# LATTICE DESIGN AND BEAM DYNAMICS OF ERL-TF IN IHEP, BEIJING

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*Abstract*

Energy Recovery Linac is considered as a potential candidate type of the next generation light source. A 35Mev ERL test facility (ERL-TF) is proposed in IHEP, Beijing, in order to test the technology and study the beam dynamics of ERL. In this paper, the lattice design and some beam simulations of the ERL-TF are described, with the focal points on the bunch length compression, emittance suppression, and energy spread compression.

## INTRODUCTION

ERL can provide high current and low emittance electron beams, and is considered to be a potential candidate for the next generation light source. But to build a qualified operational ERL, many accelerator issues and technologies are still have to be studied. In order to study the machine physics and to develop some key components, such as photo-cathode high voltage electron gun and high average CW super conducting cavity ,we are planning to design and construct a 35 Mev ERL-TF in IHEP, Beijing[1, 2].

The layout of the ERL-TF is as shown in Figure 1. The ERL-TF consists of a photo-cathode 500 kV DC gun, an energy booster of 5 MeV with 2 x 2cell 1.3 GHz SC cavities, a merger, a main SC linac with 2 x 7-cell 1.3 GHz cavities, two TBA arcs, and an undulator. For simplicity, a lattice with compact racetrack shape is employed. The 500 keV electron beam is accelerated to 5Mev by the booster, and then injected into the main Linac. Downstream the linac, the 35MeV electron beam is transported to the undulator by the first TBA arc to produce THZ wave with high average power. Then the electron beam is re-injected into the main linac at a deceleration phase for energy recovery. The main parameters of the ERL-TF are listed in Table 1.

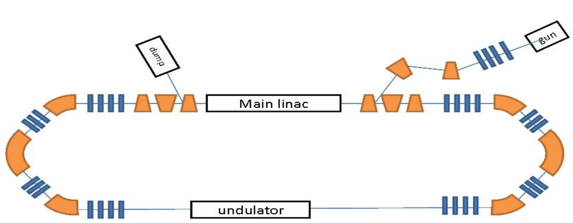


Figure 1: Layout of ERL-TF.

In the design of the ERL-TF, linear beam optics are simple, and structures of mergers and arcs are well known [3, 4]. Twiss parameters are set to meet several criteria: small beta functions throughout the loop, suitable in the arcs, dispersion free in the linac and undulator sections, etc. Nonlinear optics and collective effect play the important roles in the ERL-TF performance. In the following sections, our concern will be on beam dynamics in the first and second arcs.

Table 1: Main Parameters of the ERL-TF

| | |
|---|---|
| Injection Energy | 5 Mev |
| Maximum Energy | 35 Mev |
| Normalized Emittance at the undulator | 2.4 mm.mrad |
| Normalized Emittance after the injector | 1.5 mm.mrad |
| Beam Current | 10 mA |
| RF Frequency | 1.3 GHz |
| Nominal Bunch Charge | 77 pC |
| Bunch Length | 0.23 ps |
| Injection rate | 130 MHz |

## BUNCH COMPRESSION

In our ERL-TF design, short bunches are generated by magnetic bunch compression in the 1st TBA arc, because the bunch at the merger and in the main linac must be sufficiently long to avoid significant emittance growth and high-order-mode (HOM) effects, respectively. We choose the bunch length at the entrance of the merger to be 2ps, and it is compressed to ~200fs by the first TBA arc.

The mechanism of magnetic compression is well-known[3]. In the ERL-TF, the electron bunch is accelerated in the main linac with an off-crest phase Φ. After acceleration, electrons in the bunch will get an energy spread of

$$\delta = \frac{\Delta E}{E_f} = \frac{E_0}{E_f}\left(\cos(\phi + \frac{\omega z}{c}) - \cos(\phi)\right) \quad . \tag{1}$$

Where $\omega$ is the frequency of the main linac, c the velocity of light, and z the longitudinal position of the electron relative to the reference particle. Then the electrons pass through an arc with non-zero. At the exit of the arc, the deviation of longitudinal path length will be

$$\Delta z = R_{56}\delta + T_{566}\delta^2 + U_{5666}\delta^3 + \cdots \quad . \tag{2}$$

The optimum  can be approximately expressed as

$$R_{56} \approx \frac{c}{\omega \tan\phi} \quad . \tag{3}$$

In our design, we uses a TBA structure for its re-circulator arcs because The R56 of TBA can be easily changed. The TBA consists of three 45-90-45 dipoles and three families of quadrupoles. To optimize the parameters of the first arc to get short bunchlength and small normalized emittance at the entrance of the undulator, we used ELEGANT[4] for numerical simulation. In our simulation, the CSR and space-charge effects are considerd. Results are listed in Table 2. To achieve the minimum bunchlength, We choose the linac phase and R56 of the first arc to be 13deg and 0.16, respectively. Twiss parameters of the first arc are shown in Fig. 2.

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Table 2: Main Parameters of the ERL-TF

| Linac phase(degree) | Normalized Emittance(mm.mrad) | Bunch length(ps) |
|---|---|---|
| 13 | 2.65 | 0.178 |
| 12.6 | 2.4 | 0.25 |
| 12.3 | 2.26 | 0.33 |
| 12 | 2.16 | 0.41 |
| 11 | 1.97 | 0.7 |

## SUPPRESSION OF THE CSR INDUCED EMITTANCE

Low emittance at the undulator is the most important feature of ERL, and it can be deteriorated by Coherent Synchrotron Radiation (CSR) if bunches are very short. Hence, in the design of the first arc, suppression of the CSR induced emittance is of great importance.

There are several ways for the emittance compensation, and in our design we used the envelope matching method. In this method, we make the orientation of the phase ellipse parallel to the CSR kick by scanning Twiss parameters at the exit of the arc[5]. Parameters optimization is done by simulation code ELEGANT with CSR calculation. We set =0.202, and scan $\alpha_x$ in the range of $-5 < \alpha_x < 5$ . Normalized emittance at the entrance of the undulator as a function of are as shown in Figure 3. It shows that the emittance can be suppressed greatly by envelope matching. Particle distributions in the phase space are seen in Figure 4.

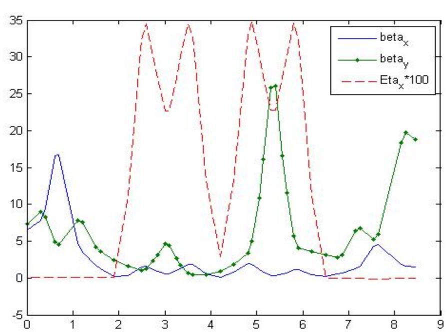


Figure 2: Twiss Parameters of the first arc.

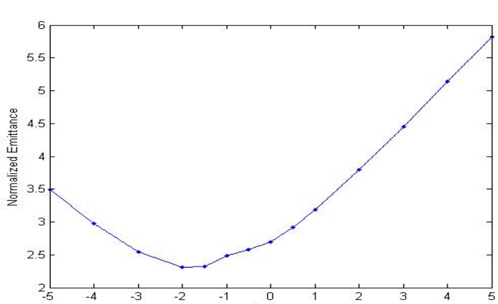


Figure 3: Normalized emittance at the entrance of the undulator.

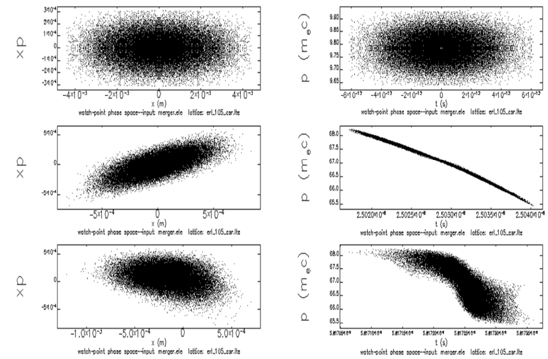

Figure 4: Beam distributions in the x and t phase space. The upper figures is taken at the entrance of Merger, the middle figures at the entrance of the first arc while lower ones at the entrance of the undulator.

## ENERGY COMPRESSION

Downstream of the undulator, the emittance of the ERL-TF is not very important unless it causes beam loss. One of the features must be considerd in the return loop is energy compression. Interactions in the undulator will cause large energy spread in the electron bunch. When the electron bunches with large energy spread is decelerated through the Linac, relative energy spread will become quite large. This energy spread can be reduced by rotating the bunch in the longitudinal phase space, as so called Energy compression[6]. In our ERL-TF, energy compression is done by setting the return arc (or say 2nd TBA arc) non-isochronous, and tuning the deceleration phase in the linac. To stretch the bunch length, is set to be -0.16 in the return arc. Linac phase is optimized by numerical simulation in Fig 5. With these optimizations, we got a beam of energy-spread 1.5% at the exit of the main linac for a 1% energy-spread beam out of undulator.

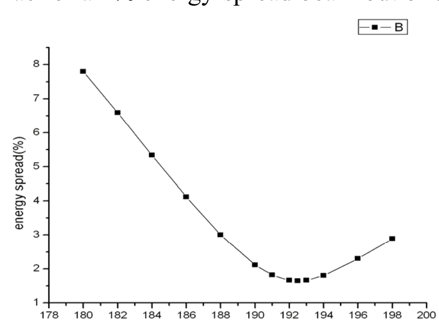


Figure 5: Energy spread after deceleration as a function of the phase in the linac.

## SUMMARY

In this paper, some preliminary beam dynamics studies on the ERL-TF in IHEP, China are presented. With the simulation of ELEGANT, we performed bunch compression, CSR suppression and energy compression. With these optimization, we got a beam with bunch length 200fs and normalized emittance 2.5mm.mrad in the undulator.



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