RF Parameter Measurement of 9/6 MeV Linear Accelerator Structure with Bead-Pulling Method

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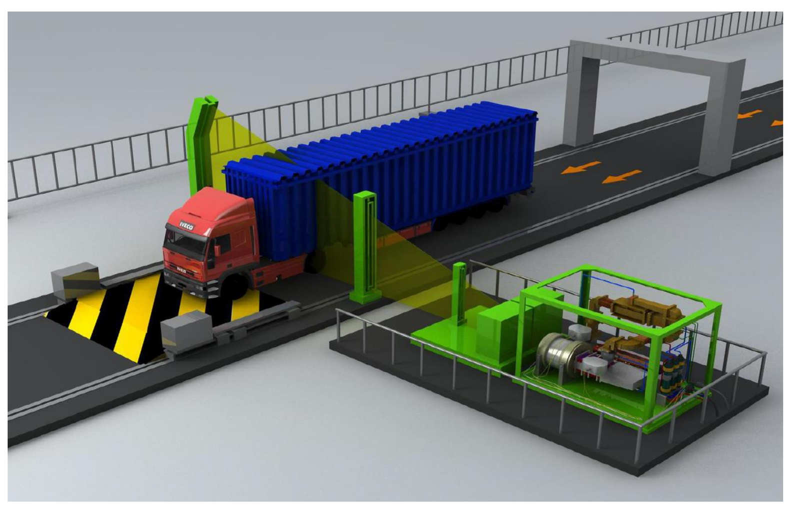
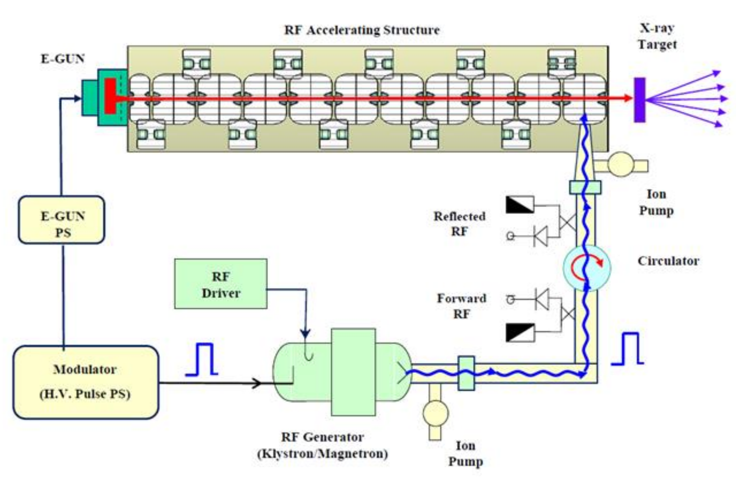
Abstract

Korea Atomic Energy Research Institute (KAERI) and Radiation Technology eXcellence (RTX) have developed a 9/6 MeV side-coupled S-band RF electron linear accelerator (linac) for various industrial applications. The linac structure consists of 2-bunching cells and 9-accelerating cells. The characteristics of S-band linear accelerator were measured with a network analyzer (NWA) by using the bead-pulling method, which is based on the perturbation theory. The on-axis electric field along the linear accelerator was measured by using a small copper bead with a radius of 3 mm. In this poster, we describe the measurement of RF parameters such as the quality factor, the resonance frequency, the bandwidth, the standing wave ratio, and the shunt impedance of the S-band linac structure with the bead-pulling method.

Introduction

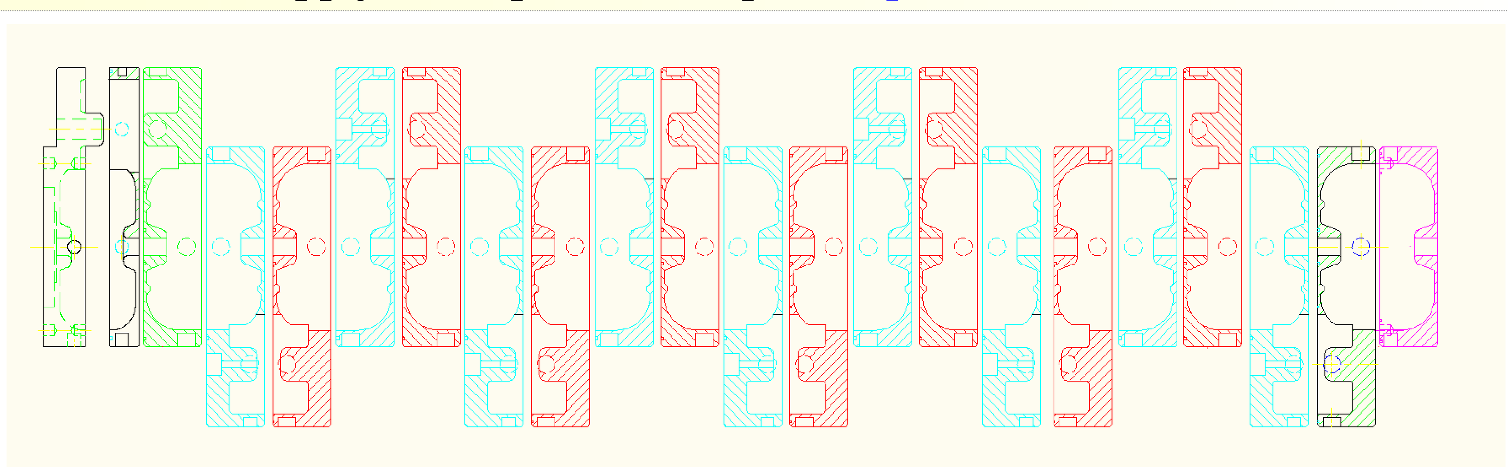




Recently, there are needs of the X-ray inspection systems around the world to combat terrorism, drug and weapons smuggling, illegal immigration, and trade fraud. To meet those growing needs, Korea Atomic Energy Research Institute (KAERI) and Radiation Technology eXcellence (RTX) have been fabricating a compact standing wave (SW) type linear accelerator (linac) for container X-ray inspection system. The inspection system consists of an electron accelerator, a target to generate the bremsstrahlung X-rays, and a detector. X-rays reveal the basic shape of the cargo inside a container and recognize materials inside it.

Fabrication and Tuning of the Structure

The ALTAIR A102414 electron gun is used and can be applied a gap voltage up to 25 kV. Since the gun is connected directly to the accelerating structure, the wall of the first cell acts as the anode. The magnetron that we have chosen for the container inspection systems is an MG6028 fast tuned magnetron made by e2v technologies. The magnetron supplies 5 MW peak RF power at 2856 MHz, which is sufficient to supply the required net input RF power of 2.75 MW for 9 MeV.



We machined 2 bunching cells and 9 normal accelerating cells including a coupling cell and 10 side-coupling cells. Then, we measured all cells one by one, and combined them to form a coupling chain. After the 1st tuning, we put whole structure in a furnace at 800 degree Celsius for three days, then took dead annealing. After the 2nd tuning at the π/2 mode, we finished fabrication of the linac structure. After installing an ion-pump and the ALTAIR electron gun, we could keep vacuum of the structure within about 3 × 10^{-7} Torr.

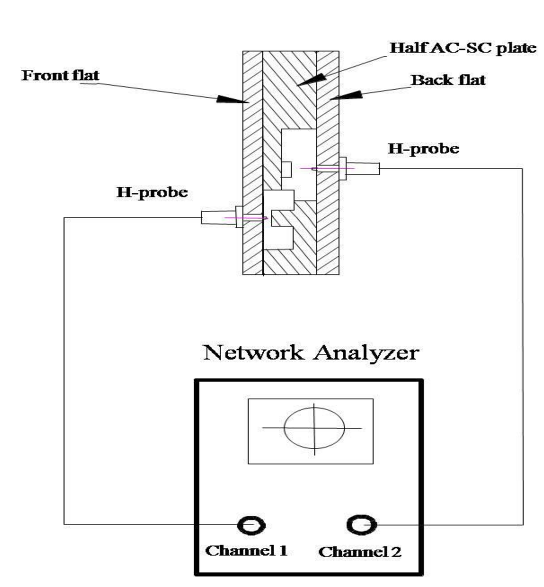
RF Parameter Measurements

* Resonance frequency (f_0), Quality factor (Q)

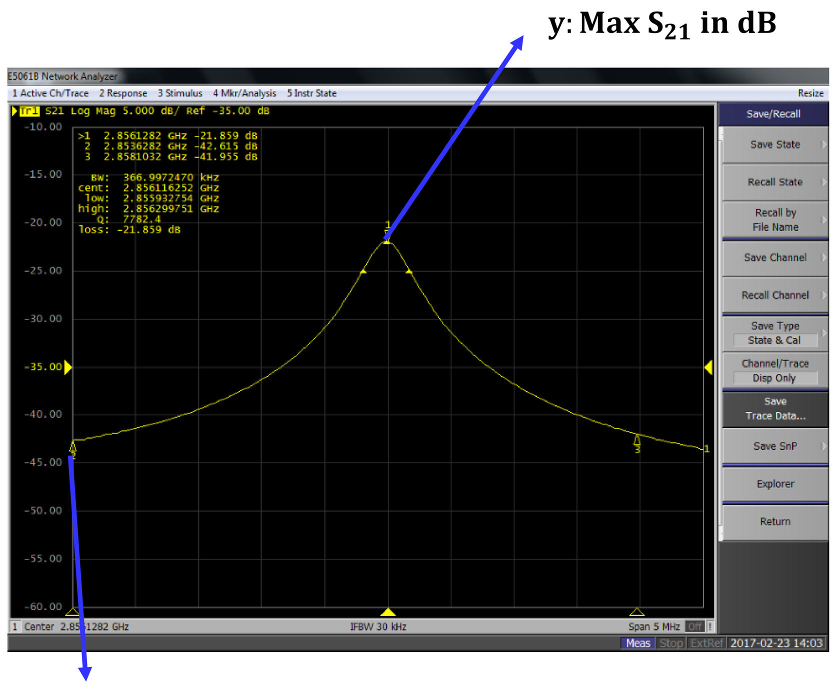
$$Q_0 = (1+\beta)Q_L \quad \text{where} \quad \beta = \text{coupling factor}$$

$$\beta = \frac{1+R_0}{1-R_0} \qquad R_0 = 10^{\frac{x-y}{10}} \qquad \begin{cases} x: \text{Min } S_{21} \text{ in dB} \\ y: \text{Max } S_{21} \text{ in dB} \end{cases}$$

$$Q_L = -\frac{f_0}{f_2 - f_1} \longrightarrow f_2 - f_1 \quad @\, z = 10\log\left[\frac{1}{2}10^{\frac{x}{10}} + \frac{1}{2}10^{\frac{y}{10}}\right]$$



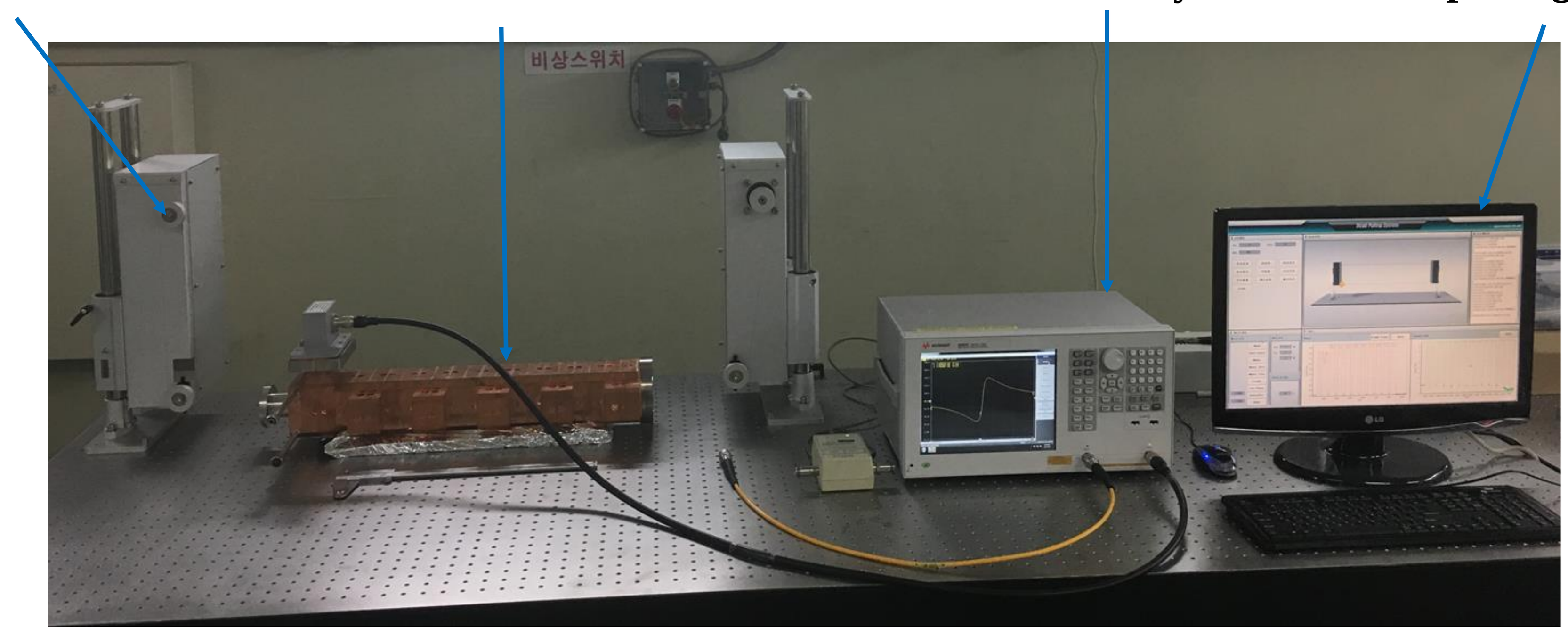
y: Max S_{21} in dB



x : Min S_{21} in dB

RF properties	Simulation	Measured
Frequency (MHz) at π/2 mode	2855.73	2856.08
Linac length (m)	0.6	0.6
Quality factor, Q	8109.72	7782
Standing Wave Ratio (SWR)	1.16	1.16
Shunt impedance, R_{sh} (MΩ/m)	82	80
External coupling coefficient	1.02	1.02
RF input power (MW)	2.2	2.2

Bead-Pulling Measurement System



To measure RF parameters of the linac structure, we used the bead-pulling system, which consists of a network analyzer, a supporting frame, a stepping motor, a Kevlar wire with a bead, wheels, and a control PC. By moving the bead along the structure, the phase change of S-parameter, which is related to the RF field inside the structure was measured by using the network analyzer. From the measurement, plotting of the electric field along the structure can be automatically done with a software. According to perturbation theory and the 1st equation below, the phase change is corresponding frequency change. Change in the resonance frequency depends on the amplitudes of electric and magnetic fields. However, the magnetic field on the axis of the structure is zero. Therefore, the on-axis electric field can be obtained by a measuring a change in the resonance frequency. We found that the measurement errors strongly depend on the tension and surface roughness of the Kevlar wire. Lastly, we got the shunt impedance from the 2nd equation. Here bead radius is 2~3 mm.

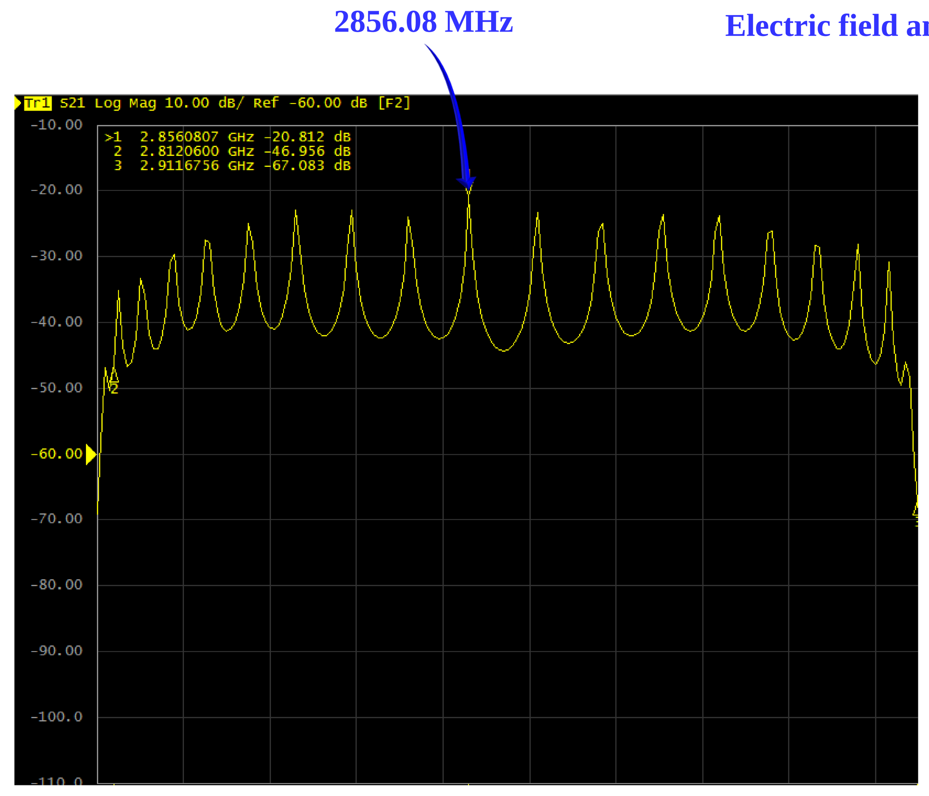
$$\Delta ang(S_{21}) \approx -2Q_L\frac{\Delta f}{f_0} \longrightarrow \frac{-|E_z(z)|^2}{wU} = \frac{\Delta arg S_{21}}{(wQ_L\varepsilon_0 F_{\text{bead}})}$$ (Phase, E-Field Equation) * $\Delta\tau = \frac{4}{3}\pi r^3$ (r : radius of bead)

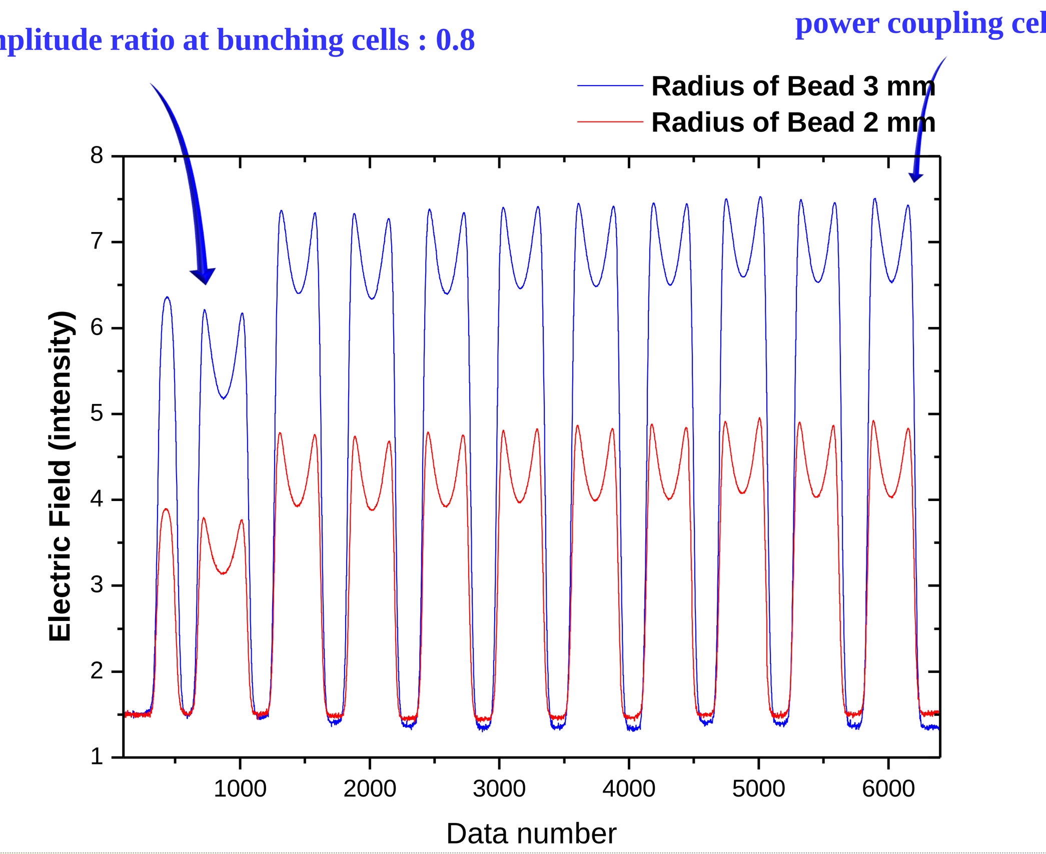
$$R_s(\text{shunt impedance}) = Q\,\frac{\varepsilon_r+2}{\varepsilon_r-1} \times \frac{\Delta f l^2}{\pi\varepsilon_0\Delta\tau f_0^2} \approx 80\ \text{M}\Omega$$

- Q : quality factor : (7782)
- l : length of gap : (60 cm)
- Δf : change of frequency : (Several MHz)
- f_0 : the resonant frequency : (2856 MHz)
- ε_r : relative permittivity : (Copper : 5.8)
- ε_0 : permittivity of free space : (8.85 × 10^{-12})

Bead-pulling Measurement Principle and Technique Used for the SRF Cavity at Jlab and Thesis of Luo

Measured Result





We also measured the smith chart characteristics by using a network analyzer (NWA) to verify that it is over-coupling. After tuning whole cells and structure, we could measure the resonance frequency of the structure, which is 2856.08 MHz at the π/2 operation mode as shown in a left figure above. From the bead-pulling measurement, we found that the ratio of electric field amplitudes between bunching cells and accelerating cells is 0.8, which is agreed with our design one. Other RF parameters are summarized in a table above. By tuning resonance frequencies of the 1.5 bunching cells and 9 accelerating cells including a coupling cell, we could get uniformly distributed electric fields along the structure as shown in a right figure above.

Summary

Successfully, we have designed and fabricated a 9/6 MeV S-band electron linac for the container inspection system. The shunt impedance of 80 MΩ and the quality factor of 7782 are obtained at the π/2 mode frequency of 2856.08 MHz, external coupling coefficient of 1.02 and Standing Wave Ratio (SWR) of 1.16. Its measured RF parameters are well agreed with design ones. It will be operated with an e2v technologies 5 MW magnetron with a macro pulse length of 4 μs.