A TUNING SYSTEM FOR THE FETS RFQ

S. Alsari, J.K. Pozimski, P. Savage, O. Zorba (Imperial College of Science and Technology, London, UK), A.P. Letchford (STFC RAL, Didcot, UK)

Abstract

The Front End Test Stand (FETS) is an experiment based at the Rutherford Appleton Laboratory (RAL) in the UK. The test stand is being constructed in collaboration between STFC, Imperial College London, ASTeC, the University of Warwick and the Universidad del Pais Vasco. This experiment will design, build and test the first stages necessary to produce a very high quality, chopped H- ion beam as required for the next generation of high power proton accelerators (HPPAs). HPPAs with beam powers in the megawatt range have many possible applications including drivers for spallation neutron sources, neutrino factories, accelerator driven sub-critical systems, waste transmuters and tritium production facilities.

An automatic tuning system has been developed for the main 324MHz 4-vane RFQ accelerator and has been tested to fine tune the frequency changes due to temperature variation in the resonant frequency of a 324MHz 4-vane cold model RFQ, which been designed as part of the development of the test stand.

This paper will present the electronics design of the automated tuning system along with the mechanical tuner structure. The design concepts will be discussed. Furthermore, results of the RF tuning would be presented.

INTRODUCTION

As part of the FETS project, the 4-metre long 4-vane RFQ is designed to have a resonant frequency of 324 MHz, this frequency would have to be stable and in synchronization in all times with other parts of the system, in terms of the resonant frequency, in order to achieve the optimum acceleration performance acquired from the RFQ. A detailed description of the project and the current status is given in [1].Therefore, the RFQ would need a precise and robust tuning system to maintain and control the resonant frequency to 324 MHz, this system would be used alongside other controlling mechanisms such as the RFQ water cooling system.

The preliminary mechanical design [2] of the RFQ suggest to have a total of 16 plug tuners with at least one automated tuner in each part of the 4 one-metre sections of the RFQ. The mechanism of these motorized tuners would be based on linearly shifting the tuners copper plugs using a stepper motor and an edge welded bellows, shown in Figure 1. A detailed description of the up to date design of the RFQ, the tuners and the current status of the designs are given in [3].

*Electronics built by Vera Kasey from Imperial College HEP Group workshop

#v.kasey@imperial.ac.uk

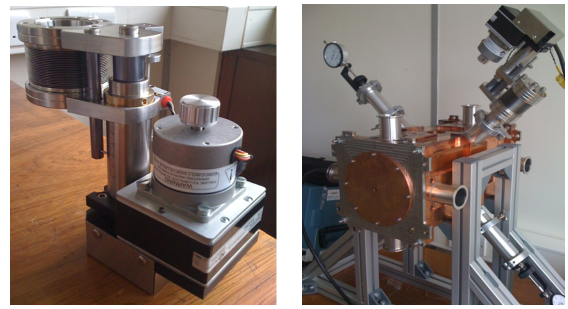

Figure 1: The tuner stepper motor with welded bellow alone, and fitted on the RFQ cold model.

THE SYSTEM CONCEPT

In order to be able to re-adjust the RFQ resonant frequency, we would need to have a feedback system to detect, in addition to the frequency variation, other significant changes combined with that frequency variation, which can be used as an indicator to provide an additional axes information such as direction for this variation. We have make use of the RF signal phase as the key factor for our controlling system, Figure 2.

Other field indicators such as reflected power, for instance, can be used to feedback the tuning system but then it would need to apply more complicated designs in order to be able to distinguish the direction of the frequency change path whether it's on the increase or decrease direction. Therefore, the phase change of the RF power field has been nominated as a powerful indicator of swing as it will include information of direction in terms of field phase variation.

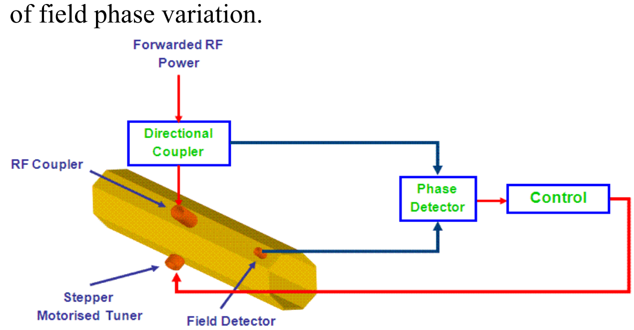

Figure 2: The tuning system layout.

In this form, we have made our RF resonant frequency information available as well as validated the phase of this signal in a feedback loop to detect continuously in order to compare with original phase details of the coupled RF frequency. Therefore, in a balancing form between these two details, we can provide a variable output which indicate and inform of differences detected in the signals accordingly, Figures 4 and 5. Finally, a controlling section of the system, Figures 6 and 7, would be responsible to eliminate the divergences and minimise the effects of the detected variation in order to recover the reference RFQ properties and accordingly maintain the resonant frequency.

THE SYSTEM SECTIONS

As the general system layout showing in Figure 2, we would need to maintain our reference phase which is represented by the input coming from the signal generator fed to the input coupler, Therefore, the RF input signal has to been fed through a directional coupler to provide the reference phase signal to the phase detector circuit, then through the directional coupler to the RF coupler, Figure 3, to feed the RFQ. The second input signal to the phase detector would be the feedback RF signal detected from the RFQ through a field detector formed using an RF coupler mounted in the RFQ to detect the RFQ electric field.

AD8302 RF/IF Gain and Phase Detector were used to build the phase detector circuit, Figure 4, in our workshop at Imperial College. The output of this detector is a DC voltage of 0 to 1.8 V and phase range of 0° to 180° scaled in a linear slope of 10mV/degree reflecting the relationship between the phase variation and the output voltage of the circuit. The phase accuracy measurement of the detector is independent of input signal level over a wide range.

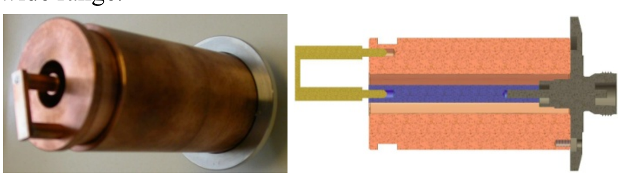

Figure 3: Input RF coupler, design cutaway.

As we now have an output voltage reflecting the phase relation between input and feedback RF power, we have to fix this phase difference to a point to use as a reference point linked to out resonant frequency. Now, any phase variation occur to the field of the RFQ would be directly reflected as phase change on the feedback RF signal.

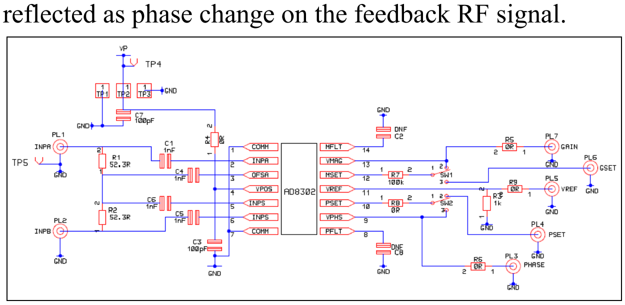

Figure 4: Phase detector circuit schematic.

Moreover, the corresponding voltage was preset as reference voltage on our controlling circuit which in turn will compare with the phase detector's variable output voltage. The controller circuit consisting two voltage comparators, one for each direction in a form to allow enabling the stepper motor to move forward if the voltage is decreased indicating an increment in the phase deference between the coupled and the feedback signals. Opposing, the second voltage comparator will enable the motor reversed motion indicating negative effect in order to recover the resonant frequency.

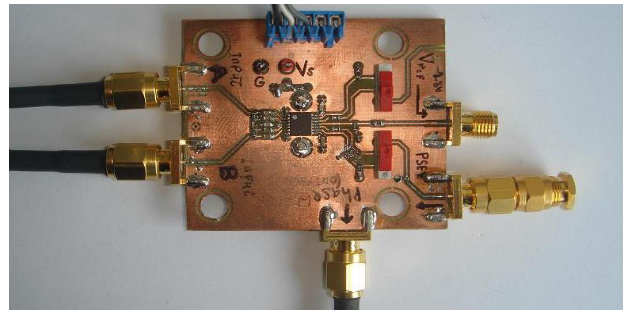

Figure 5: Phase detector circuit.

In order to have a steady state where we have a case of no phase change or a difference within an acceptable limits, a margin threshold is produced in the system before it enable the motor in either sides. This margin is adjustable accordingly to the need for sensitivity in the application.

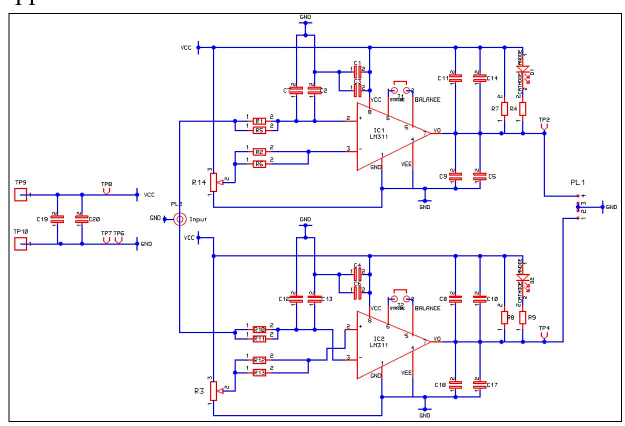

Figure 6: Tuner control circuit schematic.

The output of the controller board is connected to the stepper motor drive (PM546 Bipolar Stepper Motor Translator, by Mclennan Servo Supplied Ltd.) to control the movement of the stepper motor. This drive can be controlled to have a fixed speed or variable ramp controlling settings through the onboard oscillator. The stepper motor model is Mclennan 23HS-108E [4].

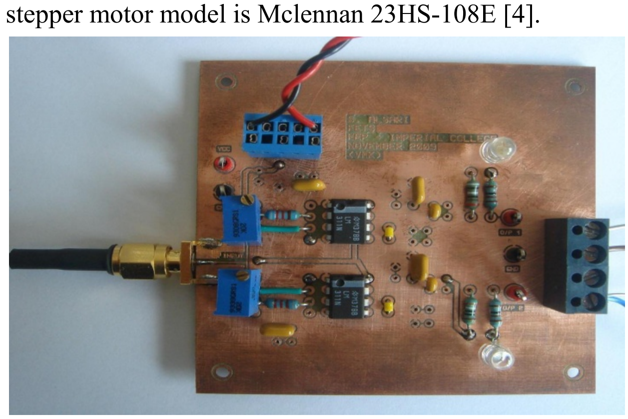

Figure 7: Tuner control circuit.

For the design security, the motor has two safety limiting switches to protect the mechanical arm in case of shifting to the far ends of the scale. These switches are connected in serial to the controlling circuit to disable the motor once it reaches the far edges.

MEASUREMENTS AND RESULTS

We have measured the changes of the cold model RFQ resonant frequency with respect to time while feeding a CW 60W RF power. As shown in Figure 8, the corresponding frequency shift been correlated to the rise in the temperature of the RFQ. Therefore the expansion factor of the RFQ body due to the temperature increment was investigated by correlating the resonant frequency with the RFQ body temperature. Figure 8 is showing the relation between the temperature and the resonant frequency through a time period while feeding the 60W power without using our tuning system.

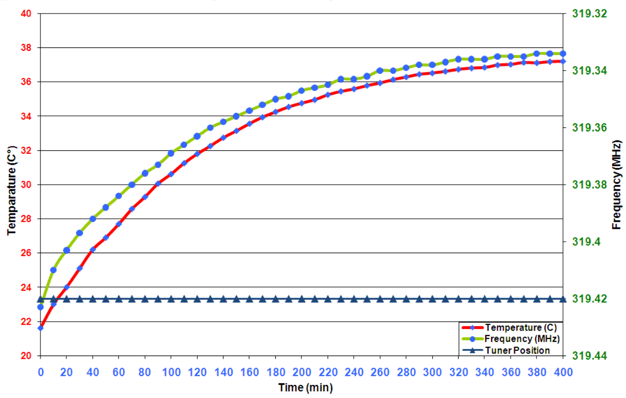

Figure 8: RFQ temperature and frequency vs. time.

In order to keep our desired resonant frequency unchanged through this temperature increment, we have used our tuning system to re-tune the RFQ accordingly to maintain the frequency throughout that scale. Figure 9 shows the corresponding normalised tuner position versus time to maintain the starting appointed resonant frequency while feeding the 60W power on. From the graph, we can see that in the range of the original tuner position, it moves linearly with time to maintain the phase difference between the two signals constant which consequently mean maintaining the RFQ resonant frequency.

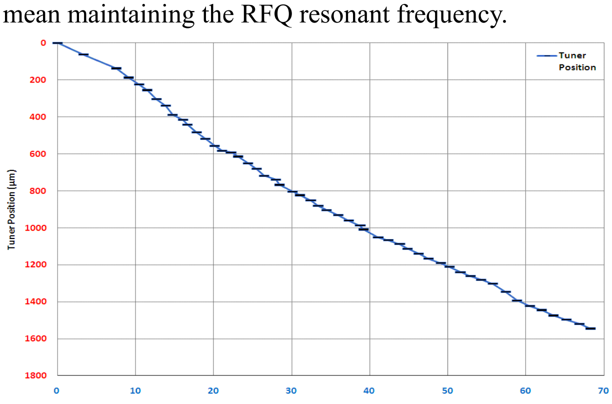

Figure 9: RFQ motorised tuner position against time.

An important mechanical design fact to keep in mind with the tuners is that the optimum region for the tuner is in the range where it just in line with the internal surface of the RFQ in order to get a good tuning sensitivity as well as minimum effect to the RFQ field and therefore the reflected power and the RFQ quality factor [5].

In the case that the tuner is far out from the surface, it would not have much tuning effect, on the other hand if it's too far deep, it will affect the electric field of the RFQ and therefore will increase the reflected power as well as reducing the quality factor of the RFQ even if it's in the resonant region. Figure 10 below shows the tuner displacement with reference to the "zero point" where the tuner surface is in line with the internal surface of the RFQ. It's clearly reflecting the change in the tuning sensitivity considering the original position of the tuner.

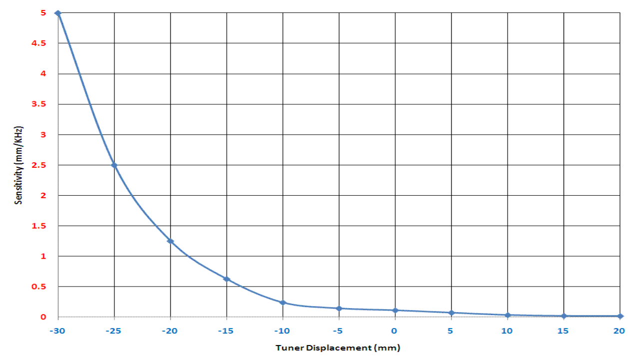

Figure 10: RFQ tuner sensitivity against position.

CONCLUSION

An automated tuning system has been built and tested on the FETS cold model RFQ. Measurements and results presented showed that the resonant frequency been kept constant during a continues wave RF power coupling at 60W during a period of time which would have caused considerable frequency shifting due to RFQ temperature increment if the tuning system was not in use.

REFERENCES

[1] Alan P. Letchford *et al* "Status of the RAL Front End Test Stand", IPAC'10, Kyoto, May 2010, MOPEC075.
[2] Alan P. Letchford *et al* "Mechanical Design and RF Measurement on RFQ for Front-end Test Stand at RAL" Proceedings of EPAC'06, Edinburgh, June 2006, MOPCH117, p. 318 (2006); http://www.JACoW.org.
[3] P. Savage *et al* "The Mechanical Engineering Design of the FETS RFQ", IPAC'10, Kyoto, May 2010, MOPD056.
[4] Mclennan Servo Supplies, www.mclennan.co.uk
[5] A. Kurup *et al* "Electromagnetic Design of a Radio Frequency Quadrupole for the Front End Test Stand at RAL", Proceedings of EPAC'06, Edinburgh, June 2006, MOPCH116, p. 315 (2006); http://www.JACoW.org.