DIAGNOSTIC TEST-BEAM-LINE FOR THE MESA INJECTOR

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Abstract
With the test-beam-line it is possible to measure the two transverse phase-spaces and the temporal distribution of the electron bunches. It is also possible to investigate the emittance close to the source and further downstream to check the emittance evolution along the beam-line. Further more the beam halo can be studied. The beam-line components will be introduced and some preliminary results will be presented.

INTRODUCTION
MESA will be a multi-turn Energy Recovery Linac (ERL) which can be operated in different modes. An ERL Mode (105 MeV) or an External Beam (EB) Mode (155 MeV) [1, 2]. The source will be a 100 keV dc photo gun which delivers polarized electrons with a current of 150 µA and an unpolarized electron beam with a current of 1 mA in stage 1 and 10 mA in stage 2. Close to the source there will be a spin manipulation section with two Wien-Filters and a solenoid followed by a chopper-buncher section consisting of four normal conducting cavities. The injector will be normal conducting with an output energy of 5 MeV. After the injector follow two superconducting linac modules which produce an energy gain of 25 MeV each. In figure 1 a view of MESA is shown. The goal is to operate in cw-mode which means a bunch charge of 0.8 pC in stage 1 and 8 pC in stage 2.

The task of the diagnostic test-beam-line is to determine if the source can deliver a smaller emittance than the acceptance of the accelerator - for all bunch charges - which requires that the normalized emittance is εn ≤ 1 µm. For the operation of MESA the source should be reliable and deliver a high extractable charge with a long lifetime.

Semiconductor photo cathodes have some properties that are desirable for the source by Isc,Ilim = p0 A/U2/3. Here p0 = 2.33·10−6 A/√2 is the so-called perveance, A = 44.4·10−6 is a geometric factor with the emitting area A = 1 mm² and the cathode-anode distance d = 150 mm. The accelerating voltage U = 100 kV. With all these parameters the emittance is still < 1 µm and the current limit would be Isc,Ilim ≈ 3 mA. This leads to the expectation, that the source can fulfill the requirements of MESA stage 1. This is also supported by CST-computersimulations [4]. Nevertheless a new 200 keV source is in production to increase the current limit to the requirements of MESA stage 2 [4].

COMPONENTS
beam line
A schematic overview of the beam-line setup is given in figure 2. In the upper left side there is the dc photo gun with 100 kV and the electrons get accelerated in the vertical direction. After 1 m of beam-line the first analyzing stage (scanner 1) is placed followed by an α-magnet which bends the electrons 270° from the vertical to the horizontal direction. Scanner 1 is positioned close to the source so that it is possible to measure the emittance without large influence of other beam manipulating elements. Between the both α-magnets the second analyzing stage (scanner 2) is mounted.

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Figure 1: Floor plan of the MESA accelerator facility. In the left mid side sits the 100 keV dc photo gun, followed by some spin manipulation elements and the normal conducting injector. The main linac consists of two superconducting linac modules with two or three recirculations, depending on the operation mode. The experiments will be located further on the right side and are not shown here to enhance visibility.

Figure 2: Schematic overview of the beam-line setup.

Here the evolution of the emittance with respect to the position of scanner 1 can be studied. If the second α-magnet is switched off investigations of the temporal distribution of the electron beam can be done with a deflecting cavity [5, 6, 7] and a Ce:YAG screen. If the second α-magnet is switched on the electrons pass by the third analyzing stage (scanner 3) where it is possible to take a closer look to the beam halo. Behind scanner 3 there is a Wien-Filter for spin manipulation and a double scattering Mott polarimeter. This device promises to yield very precise polarization measurements for the experiments foreseen at MESA. It is, however, not relevant for the contents discussed here, and we will therefore not discuss more details. All components between the source and the second α-magnet/scanner 3 are UHV compatible and bakeable. There are focusing elements like quadrupoles (blue) and solenoids (green) as well as several steering magnets which are not shown in figure 2.

The UV-VIS laser system (405 & 520 nm) is installed on the “first floor” (2 m above ground) close to the source chamber to create a minimized beam spot on the photo cathode and due to the lack of space. For spin polarized electrons it is necessary to illuminate the photo cathode perpendicular to the surface with circular polarized laser light and because of that the IR laser system (780 nm) sits under the first α-magnet.

laser system

The laser system consists of three laser diodes with different wavelengths. The 405 nm and 520 nm laser diodes are mounted close to the source and illuminate the cathode through a view-port on the bottom of the source chamber. A schematic sketch is shown in figure 3. At short distance after the two laser diodes there is an anamorphic prism pair
to compensate the astigmatism of the diodes. After the prism pair a dichroic mirror to combine both wavelength is installed, followed by a remotely controlled attenuator and shutter. The next element is a variable telescope to create different beam spot sizes on the photo cathode. The penultimate element is an uncoated beam splitter which couples out 3% of the laser power and brings it onto a CCD-camera which works as virtual cathode to determine the beam spot size of the laser. The rest of the laser power gets reflected onto the photo cathode via a mirror. An example of the laser spot shape is given in figure 4. This 2D plot shows the normalized intensity over the pixels of the camera which have a size of 6.6 µm. The IR laser system which is very similar to the UV-VIS system will be used to produce spin-polarized electron beam and is not shown here.

The laser system can be operated in three different modes. One is to create a dc beam. Here the maximum power and the average power are the same and below 300 mW. In the next mode it is possible to get dc pulse trains to decrease the thermal load on the screens. The pulses have a length of 10 – 200 µs and a repetition rate of approximately 5 Hz. With this mode the average laser power can be decreased by a factor of 1000 but the maximum power remains the same. In the last operation mode it can produce macro pulses by the superposition of the dc-current from the laser diode driver with additional RF-power up to 1.7 W. Measurements have shown that the average power remains the same as in mode 2 but the maximum power can be increased by a factor 5, depending on the pulsing behavior of the laser diode (see figure 7). In figure 5 is plotted the average output power of different laser diodes over the injection current (\( I_{\text{inj}} \)). The closed data points are for dc-current and the open data points are with RF-power. The data for the blue laser diodes belong to the left and the lower axis and for the green one to the right and the upper axis.

With this kind of measurement it can’t be ensured that the laser diode is pulsing as wanted and thus, it is necessary to take a closer look to the pulse structure of the lasers. This can be done with a fast photo detector in the optical regime or with a deflecting cavity with the electron beam. The deflecting cavity transforms the longitudinal structure of the electron beam onto a transverse circle which can be observed over a screen behind the cavity. The bunch charges are too small to allow a single shot measurement, the picture represents many bunches which all impinge on the same area on the screen due to the synchronization between the cavity and the laser-system. A short description of the working principle of the deflector cavity is given in [5, 6, 7]. In figure 6 we present two examples, one for
They have a slit width of 25 µm and a spacing of 250 µm to make emittance measurements complementary to quad scan results. In scanner 2 the slits are replaced by a hole mask (pepper pot) with 21 x 21 holes with a diameter of 25 µm and a spacing of 250 µm in both directions. The purpose of scanner 3 is halo investigations and for that there are mounted two additional Ce:YAG screens. One with a 2 mm hole and the other one with a 3 mm hole.

RESULTS

quad scan

For the quadrupole scan the inverse focal length of one quadrupole is varied from $-5 \text{ m}^{-1} \leq f^{-1} \leq 5 \text{ m}^{-1}$ and the beam profile is obtained from a Ce:YAG screen with a CCD-camera. The squared beam diameter can be plotted over the RF-phase of the cavity for three different $I_{inj}$ (170, 180, 190 mA) of the laser diode. The peak power is more than five times larger than the the power measured at the same drive current in dc operation. All three $I_{inj}$ deliver a transmission of 95% within a phase acceptance of 120°.

The green laser diode is mounted in the laser system to check how big the influence of the wavelength depending emittance is and if they show a better pulsing behavior than the blue ones.

scanner devices

All three scanners have a Ce:YAG screen with a diameter of 25 mm to optimize the beam trajectory and to make emittance measurements by quadrupole scans. Scanner 1 and 2 also contain tungsten wires with a diameter of 40 µm for emittance measurements and to investigate the halo distribution because of the higher dynamic range in comparison to the CCD-camera. Furthermore scanner 1 has two slit arrays which are oriented perpendicular to each other.

Figure 6: Example of pulse profiles behind the deflection cavity for dc beam (left) and RF-synchronized beam (right). The diameter is $\approx 30 \text{ mm}$ with 120 W RF-power.

Figure 7: Normalized intensity profile for three different $I_{inj}$ of the green laser diode plotted over the RF-phase.
increasing the permeance.
emittance is real and if it can be mitigated, for instance by
as in figure 8. This will clarify if the seeming increase in
is good reason to believe that in the near future slit mask
measured slit mask @ 0.5 mA
measured with the slit mask. The color code and the
point size indicates the normalized slit intensity.
if this has an influence on the emittance calculation. Up
to now - unfortunately - it was not possible to measure with higher beam currents because of an accident where
the photo cathode has lost a lot of QE. Nevertheless there
is good reason to believe that in the near future slit mask
measurements will be performed in the same current range as in figure 8. This will clarify if the seeming increase in
emittance is real and if it can be mitigated, for instance by increasing the permeance.

**SUMMARY**

The diagnostic test-beam-line is build up and ready to
get used. Investigations of the two transverse phase-spaces
with quadrupole scan technique and the determination of
the beam profile with a screen or with wires are possible.
The beam-line gives the possibility of a cross check be-
tween quadrupole scan and slit mask measurements. The
temporal distribution can be inspected with a deflector
cavity that transforms the longitudinal distribution into an
transverse one and deflects the beam onto a circle which
can be observed with a Ce:YAG screen and a CCD-camera.
All this can be done with three different laser wavelengths
(405, 520, 780 nm) and for different laser spot sizes.
The first preliminary results of the emittance look promising to match the requirements of MESA stage 1.
Further investigations of higher bunch charges etc. have
to be done.

In the future it is planned to get more experience with the beam-line and the measurement techniques to charac-
terize if the electron bunches from the source are suitable for MESA stage 1. Furthermore a closer look to helicity
 correlated halo effects is in preparation.

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