# DESIGN AND CONSTRUCTION OF A PRE-BUNCHER FOR IRANIAN LOW ENERGY LINEAR ACCELERATOR

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## Abstract

Iranian IPM low energy linear accelerator project (e-Linac) is in its final steps for commissioning. Beam dynamic simulations with and without Pre-buncher prior to buncher were done. The results represent improvement in capturing efficiency better than 25% by application of Pre-buncher cavity. In this paper, we present the simulation, construction, RF measurements and vacuum test results. After construction, we measured RF reflection coefficient better than -33 dB in the nominal frequency of 2997.9 MHz with quality factor of 4500.

## INTRODUCTION

Travelling wave linear accelerators have two types of constant impedance and constant gradient. Constant gradient structures have uniform accelerating gradients along the linac in comparison with constant impedance structures that the amplitude of accelerating gradients decreases along the cavity length. But, constant impedance has simpler structure in comparison to constant gradient accelerator cavities. Travelling wave linear accelerators have higher capture efficiency in contrast to standing wave cavities [1, 2].

Travelling wave linear accelerators consist of several sections with special configurations to increase the bunching and acceleration efficiency and to decrease energy spread and beam emittance at the output of linac. These sections are normally single or multicell Pre-Buncher, buncher and accelerating cavities with focusing solenoids around them. The Pre-buncher has responsibility for velocity modulation of continuous beam that is generated by the electron gun as buched electrons around stable accelerating phase [3].

The IPM electron linear accelerator is an 8 MeV traveling wave electron Linac with the maximum current of 10 mA. This is an S-Band Linac that works in π/2 phase advance operation mode. This accelerator has 50 keV triode gun with dispenser flat cathode.

Based on beam dynamic studies, the capturing efficiency increased from 67% to 91% with application of a simple single cell pre-buncher. In this paper we present design, RF simulation, construction and experimental measurements of Pre-buncher of IPM e-Linac project. Two number of pre-buncher will be used for velocity modulation of electron beams and detection of bunch formation.

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## DESIGN AND SIMULATION

The electrons are accelerated or decelerated according to the phase of the applied RF voltage ($U_C$). After a drift distance D, the fastest electrons reach up the slowest; this results in a longitudinal compression, called "Pre-bunching". Let $\varphi_1$, be the RF phase at the time $t_1$, when the electron crosses the cavity gap; $\varphi_2$, the RF phase at the time $t_2$ when the electron reaches the end of the drift space D; $\varphi_0$, the RF phase at the time $t_0$ that the central electron (the electron at 0 voltages) arrives at the end of D. Then according to Equation (1), we can compute phase ($\varphi_2$) and energy ($\beta$) of particles at the output of Pre-buncher [4].

$$\varphi_2 - \varphi_0 = \varphi_1 + \frac{2\pi D}{\beta_0 \lambda_0}\left(\beta/\beta_0 - 1\right) \qquad (1)$$

Where $\beta_0 = v_0/c$, with $v_0$ the velocity of the electrons leaving the gun, $\beta = v/c$, with $v$ the velocity of the electrons after the cavity, and $\lambda_0$, is the free space wavelength. Knowing U, D and $U_0$, ($U=U_0+U_c \sin\varphi_1$), we can compute $\beta$ and $\varphi_2$.

The compression will be greater if the higher the ratio ($U_c/U_0$)D. We generally use the standardized ratio $R=\pi DU_c/\beta_0\lambda_0 U_0$ called the bunching parameter and in our calculations we considered its value R=2.

Pre-buncher of IPM e-linac is one cell standing wave cavity with loop antenna RF coupling. For simplicity of calculations, the phase of Pre-buncher zero crossing particle is subtracted from other particles. But for correction, the entrance phase to the buncher is added to all of them. Drift length asumed equal to 40 mm and $U_c$=4.6 KV in our calculations. The phase of pre-buncher should be about 85° for the optimum result. Pre-buncher does the initial bunching to put the particles in the catching range of the buncher.

By calculations based on Equation 1, the final distribution of Pre-bunched electrons take placed in the phase of -95.04±6.62 deg equal to 3.7 mm bunch length. Continuous beam is entered to the pre-buncher and bunching beam is entered to the buncher. The Capturing was done in the initial phase from -162 to 167 equal to 329 deg. Particle energy gain relative to its entrance phase in the gap of Pre-buncher and Particle input and output phase after passing Pre-buncher are shown in Figures 1 and 2 respectively. Also, particles energy and energy spread at the output of linac with presence of Pre-buncher is shown in Figure 3.
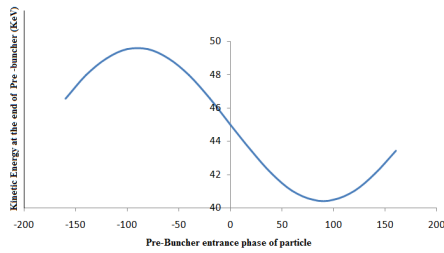
Figure 1: Particle energy gain versus entrance phase.
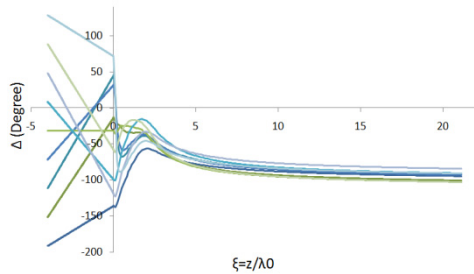


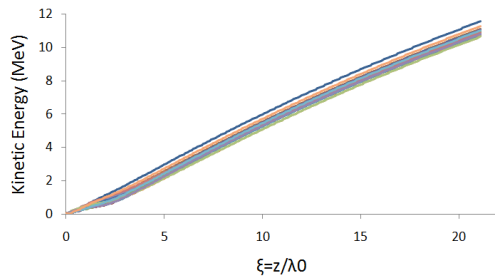Figure 2: Particle input and output phase after passing Pre-buncher.



Figure 3: Linac output energy and energy spread in presence of Pre-buncher.

Final Kinetic Energy reaches to 10.97MeV with ±0.19 (1.7%) energy spread in comparison with ±0.26 (2.3%) without prebuncher. After these analytical and other simulations of beam dynamics with ASTRA, It is considered that the linac capturing efficiency increased to 91% in comparison to 67% in the case of application of the Pre-buncher.

Based on these calculations, the cavity electromagnetic design and simulation was done with CST Studio Suit [5]. With electromagnetic simulations, the dimension of RF coupling loop was optimized for operation in critical coupling with quality factor of 9700. The simulated model and results from CST simulations are represented in Figure 4.
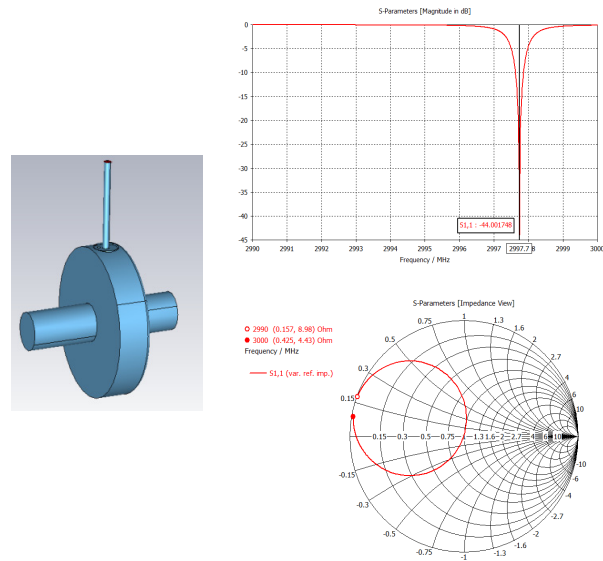


Figure 4: (Left) CST simulation model, (Right) Output results of $S_{11}$ and coupling factor.

## CONSTRUCTION, TUNING AND MEASUREMENTS

For reduction of costs, the cavity constructed from aluminium and all parts connected by Viton orings for vacuum sealing. The schematic and engineering drawings are shown in Figure 5. It has 4 parts included coupling antenna, frequency adjustment plunger and two part of cavity structure. Plunger and Antenna sections are shown in Figure 6. The plunger frequency tuning range considered ± 2.5 MHz around design frequency of 2997.9 MHz. In the design of coupling section, it is considered to implement the coupling loop rotation capability without any decreasing in vacuum level in the order of 6×10-6 mbar. The cavity RF parameters measured by vector network analyzer and the measurement results are shown in Figure 7. Based on measurements, The quality factor is 4000.
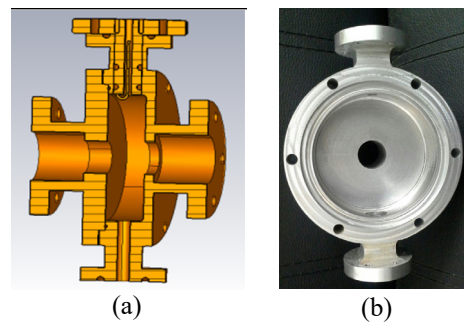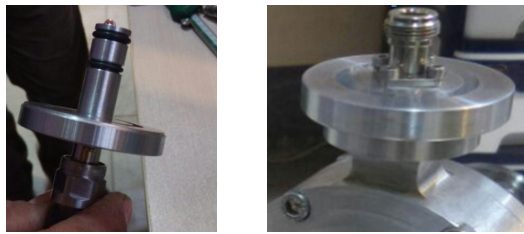


Figure 5- Pre-buncher cavity (a) Schematic drawing, (b) constructed cavity.

(a)



(b)

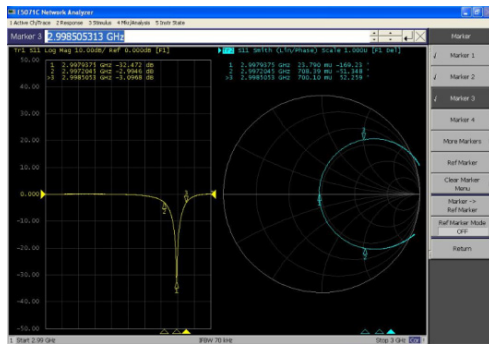Figure 6: (a) RF power coupling loop, (b) Frequency tuning plunger.



Figure 7: Reults of Pre-buncher RF measurement by VNA.

The parameter of R/Q is only dependent on Geometry. So, the shunt impedance of cavity by application of R/Q from simulation should be around $0.23 \times 106$ MΩ. So, according to Equation (2) the required input power for 4.6 kV in Pre-buncher 20 mm gap is calculated 100 Watt. After frequency tuning, all of components connected to each other with screw pressure. The vacuum measurement result is shown in Figure 8.

$$U_c = \sqrt{R_{sh}P} \qquad (2)$$

The Pre-buncher and diagnostic cavities are connected to beam pipes after electron gun, steering magnet and focusing solenoid and is shown in Figure 9. The RF power amplifier for Pre-buncher is designed and constructed and required readout circuit for second diagnostic cavity is under construction and testing.
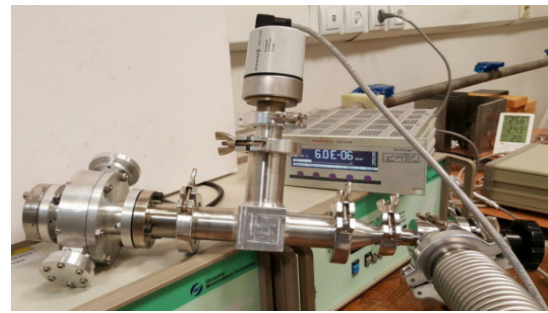
Figure 8: Vacuum sealing and measurement.



Figure 9: Prebuncher and diagnostic cavities with similar structures in connection with linac beam pipe.

## CONCLUSION

Beam dynamic studies with ASTRA and analytical calculations were done for investigation of Prebuncher effects on capturing efficiency of IPM e-Linac. By application of Prebuncher, capturing efficiency improved from 67% to 91%. The cavity was simulated in CST Studio Suit and constructed. The RF measurement and tuning was done successfully. The vacuum level of cavity was measured around $6 \times 10^{-6}$ mbar. The cavity constructed by aluminum and without application of brazing. The vacuum sealing was provided by Viton O-rings. Two number of this cavity are constructed and connected to linac beam pipes. One of them will used as Prebuncher and other one as diagnostic tool for measurement of bunching characteristics.

## REFERENCES

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