RF system in Accelerators

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Abstract

In accelerators, RF wave is commonly used for acceleration of charged particles. The RF acceleration is enable by RF modulator and amplifier, RF cavity, and low-level radio frequency(LLRF) system. In this report, measurement of beam position by oscilloscope, detection of impedance discontinuity by time domain reflectometer(TDR), and measurement of resonant frequency of pill-box cavity by vector network analyzer(VNA) were conducted in PAL-eLabs.

INTRODUCTION

In accelerators, electric field is used to accelerate charged particles. However, high voltage DC acceleration causes breakdown and spark. Thus, radio frequency(RF) wave, which applies time-varying electric field, is commonly used for acceleration.

RF system consists of RF cavity, DC power supply, amplifier and low level RF(LLRF) system. Electric power generated by DC power supply is amplified and converted to RF power by RF amplifier(solid state modulator and klystron) and passes through the waveguide. RF wave is finally delivered to the RF cavity and used to accelerate the charged particles. Lastly, LLRF system controls overall process.

In this report, experiment using oscilloscope, time domain reflectometer(TDR), and vector network analyzer(VNA) was conducted in eLabs.

EXPERIMENTS

Measurement of resonant frequency of RF cavity

In this section, measurement of resonant frequency of pill-box cavity was conducted. In this experiment, the cavity was connected to VNA.

In the pill-box RF cavity, the solution of Maxwell equation is shown in (1-3).

$$E_z = EJ_0(k_c r)cos(k_z z) \tag{1}$$

$$E_r = \frac{Ek_z}{k_c}J_r(k_c r)sin(k_z z) \tag{2}$$

$$B_\theta = -\frac{ikE}{ck_c}J_1(k_c r)cos(k_z z) \tag{3}$$

where J_n is Bessel function of the first kind.

The solutions for RF cavity can be categorized to three groups. First, TEM modes do not contain either longitudinal electric wave or longitudinal magnetic wave. Secondly, TE modes indicates the solutions that do not contain longitudinal electric field. Lastly, TM modes do not contain magnetic field that is parallel to the direction of propagation.

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Figure 1: (a) Picture of inside of pill-box cavity. (b) calibration kit used for VNA. (c) picture of pill-box cavity connected to vector network analyzer.

In TM mode $TM_{\theta rz} = TM_{0nq}$, the resonant frequency of the wave can be written as (4).

$$\omega_{0nq}^2 = (\frac{x_n}{R/c})^2 + (\frac{q\pi}{l/c})^2 \tag{4}$$

where x_n is nth root of Bessel function, and R and l are radius and length of pill-box cavity respectively. Therefore. the lowest resonant frequency is $\omega_{010} = \frac{2.4048c}{R}$.

Fig. 1-(a) shows inside of pill-box cavity. Fig. 1-(b) shows the calibration kit used for removal of systematic errors of VNA, and Fig. 1-(c) shows the pill-box cavity connected to vector network analyzer.

After the cavity was connected to VNA, resonant frequencies of pill-box cavity were measured by measuring the reflection coefficient S_{11}. In the graph(see Fig. 2), the dips in the graph correspond to resonant frequency.

Beam position monitor

In this section, position of the electron beam, which was demonstrated by wire and signal generator, was measured. An oscilloscope was connected to the beam pipe to show the measurement result of stripline BPM. Fig. 3 show the

Figure 2: Graph of S_{11}(green) measured by VNA.

layout of setup for beam position monitor and measurement result by BPM.

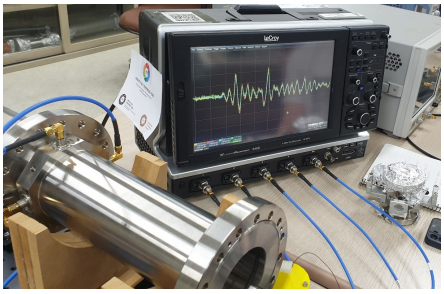

Figure 3: Layout of setup for beam position monitor.

Time domain reflectometer

Time domain reflectometry is a method for measuring impedance. It can detect the location of discontinuity of impedance by sending step signal and detecting the reflected signal. Fig. 4-(a) and (b) show the setup for TDR and resulted graph of TDR respectively.

CONCLUSION

In accelerators, RF wave is commonly used for acceleration of charged particles. In this report, measurement of beam position by oscilloscope, detection of impedance discontinuity by time domain reflectometer(TDR), and measurement of resonant frequency of pill-box cavity by vector network analyzer(VNA) were conducted.

REFERENCES

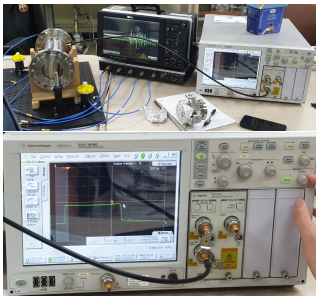

Figure 4: (a) The setup for time-domain reflectrometer. (b) Resulted graph of TDR.