CURRENT STATUS OF THE MILLIAMPERE BOOSTER FOR THE MAINZ ENERGY-RECOVERING SUPERCONDUCTING ACCELERATOR*

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Abstract

The 'Milliampere Booster' (MAMBO) is the injector linac for the 'Mainz Energy-recovering Superconducting Accelerator' MESA. The MESA facility is currently under design at the Institute for Nuclearphysics (Institut für Kernphysik - KPH) at Johannes Gutenberg-University of Mainz (JGU). In this paper we will present the current design status of the linac.

INTRODUCTION

The MESA accelerator is a small energy recovery linac (ERL) working at low energy for particle physics experiments. MESA will be operated in two modes: the first is the external beam (EB) mode; there the beam is dumped after being used with the external fixed target experiment P2. This experiment measures the weak mixing angle to a high precision by parity violation. The current required for P2 is 150 μA with polarised electrons at 155 MeV. The second mode is energy recovery (ER). The experiment served in this mode is an internal fixed target experiment named MAGIX (MESA Gas Internal target eXperiment). It demands an unpolarised beam of 1 mA at 105 MeV. In a later stage a current upgrade towards 10 mA is planned in EB-mode.

The general concept of MAMBO was presented in [1]. MAMBO consists of a low energy beam transport section (LEBT) preparing the beam with a chopper buncher system for capture in the first linac RF-section. The electrons are provided by a 100 keV DC photo gun called STEAM (Small Thermalized Electron Apparatus in Mainz [2]) that is driven by a pulsed laser. A chopper system is installed to cut off tails. STEAM, a spin rotator to manipulate the electron spin and the succeeding LEBT form the 'MESA Low energy Beam Aparatus' (MELBA). The spin rotator consists of two Wien-filters rotated by 90° to each other and a solenoid in between them.

The electrons are accelerated by four room temperature RF-sections to 5 MeV. The frequency is determined by the SRF structures of the main linac, which are using TESLA technology at 1.3 GHz. The normal conducting structures are bi-periodic $\pi/2$ standing wave structures. The first section is a graded-β, the 2nd section has a constant $\beta < 1$ and the last two sections are $\beta = 1$. The geometry of the cells is derived from the MAMI injector [3].

* Work supported by German Science Foundation (DFG) under the Cluster of Excellence "PRISMA", EXC 1098/2014

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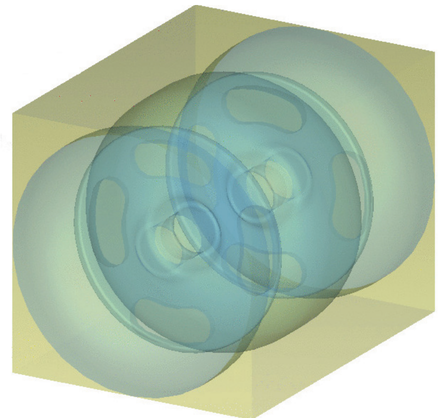

Figure 1: Geometry used for multipacting simulation.

MULTIPACTING ANALYSIS

The mechanism of multipacting (MP) [4,5] is an RF-field induced electron discharge in vacuum that causes a break down of the accelerating field. MP can take place between opposing surfaces or on the same surface the electrons are emitted from (two-point or one-point MP). The energy of the electrons impinging has to be above secondary electron emission (SEE) threshold, the secondary electron yield $\delta(E)$ has to be larger than unity and the time of flight has to be a multiple n of the RF-period. The scaling of the threshold electric field E_n for two-point MP is [4]:

$$E_n \propto \frac{\text{distance of surfaces}}{\text{RF wavelength}^2} \tag{1}$$

The region most prone to two-point MP in the bi-periodic structure is the coupling cell (CC), which resembles two facing surfaces in a short distance.

As there was no MP in the MAMI structures, we did not expect the effect in the MESA structure either. Non the less, the CC were researched for MP by CST particle studio simulations. The simulation setup is shown in Fig. 1. The RF-structure consists of five resonators: two CC, one full and two half accelerating cells (AC). The half AC at both ends were chosen to have proper boundary conditions. The model of SEE chosen was 'copper (ECSS)' from the CST library. The CST PIC solver is able to identify MP by an exponential growth of the number of particles and then stops.

Three situations were researched: an area particle source on one web of the CC at 2 eV and one at 10 eV, but also a Maxwell distributed electron cloud inside the CC.

With the RF design presented in [6], MP was already found at field gradients lower than the specified accelerating field. The results of the several situation were slightly differ-

ISBN 978-3-95450-147-2

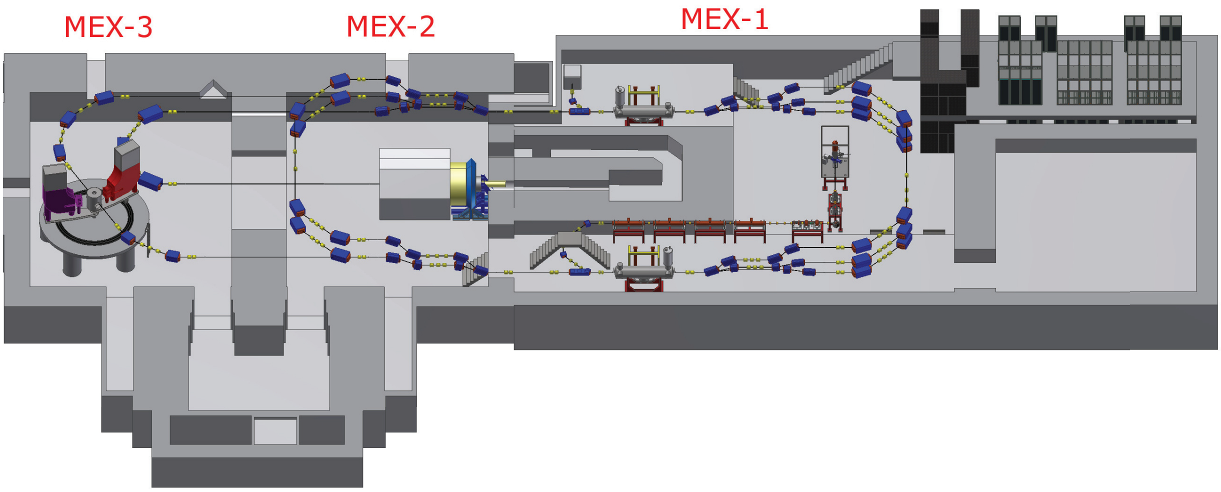

Figure 2: Layout of the MESA facility with the new MESA experimental hall 1 (MEX-1) on the right hand side and the two existing halls on the left-hand side, now renamed to MESA experimental hall 2 and 3 (MEX-2 and MEX-3).

ent, leaving space for interpretation regarding the threshold of MP.

There are two possible cures of MP, both are cancelling the resonance of MP:

1. change the distance between the MP surfaces, i.e. length of CC (l_{CC}):

   Starting from the design of [6] with l_{CC}= 7.2 mm, different lengths of the CC were checked. From Eq.1 l_{CC}= 14.4 mm can be assumed as save length, but with low R_s. Simulations gave hints, that for $l_{CC} \geq 11.2$ mm there may also be no MP (see Fig. 3).

2. applying a low magnetic field B_{MP} to change the time of flight of the secondary electrons:

   A longitudinal, as well as a transverse magnetic field of 5 G, 10 G, 25 G and 50 G was applied to the geometry shown in Fig. 1 at an accelerating field of 1 MV/m and l_{CC}= 7.2 mm, 11.2 mm and 14.4 mm. At l_{CC}= 7.2 mm the magnetic fields did not have a positive influence. With l_{CC}= 11.2 mm a transverse field of 25 G seems to be helpful, while a longitudinal field of 50 G and above stimulates MP. This may cause issues in high current operation (1 mA and above), where a solenoid field of up to 100 G must be applied over the graded-β to counteract space charge defocussing of the low energy beam.

Both methods have drawbacks:

1. increasing l_{CC} will lower the shunt impedance R_s, especially of the graded-β section, which increases RF-losses. The mean shunt impedance of our graded-β decreases by 10% when l_{CC} is doubled.

2. applying B_{MP} may steer the beam. A transversal field of 20 G causes a 100 keV electron to circle with a bending radius of 0.56 m.

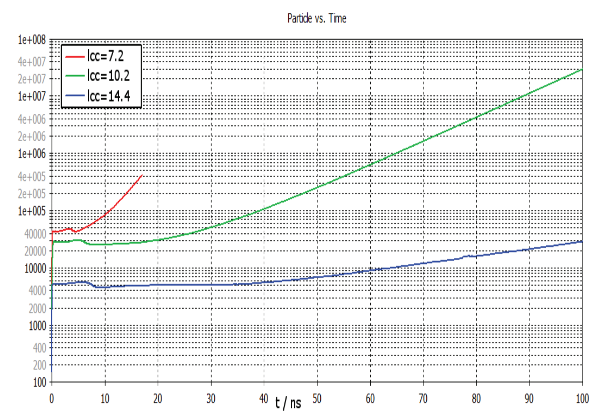

Figure 3: Plot of the temporal evolution of the number of particles due to SEE over 100 ns for several lengths of CC: l_{CC}= 7.2 mm (red), 10.2 mm (green) and 14.4 mm (blue) at E_{acc}=1 MV/m. The red line stops at 17 ns, because MP was detected by the solver.

A moderate elongation of the CC together with lowering the gradient of the accelerating field seems to be the right cure for the MP issue.

LAYOUT CHANGES

The latest lattice of MESA can be seen in Fig. 2. MESA shall be built inside existing halls of the KPH building and an experimental hall, that was granted as a research building by DFG recently. During the planning process it turned out, that large openings planned inside the wall between the halls MEX-2 and MEX-3 (see Fig. 2) would lead to a structural weakness of the whole building. So the layout of MESA had to be changed compared to [7], to avoid those openings. MESA and the experiments now have switched places, so only a few boreholes in that wall are needed. But this had an impact on the layout of MELBA: a 90° alpha magnet had to be introduced, to avoid interference with MESA arcs. This

Table 1: Longitudinal bunch data of the beam delivered by the gun STEAM (index i) at 100 keV and exiting the last RF-section of MAMBO (index f) at 5 MeV.

		stage -1		stage - 2
I_b	[mA]	0.15	1	10
$\Delta\varphi_i$ (RMS)	[°]	23.4	23.5	24
ΔT_i (RMS)	[keV]	0.03	0.2	1.6
$\Delta\varphi_f$ (RMS)	[°]	1.3	1.8	2.4
ΔT_f (RMS)	[keV]	0.75	1.3	4.5
$\Delta T_f/T$ (RMS)	$\times 10^{-4}$	1.5	2.5	9

increases the distance between the 2nd Wien-filter and the Chopper system.

BEAM DYNAMICS

The PARMELA [8] model has been further improved: The design of MELBA has been fixed and was incorporated into the design of MAMBO. Further the 1st and 2nd harmonic buncher cavities have been designed now in course of a master's thesis [9]. The SuperFish [10] field data of those cavities is now part of the input deck.

The particle distribution provided by the gun is obtained from the CST simulations [11] of STEAM. This should provide a more realistic input compared to the random distributions generated by PARMELA.

The drift space of MELBA is rather long. So the input phase of the graded-β section had to be lowered to $\varphi_s = -25°$ to allowed for additional bunch lengthening introduced by space-charge forces during the longer drift. To counteract MP by lowering the accelerating field, two AC were added to each RF-section. This also lowers the cavity losses and therefore the amount of RF-power to be installed.

Due to the changes mentioned above beam parameters presented in [6] are no longer valid. The beam parameters according to the latest simulations are listed in Tab. 1. While the energy spread could be maintained the bunch length has increased considerably. The phase space of the beam at different currents at the end of MAMBO is shown in Fig. 4. One can see, that at high current (red dots) the core beam and halo behave very differently. Also the number of particles is visibly lower, because a large portion of the 10 mA beam is exceeding ±90° phase angle due to space charge effects and is cut off by the chopper already.

STATUS AND OUTLOOK

The planning and construction works of the MEX-1 hall will have a strong impact on the timeline of MESA, since breaking ground will not take place before 2018. In the meantime we will set up a test facility in the MEX-3 hall (see Fig.5) for testing STEAM, MELBA and the RF-sections MAMBO No. 1 and No. 2 step by step, until building works are starting.

Currently STEAM is under construction in MEX-3 and testing will start this summer. Further the deflector cavities of the chopper are in production, as well as the buncher cavities. The chopper collimator [12] is under test at the photo gun PKA2 with a prototype deflector cavity [13].

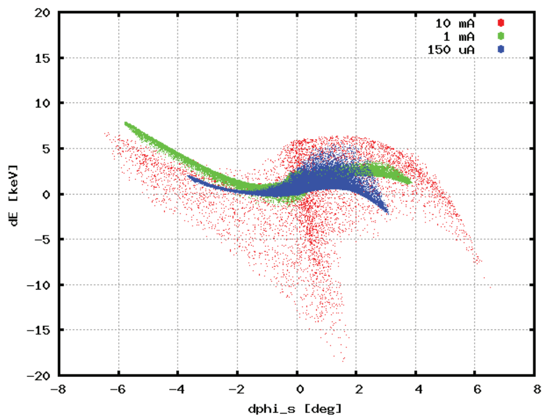

Figure 4: Longitudinal phase space of the 5 MeV beam exiting MAMBO at several beam currents. I_b = 150 μA (blue), 1 mA (green) and 10 mA (red).

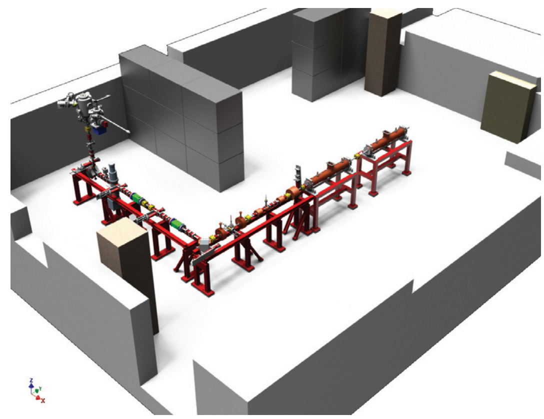

Figure 5: Test setup of STEAM, MELBA and MAMBO No. 1 & No. 2 in the MEX-3 hall. For a better overview the supports of STEAM are suppressed.

REFERENCES

[1] R. Heine et al., IPAC'13, Shanghai, China, p. 2150 (2013).

[2] S. Friederich, K. Aulenbacher, IPAC'15, Richmond, USA, p. 1512 (2015).

[3] H. Euteneuer et al., EPAC88, Rome, Italy, p. 550 (1988).

[4] A. Hatch, Phys. Rev. **112**, 681 (1958).

[5] A. Hatch, J. Appl. Phys. **32**, 1086 (1961).

[6] R. Heine et al., IPAC'15, Richmond, USA, p. 1515 (2015).

[7] D. Simon, et al., IPAC'15, Richmond,USA, p 220 (2015).

[8] L.M. Young, LA-UR-96-1835, Los Alamos, USA, (2005).

[9] P. Heil, master's thesis, JGU, (2015).

[10] J.H. Billen, SUPERFISH manual, LANL, (2005).

[11] Computer Simulation Technology, Darmstadt, Germany.

[12] B. Ledroit, master's thesis, JGU, in preparation.

[13] V. Bechtold, diploma thesis, JGU, (2013).

ISBN 978-3-95450-147-2