PERLE AT ORSAY. LATTICE DESIGN OF 250 MeV VERSION

A. Fomin*, L. Perrot, R. Abukeshek, C. Guyot, Universite Paris-Saclay,
CNRS/IN2P3, IJCLab, Orsay, France
S.A. Bogacz†, Jefferson Lab, CASA, Newport News, USA

Abstract

The PERLE (Powerful Energy Recuperation Linac Experiment) collaboration is developing a high power (with a current of up to 20 mA of 500 MeV electrons) an energy recuperation linac machine with three acceleration and three deceleration passes through two cryo-modules. Here we present the design of the first stage of this machine with one cryo-module that would demonstrate the six-passes operation at a high current with a maximal energy of 250 MeV. All the magnets and the cryo-module are chosen to be compatible with both stages to minimise the costs of upgrade to the final one. The low-beta experimental areas are foreseen in a twelve meters straight section at 250 MeV.

MOTIVATION OF 250 MeV VERSION

The first stage of PERLE (Powerful Energy Recuperation Linac Experiment) [1] machine is aimed at demonstrating six-pass operation of the ERL (Energy Recuperation Linac) at about half of the target power. At the same time, it has a simpler design and less elements compare to the full power machine [2,3] (see Figure 1, therefore it requires lower initial expense and shorter construction and commissioning times.

Another advantage of building the ERL with one cryo-module is that it can also be a “test-bench” for the new cryo-module with an advanced technology that is currently under development. Indeed, the time of construction of the elements, assembly and commissioning the machine and running the experiments at 250 MeV can be used to design and produce the second cryo-module, that could be easily tested by replacing the first one. Finally, both cryo-modules can be used together at the full power machine.

The drawback of staging is that the upgrade to 500 MeV version requires additional expenses, manpower and shutdown time for reassembly and recommissioning. All of the magnets and the cryo-module are chosen to be compatible with both versions, thus in terms of hardware for the first stage we would need to add just about 30 meters of beam pipes and the power supplies with less current for some of the magnets.

LATTICE DESIGN

In order to minimise the cost and time of upgrade to 500 MeV version, we tried to keep the footprint and the structure of two versions of the machine as similar as possible.

The fundamental difference of 250 MeV version is that the injection line and the dump are on the same side. This leads to about 2 meter longer common section as the corrector magnets for the injection and dump should be located before and after the cryo-module (see Figure 1).

In the lattice with one cryo-module it is possible to replace the spreader, merger and common beam pipe sections with three straight lines and move the experimental areas to the upper line. This change of lattice allows one to reduce the number of dipole magnets to 60 (18 less) and quadruple

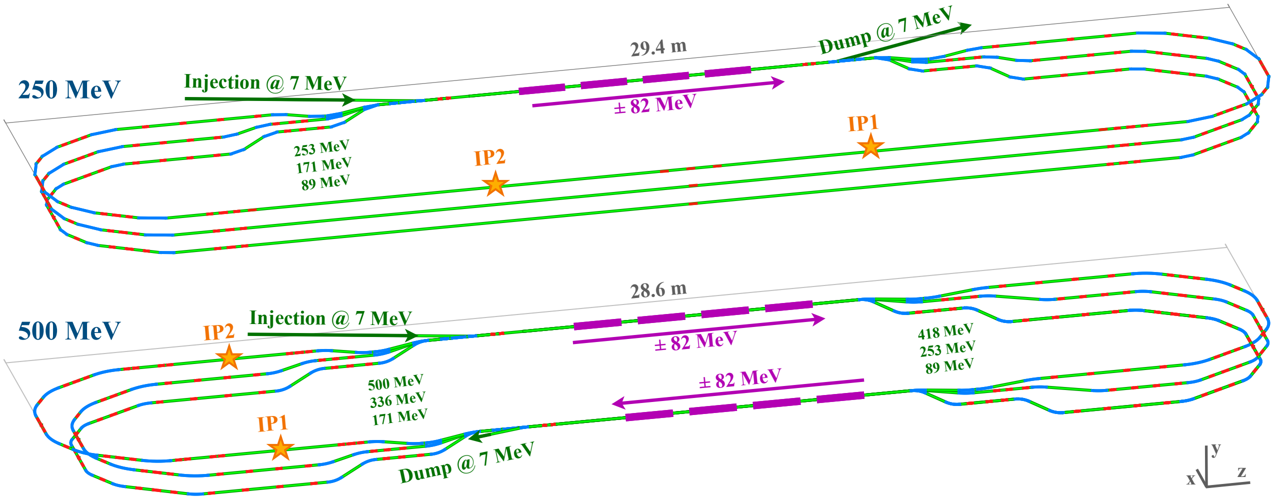

Figure 1: Baseline layout of 250 MeV (top) and 500 MeV (bottom) versions of PERLE: pipe lines (green), dipole (blue) and quadruple (red) magnets, RF cavities (purple), experimental areas with low beta (orange).

---

[*] ofomin@ijclab.in2p3.fr

[†] This work is supported by U.S. Department of Energy under DE-AC05-06OR23177

magnets to 134 (14 less) and also reduce the size of the last arc section and partially compensate the increase of the footprint due to the common section extension. Note that in 500 MeV version, the last arc section (before the deceleration stage) is extended in order to accommodate two experimental areas. Another benefit of 250 MeV version is that the place for the experimental area is larger, so it is possible to have 2 or 3 low-beta experimental areas with easier access.

The energy ratio at the arc sections of 250 MeV version is very close to the one after the second cryo-module:

$$\Delta E + E_0 : 2\Delta E + E_0 : 3\Delta E + E_0 \approx 1 : 1.92 : 2.84,$$
$$2\Delta E + E_0 : 4\Delta E + E_0 : 6\Delta E + E_0 \approx 1 : 1.96 : 2.92,$$

where $\Delta E \approx 82$ MeV is the energy gain per cryo-module, and $E_0 = 7$ MeV is the injection energy. Thus, the corresponding switchyard layouts are very similar between the two versions. The lowest energy line is identical, the closest magnet to the arc of the middle energy should be shifted longitudinally (z axis) by 3.5 cm and rotated by about 0.3 degree together with the neighbouring magnet (see Figure 2). In such configuration the trajectory is shifted by less than 5 mm in vertical plane (y axis), that might require small adjustment to the beam pipe.

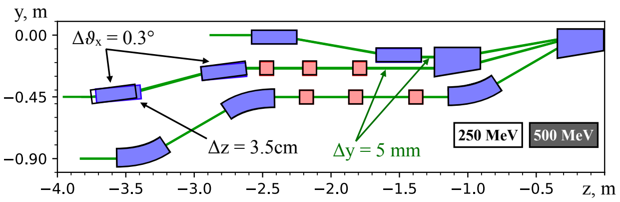

Figure 2: Switchyard layouts of 250 MeV (contour) and 500 MeV (solid) versions of PERLE.

FILLING PATTERN

The ratio between the frequencies of RF cavity (801.58 MHz) and the injection (~ 40 MHz) is chosen to give 20 λ_{RF} spacing between consecutive injections, where $\lambda_{\mathrm{RF}} = 37.4$ cm is the wave length. By adjusting the distance between the arcs, one can change the path length of the bunch between consecutive passes, and form the filling pattern, i.e. placement of accelerated bunches between the injected bunches. In order to reduce the risk of beam break-ups we chose to have a uniform filling pattern (with one 2.5 λ_{RF} spacing and others with 3.5 λ_{RF}), by adding a shift after each pass of 7 (or 6) λ_{RF}. At ERL with one cryo-module the deceleration passes are following the same pattern as the acceleration passes but in reverse order, e.g. in our case passes 1 and 5 and passes 2 and 4 contain the same arcs sections, so they give the same shifts (see Table 1). The shift after the pass 3 should be reduced by 3.5 λ_{RF} in order to bring the bunch to the deceleration stage, and may need to be extended by 6, 7, 13 or 14 λ_{RF} in order to respect the uniform filling pattern (see Figure 3).

Table 1: Shifts forming the uniform filling patterns

Pass	1	2	3	4	5
Arcs	1+2	3+4	5+6	3+4	1+2
Option	**Shifts after passes, λ_{RF}**				
1	7	7	$6+7-3.5$	7	7
2	7	7	$6-3.5$	7	7
3	7	6	$7+7+7-3.5$	6	7
4	7	6	$7+7-3.5$	6	7
5	6	7	$7-3.5$	7	6
6	6	7	$7+6+7-3.5$	7	6

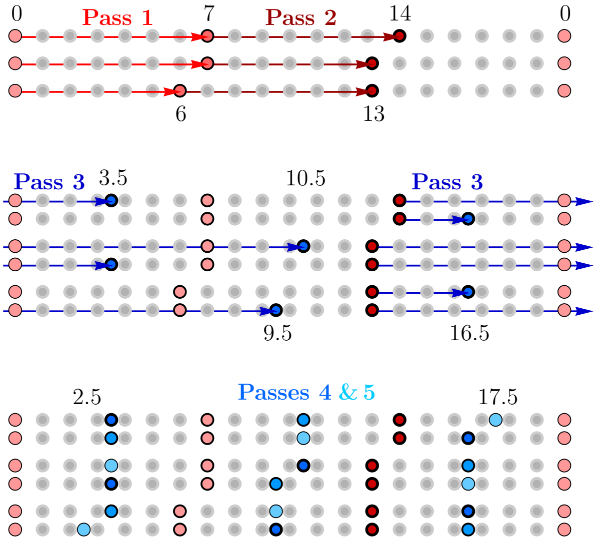

Figure 3: Six possible options of uniform filling patterns for 250 MeV version PERLE.

In fact, there are 12 possible uniform filling patterns for this layout as the shift can be positive and negative (this is identical to having the shifts of 14 or 13 λ_{RF}). The minimal length of the passes is about 173 λ_{RF}, so options 2 and 5 with negative shift would provide the smallest footprint 5.5 m × 29.4 m. Also, these options have the best separation of low energy bunches (see Figure 4), that should reduce the risk of beam break-ups. Further, more detailed studies on the subject (see e.g. [4, 5]) will follow.

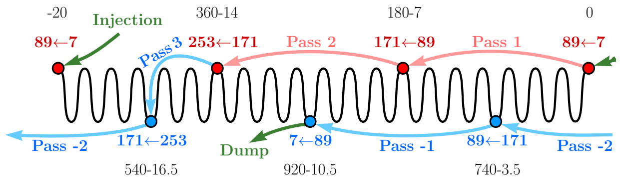

Figure 4: Filling patterns for 250 MeV version of PERLE. Length of one pass: $(180 - \Delta)\,\lambda_{\mathrm{RF}}$, $\Delta = 7, 7, 2.5, 7, 7$ (option 2).

CONCLUSIONS

Building the PERLE machine in two stages (i.e. first with one and then with two cryo-modules) would not only allow us to significantly reduce the construction and commissioning time for the demonstration of six passes ERL operation at half of the nominal power, but would also provide a possibility of using it as a test-bench for a new cryo-module that is currently under development. Despite of differences in the layouts, it is possible to keep almost the same footprint, and all the magnets and cryo-module are compatible with both versions. The drawback of staging is that the upgrade would require additional expenses, manpower and shutdown time for reassembly and recommissioning.

REFERENCES

[1] D. Angal-Kalinin *et al.*, "PERLE. Powerful energy recovery linac for experiments. Conceptual design report", *Journal of Physics G: Nuclear and Particle Physics*, vol. 45, no. 6, p. 065003, May 2018. `https://doi.org/10.1088/1361-6471/aaa171`

[2] S.A. Bogacz *et al.*, "PERLE - Lattice Design and Beam Dynamics Studies", in *Proc. IPAC2018*, Vancouver, BC, Canada, May. 2018. `doi:10.18429/JACoW-IPAC2018-THPMK105`

[3] S.A. Bogacz, "Lattice Design (Including IR)", presented at PERLE Collaboration Meeting, Orsay, France, Jan. 2022. `https://indico.ijclab.in2p3.fr/event/7907/contributions/24618/attachments/18115/23953/PERLE_Collab_2022.ppt`

[4] S. Setiniyaz, *et al.*, "Filling pattern dependence of regenerative beam breakup instability in energy recovery linacs", *Phys. Rev. Accel. Beams*, vol. 24, no. 6, p. 061003, Jun 2021. `https://link.aps.org/doi/10.1103/PhysRevAccelBeams.24.061003`

[5] K. Andre, "Beam Dynamics and Performance Studies of PERLE", presented at the Int. Workshop on Energy Recovery Linacs (ERL'22), Ithaca, NY, USA, October 2022, `https://indico.classe.cornell.edu/event/2018/contributions/1835/`