OPERATION OF A SLIT EMITTANCE METER IN THE MAX IV GUN TEST STAND

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Abstract

The MAX IV facility in Lund, Sweden is currently under commissioning. There are two guns in the current MAX IV injector, one thermionic gun for storage ring injection and one photocathode gun for the Short Pulse Facility. There is a possibility of extending the facility to include a Free Electron Laser. To investigate how the beam from the injector can be improved and how to match it to the future requirements for a FEL, the emittance meter from SPARC has been recommissioned at the MAX IV gun test stand. In this paper we report on the progress of this work and results from the first measurements.

INTRODUCTION

The MAX IV facility [1] is under construction in Lund, Sweden and includes two storage rings for production of synchrotron radiation and a short pulse facility (SPF) [2]. Both storage rings and the SPF are injected from a full energy LINAC and the injector for the LINAC has two different guns, a thermionic gun and a photocathode gun. The thermionic gun is used for ring injection but due to the requirements of short bunches and the long tail of low energy electrons, the thermionic gun is unsuitable for injection to the SPF. A 1.6 cell photocathode gun will be used instead, based on the BNL/SLAC type for FERMI@Elettra [3], operating at a frequency of 2.9985 GHz.

The performance of the photocathode gun needs to be improved, especially with regards to the emittance. Better experimental understanding of the different components of the injector is needed to find parameters to deliver an electron beams that meets the requirements. One of the diagnostic possibilities is to measure the emittance and beam envelope evolution along the injector. Earlier experiments using a pepperpot [4] has been carried out, but that setup was limited to one longitudinal position. The SPARC [5] emittance meter was placed in the vicinity to the MAX IV gun test stand after earlier experiments, and it was investigated to see if the slit- and mechanical parameters of the emittance meter was compatible with the expected beam performance from the MAX IV test gun.

MEASUREMENT PARAMETERS

The beam properties from the gun were simulated using ASTRA [6]. The result from simulations is a beam with kinetic energy of 3-5 MeV, charge of 50 - 500 pC and an emittance in the range of 0.3 to 5 mm mrad depending on operating parameters. In the first stage it is planned that the measurements are made using a single slit measurement device. Using the formulas from the appendix in [7] it is possible to estimate the dimensions of the mask and drift length to be able to resolve a beam with these properties.

The dimensions of the slit are a thickness of at least 0.5 mm tungsten to scatter the unwanted parts of the beam and a slit width of 50 μm to create emittance dominated beamlets. A slit separation of 200 μm was decided upon and to properly be able to resolve the divergence of the beam a drift space of 0.2 - 0.4 meters was used. The first tests were done using the same slit separation for all positions along the beam.

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MEASUREMENT SYSTEM

The parameters for the emittance measurement device for the MAX IV gun test stand [8] are compatible with the SPARC emittance meter parameters. It was decided to recomission the SPARC emittance meter and install it into the MAX IV gun test stand to use it to investigate the beam performance. Motors, motor control and cameras was changed, but no mechanical changes were made to the system and it is in principle as described in reference [5]. The different motor axis were configured and calibrated, and after calibration the position accuracy was checked to make sure that the different axis positions could be repeated.

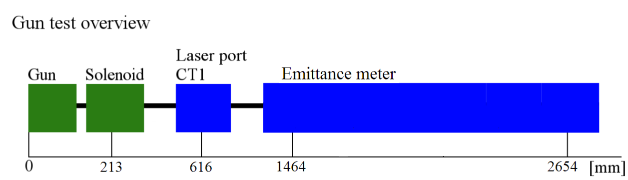

Figure 1: Schematic over the MAX IV test gun stand with emittance meter installed, the minima and maxima positions of the slit is marked.

A schematic of the test stand after the installation of the emittance meter can be seen in Figure 1 and Figure 2 shows a picture of the actual complete system. With the emittance meter installed at its current position in the beamline it is possible to measure with slit positions from 1.46 m up to 2.65 m.

The gun used in the test stand is of the same design as the gun currently used in the injector for the SPF at MAX IV. Measurements using the bead pull technique has verified that the field in this gun matches the field in the installed gun well. For the test setup a solenoid magnet produced by Scanditronix is used which is able to produce a maximum

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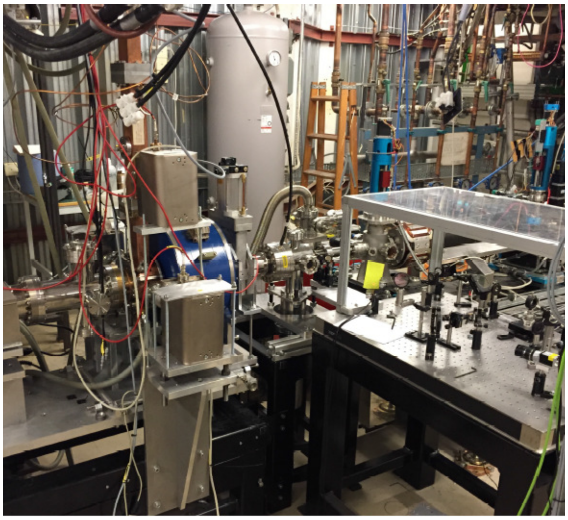

Figure 2: Picture of the gun test stand with the emittance meter visible behind the laser table.

field of 0.3 T along the main axis. The current out from the gun is measured with a in flange fast current transformer from Bergoz connected to an oscilloscope.

The laser system is a Ti:sapphire system, an oscillator locked to the 3 GHz RF feed laser pulses into a regenerative amplifier. The output from the amplifier is then fed into a multipass amplifier, and the output from this stage is frequency tripled using a BBO crystal. After the frequency tripling there is a delay stage to make it possible to adjust the timing, i.e. the injection phase. The transport system from the laser room to the test setup is in air but inside tubes. The beam is transported to a laser table next to the gun where it is focused on an iris that can cut the beam transversely. Finally the iris is imaged to the cathode, and the laser beam enters the gun system close to on axis through a port in the laser chamber.

A YAG screen is used to image the electron beam after the drift space, and the images was captured using a CCD camera from Basler. Calibration was done using existing measurement marks on the YAG screen of the emittance meter. The resolution of the camera with lens is 12.97 μm per pixel.

DATA COLLECTION

At an early stage it was realized that the test system had a lot of shot to shot fluctuations. To mitigate this problem it was investigated if it was possible to sort out bad data at an early stage in the measurement. The fast current transformer was connected to a Red Pitaya [9] board used as an oscilloscope, which in turn was connected to the control system. This created the possibility to filter captured images based on both charge output and intensity after the slit, so even though the measurement is multishot it is possible to discard measurement shots that deviates significantly.

In practice this was done by collecting 20 measurements, taking the average of these measurements with regards to charge and intensity and then acquiring 10 images that matches this average. The idea is that similar beam properties would have similar charge out from the gun and similar intensity after the slit.

DATA ANALYSIS

To get consistent results from the emittance measurement a good signal to noise ratio is needed, and it is important to handle the acquired data in a robust way. A set of MATLAB scripts were created to do background subtraction and filtering of the data.

The background subtraction was done in three steps. First a background image from the camera was subtracted from the real image to get rid of most of the background. After that a 2d median algorithm was applied to remove smaller spots and similar artifacts. Finally the image is summed in the horizontal (vertical) direction. For the summed image it was seen in many cases that the background subtraction did not manage to remove all of the background. For the images were the background was not removed, it was possible to do subtraction of a linear average and remove most of the remaining background data without affecting the signal shape.

At this point the RMS width and position of the data is calculated. For each summed image a gaussian fit is made to find the center position. The ROI of the data is then narrowed to better include only relevant data and the gaussian fit is done again. After that the data is analysed and the RMS width, position and intensity (area) of each peak is calculated.

In the next step the results are analysed to try to filter out datapoints that are too far from the nominal. It is assumed that captured images coming from shots with similar beam properties should also give similar analyzed values. After this filtering, the arithmetic mean of the acceptable data points for each slit is used as the data for that slit.

Finally the emittance and spot sizes are calculated using the formulas and method from Zhang [10].

RESULTS

The gun was put into operation in the MAX IV gun test stand during late 2014. The cathode used was a machined copper cathode similar to the cathode used with the commissioned gun. For the commissioned gun the quantum efficiency is measured to be $2.2 \cdot 10^{-5}$, and similar performance was expected from the new installation due to the similarity in manufacture and material. After initial conditioning of the gun the power could be brought up to around 90 MV/m maximum field amplitude along the main axis, and beam investigations started. The quantum efficiency was measured to $1 \cdot 10^{-6}$ and the cathode was baked to try to improve the quantum efficiency without any measurable success.

Due to the low quantum efficiency the charge in the measurements were typically between 50 and 100 pC. It was still possible to do a number of measurements and to test the

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experimental setup under real operations. A complete set of methodical measurements of the emittance evolution along the beamline for different parameters was not possible in the available operations timeframe during the spring of 2015.

The measurements were all done for horizontal beam properties, but the system is also able to characterize the vertical emittance.

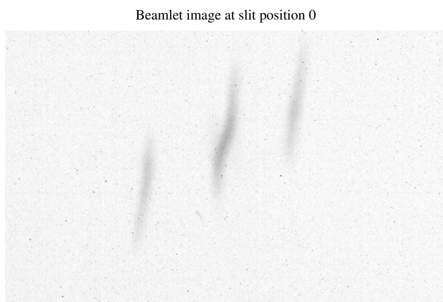

Figure 3: Beamlet image for slit position 0.

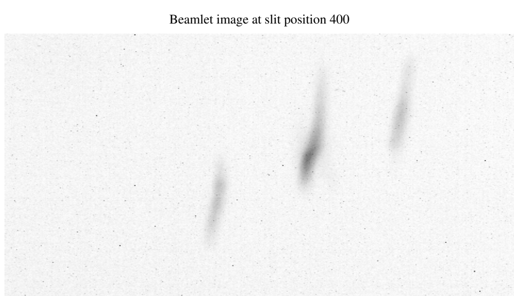

Figure 4: Beamlet image for slit position 400.

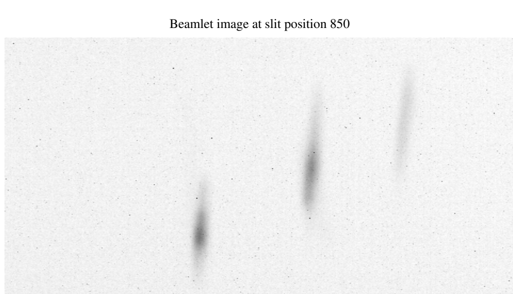

Figure 5: Beamlet image for slit position 850.

In Figures 3, 4, 5 a set of beamlet images from an emittance measurement can be seen. This set is for a measurement for 45 pC charge and 84 MV/m at positions 1.46 (0), 1.84 (400) and 2.25 (850) from the cathode. Not all beamlets are shown, every 5th beamlet is shown, and the distance is about 1 mm between each beamlet.

Figure 6 shows the measured emittance and the RMS spot size evolution at a field of 78 MV/m with 60 pC of charge

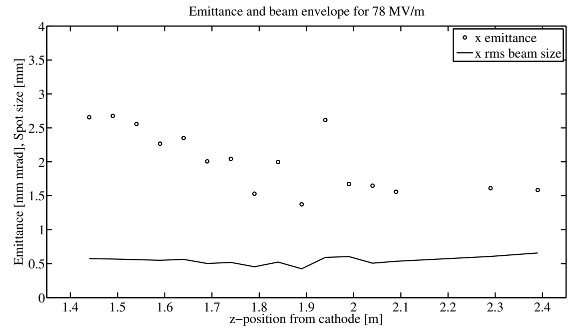

Figure 6: Emittance and beam envelope for 78 MV/m beam.

and a solenoid setting of 0.152 T. The injection phase of the laser was 30° where phase is measured from the zero crossing and checked for every measurement with a phase scan. The laser spot size was about 1 mm in diameter on the cathode.

Figure 7 shows the measured emittance and the RMS spot size evolution at a field of 84 MV/m with 45 pC of charge and a solenoid setting of 0.156 T. The injection phase is 30°m and the laser spot size about 1 mm in diameter on the cathode.

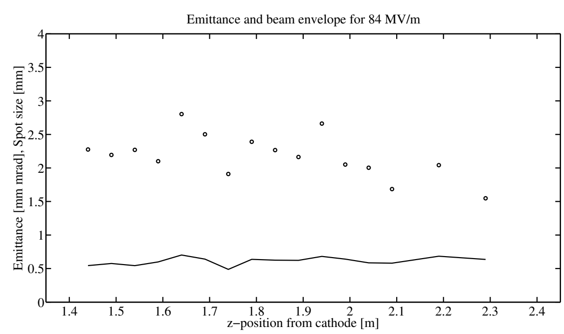

Figure 7: Emittance and beam envelope for 84 MV/m beam.

Compared to simulations, the measured emittance was larger than expected, and the emittance evolution does not match the one seen in simulations. The original simulations show an emittance around 1.5 mm mrad for the parameters of the test setup. Further investigations indicated that a larger spot size on the cathode, in the order of 2 mm, shows a larger emittance with an emittance evolution that is similar to the measured one. Further work will be put into verifying the beam size on the cathode and match the measured data to simulations.

A typical measurement took 4 hours for a total longitudinal movement of 900 mm with measurements points every 50 mm. This time needs to be reduced, the long measurement time is an issue both from the operating point of view and from the data stability point of view. It was also discovered during the measurements that there was a phase drift of about two degrees every hour. To limit the effect on the measurements the phase was rechecked periodically during every measurement, about every 20 minutes.

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FUTURE WORK

The position where the emittance meter today is installed limits the measurement range to be from 1.46 to 2.65 m. The current design of the MAX IV injector has the first LINAC structure at 1.5 m from the cathode plane and the emittance evolution needs to be measured from a position closer to the cathode in the test setup. To do this a mechanical redesign for some parts of the test stand is needed and it is being investigated in what way this could be done.

During the next operating period more measurements will be made with focus on the impact of different parameters of the injector. There will also be further investigations into the cathode performance to figure out why the quantum efficiency is so low and how this can be improved. Experience will be collected from other labs to be able to do this investigation more efficient.

CONCLUSIONS

The SPARC emittance meter has been re-comissioned at the MAX IV gun test stand. A package of scripts and tools has been developed and tested to be able to do automatic measurement, and analyze data from the emittance meter. Within the the operating period we were able to show stable results from the emittance meter, but it was not possible to completely match the results to simulations.

In the next operating period more detailed studies will be done. The data analysis will also be improved further and errors in the system will be looked into in more detail to be able to create a realistic error model for the measurements results.

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