

# INJECTOR SYSTEM FOR THE IR-FEL AT RRCAT

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## Abstract

An infrared (IR) free-electron laser (FEL) has been proposed to be built at the Raja Ramanna Centre for Advanced Technology (RRCAT). RadiaBeam is currently involved in the design of the RRCAT FEL's injector system. The injector will deliver an electron beam with a variable energy (from 15 up to 25 MeV) and up to 1.35 nC at 36.6 MHz repetition rate. We show here the beam dynamics of the beam transport through the injector as well as the RF design and mechanical model of the system.

## INTRODUCTION

RRCAT's injector system, for the proposed IR-FEL [1], consists of a 90 keV electron gun modulated at 36.6 MHz and a sub-harmonic prebuncher (SHPB) operating at 476 MHz. The rest of the injector system, as specified in the tender, is required to accelerate to energy in the range of 15-25 MeV while maintaining good beam parameters and high transmission. The high transmission requirement necessitates the use of a fundamental frequency pre-buncher (PB). This is followed by an accelerating buncher (AB), operating with a fixed RF power, to bring the beam energy to 4 MeV ( $\beta \approx 1$ ). The subsequent main linac can then accelerate the beam to a final energy between 15 and 25 MeV by varying input power and phase. The main linac will be a standard SLAC-type 3 m traveling wave accelerating section; this will allow for the option to accelerate to higher energies in the future (50 MeV or higher). A diagram of the proposed system is shown in Figure 1.

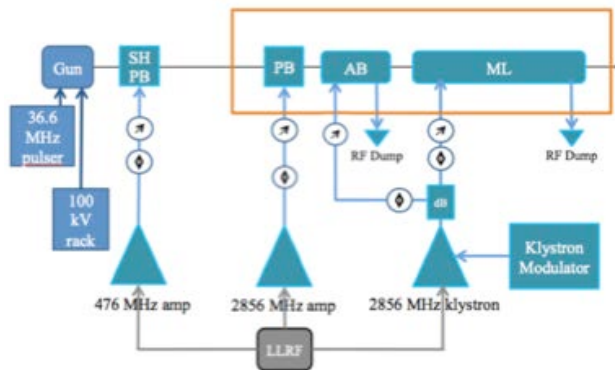


Figure 1: Diagram of proposed injector system for the RRCAT IR-FEL.

## INJECTOR SYSTEM DESIGN

In order to begin the process of the injector system design, the first step is to develop the basic design of the

three RF structure: the pre-buncher, the accelerating buncher, and the main linac. The design of the main linac is already complete, as we will be using a standard SLAC section. The main output beam parameters after the Linac are given in Table 1.

Table 1: Main Output Beam Parameters.

Parameter	Value
Energy Gain	15-25 MeV
RMS energy spread	$\leq 0.5 \%$
Charge per micropulse	$\geq 0.75$ nC
Micropulse Width	10-12 ps FWHM
Transverse RMS norm. emittance	$\leq 30$ mm-mrad
Transverse RMS beam size	$\leq 2$ mm

## RF Design

The RF design of the PB and AB was performed by using SUPERFISH and HFSS for 2D and 3D simulations, respectively. The main RF parameters of the cavities are given in Table 2.

Table 2: Main RF Parameters.

	SHPB	PB	AB	ML
Geometry	Re-entrant SW cavity	Re-entrant SW cavity	12-cell TW cavity	3m SLAC section
Frequency	476 MHz	2.856 GHz	2.856 GHz	2.856 GHz
Shunt Impedance	170 M $\Omega$ /m	1.2 M $\Omega$	50 M $\Omega$ /m	57 M $\Omega$ /m
Cavity Voltage	$\pm 30$ kV	$\pm 38$ kV	4MV	15-25 MV

## Beam Dynamics

The initial beam dynamics simulations were performed with PARMELA using the field input files generated in the RF design. The goal was to transport as much beam as possible ( $\geq 60\%$ ) through the system while maintaining

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the required energy spread, bunch length and emittance, over the energy range from 15 to 25 MeV. In the beam dynamics simulations we will start from the initial phase space of the electrons at the cathode plane.

The phase space of the input beam at the cathode grid location of the triode gun and it is shown in Figure 2. It is a 1ns FWHM electron bunch with a transverse size  $\sigma_{x,y}=2.5\text{mm}$  and transverse normalized emittance  $\epsilon_{x,y}=10\text{ mm-mrad}$ . This beam is modeled assuming the 90kV electron source model YU171 from CPI. The bias voltage at the grid is 100V [2].

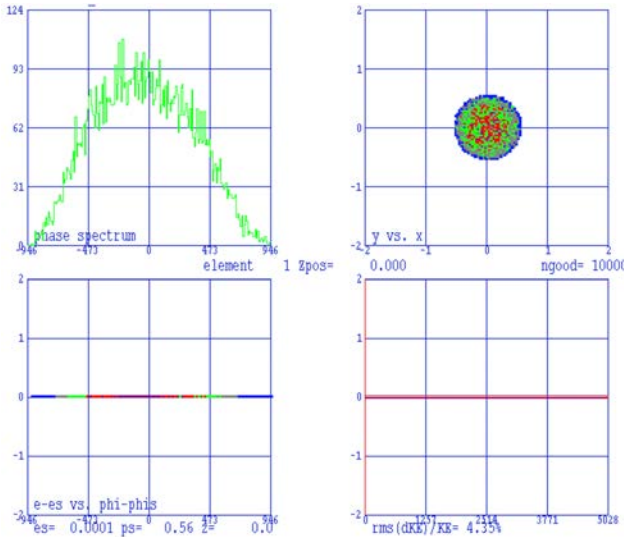


Figure 2: Phase-space of the input electron beam, from PARMELA.

The proposed injector system is modeled in PARMELA by using 2D electromagnetic fields imported from SUPERFISH, as given in the plot of Figure 3.

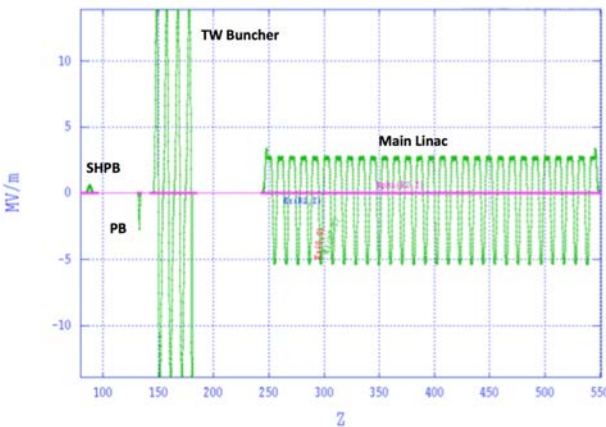


Figure 3: 2D electromagnetic RF fields imported from SUPERFISH into PARMELA.

The beam output parameters are similar for both energy cases (15 and 25MeV). We show here the beam output parameters for the higher energy case. The energy gain of the beam from the input at the cathode through the whole injector system is shown in Figure 4. The input energy of

90keV is constant until the entrance of the buncher, at the end of which the beam becomes relativistic with about 4 MeV. It is then injected into the main Linac for further acceleration (up to 25 MeV).

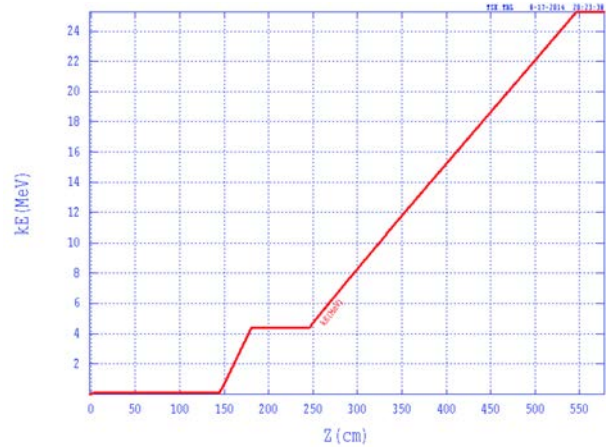


Figure 4: The energy gain of the beam from the input at the cathode through the whole injector system.

The total beam capture is about 94% (10,000 macroparticles were loaded at the cathode). In Figure 5, we show the phase space plots of the beam at the exit of the main accelerating Linac for the 25MeV case. From the phase spectrum, we can deduce that 50% of the particle are distributed within 15deg FWHM of 2856 MHz with an rms energy spread of about 0.5%. The transverse normalized emittance is  $\epsilon_{x,y}<30\text{ mm-mrad}$  and rms spot size  $\sigma_{x,y}<2\text{ mm}$ .

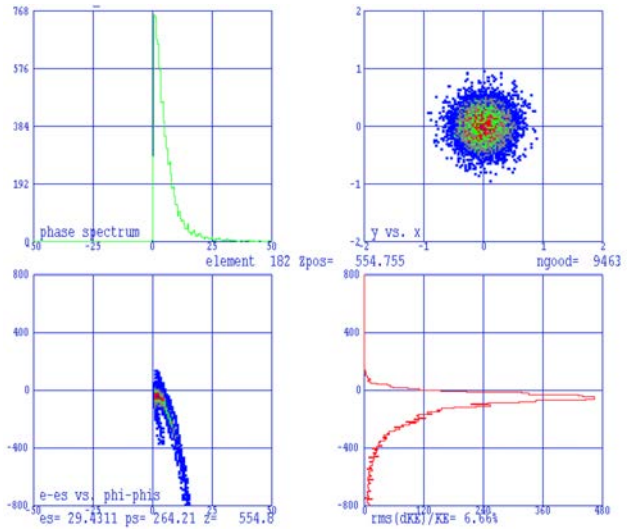


Figure 5: Phase-space plots of the beam at the exit of the main accelerating Linac (25 MeV case) Degrees of 2856 MHz.

In Figure 6, we show the evolution of the electron bunch longitudinal phase-space from the gun (1ns FWHM or  $\sim 1000\text{deg}$  phase extension at 2.856GHz) through the exit of the main linac where more than 50% of the particles are bunched within S-band 10deg or 10ps.

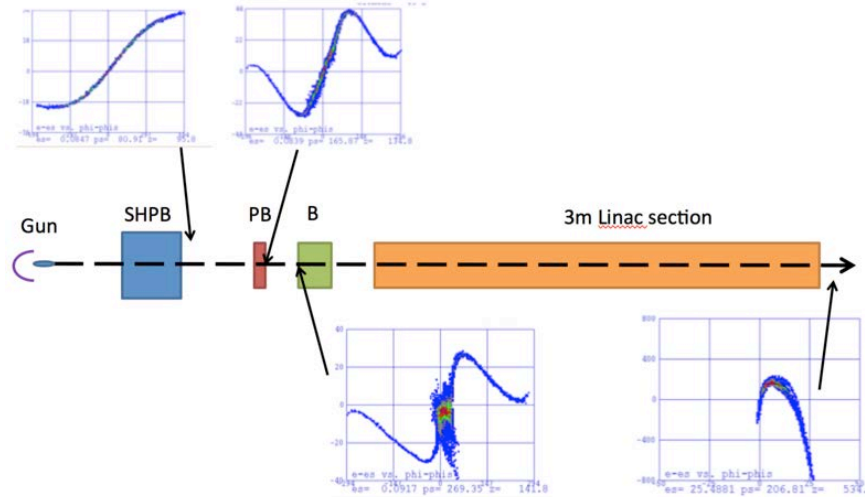


Figure 6: Evolution of the beam longitudinal space.

### Beam Loading

Beam loading is a consequence of longitudinal long-range wakefields. There are two types of beam loading: transient and steady-state. The latter is easier to handle by simply increasing the rf power and adjusting the phases of the single cavities accordingly. As for transient beam loading, there are no easy solutions. It is possible to decrease its effects by adjusting the pulse injection time but the most effective way is to use a properly shaped RF waveform from the klystron.

In order to achieve 25 MeV at the exit of the main Linac, we assume a 5.2 MW square RF pulse, we plot the RF voltage inside the main Linac in Figure 7. The red line is the voltage corresponding to the beam loading effect, that decreases the desired final energy by BL= -2.3 MeV. In order to cancel such an effect (see blue line), the RF power waveform needs to be properly programmed.

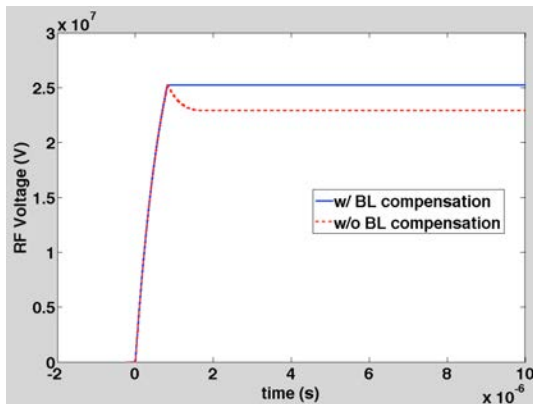


Figure 7: red, RF cavity voltage with beam loading; blue, RF Voltage with beam loading compensation.

The corresponding RF power waveforms that were used are shown in Figure 8. The red line is the 5.2 MW square pulse that is not properly shaped for beam loading compensation. On the other hand, it is possible to exactly

find the power waveform shape in order to cancel total the beam loading (see red line). The RF power is ramped up to 6.19 MW.

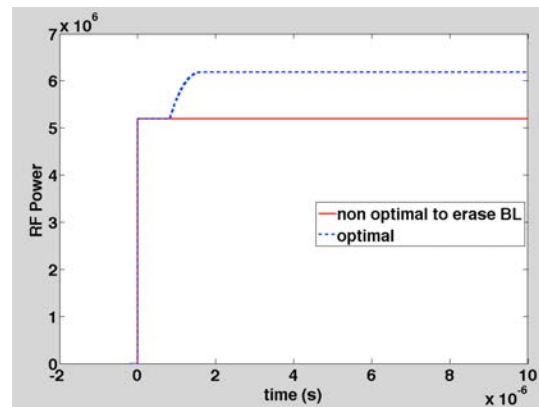


Figure 8: red, RF power waveform non=optimal for beam loading compensation; blue, RF power waveform properly shaped for beam loading compensation.

### CONCLUSION

We presented the design of the Injector system for the IR-FEL being built at RRCAT, India. The RF and Beam Dynamics results for optimum beam capture and bunching are illustrated. The scheme for beam-loading compensation is discussed as well. The main application of the IR-FEL will be for materials investigation with an electron beam with energy in the range 15-25 MeV and higher in a subsequent phase.

### REFERENCES

- [1] S. Krishnagopal et al., PRELIMINARY DESIGN OF THE PROPOSED IR-FEL IN INDIA, RRCAT, Indore, M.P. 452013, India
- [2] S. Chouksey et al., *Design and Fabrication of a 476 MHz Sub-Harmonic Buncher Cavity*, RRCAT Indore India.