AN UPGRADE OF SC LINAC AT KAERI TO ERL

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Abstract

A project of a high-power FEL at Korea Atomic Energy Research Institute is described. The FEL is driven by a superconducting energy recovery linac. The future ERL will be connected to the existing machine without any modification. It consists of two 180º bents and two straight sections: one is for the FEL, another for a Compton X-rays source. One can choose the regime controlling the lenses. The total ERL is isochronous to avoid any problems with longitudinal beam instability. The total relative emittance degradation through the whole machine is ≈ 1.5. The FEL will be based on a 2 m helical in-vacuum undulator made of permanent magnets. One mirror of the optical cavity is blind and made of copper, the other one, the outcoupler, is semi-transparent and made of CVD diamond. The expected average power is a few kW, the tuning range 35…70 µm.

INTRODUCTION

At present time, a superconductive linear accelerator successfully operates at KAERI. It consists of an injector with injection energy 2 MeV, injection beamline, cryogenic accelerating module, which contains two cavities. Electron beam parameters are following:

- bunch duration: 100 ps;
- number of electrons per bunch: 10^{10};
- electron energy (full): 10 MeV;
- repetition rate: 5.6 MHz;
- emittance: 2π mm·mrad;
- energy spread (relative): $6 \cdot 10^{-3}$.

A future ERL based on this linac will be build at KAERI. An FEL and a Compton source will be driven by it. A project of the ERL should meet the following requirements:

- Accelerator should have two regimes, one for the FEL and the other for the Compton source. The regimes will be switched with magnets.
- The machine should operate in a wide energy range in order to provide broad band FEL retuning. The ERL will operate at the energy from 12 MeV up to 22 MeV.
- The possibility to control both S_x and S_y transport matrix elements independently and total isochronism of the ERL is necessary to suppress longitudinal and regenerative transverse beam instability. This possibility permits to increase the beam current and the FEL power.
- Low beam emittance degradation in the beamline is necessary for successful FEL operation and beam energy recovery. Therefore we should use sextupoles

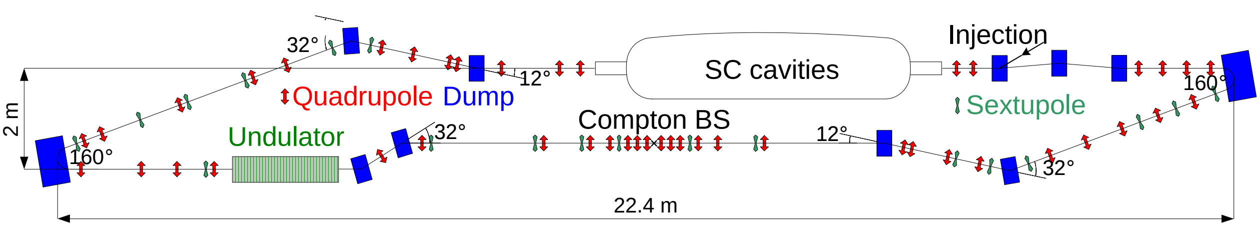

Figure 1: The layout of the ERL.

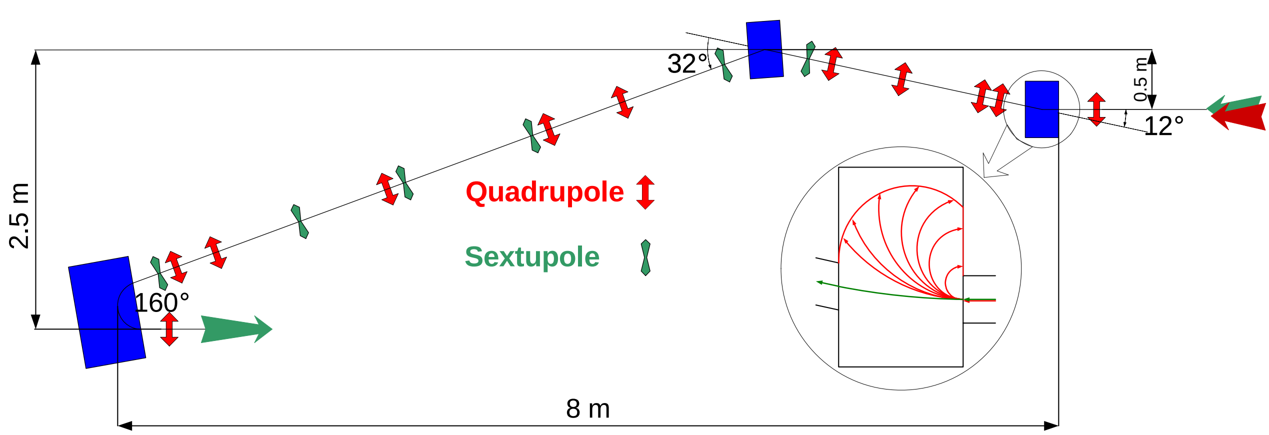

Figure 2: The layout of the first bent.

to suppress chromatism which is the main reason of emittance dilution.

- Large energy aperture of the dump and the beamline after the undulator is necessary to obtain high FEL efficiency, as the energy spread after the FEL is proportional to its electron efficiency.

ELECTRON OPTICS

The machine consists of two isochronous near achromatic bents (their small chromatism compensates $v < c$), and two straight beamlines separated by a dogleg. The FEL and the Compton source will be installed on these straight parts. The layout of accelerator optics is shown in figure 1.

Consider the first bent. It is necessary to control the longitudinal dispersion from 7 up to 17 cm to compensate the one of the whole machine due to $v < c$. Emittance degradation in the bent should be low to keep FEL radiation quality. The dump is installed inside the first dipole of the bent. This design allows to avoid an extraction chicane. It also has a big energy aperture (> 1 MeV in the whole energy range) to collect the whole waste beam without loss. The accelerated beam moves through the common track together with the decelerated beam. Due to that, the capability to control the common track optics is very limited. Also the beam state at the entrance of the accelerating module is known only approximately. So the bent should operate successfully in the following range of the entrance lattice functions:

$$\begin{cases} \beta_z \quad \text{from} \quad 25\,\text{m} \quad \text{to} \quad 80\,\text{m} \\ \beta_x \quad \text{from} \quad 35\,\text{m} \quad \text{to} \quad 140\,\text{m} \\ \left|\alpha_{x,z}\right| \le 3 \end{cases}$$

The layout of the first bent is shown in figure 2.

It consists of three bending dipoles for 12°, 32° and 160°, the first dipole bends beam to the right while the two others to the left. It allows setting large negative η-function in the second dipole to compensate the longitudinal dispersion which gains in the mirror. The lattice functions in the bent in the FEL mode are shown in figure 3. Controlling η-function in the second dipole modifies the longitudinal dispersion in the whole bent within the necessary range. Sextupoles are installed in the bent in places with big η-function and small β-function to suppress chromatic aberration. The strengths of sextupoles are selected to zero $\partial\eta/\partial p$ and $\partial\eta'/\partial p$, and to decrease $\partial\alpha_{xy}/\partial p$ and $\partial\beta_{xy}/\partial p$ to the level where emittanse dilution due to chromatic aberration is equal to one due to nonlinear focusing in the sextupoles. This optimization leads to comparably small emittance dilution through the whole bent $\sqrt{\Delta\varepsilon^2}/\varepsilon \le 0.75$.

The beamline after the undulator consists of a dogleg (two 32° dipoles), a strait beamline for the Compton source, the second bent similar to the first one, and an injection chicane. The main feature of the beamline after the undulator is big energy spread of the beam in the FEL regime. It leads to high emittance degradation as a result of chromatic aberration. Also large beam size due to nonzero η and high energy spread leads to significant edge aberration in quadrupoles. Chromatic aberration can be suppressed by sextupoles while edge aberration prevents to conduct a beam with relative energy spread greater than 0.06. Suppression of chromatic aberration is made similar to the first bent. The only difference is one needs more sextupoles as their strengths are limited by emittance degradation. This method of suppression of chromatism provides a possibility to conduct a beam with relative energy dispersion 0.05 through the beamline with emittanse degradation $\sqrt{\Delta\varepsilon^2}/\varepsilon \approx 1$. The lattice functions in the beamline after the undulator in the FEL mode are shown in figure 4.

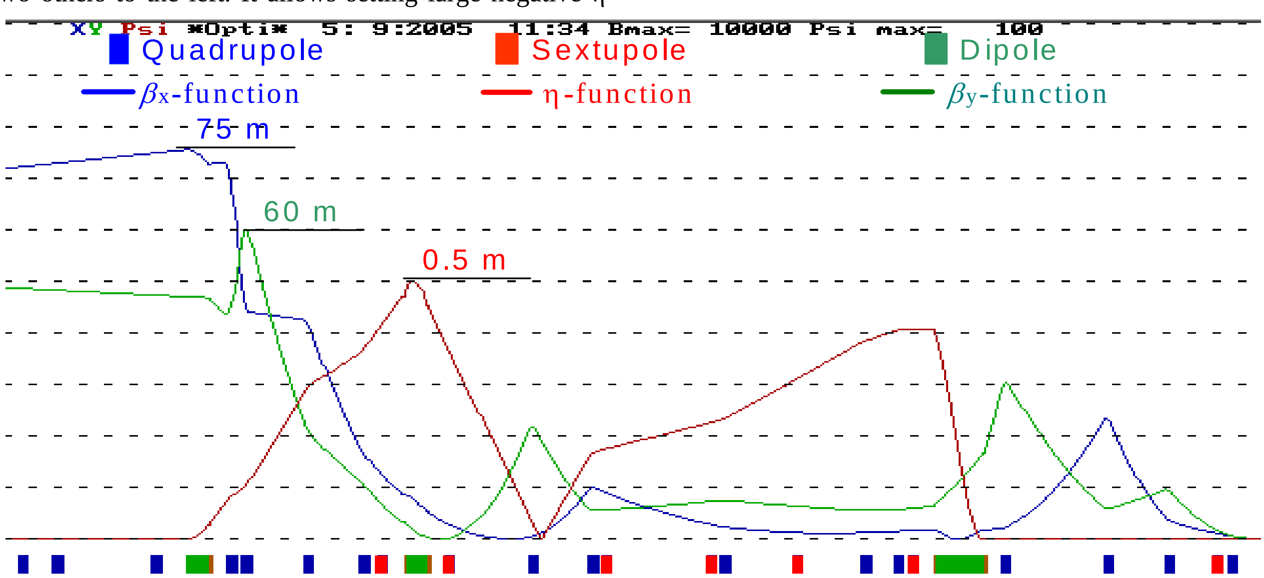

Figure 3: The lattice functions in the first bent.

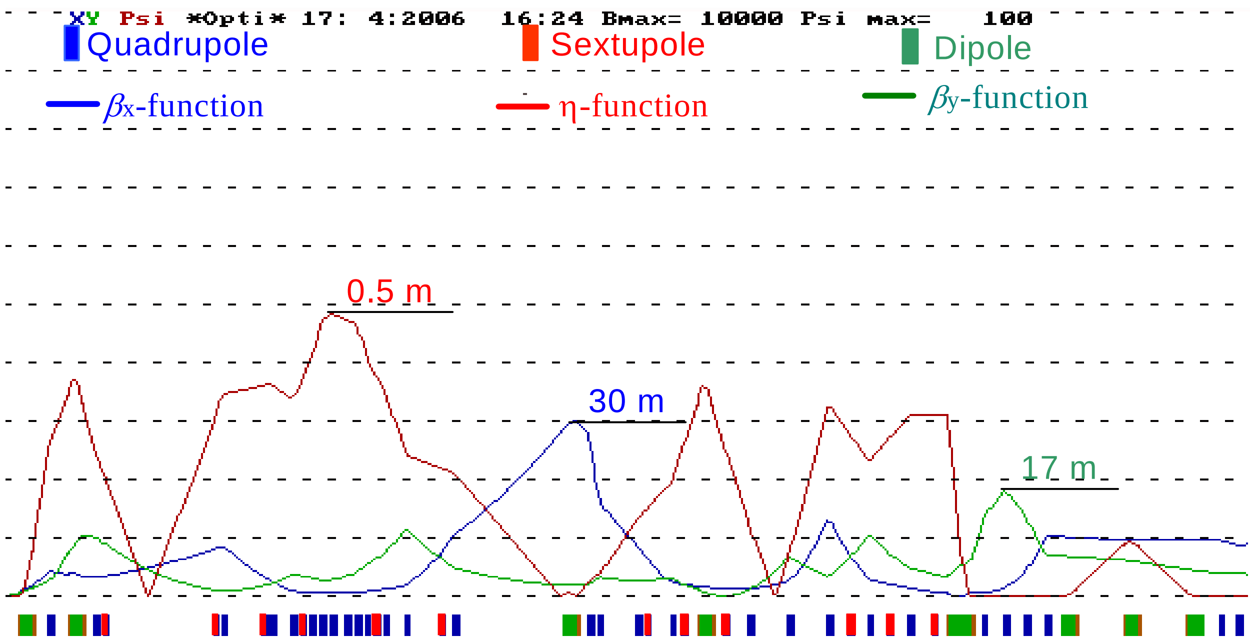

Figure 4: The lattice function in the beamline after the undulator in the FEL regime.

The beamline was simulated with OPTI code based on the linear transverse single-particle dynamics model. This model neglects space charge effect, so can't be used for the extraction beamline. We should take space charge effect into account due to small beam energy in this part of the accelerator. It was made by code I&Eps [1]. In this simulation, focusing of the cavity was considered as concentrated at the edges of the cavity.

SUMMARY

This design provides operation with high electron efficiency in the range of electron energies from 12 up to 22 MeV. It also allows suppressing longitudinal and regenerative transverse beam instability to increase beam current. The output power of a future FEL will be a few kW in the wavelength range from 35 to 70 µm.

The most desirable upgrade is one more pair of SC cavities. In this case the maximum beam energy of the ERL will exceed 40 MeV. It will enable to make an FEL in the near-IR region. Of course, a new beamline is to be designed in this case.

REFERENCES

[1] S.V.Miginsky An optimizer for high-current beamlines, NIM **A** **558** (2006) 127-130.