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Fabrication and Measurement of 9 MeV S-band Electron Liner Accelerator Structure

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1. Introduction

Recently, there is a need for X-ray inspection systems around the world to combat terrorism, drug and weapons smuggling, illegal immigration, and trade fraud [1]. To meet these 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 a container X-ray inspection system. The inspection system consists of an electron accelerator, a target to generate bremsstrahlung X-rays, and a detector. X-rays reveal the basic shape of the cargo inside a container and recognize materials inside it.

2. Methods and Results

The ALTAIR A102414 electron gun is used and can be used to 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 the whole structure in a furnace at 800 degree Celsius for three days, then did dead annealing. After the 2nd tuning at the **π**/2 mode, we finished fabrication of the linac structure (Fig.1). After installing an ion-pump and the ALTAIR electron gun, we could keep a vacuum of the structure within about 3 × 10-7 **Torr**.

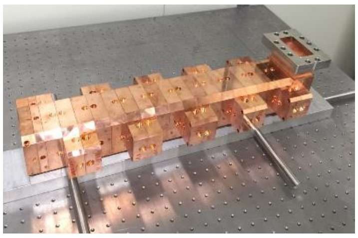

Fig. 1. 9 MeV S-band Linac Structure

2.1 Perturbation Theory

According to the classical Slater perturbation theory, cavity volume is changed by a very small amount ΔV or by a tiny perturbing object, more commonly referred to as a bead having volume. If ΔV perturbs the stored energy of the resonant system by a very small amount, there will be a small shift in resonant frequency which is shown by

$$\frac{\Delta f}{f} = \frac{\Delta U_E - \Delta U_M}{U} \quad (1)$$

For the case of a small non-conducting sphere with radius "r", where the unperturbed field may be considered uniform over a region larger than the bead, it can be shown as

$$\frac{\Delta f}{f} = \frac{\Delta U}{U} = -\frac{\pi r^3}{U}\left[\varepsilon_0 \frac{\varepsilon_r - 1}{\varepsilon_r + 1} E_0^2 - \frac{\mu_0}{2}\frac{\mu_r - 1}{\mu_r + 1} H_0^2\right] \quad (2)$$

For a dielectric bead (μ_r=1) the expression reduces to

$$\frac{\Delta f}{f} = -\frac{\pi r^3}{U}\left[\varepsilon_0 \frac{\varepsilon_r - 1}{\varepsilon_r + 1} E_0^2\right] \quad (3)$$

Where, Δf = frequency shift, f = unperturbed frequency, U= energy stored in the cavity, ΔU= change in stored energy, E_0 = amplitude of electric field, ε_r = relative permittivity of the bead, ε_0= permittivity of vacuum, μ_r= permeability of vacuum, μ_0 = relative permeability of the bead. So, in the present measurement technique, instead of measuring the frequency-shift, the phase-shift is measured and then transformed into the frequency-shift [2].

$$\frac{\Delta f}{f} = \frac{f_p - f_0}{f_0} = \frac{\tan\emptyset(f_0)}{2Q} \quad (4)$$

where, f_p = perturbed frequency, f_0 = unperturbed resonant frequency, Q = quality factor of the unperturbed cavity, tan∅ = shift in phase angle as a function of f_0. From equation (3) and (4), we can get this equation.

$$-\frac{\pi r^3}{U}\left(\varepsilon_0 \frac{\varepsilon_r - 1}{\varepsilon_r + 1} E_0^2\right) = \frac{\tan\emptyset(f_0)}{2Q} \quad (5)$$

It means that the electric field square is a proportioned phase shift. This leads to the field distribution result (Fig.3).

2.2 Bead-Pulling RF Measurement System

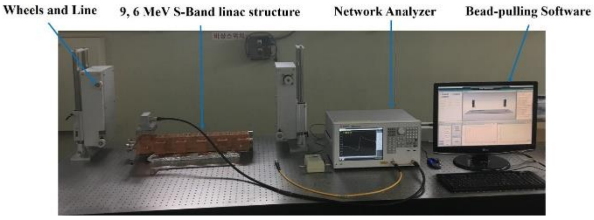

Fig. 2. Bead-pulling system for S-band Linac Structure

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 (fig.2). 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 software. According to perturbation theory and the 1st equation above, the phase change to frequency change [3]. 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 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 [4]. Lastly, we calculated the shunt impedance from the 2nd equation. Here the bead radius is 2~3 mm (fig.3).

2.3 Measured Result

We also measured the Smith Chart characteristics by using a network analyzer (NWA) to verify that it is over-coupling. After tuning the whole cells and structure, we could measure the resonance frequency of the structure, which is 2855.2750 MHz at the $\pi/2$ operation mode as shown in a fig.4.

From the bead-pulling measurement, we found that the ratio of electric field amplitudes between bunching cells and accelerating cells is 0.8, which agrees with our designed one. Other RF parameters are summarized in Table.1. 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 Fig.3 below[5]. The RF parameters are summarized in Table.1. We also measured RF parameters such as the quality factor, resonance frequency, bandwidth, and standing wave ratio of the S-band linac structure [6].

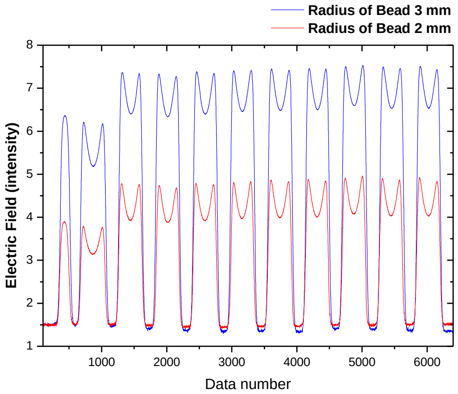

Fig. 3. Field distribution measurement results

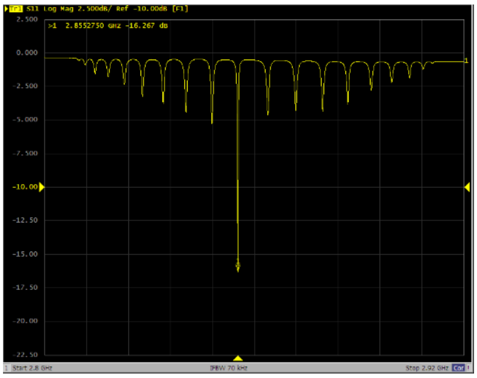

Fig. 4. Reflection spectrum from the power coupler S11

3. Conclusions

Successfully, we have designed and fabricated a 9 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 $\pi/2$ mode frequency of 2855.2750 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.

RF properties	Simulation	Measured
Frequency (MHz)	**2855.73**	**2856.08**
Linac length (m)	**0.6**	**0.6**
Quality factor, Q	**8109.72**	**7782**
Standing Wave Ratio	**1.16**	**1.16**
Shunt impedance, R_{sh} (MΩ/m)	**82**	**80**
External coupling coefficient	**1.02**	**1.02**
RF net input Power	**2.75**	**2.75**

Table.1. 9 MeV Electron Linac Parameter[6]

REFERENCE

[1] The Development of Accelerator Applications in China, Proceeding of APAC 2004, Gyeongju, Korea

[2] Sumit som, Sudeshna Seth, Aditya Mandal, Surajit Ghosh, Proceedings of IPAC2011, San sebastain , Spain

[3] CHARLES W. STEELE, Transactions on microwave theory and techniques, VOL. MTT-14, NO.2

[4] J.R. Lewandow-ski, G.Bowden, R. H. Miller, J. W. Wang, SLAC, Menlo Park, Ca 94025, USA, SLAC-PUB-11193, May 2005

[5] Song, K.B., Li, Y., Lee, S. et al. Journal of the Korean Physical Society (2013) 63:174

[6] P.Buaphad, Y.J.Kim, S.S.Cha, B.C.Lee, H.K.Cha, H.Ha, K.B.Song, H.D. Park, S.Y. Yoo, Proceedings of IPAC2016, Busan, Korea