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LATTICE AND START TO END SIMULATION OF THE MAINZ ENERGY RECOVERING SUPERCONDUCTING ACCELERATOR MESA*

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Abstract

The institute for nuclear physics (IKPH) at Mainz University is designing a multi-turn energy recovery linac for particle physics experiments [1,2]. We present the current status of the lattice development of the Mainz Energy recovering Superconducting Accelerator (MESA) together with a PARMELA start to end simulation.

INTRODUCTION

The MESA accelerator shall operate in two modes: an energy recovery mode (ER) with high currents (up to 10 mA in stage-2) and an external beam mode (EB) with polarized currents of up to 150 μA. In [1] we presented among others the concept of a double sided accelerator design with vertical stacking of return arcs. At that stage of design the vertical spreaders and the return arcs have been studied separately.

In the progress of the design process the recirculations were connected and adapted to space restrictions introduced from the existing building. The linear optics was designed with our own matrix optics program "beam optics" and also with Mad X [3]. To allow for space charge effects and pseudo damping of the TESLA 9-cell cavities [4] the lattice was additionally simulated with PARMELA [5].

LATTICE DESIGN

The existing building restricts the available footprint area to circa 7.7 m × 27 m. One of the most promising designs for MESA to fulfil the design criteria follows a proposal for the LHeC ERL test facility [6]. In this design the main accelerator is a double sided accelerator with vertical stacking of the 180° arcs. In ER mode there are four passes through the cryomodules, of which two are accelerating. In the EB mode there are three passes through the cryomodules to reach the desired energy. As shown in Figure 3, MESA consists of:

- a normal conducting injector linac with an extraction energy of 5 MeV,
- two superconducting linac modules with an energy gain of 25 MeV each,
- four spreader sections for vertically separating and recombining the beam,
- five 180° arcs for beam recirculation,
- two chicanes for the injection and extraction of the 5 MeV beam,

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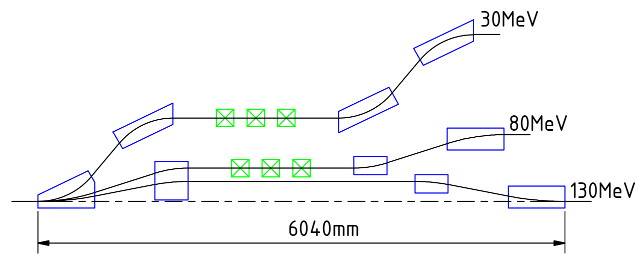

Figure 1: The 30 MeV-80 MeV-130 MeV beam spreader layout. blue: dipole; green: quadrupole.

- an 180° bypass arc for ER mode incorporating the internal experiment
- and a beam line to the external experiment.

Figure 1 shows one of the four beam spreaders. For cost reduction only five different types of dipoles are used in those sections. Due to the limited space the beam line of the highest energy is designed as a chicane, which is also compensating the dispersion in this part of the beam line and no quadrupoles are needed.

To reduce the energy spread of the beam, MESA is designed as a non-isochronous recirculator, as proposed in [7], but the possibility of isochronous recirculation in ER mode is desired, too. Thus highly flexible arcs are needed to adjust R_{56} and compensate the momentum compaction of the beam spreaders. The dispersion and the momentum compaction for the 30 MeV arc with a setting of R_{56} = -0.3 mm/‰ are

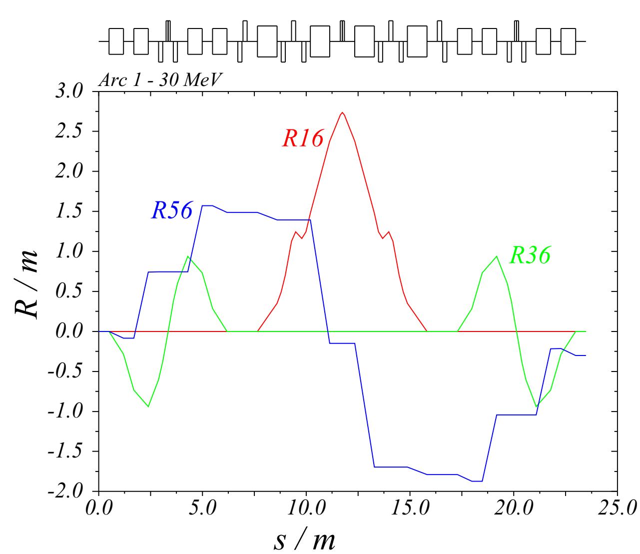

Figure 2: The dispersion and the momentum compaction of the 30 MeV arc including the two beam spreader.

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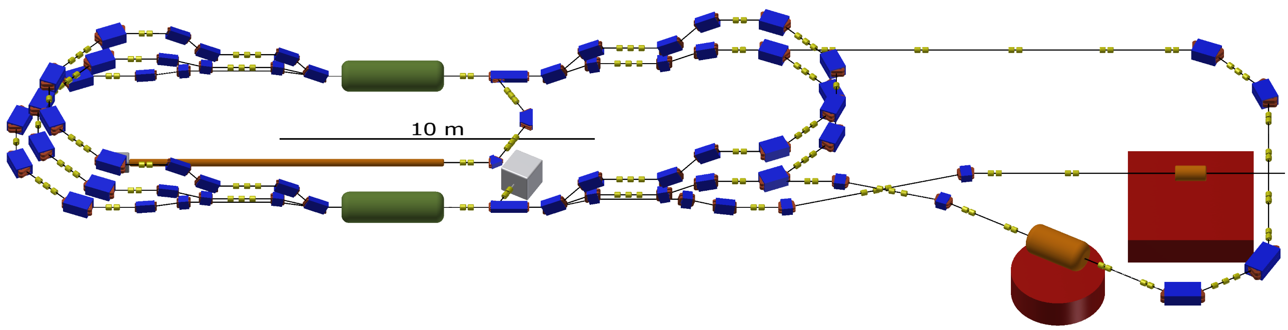

Figure 3: A 3D sketch of MESA: The main accelerator consists of two superconducting linac modules, the vertical beam separations and five 180° arcs. The experiments are an internal experiment for the ER mode with a beam energy of 105 MeV and an external experiment at 155 MeV. The red blocks mark the footprint area reserved for the experiments.

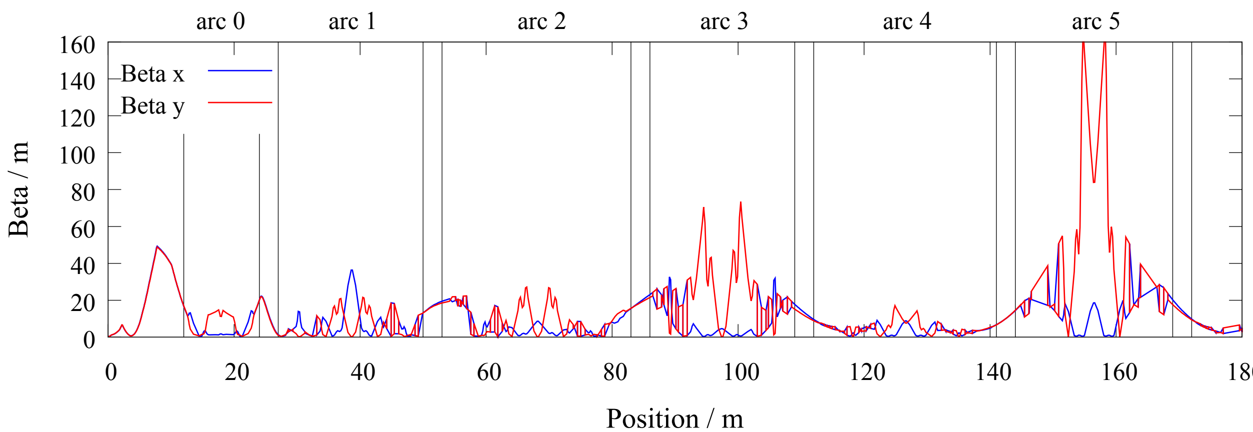

Figure 4: Beam beta functions of MESA in EB mode including space charge calculated with PARMELA.

shown in Fig. 2. In this design the arcs are made up of four 45° sector bending magnets. By now the lattice is only capable of serving EB mode.

PARMELA SIMULATIONS

The PARMELA simulation is based in the normal conducting injector presented in [2], but with an improved space charge mesh and $I = 150\,\mu$A. The measures of the cryomodule were taken from the ELBE modules [8,9], but the type of cryomodule has not yet been chosen [10]. The accelerating field data was obtained from Superfish for a TESLA 9-cell cavity. To gain insight into the phase slippage each cell was modelled individually. The two endgroup cells also include the beam pipes to allow for fringe field effects.

The optics input was taken from the lattice design and then the simulation output was given back to the lattice design to refine the matrix calculation. It was necessary to progress arc by arc to match the optics, but also to adjust the lengths of the arcs properly. An overview of the beta functions obtained from PARMELA are shown in Fig. 4.

Further a coarse scan of R_{56} vs. synchronous phase ψ_s of the main linac for two different longitudinal phase space settings of the injector was conducted to find good settings. The "standard" setting [2] of the injector gives $\Delta E_1 = \pm 1.4$ keV, $\Delta\psi_1 = \pm 0.82°$ at the exit. The bunch length is constant in the following drift space. In the second setting the bunch exits the injector at $\Delta E_2 = \pm 7.5$ keV, $\Delta\psi_2 = -0.68° \cdots + 0.76°$. The ellipsis is more upright, the bunch still converging. To neglect a change of shape, energy spread and bunch length are taken as full widths at the bottom of the distributions and are plotted against R_{56} with ψ_s as parameter in Fig. 5 and 6.

One can see that for this lattice the minimum of the energy spread is at a R_{56} between -0.2 mm/‰ and -0.3 mm/‰, if ψ_s is positive or slightly negative. For larger negative ψ_s the minimum occurred at $R_{56} \geq 0$. The minimum in bunch length is as expected in the vicinity of the minimum energy spread. The synchronous phase most indifferent to changing R_{56} is $\psi_s = -2°$, which is now regarded as standard phase.

In a first attempt to model the ER mode at 10 mA, the 105 MeV arc was lengthened by $\lambda/2$ and then the preceding arcs were repeated in the input deck. This was more or less done to check phasing of the linac modules. Due to the asymmetric lattice functions the energy recovered beam was lost for the most part. So the EB lattice has to be symmetrised to be also capable of energy recovery or a dedicated lattice has to be designed. Further one has to take into account the large difference of space charge forces due to very different beam currents at the two modes of operation. This also influences the lattice focussing strongly.

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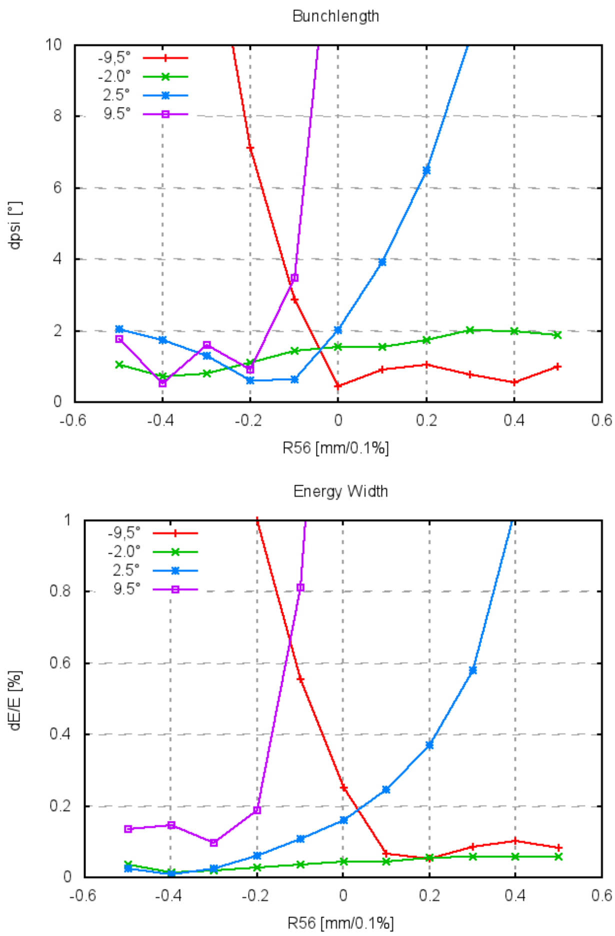

Figure 5: Bunch length and energy spread at $E_0 = 155\,\mathrm{MeV}$ as a function of R_{56} for different ψ_s taken at the bottom of the distribution. The injector was delivering ΔE_1 and $\Delta\psi_1$.

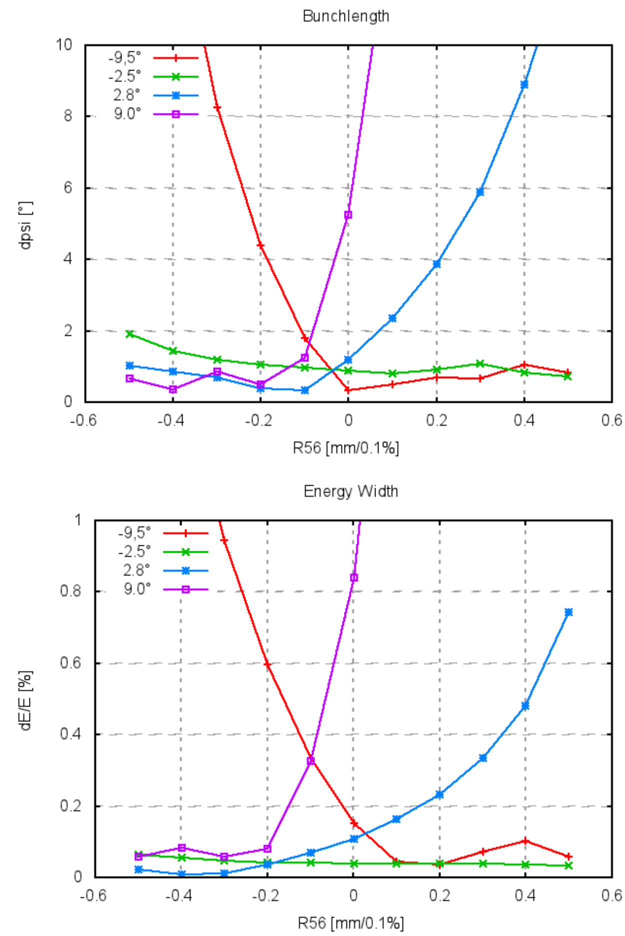

Figure 6: Bunch length and energy spread at $E_0 = 153\,\mathrm{MeV}$ as a function of R_{56} for different ψ_s taken at the bottom of the distribution.The injector was delivering ΔE_2 and $\Delta\psi_2$.

SUMMARY & OUTLOOK

We have presented a design for an EB mode lattice. This lattice has been simulated with PARMELA from which proper adjustment of the lengths of the arcs and space charge defocussing was obtained in an optimisation procedure. Further an optimum R_{56} and synchronous phase was found in a parameter scan.

Due to the asymmetric beta functions energy recovery is not possible with this lattice. The next step is to symmetrise the lattice around the mirror plane of the main linac cryomodules. The allowable beta functions enclosing main linac is of the order of magnitude of the length of the modules and has to be the same for all arcs. One also has to take into account the m_{12}-matrix element for beam break-up [10]. This process of redesign will again incorporate co-optimisation with tracking and matrix calculations.

REFERENCES

[1] R. Heine et al., IPAC 2012, New Orleans, USA, TUPPR073, (2012). `http://accelconf.web.cern.ch/AccelConf/IPAC2012/papers/tuppr073.pdf`

[2] R. Heine, K. Aulenbacher, IPAC 2013, Shanghai, China, WEPWA011, (2013). `http://accelconf.web.cern.ch/AccelConf/IPAC2013/papers/wepwa011.pdf`

[3] W. Herr, F. Schmidt, "A MAD-X Primer", Geneva, Switzerland, CERN-AB-2004-027-ABP, (2004). `http://cern.ch/madx/doc/madx_primer.pdf`

[4] B. Aune et al., Phys Rev ST-AB **3**, 092001 (2000).

[5] L.M. Young, "PARMELA", Los Alamos, USA, LA-UR-96-1835, (2005). `http://laacg.lanl.gov/laacg/services/serv_codes.phtml`

[6] A. Valloni et al., IPAC2013, Shanghai, China, TUPME055, (2013). `http://accelconf.web.cern.ch/accelconf/IPAC2013/papers/tupme055.pdf`

[7] H. Herminghaus, NIM A **314**, 209 (1992).

[8] P. McIntosh et al., SRF2009, Berlin, Germany, MOOBAU05, (2009). `http://accelconf.web.cern.ch/accelconf/SRF2009/papers/moobau05.pdf`

[9] J. Teichert et al., NIM A **557**, 239 (2006).

[10] F. Schlander et al., IPAC14, Dresden, Germany, WEPRI013, (2014). `http://accelconf.web.cern.ch/accelconf/IPAC2014/papers/wepri013.pdf`