ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOPT007

HIGH BUNCH CHARGES IN THE SECOND INJECTION BEAMLINE OF MESA

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Abstract

MESA (Mainz Energy-recovering Superconducting Accelerator) is an accelerator with two laser-driven electron sources (polarized and unpolarized) operating at 100kV, which is under construction at the Johannes Gutenberg University in Mainz.

The unpolarized electron source MIST (MESA Injector Source Two) allows producing highly charged electron bunches. This source and a double Mott polarimeter will be arranged on the same height above the MESA injector main beamline. A parallel shifting beamline was developed for transporting highly charged bunches from the source MIST to the main MESA beamline.

This report is dedicated to the design of the separation beamline which transports and compresses highly charged electron bunches from the electron source MIST to the first acceleration section of MESA.

INTRODUCTION

An important operation mode for MESA is using spin-polarized beam which will be covered by the STEAM electron source. STEAM will operate at a rather low potential of 100keV in order to maximize operational safety, in particular in view of the very sensitive NEA-photocathodes needed for spin-polarized beam. For the second, unpolarized, source at MESA, called MESA Injector Source Two (MIST), these restrictions do not apply in principle, however, in this paper we restrict ourselves to 100keV beam too. The MESA project aims at an average current of 10mA, which corresponds to a bunch charge of 7.7pC if MESA is operated CW at 1.3GHz. Hence, 100keV at 7.7pC are basic design objectives for this investigation. The goal is to design a separation beamline system which allows to compress and transport electron beam to the first acceleration section of MESA. This beamline should be operated in two different modes. The first mode should allow transporting the beam from the electron source STEAM [1] to the double scattering Mott polarimeter (DSMP). The second mode should allow injecting the beam from the second electron source MIST to the first acceleration section of MAMBO (Milliampere Booster) [2].

ELECTRON SOURCE

MIST is used as second photo electron source for the MESA project [3]. This source allows to produce unpolarized electron pulses from more robust materials. The design of this inverted electron source allows operating at up to 200keV but in this paper, we only consider 100keV which yields approximate values of the Lorentz-factor $\gamma = 1.2$ and $\beta = 0.548$).

The initial RMS length of produced electron bunch was set to 27ps. In the experiment this depends on length of laser-driver pulse and 27ps is a value which was already achieved with a compact laser diode [4]. The simulated bunch with 7.7pC charge has $2.7\cdot10^{-3}$ RMS energy spread.

SEPARATION BEAMLINE

MIST is potentially better suited for high bunch charge operation than STEAM. Since no spin polarization is foreseen, the complex and long spin rotation system of STEAM can be avoided. In contrast to STEAM no chopper system, must be foreseen since we believe that the hard limitation of longitudinal acceptance that the chopper produces gives an advantage only for the high precision spin polarized experiments, if a suitable synchronized laser is used. This concept was realized already at the Cornell photoinjector [5]. Moreover, as already mentioned, the source may be used in a later stage with higher potential which would allow for much high charges. On the other hand, the geometrical restrictions in the building require to inject the beam with large angle deflections which makes beam dynamics more complicated.

The electron source MIST and DSMP will be arranged on the same height above the MESA injector main beamline. Thus, it was necessary to develop a parallel shifting beamline in the vertical plane to transport the emitted electron beam.

This beamline has two different operation modes.

1. Transport the beam from the STEAM to the DSMP.
2. Transport the MIST beam to the first MAMBO acceleration section and compress this beam with a buncher which will be installed after the second dipole magnet (B2 in Fig. 1).

In order to fulfill both functions, the magnets must have three output ports. For 90 degree deflection this is difficult to realize with H-type magnets or the alpha-magnets which we have employed so far for low energy deflection. Therefore C-type magnets have been studied.

The optical structure of the proposed beamline consists of two quadrupole doublets and deflection arc. The dispersion function outside this deflection arc should be zero.

The scheme of the designed beamline is shown in Fig. 1.

Three types of optical schemes for the deflection arc were considered:

- Double bend achromat,
- 90° dogleg and
- 4 alpha magnets.

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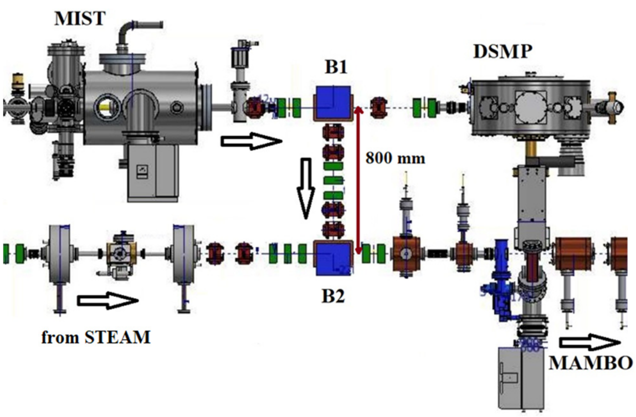

Figure 1: Scheme of the designed separation beamline. 90° dipole magnets (blue), quadrupoles (green), dipole correctors (brown). (By courtesy of Dr. Simon Friederich).

Beam dynamic simulations with program package MadX show that a 90° dogleg is the most flexible solution for this beamline. The dogleg scheme consists of two 90° degree dipole magnets and a quadrupole triplet between them. The beam dynamic simulations of the separation beamline were made with the program packages MadX , OPAL and CST Studio Suite®.

The results of dynamics simulations for the transverse RMS beam sizes in the designed separation beamline are shown in Fig. 2. and the RMS dispersion functions are shown in Fig. 3.

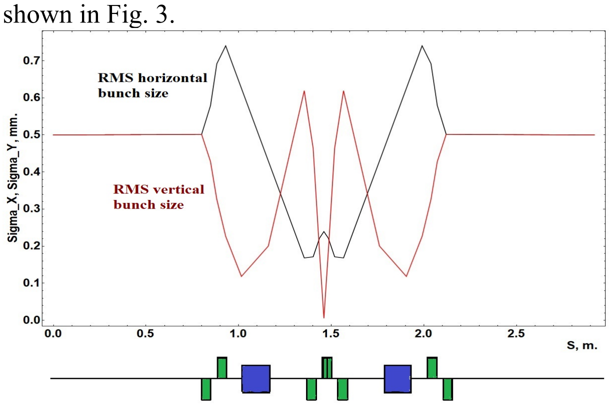

Figure 2: RMS transverse beam sizes in the separation beamline divergence and non-divergence plane.

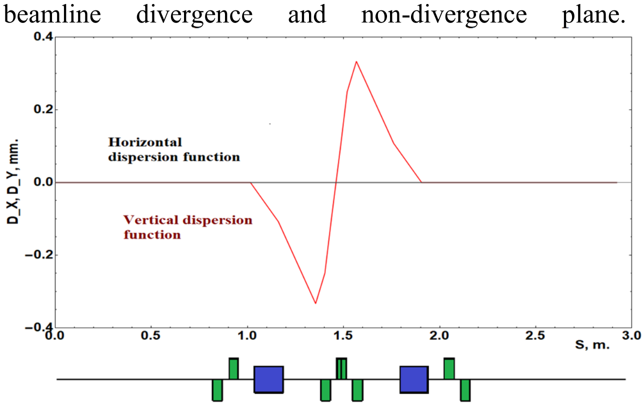

Figure 3: RMS dispersion functions in the separation beamline for the dispersive and non-dispersive plane.

C-SHAPE DIPOLE MAGNETS DESIGN

The designed separation beamline requires two special 90° bending magnets (B1/B2) which should be operated in 3 different modes. For example, Fig. 4 shows the operation regimes for the second bending magnet B2 (see Fig. 1 for position in beamline).

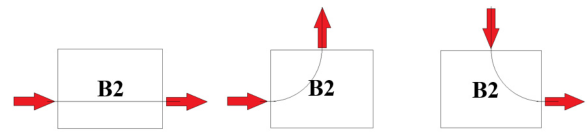

Figure 4: Different operation modes for the designed dipole magnet B2. Left: STEAM to MAMBO – normal operation for experiment with B2 switched off. Middle: STEAM to polarimeter – measurement of spin-polarisation. Right: MIST to experiment with high beam currents or bunch charges. Red arrows show the direction of motion of the electron beam.

Two models of dipole magnets were considered for the separation beamline. Dipole magnet with bending radius 100mm and with 50mm.

A bending radius of 100mm was identified as a good compromise between field quality and compactness. The CAD model of designed bending magnet is shown in Fig. 5.

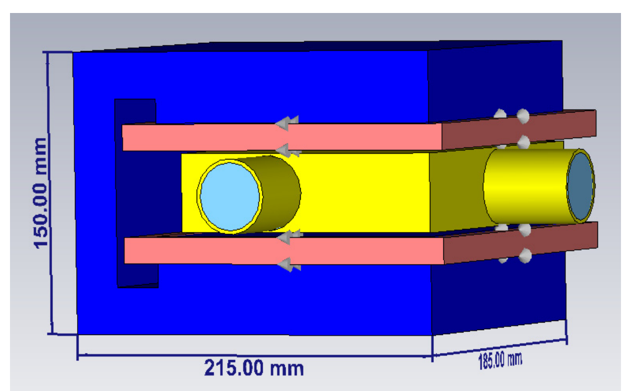

Figure 5: CST model of bending magnet.

This dipole magnet operates at 12mT and has a gap of 46 mm and bending angle 90°. Current density (1.75 A/mm^2) and power are small enough to allow cooling by convection only.

The CST simulation shows that a good field region for such dipole magnet with an accuracy of $\Delta B/B = \pm 10^{-3}$ is 41mm and with an accuracy of $\Delta B/B = \pm 10^{-4}$ is 5mm (see Fig. 6).

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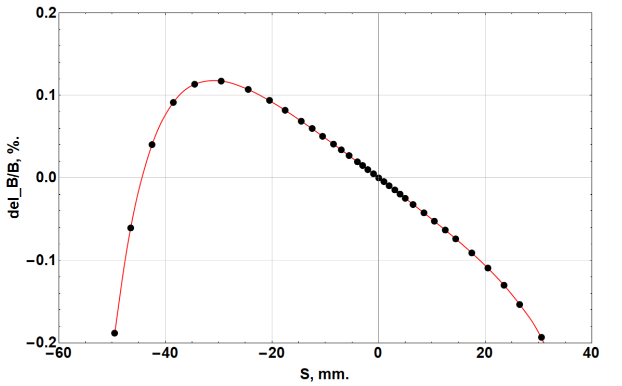

Figure 6: Good field region for the designed dipole magnet. S – line in horizontal plane through the center of the dipole magnet perpendicularly to the beam trajectory. 0 – position of the beamline center.

CST SIMULATION

To consider all 3D effects (Coulomb interactions in a beam, effects of fringe field of designed magnets etc.) numerical calculations with the software package CST 2019 were performed. For simulation with CST were used CST models of existing quadrupole lenses [6].

The CST model of designed separation beamline is shown in Fig. 7.

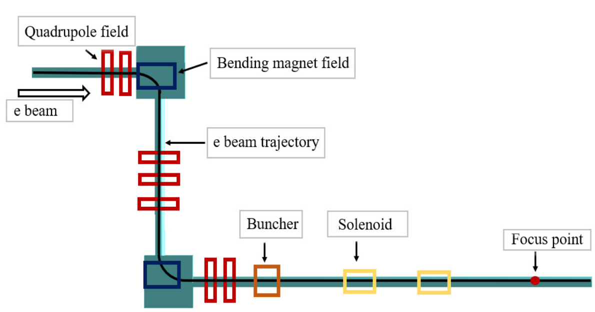

Figure 7: CST model of the injection beamline. 90° dipole magnets (blue), quadrupoles (red), solenoids (yellow), buncher (brown).

It was assumed that the buncher phase is optimal. The maximal electric field in the buncher was $E_b = 310$kV/m. CST calculations show that the designed separation beamline allows to compress the electron beam with the bunch charge of 7.7pC to about 1.78mm RMS length and the energy spread in this case will be 1.6%.

The results of simulations of the longitudinal phase-space of the electron bunch in the entrance to the first acceleration section of the MAMBO is shown in Fig. 8.

CONCLUSIONS AND OUTLOOK

The designed beamline is planned to be built to the end of this year in the Institut of Nuclear Physics in Mainz. Further studies will deal with operation at higher voltages and the capabilities of an arrangement where the MIST source is placed directly in front of the buncher.

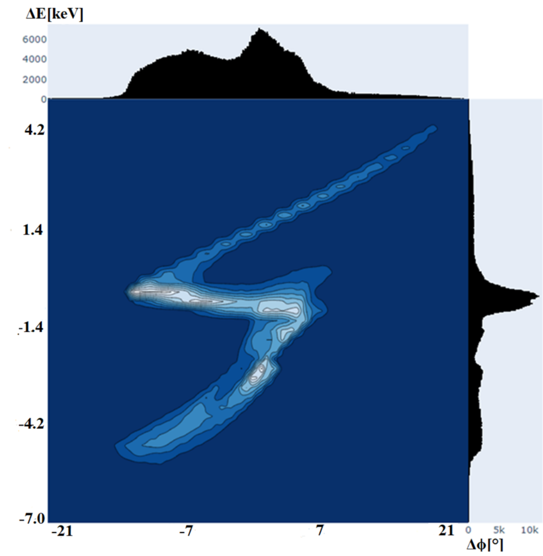

Figure 8: The longitudinal phase-space of the electron bunch in the entrance of the first acceleration section of MAMBO.

ACKNOWLEGMENTS

I am very grateful to Dr. Robert Heine for additional supervision and advice. I express my gratitude to Daniel Simon, for the help with beam dynamics and bending magnets design. We acknowledge support from the Deutsche Forschungsgemeinschaft (DFG) through Graduiertenkolleg 2128 "ACCELENCE" and from the Federal ministry of research (BMBF) under the Project 05K19UMA (Compact sources of brilliant beams, CSBB).

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