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ELECTRONICS FOR BEAD-PULL MEASUREMENT OF RADIO FREQUENCY ACCELERATING STRUCTURES IN LEHIPA

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Abstract

For carrying out bead-pull characterisation of RFQ and DTL at the Low Energy High Intensity Proton Accelerator of BARC, a controller for simultaneous motion of 64 axis, tuners or post couplers, was developed. Also, a bead motion controller with integrated phase measurement sensor was developed. The paper discusses the requirements of the system, the architecture of the control systems, operation and results. The results obtained from the sensor was compared to that obtained using an independent USB VNA. The advantages of the system especially with addition of internal phase measurement sensor including minimising position error, flexibility in bead-pull to selectively increase resolution at specified locations and ease of implementing auto-tuning algorithms are discussed.

INTRODUCTION

A Low Energy High Intensity Proton Accelerator (LEHIPA) is being developed by Ion Accelerator Development Division at Bhabha Atomic Research Center. The first accelerating stage of LEHIPA is a Radio Frequency Quadrupole (RFQ) with 64 offline tuners. The RFQ was tuned to obtain required field flatness observed using a bead-pull system [1]. For the movement of the tuners with precision of few micrometers, a 64-axis stepper motor controller with feedback system was developed. A DC motor was used for moving the bead and a Vector Network Analyser (VNA) was used to measure the field characteristics. The VNA acquires phase data during the motion of the bead. The bead movement was assumed to have uniform velocity and thus the phase vs time plot obtained was directly converted to phase vs distance plot for analysis.

In the Medium Energy Beam Transport (MEBT) buncher tuning, the same stepper motor-based motion control system was used for offline tuning. The bead movement was also controlled using an axis of the stepper motor control system. The motion did not have uniform velocity during the movement and error in the position that was extrapolated assuming uniform velocity became a concern. For the long-distance tuning required for Drift Tube Linacs (DTLs), a new system with inbuilt phase and gain measurement chip was used for the bead-pull and field measurements. The tuners and post-couplers were controlled using the 64-axis tuner.

This paper describes the 64-axis motion control system and the bead-pull control system including the requirements, architecture and operation results.

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64-AXIS MOTION CONTROLLER

Requirements

The RFQ had four segments, each segment had four quadrants with four tuners each. Each tuner axis required generation of signals for the motor driver as well as feedbacks from the encoder and limit switches.

For tuning up to two segments of the RFQ an off-the-shelf CPCI based stepper motor controller was used. The controller had 8 slots. One slot was occupied by the CPU and 8-axis motion controller cards were mounted on the remaining 7 slots thus making it a 56-axis controller. Remaining 8 axis required a separate crate with independent CPU. Easily expandable alternatives were explored. Four-axis motion controllers with serial interface were found to be easily available. An existing four-axis motion controller design was modified to develop a compact expandable motion control system. Eight such controllers were mounted along with power supplies in a 19” sub-rack to create a 32-axis motion control system as shown in Fig. 1 and two such systems could be looped together to achieve 64-axis control system.

Figure 1: (Left) 32-axis controllers. (Right) Two 32-axis controllers looped together.

Ease of cabling, compactness, EMI resilience and expandability were the main requirements in this system. The precision of the end position of the tuners at a moderate speed was the main functional requirement.

Architecture

The architecture of the system is shown in Fig. 2. The motor driver signals are generated using I2C port expanders and the limit switches are also read using it. The encoder is connected to the quadrature encoder counter. The power and communication buses of each axis are connected to the main processor through ribbon cables. The external signals of each axis are carried by two RJ45 connectors and ethernet cables carry the signals to the breakout boards placed near the tuners. This technique has reduced the challenge of wiring 64-axis to the control system to minimal. Each mother board is connected to the RS-485 based backplane which makes it extendable. The PC is

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connected to the backplane though a USB-Serial adaptor. The PC software communicates with each of the processors to read and set values as well as send commands as per the application requirements. The PC software also stores the position information required by the system. The PC software GUI is shown in Fig. 3.

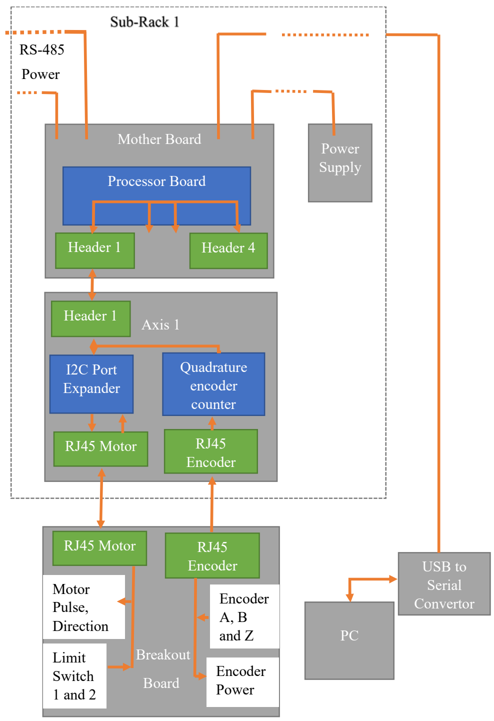

Figure 2: Architecture of the 64-axis motion controller.

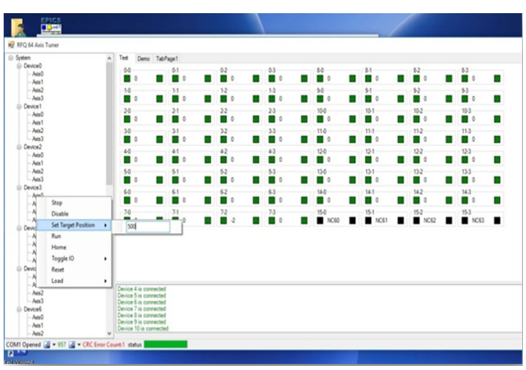

Figure 3: Screenshot of the GUI of the PC software.

BEAD-PULL CONTROLLER

Figure 4 shows the major components and interfaces of the bead-pull control system. A PLL with integrated VCO was used to generate RF signals required for the bead-pull measurements. The signal was split into two using a 3 dB splitter and one part was used to excite the cavity using RF couplers mounted on the cavity's RF input port while the other was used as reference for the measurements. The signal from the RF output coupler port was also connected to the RF measurement sensor which measured the gain and phase of the RF output with the RF input as the reference.

Using the USB program for frequency locking of the RF source, the frequency was varied to find the frequency with highest gain. After that the bead was moved axially inside the cavity and the measured phase was plotted during the movement.

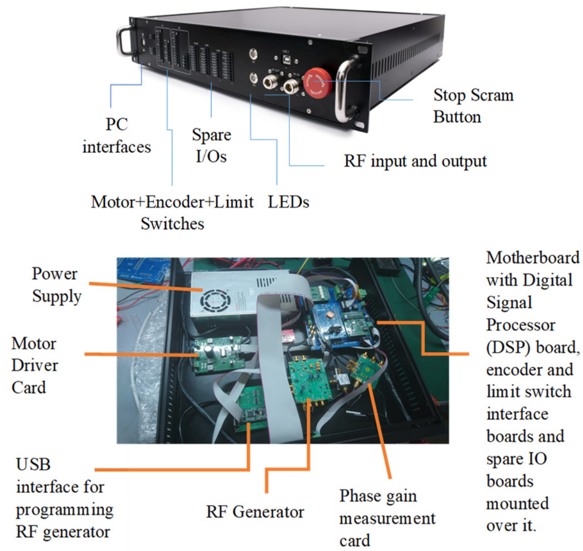

Figure 4: Major components of the bead-pull control system.

Preliminary Results

The phase measurements during bead-pull taken in a DTL cavity is shown in Fig. 5. 25 dips corresponding to the 25 accelerating gaps was observed. Due to large amount of high frequency noise present in the raw data spanning 4 degrees an internal moving average filter was applied. However, this filter was found to have reduced the peaks. To avoid this, more data needs to be obtained at these locations and redesigning of the filter can also be explored.

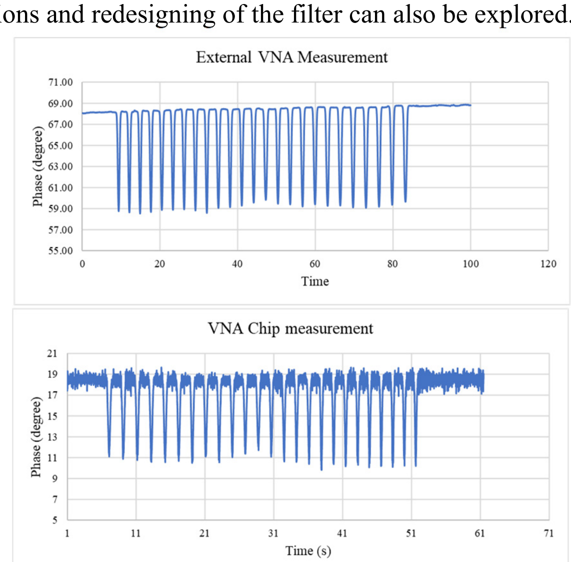

Figure 5: Phase vs time measured during beadpull using (Upper) external VNA and (Lower) VNA chip inside the bead-pull control system.

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Advantages

In this system, control of the phase measurement and the bead movement is done by the same processor which opens many possibilities in the measurement. It was possible to plot the phase vs position obtained from the encoder online. This made it possible to slow, pause or move backward and obtain more measurements at locations where required with ease.

The Digital Signal Controller (DSC) had internal encoder read-back and PWM outputs which was used to control the motor driver. High speed and precision control of the position was possible with this system. Vibration of the bead and motor at higher speed decides the speed limit. 128 MB flash memory was connected to the DSC which makes it possible to store motion routines as well as acquired data. Software to read and write to the memory from computer interface has been developed and tested. As per the requirement of the cavity, application program can be developed to automatically obtain maximum data from the positions of interest and generate the optimum position for the next iteration of tuners. This could be automatically fed to the tuner control system to obtain an automatic bead pull based cavity tuning system.

CONCLUSION

Custom designed and developed control systems and application software for offline tuning of RF accelerating cavities have shown promising results. Precise movement of around 64 motor controlled tuning axis and the highly flexible bead-pull motion control along with in-built RF phase and gain measurement modules opens the possibility of automation of the complete process which is being explored. Suitable algorithms need to be developed to automatically identify the positions of interest and the optimum rate of data acquisition at these positions. Noise filtering also needs to be optimised for the rate of measurement and accuracy requirement. Large number of data acquisition cycles can be carried out to develop tuning procedures for a given cavity that can optimally use the capabilities of this system.

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