LINAC OPTICS OPTIMIZATION FOR ENERGY RECOVERY LINACS

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Abstract

Linac optics of an energy recovery linac (ERL) is optimized to ensure the high average current electron beam to drive synchrotron light sources and free-electron lasers. Genetic algorithm is utilized to search globally optimum parameters of the linac optics. Multi-pass transverse beam-break-up (BBU) threshold current is estimated by numerical simulation with the optimized optics parameters. It is shown by numerical simulations that over 100 mA of multi-pass transverse BBU threshold current can be achieved in a simple one-pass ERL with cavity gradient of less than 15 MV/m.

INTRODUCTION

A superconducting linac based ERL is an extremely efficient accelerator for synchrotron light sources and free-electron lasers. The performance of the ERL light sources is improved as the beam average current is increased. The average current, however, is limited by instabilities such as multi-pass transverse BBU. It was shown by an analytical solution [1] that the BBU threshold current is inversely proportional to the Q factor of the higher-order-mode (HOM) and transfer matrix elements of divergence to transverse position (R_{12} and R_{34}). To suppress the BBU instability, the HOM should be damped sufficiently. The HOM damping should be incorporated into the superconducting cavity design. To achieve high BBU threshold current, transport optics along the superconducting linacs should be optimized to minimize R_{12} and R_{34}. This optimization can be performed through a numerical design of the linac optics.

Result of local optimization method such as Newton method strongly depends on starting parameters. A set of initial parameters to start the optimization cannot be fixed a priori for a system with a lot of free parameters such as linac optics design of the ERL. The linac optics has many free parameters because of the lengthy structure of the linac. The local optimization method is therefore not suitable to find directly the optimum parameters of the linac optics. Genetic algorithm [2] is well known as an optimum parameter global search method. In the case of many free parameters, however genetic algorithm spends a lot of computation time. Hence we employ two-step optimization utilizing the local and global optimization methods. Genetic algorithm is only used to find the starting parameters of the local optimization, and the parameters are refined by the following local optimization. The optimum parameters of the linac optics for a simple one-pass configuration ERL are easily found using the two-step optimization method.

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In this optimization, we assume a conceptual ERL with a simple one-pass configuration and external quadrupole triplets between cryomodules as shown in Fig. 1. Each cryomodules includes eight cavities, which are 9-cell 1.3 GHz TESLA cavities [3]. A 10 MeV electron beam with small transverse emittance is injected to the main linac. The main linac accelerates the beam to 6 GeV. Subsequently, the beam is transported through the recirculation loop where it is used to produce high brightness X-rays. The beam is then returned to the main linac with decelerating rf phase for energy recovery. In the linac the recirculated beam gives back its energy, which is used for the acceleration of successive beams. The low energy beam after energy recovery finally goes to the dump.

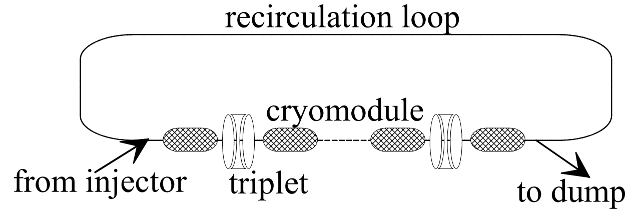

Fig. 1: Conceptual ERL layout.

The linac optics is numerically optimized based on Bazarov's guideline [4] as following:

1) Minimize the β-function in the linac by adjusting the strength of the quadrupole triplets and by matching the envelope of the injected beam.
2) Set the phase advance of the recirculation transport loop to minimize R_{12} and R_{34}.

The optimization code takes the two-step optimization method to find quickly and globally optimum parameters. At first step, proper starting parameters for the local optimization are found by genetic algorithm. The parameters are then refined in the local optimization step by BFGS method [5].

In the optimization code, the β-function and R_{12} and R_{34} are calculated by transport matrix of the optic element, which is basically same as TRANSPORT [6]. Unfortunately, TRANSPORT dose not support standing-wave cavity such as the superconducting cavity. In order to simulate transverse beam dynamics in the linac, it is indispensable to include rf focusing of the cavity. The transport matrix of the standing-wave cavity was derived by the study of transverse particle motion in the cavity [7].

RESULTS OF THE OPTIMIZATION

As a result of the optimization for the simple one-pass ERL with cavity gradient of 15 MV/m, β-function of the linac is presented in Fig. 2. The linac contains 48 cryomodules and 47 external quadrupole triplets, and its length is about 600 m. The strength of quadrupole triplets, which is field gradient normalized by beam rigidity, is shown in Fig. 3. All quadrupoles in the triplet are of the same strength. The middle and the end quadrupole of the triplet are 50 cm length and 25 cm length, respectively. It can be seen in Fig. 3 that triplets are set in such a way as to produce a nearly constant focusing length for lower energy beam at the same triplet.

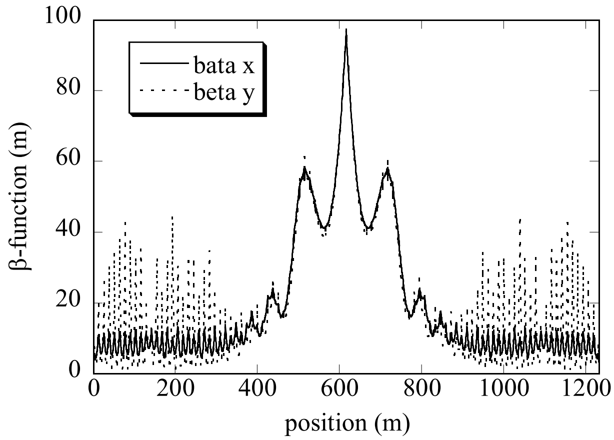

Fig. 2: β-function in the linac as a result of the optimization.

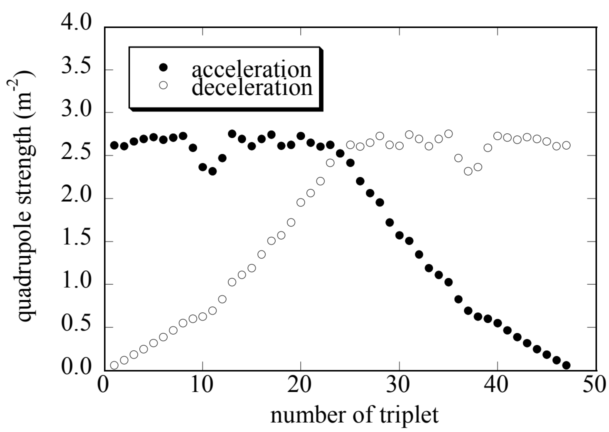

Fig. 3: Strength of the quadrupoles along the linac corresponding to Fig. 2.

Numerical simulation code BBU-R [8], which is similar to TDBBU [9] is used to determine the BBU threshold current. Calculated HOM data [10] as shown in Table 1 are taken into BBU-R. To mimic the expected frequency spread of the HOMs in the actual cavities, the HOM frequencies are chosen to be random. The BBU threshold current for the linac optics optimized ERL is presented in Fig. 4. As shown in Fig. 4, by increasing frequency spread of the HOM it is possible to increase the BBU threshold current up to 100 mA or more. It is found that the threshold current depends much on the sorting order of the randomized HOM frequencies. The error bars seen in Fig. 4 correspond to different sorting orders.

Table 1: HOM parameters used in BBU-R

f [MHz]	Polarization	R/Q [Ω]	Q
1734	x/y	116.7	3400/4500
1865	x/y	42.4	50600/26500
1874	x/y	56.8	50200/51100
1880	x/y	11.8	95100/85500
1887	x/y	1.2	633000/251000

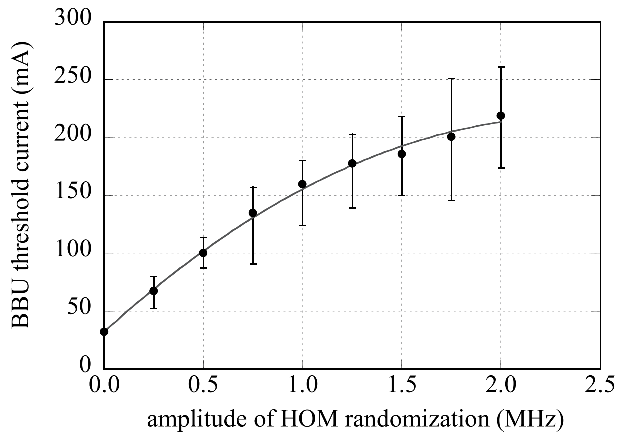

Fig. 4: BBU threshold current vs. amplitude of HOM randomization.

In the linac optics optimization of the ERL, the cavity gradient is a principal parameter. The linac optics is optimized with various cavity gradients and the threshold current is estimated with 1 MHz HOM frequency spread. As shown in Fig. 5, the threshold current is increasing with the cavity gradient. It is found that it is possible the threshold current of more than 100 mA even if the cavity gradient is less than 15 MV/m.

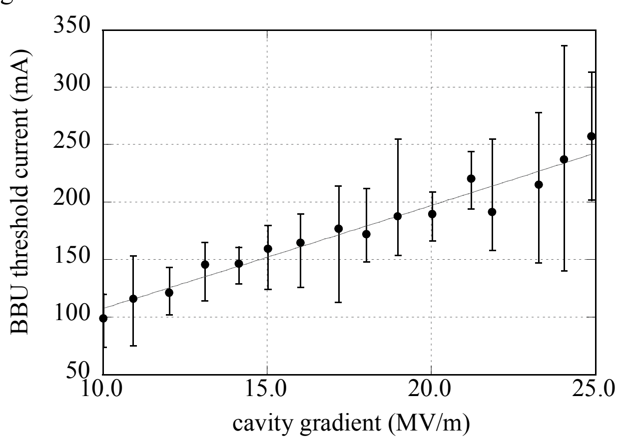

Fig. 5: BBU threshold current vs. cavity gardient.

CONCLUSION

The optimum parameters of the linac optics for a simple one-pass configuration ERL have easily found utilizing genetic algorithm. As a result of the optimization, the BBU threshold current more than 100 mA is reasonably available with cavity gradient of 15 MV/m. The cavity gradient of 15 MV/m is the most economical so far as 10-year running cost is concerned [11].

The optics has been optimized only for a one-pass simple configuration and single-parameter triplets. It will be expected to increase the threshold current by the other configurations such as cascade configuration and by two-parameter triplets or FODO like optics.

REFERENCES

[1] J.J. Bisognano, G.A. Krafft, Proc. of the 1986 Linear Accel. Conf. (1986) 452-454.

[2] M. Mitchell, “An Introduction to Genetic Algorithms”, MIT Press (1996).

[3] B. Aune, et al., Proc. of the 1999 Part. Accel. Conf. (1999) 245-249

[4] I. Bazarov, et al., CHESS Technical Memo 01-003 (2001).

[5] C.G. Broyden, J. of the Inst. for Math. and Applications **6** (1970) 222-231, R. Fletcher, Computer Journal **13** (1970) 317-322, D. Goldfarb, Mathematics of Computation **24** (1970) 23-26, D.F. Shanno, Mathematics of Computation **24** (1970) 647-656.

[6] K.L. Brown, et al., SLAC-91 (1970).

[7] J. Rosenzweig, L. Serafini, Phys. Rev. **E49** (1994) 1599-1602.

[8] M. Sawamura, et al., these proceedings (2003), M. Sawamura, et al., Proc. of the 27th Linear Accel. Meeting in Japan (2002) 275-277, in Japanese.

[9] G.A. Krafft, J.J. Bisognano, Proc. of the 1987 Part. Accel. Conf. (1987) 1356-1358.

[10] J. Sekutowicz, TESLA 94-07 (1994).

[11] M. Sawamura, et al., these proceedings (2003).