DESIGN AND SIMULATION OF PREBUNCHER FOR S-BAND LINEAR ACCELERATOR

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Abstract

An S-band Traveling wave linear accelerator with an RF input peak power level up to 2.5 MW, for accelerating 1 mA beam of electron up to 15 MeV, is under construction in Iran. This article presents design procedure of a prebuncher for this accelerator. One standing-cavity type prebuncher is required for bunching electron beam for this accelerator. The intended prebuncher is driven by a coaxial line at 2 kW and operated at the same frequency of the other parts of the accelerator. The magnetic coupling applied has been applied for power coupling to the prebuncher cavity. The optimum dimensions of the prebuncher were obtained by using 2D and 3D electromagnetic codes in the frequency domain. prebuncher cavity consists of a copper body and coupling loop feed.

INTRODUCTION

The term "Linac" is contraction of the term linear accelerator. It means that the charged particles travel in a straight line as they gain energy from the accelerating electric field. The term "linear" is used to distinguish from other types of particle accelerator, such as the cyclotron, in which the particles travel in a spiral, or the betatron, in which the particles travel in a circle [1]. Fig. 1 shows the schematic view of a travelling wave Linac.

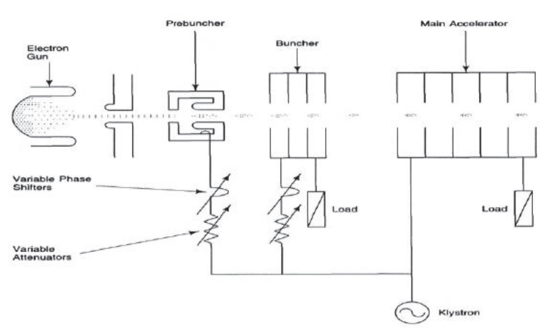

Figure 1: A schematic of a travelling wave Linac [1].

As shown in Fig. 1, the required energy for accelerating the particles is provided by an RF power source such as Klystron. The power is then transmitted to the main accelerator, the buncher, and the prebuncher by the transmission line and is injected to them with the minimum power loss. In order to inject the power from the transmission line to the accelerator, there is a need for designing some devices injecting the maximum power to the main accelerator, the buncher, and the prebuncher.

Since a Linac is being designed and developed by Shahid Beheshti University (Tehran, Iran) in collaboration with Institute for Research in Fundamental Sciences (IPM), the designs performed in this work were based on the parameters of the mentioned accelerator. The parameters and features of the accelerator are summarized in Table 1 [2, 3].

Table 1: Accelerator and RF generator properties.

Parameter	value
RF generator	
Peak Power	2 MW
RF Frequency	2.9-3.1 GHz
Operation Frequency	100 Hz
Pulse Width	7 micro second
Accelerator	
RF Frequency	2997.92 MHz
Current beam	1-10 mA
Accelerator type	Travelling Wave
accelerator Tube length	120 cm

In this paper, the design process of prebuncher for the accelerator is reported.

METHOD

In the design of prebuncher, the method of power injection to the accelerator cavity is so significant. So, we first describe the methods of injection and their importance.

The Methods of Power Injection between Two Waveguides

Because the most of power loss produced by the RF source is wasted in the power injector, optimum design of the power injector is of importance from two points of view:

- The more power reaches the accelerator, the higher energy level the electrons can be accelerated to.
- The more power reaches the accelerator, the less the reflected power to the source and lower source damage.

There are three common ways for coupling between two waveguides [4, 5];

1) Electric probe coupling;

2) Magnetic loop coupling;

3) Hole coupling.

Regarding the operation frequency, operation power, and the application type, it is possible to choose one the above methods.

The Desired Coupling Way in This Study

In this paper, the purpose is injecting a power of 2kW with the frequency of 2997.92MHz to the prebuncher cylindrical cavity using coaxial cable. Moreover, magnetic loop was applied for power coupling between the coaxial cable and the cylindrical cavity.

DESIGN PROCEDURE

In this design, the model of the prebuncher consists of a vacuum cylindrical cavity, a 50-ohms coaxial cable, and a coupling loop inside the cylindrical cavity. At two ends of the cavity, two beam tubes have been implemented for beam transmission. Fig. 2 illustrates this three-dimensional structure.

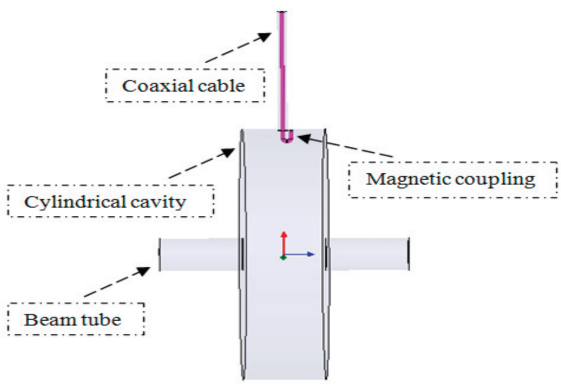

Figure 2: 3.D structure of the cavity, the coupling loop, and the coaxial cable.

Dimensions of the cavity and the coaxial cable demonstrated in Fig. 2 are shown in Table 2.

Table 2: Dimensions of the Cavity and the Coaxial Cable

Structure Parameters	value(mm)
External radius of the coaxial cable	1.1512
Internal radius of the coaxial cable	0.5
The length of the coaxial cable	40
The radius of the cylindrical cavity	38.88
The length of the cylindrical cavity	20
The radius of beam tube	5
The length of beam tube	20
Dielectric coefficient of the medium in coaxial cable	1

In the following, dimensions of the magnetic coupling loop inside the cavity is calculated using the proposed methods.

In order to calculate the coupling coefficient and the optimum dimensions of the magnetic coupling loop, two methods were used for simulations in 3-D electromagnetic software in the frequency domain.

First Method: computation of the ratio of reflected wave amplitude to wave amplitude transmitted to cavity in 3-D software:

One of software outputs is the ratio of reflected wave amplitude to wave amplitude given to input port of the desired part.

This parameter, which is in fact the parameter S_{11} in scattering matrix, is calculated by the software. But for having results in accordance with reality, boundary conditions are considered for this part.

Since the device is in practice made from copper, the boundary conditions are considered for a copper cavity and the value of S_{11} is computed for different dimensions of the coupling loop. The simulation results for some different dimensions of the coupling loop are demonstrated in Fig. 3.

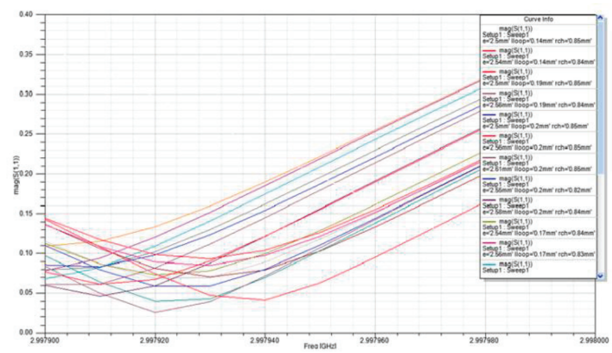

Figure 3: S_{11} value against frequency for different loop dimensions.

As expected, the best result has the lowest value of reflected wave in the desired frequency. So, the optimum dimensions are obtained regarding the lowest value of S_{11} in the desired operation frequency.

According to simulations performed, the optimum dimensions are presented in Table 3. The value of S_{11} obtains 0.02085 in this method.

Table 3: The optimum dimensions using the method of calculating the value of S_{11} in the operation frequency.

Dimensions	value(mm)
The length of the loop inside the cavity along the cavity axis	0.2
The height of the loop inside the cavity	2.61
The curvature radius of the loop inside the cavity	0.85

Second Method: calculation by perturbation method:

Perturbation method is considered as a powerful technique in coupling calculations. In the following, the simulation procedure for computing the optimum dimensions for minimizing the reflected power is explained according to the perturbation theory in ref [6].

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For simulating using this way, reflected angle in two frequencies close to the desired operation frequency should be calculated by the software and then the prebuncher of the part should be faced to perturbation by importing a metal sphere in the middle of the cavity. Fig. 4 shows the cavity in this condition.

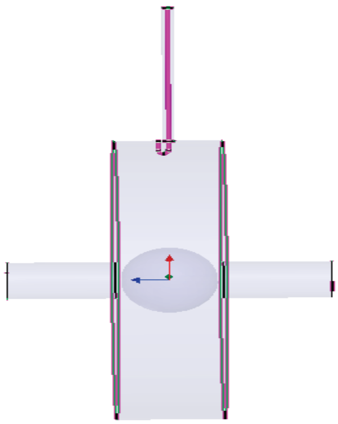

Figure 4: The prebuncher cavity in perturbation condition.

In the current design, power reflex angle is calculated in two frequencies close to the operation frequency (the same as two frequencies considered previously). Showing the difference of reflex angles in two frequencies by φ_1 and φ_2, using the equations 1 to 3, the ratio of the reversal power amplitude to the amplitude of power transmitted to cavity (S_{11}) is computed [7].

$$Q = \frac{\sqrt{\omega_1\omega_2}}{\tan\frac{\phi_1}{2}\tan\frac{\phi_2}{2}} \frac{\sqrt{\left(\omega_2 \tan\frac{\phi_1}{2} - \omega_1 \tan\frac{\phi_2}{2}\right)}}{\left|\omega_1^2 - \omega_2^2\right|} \quad (1)$$

$$\beta = \frac{Q_0}{Q} \quad (2)$$

$$S_{11} = \frac{\beta - 1}{\beta + 1} \quad (3)$$

(Notion: Regarding the calculations done in 2-D dimensional code, the value of Q should be set to 10883.)

As aforementioned, the optimum dimensions are achieved by minimizing the value of S11. Table 4 shows the optimum dimensions obtained using perturbation method. The value of S11 obtains 0.0207 in this method.

Table 4: The optimum dimensions obtained using the perturbation method.

Dimensions	value(mm)
The length of the loop inside the cavity along the cavity axis	0.2
The height of the loop inside the cavity	2.61
The curvature radius of the loop inside the cavity	0.85

The achieved results from both methods shows that the optimum dimensions presented in Tables 3 and 4 are equal. Consequently, these dimensions can be used as the optimum coupling loop dimensions.

CONCLUSION

There are different methods for design of the prebuncher and optimization of its dimensions. The two methods proposed in this paper for optimizing the dimensions of the prebuncher in 3-D electromagnetic software is efficient and can also be utilized for optimization of coupling between two waveguides.

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