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2-Pass Possibility for ERL

I.V. Bazarov
Wilson Lab, Cornell University, Ithaca, NY 14853

Abstract

2-pass possibility for ERL with its implications for multipass BBU instability is discussed.

2-Pass ERL [ERL Study]

It may be desirable for cost optimization reasons to design multipass ERL. For two-pass ERL (Fig. 1) each electron bunch traverses 2.5 GeV linac twice on crest before it is introduced with 180° offset in rf phase for two recirculations of energy recovery. Of course, the total distance of srf structure that a particle sees is the same as in the case of one-pass ERL assuming the same gradient for both scenarios. While the half-energy recirculating arc seems to provide additional leverage to transverse particle dynamics, there is a serious additional constraint on the linac optics in the case of two-pass ERL because the same optics in the linac section will have to provide adequate focusing for electron bunches of four different energies. Besides, 2-pass ERL must be designed to have twice as high BBU threshold current as in 1-pass ERL.

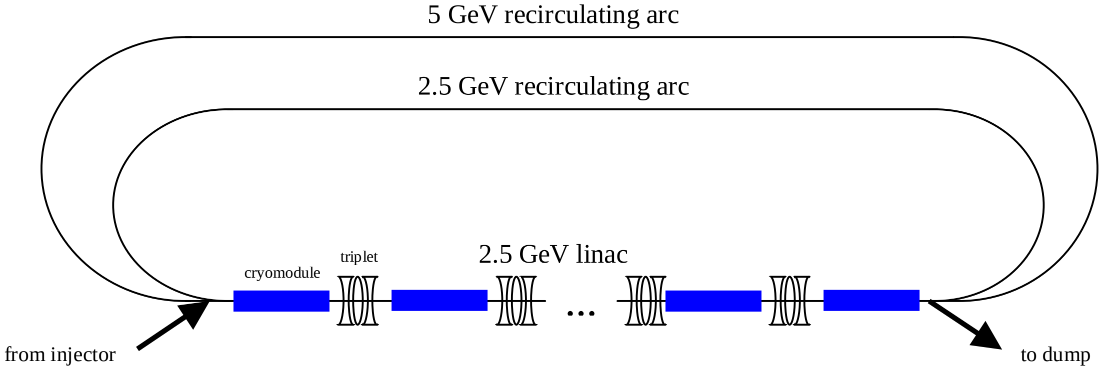

Fig. 1. Conceptual layout of two-pass 5 GeV ERL.

Quantum Excitation will not be a problem for the 2.5 GeV recirculating arc as the induced normalized emittance growth due to emission of spontaneous SR is a strong function of energy:

$$\varepsilon_{n,SR} \propto \gamma^6 \frac{1}{\rho} \theta_d^3,$$

here ρ and θ_d are the bending radius and angle of the dipoles that compose the lattice. Since this emittance growth is manageable at 5 GeV, it will be negligible at 2.5 GeV.

CSR-Induced Emittance probably can be made small in 2.5 GeV arc too, especially if the bunch is not short anywhere there. The rough scaling law for this emittance growth can be obtained as following: as the bunch traverses a dipole, it acquires an increase in divergence due to CSR-wake energy spread and finite dispersion given by $\Delta x' \sim \theta_d (\Delta E_{CSR} / E)$, which, in turn, leads to the increase in normalized emittance on the order of

$$\varepsilon_{n,CSR,d} = \varepsilon_{CSR,d}\gamma \sim \sigma_x \Delta E_{CSR,d}\theta_d \,,$$

here σ_x is transverse beam size. Energy spread induced by CSR-wake in a dipole scales like $\Delta E_{CSR,d} \propto q\rho^{1/3}\theta_d / l^{4/3}$ for q charge / bunch and l bunch length. Assuming the worst case of correlated emittance growth, the emittance growth from the whole arc is given by $\varepsilon_{n,CSR} = N\varepsilon_{n,CSR,d}$, with N being the number of cells in the lattice ($N \propto 1/\theta_d$), so one finds the following scaling law ($\sigma_x \propto \gamma^{-1/2}$):

$$\varepsilon_{n,CSR} \propto q l^{-4/3}\gamma^{-1/2}\rho^{1/3}\theta_d \,.$$

This suggests that CSR-induced emittance growth is easier to manage at higher energies, but the dependence on energy is weak. A careful design of 2.5 GeV arc may be needed to minimize CSR-induced emittance growth.

Multipass BBU in 2-Pass 5 GeV ERL

BBU in a 2-pass 5 GeV machine appears to be a major challenge. Attempts to design 2-pass ERL optics able to support 100 mA beam were made by following the same guidelines as in the case of 1-pass ERL [see ERL Study; Bazarov et al contribution to PAC'2001], complementing those with an additional requirement of minimizing elements R_{12} and R_{34} of pass-to-pass transport matrix for each successive recirculation, for two recirculations separated by another one, etc. The optimized linac optics allowed propagation of the beam envelope with relatively small β-function (< 70 m) in the srf structure (Fig. 2). Nevertheless, simulated BBU threshold current was only 15 mA (actual current in the linac is four times that). This low threshold is thought to be caused by the additional constraint on the linac optics to support particles of four different energies, e.g. quadrupole focusing has to be limited in such a way as to allow slow variations of rather large β-function (50-60 m) over almost the whole length of the srf structure on two of the passes (second pass of acceleration and first pass of energy recovery). Slowly changing large β-function suggests a small phase advance, and as a result, R_{12} and R_{34} of beam-transport matrix from a particular cavity may become large over extensive distances in the srf structure, allowing strong interaction between HOMs.

The results of simulations for the latest available to me HOM table, with HOM frequency randomization between f_{HOM} and f_{HOM} + 1 MHz, are summarized in Table 1. It also provides a comparison of 1-pass and 2-pass ERL scenarios. Injection energy is 10 MeV. The amount of Q improvement required in 2-pass ERL to be able to achieve 100 mA BBU threshold are shown in red (last two columns). Note that there is no “safety margin”, however, since the actual HOM frequency spread is much bigger than 0.3 MHz rms, that will account for the safety margin (which is smaller in case of 2-pass ERL by a factor of 2 as for the 1-pass machine).

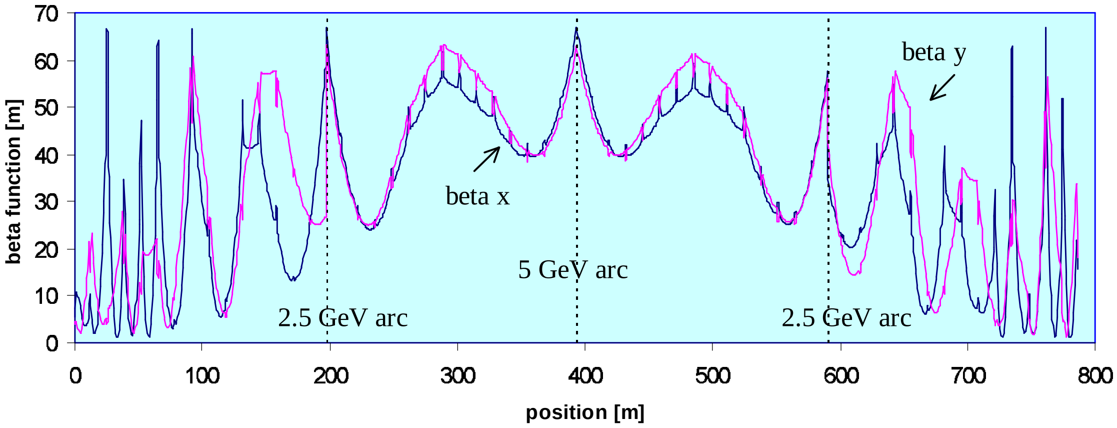

Fig. 2. Beta-functions in 2-pass 5 GeV ERL inside the linac. The linac is traversed by each bunch 4 times.

Table 1.

Results of TDBBU runs for 1-pass and 2-pass 5 GeV ERL.

new HOM table (TESLA TDR 03/2001)

f (MHz)	R/Q (Ohm)	Q	(R/Q)*Q	1-pass 5 GeV ERL BBU (mA)	2-pass 5 GeV ERL BBU (mA)	Q*	Improved by a factor of
1699	88.40	5.00E+04	4.42E+06	160	20	8.00E+02	62.5
1873	56.39	7.00E+04	3.95E+06	190	25	1.30E+03	53.8
2575	51.50	5.00E+04	2.57E+06	115	15	9.00E+02	55.6
1725	118.64	2.00E+04	2.37E+06	135	15	5.00E+02	40.0
1864	42.84	5.00E+04	2.14E+06	> 200	40	2.00E+03	25.0
1880	11.08	1.00E+05	1.11E+06	> 200	90	8.00E+04	1.3
1783	12.53	7.50E+04	9.40E+05	> 200	> 100		
1651	6.35	7.00E+04	4.45E+05	> 200	> 100		
2563	3.64	1.00E+05	3.64E+05	> 200	> 100		
1755	15.97	2.00E+04	3.19E+05	> 200	> 100		
2570	1.72	1.00E+05	1.72E+05	> 200	> 100		
1834	3.11	5.00E+04	1.56E+05	> 200	> 100		
1851	2.59	2.50E+04	6.48E+04	> 200	> 100		
1795	5.44	1.00E+04	5.44E+04	> 200	> 100		

* BBU th >=100 mA

It is clear from the Table 1 that a very significant improvement is required in HOM damping, which exceeds the-state-of-the-art by more that an order of magnitude for 5 modes with high impedance.

Multipass BBU in 2-Pass ERL Prototype

With small srf structure as the one in the envisioned 100 MeV ERL prototype, BBU instability for 2-pass scenario is less threatening. In this case, the best obtained BBU threshold is 55 mA for the HOM data in Table 1 (that is the energy after the second pass is 200 MeV). Injection energy is 5 MeV.

Conclusion

At the moment there is no solution for a 2-pass multi-GeV ERL which will allow to support high average current of 100 mA. Either a dramatic improvement in HOM *Q*'s values is required or a considerable improvement in ERL optics. A more careful scan of the arcs betatron phase advance may lead to somewhat better results than those presented here. If, at any given time, there will be sufficient justification for a 2-pass ERL prototype, the following possibilities remain with no changes to the present layout of the building:

1) 2-pass running without modifications to the hardware [see JLAB IR-FEL experiment http://www.jlab.org/~douglas/FEL/technote/JLABTN01043.pdf], final energy is the same of the second pass;
2) the second loop can be added inside the present ring with Bates. Total energy will be still 100 MeV, which will require lower gradient running in the linac.

An option of adding the second loop which will push the energy to 200 MeV would require enlargement of the present building layout, thus, is unfavorable.

In the light of the presented BBU calculations it is suggested that a 1-pass ERL should be the main scenario for the multi-GeV 100 mA ERL.