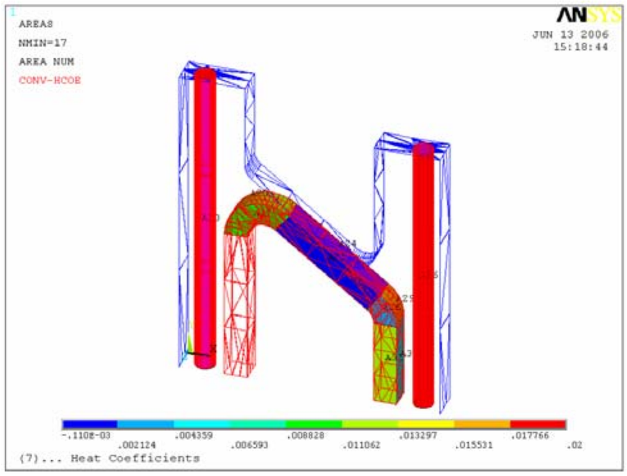

Figure 3: Preliminary result of the thermal modelling of the 4 rod structure using ANSYS. The graph is showing the thermal distribution within the stems.

BEAD PULL SETUP TEST RUN

Perturbation method

The well known perturbation method will be used to measure the electric-field distribution of the cold model along the beam axis. The perturbation method uses the fact that the square-root of the change in resonant frequency due to perturbation of the electromagnetic field in a cavity is proportional to the electromagnetic field amplitude [4]. If a dielectric sphere is used to perturb the field in the cavity the expression for the perturbation theory is given as:

$$\sqrt{\frac{\Delta f}{f_0}} = -\frac{3\Delta V}{4U}\frac{\varepsilon_r - 1}{\varepsilon_r + 2}\varepsilon_0 E \qquad (1)$$

where: Δf is the frequency shift between perturbed and unperturbed frequency [Hz]; f_0 is the unperturbed frequency [Hz]; ε_r is dielectric constant of the dielectric sphere at the resonant frequency; ε_0 is permittivity of vacuum, 8.8542×10^{-12} [V/m]; ΔV is the volume of dielectric sphere [m^3]; U is the power stored in cavity [W]; E is the electric-field amplitude [V/m].

The bead-pull measurement setup

The bead-pull measurement was performed using LabVIEW as the control program to move a nylon bead of ∅5.8mm (εr ≈ 2.3) via a JVL MAC140 motor and to synchronize the resonant frequency and Q measurement done by the Rohde&Schwarz ZVB4 model VNA. The wire used to hold and pull the bead is a normal ∅0.25mm nylon wire. A simple mechanical frame made of aluminium holds pulleys, the servomotor and a slider system.

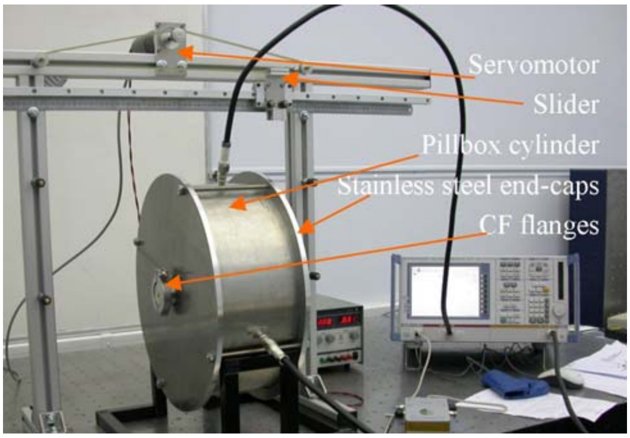

Figure 4: Bead-pull experiment setup in Imperial College London

The bead pull system (setup in Imperial College) is shown in Figure 4. The frame, fixed to an optical table, has its length variable in all directions to accommodate the sizes of the RFQ and bead positions. The nylon wire is clamped by the slider which is driven by the servomotor via a timing belt which is made to have zero back lash. By clamping the wire to the slider, slip between wire and pulley is eliminated.

Results

To ensure that the bead pull system works well and gives accurate results for the eventual investigation on the copper 4-vane RFQ cold model, the system was put to the test to perform measurements on a simple 572MHz pillbox cavity. The pillbox cavity is made from a ∅401mm inner diameter aluminium cylinder that is clamped in between the grooves of 2 stainless steel end-caps. To improve the contacts between the cylinder and end-caps, a silver braid was inserted into the grooves on the end-caps.

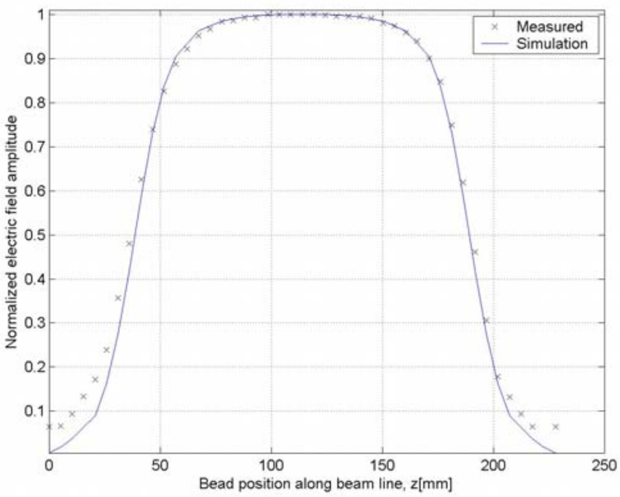

Figure 5: Electric-field distribution along beam-axis for simple pillbox cavity

Table 1 show that the measured resonant frequency is within 0.152% difference from the predicted value.

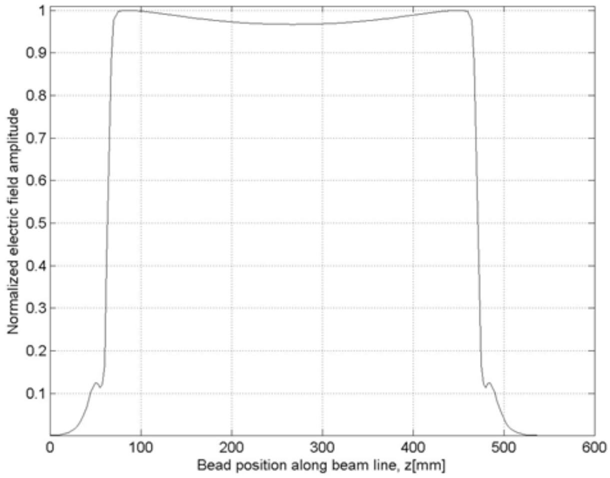

Figure 6: Simulated electric-field distribution along beam-axis for 4-vane RFQ cold model

Table 1: Comparison of pillbox cavity characteristic

	TM_{010} Frequency	**TM_{010} unloaded Q, Q_0**
Predicted	572.601MHz	20941
Measured	573.47MHz	14484

The measured Q_0 is less than the predicted value because the surface contacts between the cavity and end-caps are poor, which could be improved if the cavity and end-caps are brazed or welded together. Figure 5 shows the simulated and experimental results of the electric-field distribution along the beam axis. The comparison show good agreement for the regions within the cavity and minor disagreements at the flange positions. This indicates that the design of the bead pull system is principally good and the measured results are reliable to be used for further investigation. Figure 6 shows the predicted electric-field distribution along the beam line of the eventual copper 4-vane RFQ cold model. More details on this simulated result can be obtained from [5].

DISCUSSION AND CONCLUSION

In conclusion, the mechanical design of the copper 324MHz 4-vane RFQ cold model for the RAL FETS is complete, and manufacturing of the cold model will be completed by the end of this month. The RFQ will be ready to be tested by a bead-pull experiment which was already installed and tested in Imperial College.

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