उच्च तीव्रता प्रोटॉन त्वरक

5

अतिचालकता और सामान्य चालकता गुहिका के लिए आरएफ कैविटी एम्युलेटर

*राधिका नासेरी, संदीप भराडे, आलोक आगाशे, एम.वाई. दीक्षित एवं गोपाल जोशी
त्वरक नियंत्रण प्रभाग, भाभा परमाणु अनुसंधान केंद्र (भापअ केंद्र), ट्रांबे-400085, भारत

एम्युलेटर के साथ एलएलआरएफ एकीकरण

सारांश

निम्नस्तरीय आर एफ (एलएलआरएफ) प्रणाली के साथ एकीकृत परीक्षण के लिए एक आरएफ गुहा अनुकरणकर्ता विकसित किया गया है। गुहा मॉडल को एफपीजीए पर डिजिटल में लागू किया गया है और इसमें मौलिक गुहा गतिशीलता मोड, डिट्यूनिंग मॉडल, विलंब मॉडल और इलेक्ट्रोमैकेनिकल मोड शामिल है। आरएफ गुहा के मापदंड, जैसेकि गुहा आवृत्ति, गुणवत्ताकारक, युग्मनकारक और डिट्यूनिंग , को प्रोग्राम करने योग्य रखा गया है ताकि सुपर कंडक्टिंग और सामान्य संचालन गुहिकाएँ दोनों के व्यापक मापदंडों की श्रृंखला के व्यवहार का अनुकरण किया जा सके। एलएलआरएफ के साथ एकीकृत परीक्षण सफलतापूर्वक निष्पादित किया गया और परिणाम प्रस्तुत किए गए।

High Intensity Proton Accelerator

5

RF Cavity Emulator for Superconducting and Normal Conducting Cavity

***Radhika Nasery, Sandeep Bharade, Alok Agashe, M. Y. Dixit and Gopal Joshi**
Accelerator Control Division, Bhabha Atomic Research Centre (BARC), Trombay-400085, INDIA

LLRF integration with Emulator

ABSTRACT

A RF cavity emulator is developed for integrated testing with Low Level RF (LLRF) system. Cavity model is implemented in digital on FPGA and includes cavity dynamics of fundamental mode, detuning model, delay model and electromechanical modes. RF cavity parameters such as cavity frequency, quality factor, coupling factor and detuning are kept programmable to emulate behaviour over wide range of these RF parameters covering both, superconducting and normal conducting cavities. Integrated testing with LLRF is successfully performed and the results are presented.

KEYWORDS: *RF cavity emulator, LLRF, Controls, Signal Processing, Particle Accelerator*

**Author for Correspondence: Radhika Nasery*
E-mail: radhikan@barc.gov.in

Introduction

Accelerator Control Division (ACnD) is involved in design, development and commissioning of Low Level RF(LLRF) control system for a number of accelerators, including Low Energy High Intensity Proton Accelerator (LEHIPA) at BARC [1], Horizontal Test Stand (HTS) at RRCAT [2] and BARC-TIFR Superconducting Linac [3]. LLRF systems monitor, control and regulate the amplitude, phase and frequency of cavity RF fields in particle accelerators. LLRF signal processing algorithms are designed in digital domain to monitor the change in the RF field of cavity and to provide feedback and/or feed-forward regulations depending on system configuration and operational scenarios such as type of RF cavity : superconducting or normal, pulse width of operation, beam-loading effect, amplifier characteristics etc. Testing LLRF and control algorithms directly at plant is not only difficult but also undesirable as it involves interfacing with sensitive and costly entities such as RF cavities and RF power amplifiers. With this motivation, RF cavity emulator is developed. Fig.1 shows the simplified block diagram for testing LLRF with cavity emulator.

Using the emulator, LLRF systems and the control algorithms can be thoroughly tested in the lab before commissioning in the plant. The RF cavity model implemented in digital domain provides for programmability of cavity parameters. Cavity pickup and reflected power drives are generated for normal conducting cavities which are deployed at LEHIPA, BARC and for superconducting cavity commissioned at HTS, RRCAT. The article presents the architecture, signal processing flow and implementation aspects of RF cavity emulator. Results are illustrated in the form of pickup and reflected power for normal conducting as well as superconducting cavity. Integrated testing with LLRF system is also demonstrated.

Architecture and Implementation

The cavity emulator is cPCI crate based and its signal processing chain [1] shown in Fig.2 consists of ADC, FPGA, DAC and modulator. It takes the outputs from LLRF i.e. RF forward power drive and generates pickup and reflected power. The Forward Power output of LLRF is digitized using direct sampled ADC, using a clock that is derived from the Reference clock, and processed in FPGA. RF cavity emulator is implemented using cavity equation [3] given by:

$$\ddot{V}_c + 2 * w_{\frac{1}{2}} * \dot{V}_c + w_0^2 * V_c = w_{\frac{1}{2}} \dot{U}$$

Where V_c is cavity voltage, $w_{1/2}$ is cavity half bandwidth, w_0 is resonant frequency of the RF cavity and U is the normalized input drive to the cavity. The continuous time equation is first expressed in in-phase and quadrature signals in the base-band and subsequently transformed to discrete time and implemented on the FPGA. The in-phase and quadrature components of the drive are the inputs to this model. The output of the model is the in-phase and quadrature signal of the Pickup. The in-phase and quadrature components of the reflected signal are generated by subtracting the drive signal from the pick-up. Reflected Power and Pick-up signals in the base-band are fed to DACs. The analog outputs of the DACS are up-converted to RF in a quadrature modulator. RF reference signal feeds the RF port of the modulator. This model is for fundamental mode of the RF cavity. Quality Factor, Frequency, coupling factor and detuning are the programmable parameters of the model.

Results of Normal Conducting Cavity

The RF cavity emulator for normal conducting cavity is modeled after Drift Tube Linac of LEHIPA with a frequency of 352 MHz, Quality Factor of 38000, coupling factor of 2 [4]. All the parameters are programmable to model plant conditions. Fig.3 and Fig.4 show Pickup Power and Reflected Power RF signals on oscilloscope.

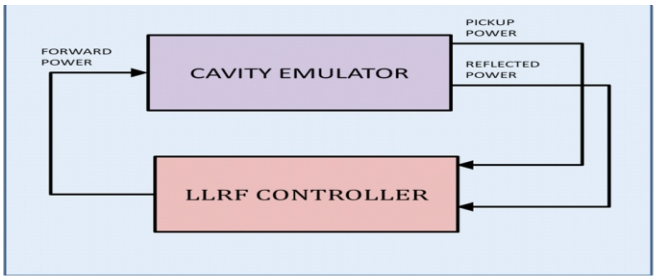

Fig.1: Testing of LLRF with Cavity Emulator.

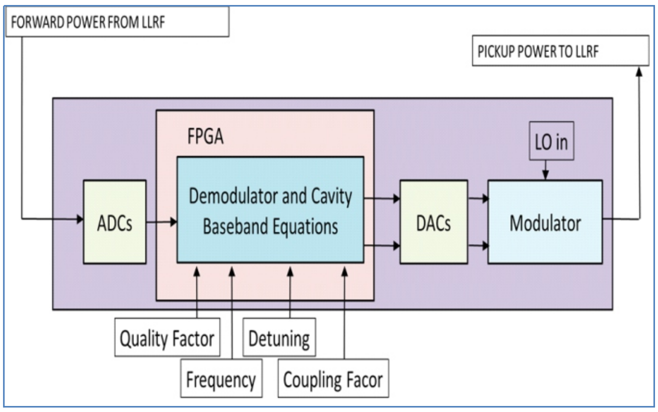

Fig.2: Signal Processing chain of RF cavity.

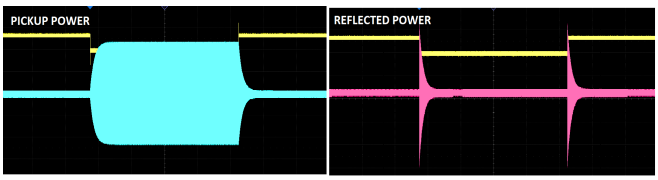

Fig.3: Normal conducting cavity with no detuning.

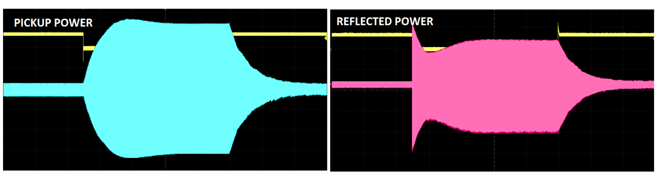

*Fig.4: Normal conducting cavity with a detuning of 2*$w_{1/2}$.*

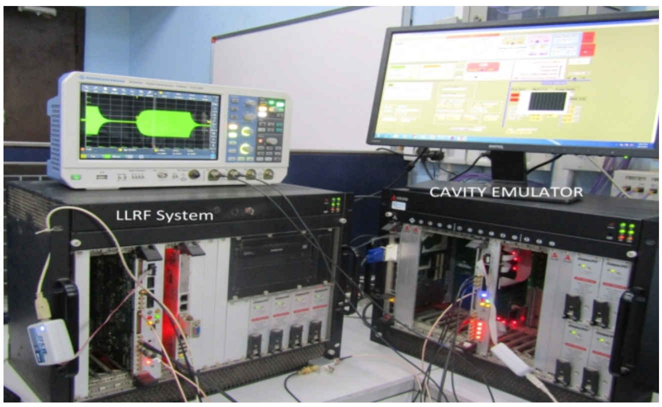

Fig.5: LLRF integration with Emulator.

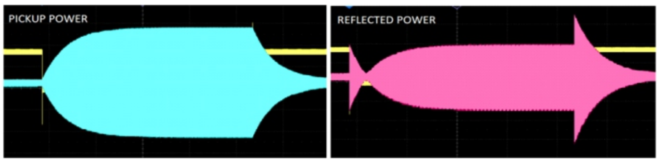

Fig.6: Superconducting cavity with no detuning.

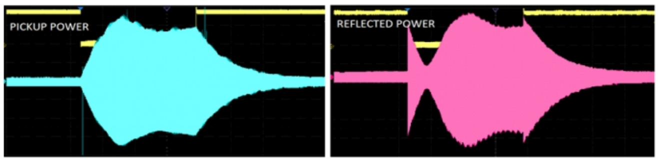

Fig.7: Superconducting cavity with Electromechanical mode at 100 Hz.

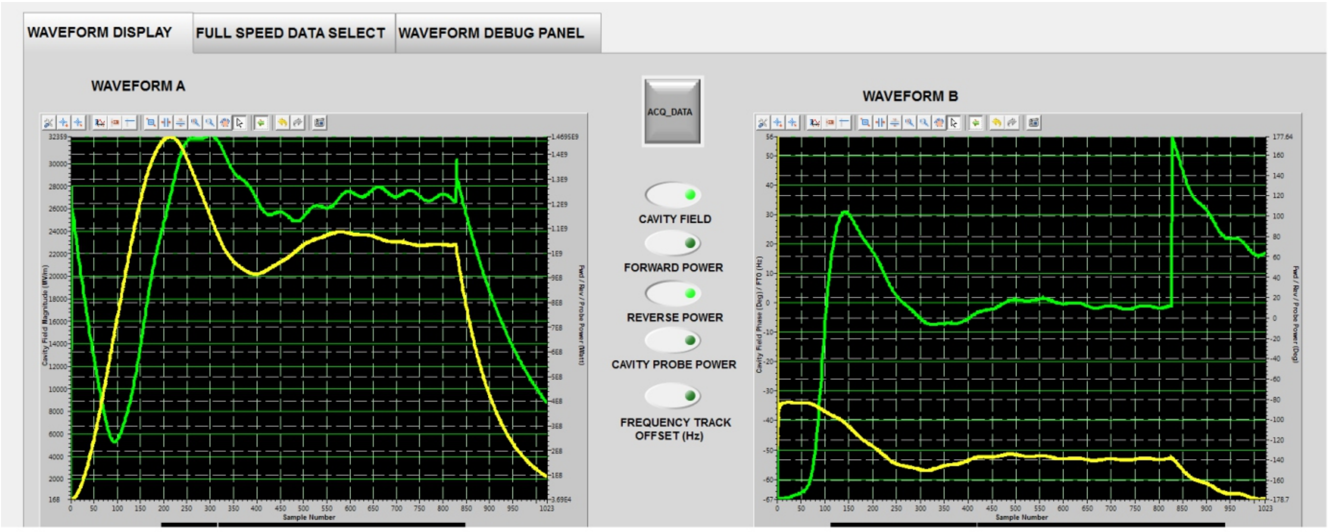

Fig.8: LLRF GUI with Reflected Power and Pickup Power.

Results of Super Conducting Cavity

The RF cavity emulator for a superconducting cavity is modeled after AES-010 [5] Superconducting RF cavity at HTS, RRCAT of 650 MHz with quality factor of $2*10^{10}$, coupling factor of 1000 and with no detuning. Fig.6 shows the successful implementation of emulator for superconducting cavity with Pickup Power and Reflected Power RF signals on oscilloscope.

Electromechanical dynamics of superconducting RF cavities cause detuning, called Lorentz force detuning (LFD), which is given by the equation given below [3].

$$\Delta \ddot{w}_1 + \frac{w_1}{Q_1}\Delta \dot{w}_1 + w_1^2 \Delta w_1 = -k_1 {V_{cav}}^2 w_1^2$$

Where w_1 is the resonance frequency of mechanical mode, Q_1 is the Quality factor of mechanical mode 1, k_1 is the dynamic detuning coefficient of mode 1, V_{cav} is the cavity voltage. Detuning effects of LFD are also implemented in the cavity emulator and Fig.7 shows the results.

Conclusion

RF cavity emulator has been successfully developed and demonstrated for normal conducting cavity as well as for superconducting cavity with electromechanical modes. Integrated testing with cPCI based LLRF system developed for LEHIPA DTL normal conducting cavity 352 MHz is successfully carried out. Integrated testing with LLRF system developed for HTS, RRCAT superconducting cavity of 650 MHz is tested. Using this emulator, resonance control system's detuning correction algorithms are being tested.

References

[1] Alok Agashe, P.D. Motiwala, S.K. Bharade, Shyam Mohan and Gopal Joshi, “Digital LLRF System for RFQ” InPac2015, Mumbai, India.

[2] Nibandh Kumar Shahi, Paresh Motiwala, Radhika Nasery, Rajesh Keshwani, C.I. Sujo, Sandeep Bharade, Gopal Joshi, Dheeraj Sharma, Ekansh Mishra “Commissioning of LLRF system for control of field in AES-10 SCRF cavity in HTS at RRCAT”, InPAC2022, Kolkata, India.

[3] Gopal Joshi et al., “Development of the Model of a Self Excited Loop,” PAC' 09, Canada.

[4] Shweta Roy (2015), “Physics Design and Prototype Development of Drift Tube Linac Cavity for High Current Applications”, Homi Bhabha National Institute.

[5] A. Sukhanov et al., “STC QUALIFICATION TESTS OF PIP-II HB 650 CAVITIES”, 20th Int. Conf. on RF Superconductivity, USA.