CURRENT STATUS OF THE MESA PROJECT*

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Abstract

Most of the components of MESA are approaching a finalised design. Issues concerning beam dynamics, cryomodule operation and adaptations of the existing building constraints will be discussed. The current status will be presented.

INTRODUCTION

The Mainz Energy-recovering Superconducting Accelerator (MESA) is a low energy CW recirculating electron linac for particle physics experiments to be built at the Institut für Kernphysik (KHP) of the Johannes Gutenberg University of Mainz (JGU). MESA will be operated in two modes: the first is the external beam (EB) mode; the beam is dumped after being used with the external fixed target experiment P2. 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 (pseudo) internal fixed target experiment named MAGIX. It demands an unpolarised beam of 1 mA at 105 MeV. In a later stage-2 the ER-mode current shall be upgraded to 10 mA.

MAIN ACCELERATOR LATTICE

The accelerator has to fit into the existing building of the KPH. The place foreseen for MESA has been used by the P2 predecessor experiment, which has ended data taking in 2012 and the caves have been emptied recently to prepare the place. Designing an accelerator to fit into an existing building imposes many constraints to the lattice, rather due to civil engineering requirements, than accelerator physics.

The lattice design of the accelerator is a double sided recirculating linac with vertical stacking of the return arcs (see Fig. 2), which is a very compact set up in lateral dimensions. A similar design is planned for the LHeC ERL test facility [1]. The EB mode optics is that of a simple recirculating linac. In ER mode the beam will pass the main linac modules twice on the accelerating phase and also twice on the decelerating phase. Afterwards the beam is dumped at injection energy of 5 MeV. The lattice consists of:

- 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,

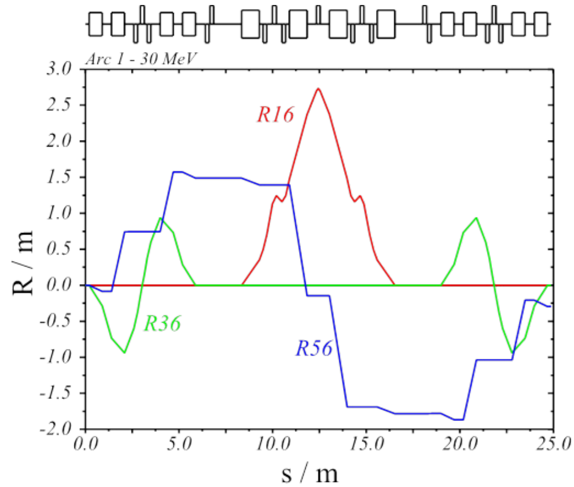

Figure 1: Dispersion and momentum compaction of the 30 MeV arc including the beam spreaders.

- an 180° bypass arc for ER mode incorporating the MAGIX experiment
- and a beam line to the P2 experiment.

The accelerated and the decelerated beam share the same arcs, therefore special care has to be taken on the optics of the low energy recirculations to avoid beam loss. To push the beam break up limits for ER-mode towards 1 mA the beta functions inside the main linac modules have to be of the order of magnitude of the length of the modules itself and have to be the same for all passes. The arcs are made of two double bend elementary cells, with a maximum of horizontal dispersion in the middle of the arc (Fig. 1). The arcs are as a whole achromatic. The momentum compaction R56 of each arc can be adjusted from 0.5 cm/% to -0.5 cm/% to allow for isochronous as well as non-isochronous operation. The optics of an arc is only slightly depending on the R56 and can be readjusted easily. The non-isochronous operation is needed to deliver a beam with low energy spread to the external experiment P2. The energy recovery shall also take place with phase focussing.

The design tools used for lattice design are, besides an in-house matrix optics program “beam optics”, which features an online preview of the optical functions, MAD-X [2] for the automatic optimisation routine and PARMELA [3] to allow for space charge and pseudo damping of the main linac cavities by using field data obtained from SuperFish. Due to the low injection energy and the large dynamic range of the beam current, the influence of space charge effects on the optics is strong and has to be considered.

The PARMELA tracking simulations of the ER-mode (Fig. 3) show a strongly peaked horizontal beta function in the 2nd arc, which is even stronger for the decelerated beam.

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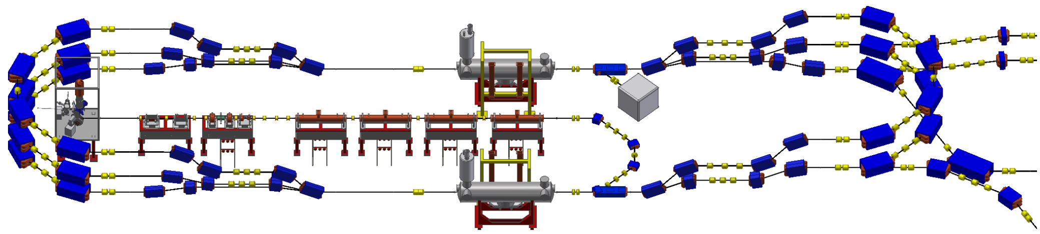

Figure 2: Overview of the MESA lattice. The experiments, as well as the energy-recovery arc, that continue to the right of the picture, have been cropped to enhance visibility.

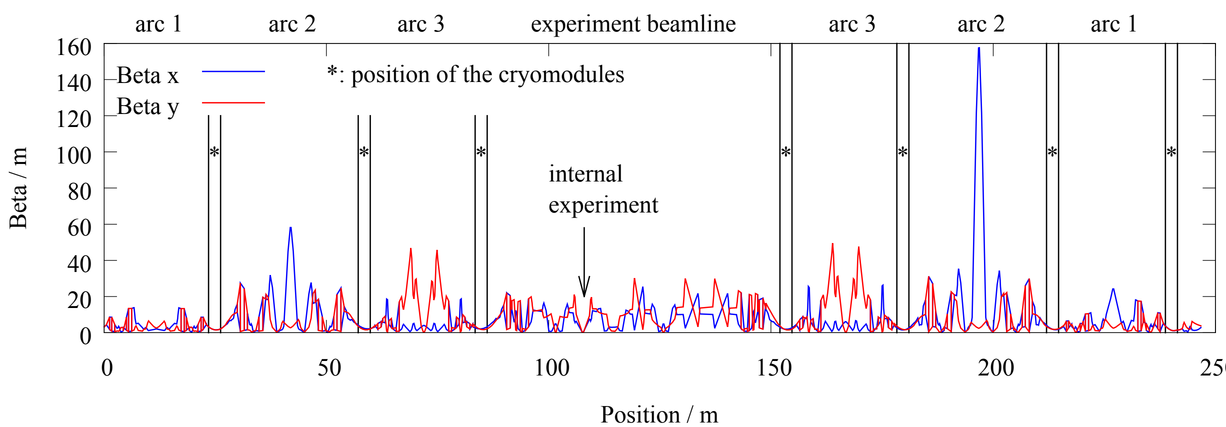

Figure 3: Beta functions of the ER mode lattice obtained from tracking simulation with PARMELA. The simulation starts after the first pass of the first cryomodule and ends at the beam dump. The injector and the first pass of the cryomodule are excluded. The simulation assumes a beam current of 150 μA.

This may lead to beam loss, deteriorating the efficiency of the energy-recovery. Optimisation of this arc is ongoing.

Optics for both EB and ER mode have been successfully tracked in PARMELA, the results as well as the development of the lattice can be followed in [4, 5].

MAIN LINAC MODULES

As can be seen in Fig. 2 the main linac will have two ac-celerating modules. In [6] several accelerator modules have been considered for their suitability for MESA. The modifi-cations necessary to the chosen ELBE-Rossendorf cryomod-ules [7] to fit the needs of MESA result in the MEEC module (MESA Enhanced ELBE Cryomodule). The changes to the HZDR design are as follows:

- sapphire feedthroughs for the couplers of higher order mode dampers, which shall enhance the thermal stability of the cavity in CW operation,
- the Rossendorf tuner is replaced by XFEL tuner which incorporates piezo actuators to fight against microphonics,
- alteration of the liquid helium (LHe) tank and of the interior of the cryostat to fit in the above

All adaptations will be planned and executed by the manufacturer RI Research Instruments GmbH, Bergisch-Gladbach. The cavities will undergo the preparation process according to European XFEL specification. More information can be found in [8]. Besides these adaptations RI will also provide cold boxes and control system for the 2K/4K LHe production. So KPH only has to provide the interfaces from the 4K LHe supply and the sub-atmospheric pumping units.

INJECTOR LINAC

The normal conducting linac MilliAMpere BOoster (MAMBO) is the injector for MESA. It has a start energy of 100 keV and a final energy of 5 MeV. Since the beam currents range from 150 μA to 10 mA, the RF sections have to cope with a large dynamic range of beam loading. At low energy space charge has a strong influence on the beam dynamics, so providing a sufficient beam quality under all conditions is challenging.

The concept of MAMBO is derived from the MAMI injector linac ILAC [9]. MAMBO has a circular chopper, a harmonic buncher system and four bi-periodic standing wave RF-structures for beam preparation and acceleration. The RF structures have a frequency of 1.3 GHz providing an energy gain of 1.25 MeV each. The first structure is a graded-β with $\beta_1 = 0.55 \ldots 0.96$, the following sections have no β-profile, but $\beta_2 = 0.98$ and $\beta_{3,4} = 1$. The beam dynamics design has been carried out with PARMELA using the 3D space charge routine with 300,000 particles to have enough statistics and also research the effect of halo particles.

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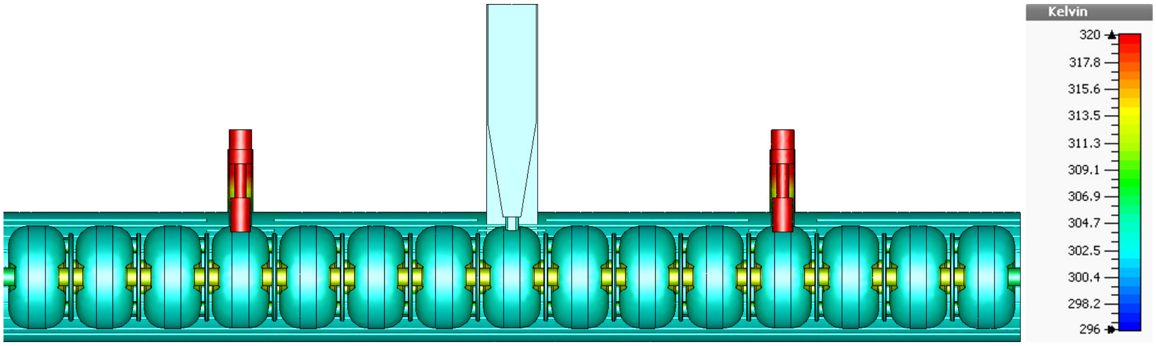

Figure 4: Thermal design of the MAMBO $\beta = 1$ section as presented in [12].

The basic RF-design was started with SuperFish and later improved with CST Studio [10]. Thermal design was also done with this software (Fig. 4). An in deep presentation of the development of the injector can be found in [11, 12].

Circular Chopper

The principle of the circular chopper is shown in Fig. 5. The beam is forced onto a conical area by a transverse deflecting resonator. The TM_{011} mode of the resonator is modified by Z-like grooves inside the caps, so the field pattern is superposed by a magnetic field component perpendicular to that of the undisturbed mode. The resulting force induces the circular deflection. A solenoid bends the beam back onto the beam axis and a second circular deflecting resonator placed at the crossing of the axis closes the orbit bump. At the point of maximum deflection, i.e. inside the solenoid, one places a collimator, to separate the accelerated from the rejected beam phase. Two movable scrapers can be used to select the bunch length of the chopped beam via the width of the arising slit between them.

The deflecting cavity was redesigned from the MAMI design [13] for f=1.3 GHz in course of a Diploma thesis and an Al low power and a Cu high power prototype were built and measured [14]. The Cu prototype was set into operation

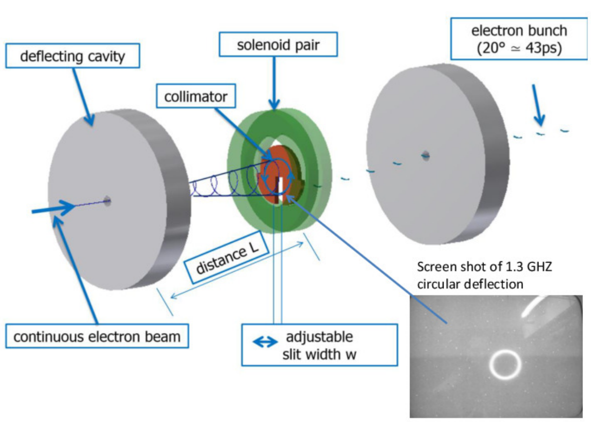

Figure 5: Sketch of a circular chopper system as used for MAMBO. On the bottom right a picture of the circularly deflected beam as seen on a luminescent screen is shown.

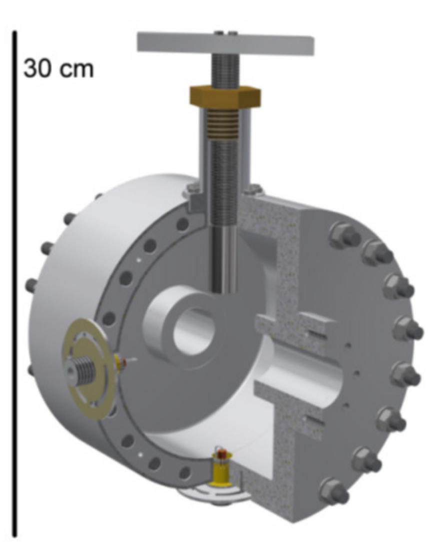

Figure 6: Prototype of the fundamental buncher cavity.

at the test bed photo source PKA2 in course of a Bachelor's thesis [15]. The circular deflection was monitored on a luminescence screen (see Fig. 5 bottom right). To achieve a sufficient deflection less than 100 W RF-power is needed. Currently the chopper set up is completed by master students in course of their theses [16, 17].

Harmonic Buncher

The harmonic buncher system of MAMI is described in [18]. It is used to increase the capture efficiency of the linac when the photo source is operated. Since the life time of a photo cathode is correlated to the amount of charge extracted, one is interested in not wasting too many particles. The harmonic buncher consists of two cavities, one at the fundamental frequency and one at the first harmonic. The resonators are separated by a drift space. The harmonic cavity acts as a debuncher on the beam, so energy spread is reduced. Further the superposition of the RF-fields generates a linear potential near the bunch centre, so less halo is produced. The drift space is a half-integer multiple of the fundamental wavelength, so the third harmonic is introduced with the proper algebraic sign, generating a good approximation of a linear potential.

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The design of the buncher is currently adapted to the MESA frequency [19]. The RF-design of the fundamental and the harmonic cavity is finished. A low power prototype of the fundamental cavity (Fig. 6) has been produced and measured on a bead pull system. The high power prototype is currently in production, as well as the low power prototype of the harmonic resonator.

RF POWER SYSTEMS

At HZDR solid state amplifiers (SSA) have been proven to be a reliable choice for generating RF-power [20]. Therefore all RF-power transmitters of the MESA facility will be based on solid state technology. Scalability and redundancy are the main arguments for SSA, besides the ceasing availability of tube based power sources and a lack of tubes in the right power range for MAMBO. For MESA power sources of some 100 W (Chopper/Buncher), 10-15 kW (MEEC) and 45-75 kW (MAMBO) are needed.

In the low power range an in house solution is available for 1.3 GHz and 2.45 GHz. Both frequencies are actually used at the test photo sources PKA2 and PKAT at KPH [21]. In the kilowatt regime a commercial solution is favoured.

PARTICLE SOURCES

MESA will have a 100 keV GaAs photo source for polarised and non-polarised electrons. The gun to be used for MESA is PKA2 (Fig. 7), a copy of the well proven MAMI design [22] currently used as test bed. Although the restriction to 100 keV beam imposes strong space charge forces during the high current non-polarised beam operation, it is of high benefit for the control of the spin at low current polarised operation and e.g. the insertion length of the spin diagnostic and manipulation devices, such as Wien-filters, scales with the beam energy.

At MAMI the gun is used with a DC beam, the PKA2 has been equipped with an RF-synchronised pulse laser [21]. So a short bunch can be generated already at the gun, the chopper is only needed to cut away tails generated from e.g. stray light, dark currents or delayed emission. The amount of charge wasted is decreased significantly, improving cathode life time and radiation levels.

As an upgrade during stage-2 a new photo source the “Small Thermalised Electron source Mainz” (STEAM) is designed [23] based on the JLAB inverted gun [24]. The technical design of STEAM is finished (Fig. 8) and production of the parts has started. It is constructed for 200 keV beam energy, but also operation at 100 keV is possible. As the accelerating field of STEAM at 100 keV is still higher than compared to PKA2, the energy spread of the emitted electrons is smaller, leading to a better acceleration of a high current beam in MAMBO. Alternatively the low energy section of MAMBO including the graded-β could be redesigned for stage-2.

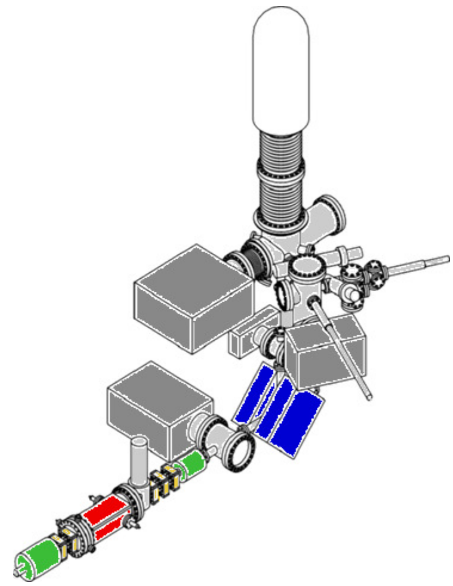

Figure 7: Technical drawing of the 100 keV photo source PKA2, which is currently used as test bed for MAMBO components.

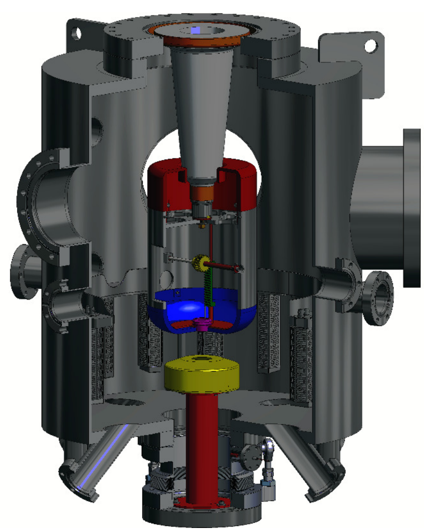

Figure 8: Technical drawing of the 200 keV photo source STEAM.

SUMMARY

The MESA project is well on the way. The core components are designed or their design is close to completion. First subcomponents are either in stage of production or testing. Assembly and commissioning of the low energy beam transport line of MAMBO is planned for 2016.

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REFERENCES

[1] A. Valloni, et al., "Strawman Optics Design For the LHeC ERL Test Facility", IPAC2013, Shanghai, China, TUPME055, p. 1694-1696, (2013).

[2] W. Herr, F. Schmidt, "A MAD-X Primer", Geneva, Switzer-land, CERN-AB-2004-027-ABP, (2004).

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

[4] R. Heine, D. Simon, et al., "Lattice and Start to End Simulation of the Mainz Energy Recovering Superconducting Accelerator MESA", IPAC'14, Dresden, Germany, p. 346 (2014), MOPRO108.

[5] D. Simon, R. Heine, et al., "Lattice and Beam Dynamics of the Energy Recovery Mode of the Mainz Energy-recovering Superconducting Accelerator MESA", IPAC'15, Richmond, USA (2015), MOPWA046.

[6] F. Schlander, et al., "Investigation of Cryomodules for the Mainz Energy-recovering Superconducting Accelerator MESA", IPAC'14, Dresden, Germany, p 2505 (2014), WEPRI013.

[7] J. Teichert, et al., Nucl. Inst. and Meth. A **557** (2006) 239.

[8] F. Schlander, et al.,"1.3 GHz SRF Cryomodules for the Mainz Energy-recovering Superconducting Accelerator MESA" , IPAC'15, Richmond, USA (2015), WEPMA041.

[9] H. Euteneuer et al., "The Injector Linac for the Mainz Microtron", EPAC88, Rome, Italy, p. 550 (1988).

[10] CST - Computer Simulation Technology, Darmstadt, Germany.

[11] R. Heine et al., "Injector Linac for the MESA Facility", IPAC'13, Shanghai, China, p. 2150 (2013), WEPWA011.

[12] R. Heine et al.,"Further Investigations on the MESA injector", IPAC'15, Richmond, USA, (2015), TUPWA045.

[13] H. Braun et al., "The Gun/Chopper System for the MAINZ Microtron", EPAC88, Rome, Italy, p. 997 (1988).

[14] V. Bechtold, "Eine Deflektor-Kavität für den MESA Beschleuniger", Diploma thesis, JGU Mainz, Germany (2013).

[15] B. Ledroit, "Hochfrequenzmessungen am Chopperresonator für MESA", Bachleor's thesis, JGU Mainz, Germany (2014).

[16] B. Ledroit, "Aufbau und Test des MAMBO-Chopper", Master's thesis, JGU Mainz, Germany, in preparation.

[17] C. Stoll, "Bau und Test von Solenoiden für MAMBO", Master's thesis, JGU Mainz, Germany, in preparation.

[18] V.I. Shvedunov et al., "Design of a Prebuncher for Increased Longitudinal Capture Efficiency of MAMI", EPAC96, Sitges, Spain, p.1502 (1996).

[19] P. Heil, "Design und Test eines harmonischen Buncher für MAMBO", Master's thesis, JGU Mainz, Germany, in preparation.

[20] H. Büttig, et al., "Two Years Experience with the Upgraded ELBE RF-System Driven by 20 kW Solid State Amplifier Blocks (SSPA)", IPAC'15, Dresden, Germany, p 2257, WEPME003.

[21] I. Alexander, "Diagnostic Test-Beam-Line For The MESA Injector", ERL2015, Stony Brook, USA, (2015), THIALH2069.

[22] K. Aulenbacher, et al., AIP Conf. Proc. **675** (2002) 1088

[23] S. Friederich, K. Aulenbacher, "Test electron source for increased brightness emission by near band gap photoemission", IPAC'15, Richmond, USA, (2015), TUPWA044.

[24] P.A. Adderley, et al., Phys. Rev. ST-AB **13** (2010) 010101.

ISBN 978-3-95450-183-0