Single-shot emittance measurement of a 508 Mev electron beam using the pepper-pot method.*

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Abstract

We describe a method that uses a modified pepper-pot design to measure in a single shot the emittance of electron beams with energies above 100 MeV. Our setup consists of several thin layers of tantalum with spacers in between to leave slits through which the electron beam can be sampled. We report on a measurement done using this method at the DAFNE BTF with a 508 MeV electron beam.

SINGLE-SHOT EMITTANCE MEASUREMENT ABOVE 100 MEV

During the past few years new acceleration techniques have made tremendous progress. It has been demonstrated that electrons can be produced and accelerated to energies up to 1 GeV in an accelerating structure as short as 33 mm[1, 2]. The ultra high energy reached means that some of the diagnostics traditionally used in electron guns are not available and thus the characterisation of the beam is a challenge in itself.

The pepper-pot method is widely used to measure, in a single shot, the emittance of a beam produced by particle guns. In this method the particle beam is passed through a thin plate in which small holes have been drilled. This method works well at electron energies below 100 MeV[3] but it can not easily be extended to electron energies above 100 MeV as electrons can then travel through the thin plate without being scattered.

To extend the energy range in which a pepper-pot can be used a thicker plate of dense material is required; however the machining of deep holes with a small diameter in dense materials is very difficult. Instead we took a different approach and designed a pepper-pot made from a sandwich of tantalum plates and vacuum gaps as shown on figure 1. The use of steel shims allows the creation of very thin gaps between each tantalum plate. We have built such a pepper-pot and tested it at the Beam Test Facility of the Frascati National Laboratory.

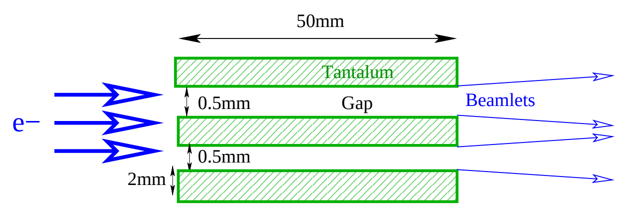

Figure 1: Design of a sandwich pepper-pot: the tantalum plates are separated by thin steel shims (not shown) creating thin gaps which can be used to sample the electron beam.

EXPERIMENTAL SETUP

The Beam Test Facility of the Frascati National Laboratory [4, 5] is an extraction line located near the end of the DAFNE linac. A pulsed magnet is used to switch electrons from the linac into the BTF transport line. The electrons are then transported over a distance of 21 m, passed through a 500 μm thick beryllium window. A 100 mm air gap isolates the transport and linac vacuum from the test facility vacuum. Electrons enter the test facility vacuum chamber through a 40 μm thick mylar window, and are bent toward the test facility area by a final bending magnet.

For our experiment the beam line was extended by more than two metres after the final bending magnet. The pepper-pot was fitted on an actuator mounted inside a 4-way cross installed 2.2 m after the bending magnet. The pepper-pot could be inserted when emittance measurement

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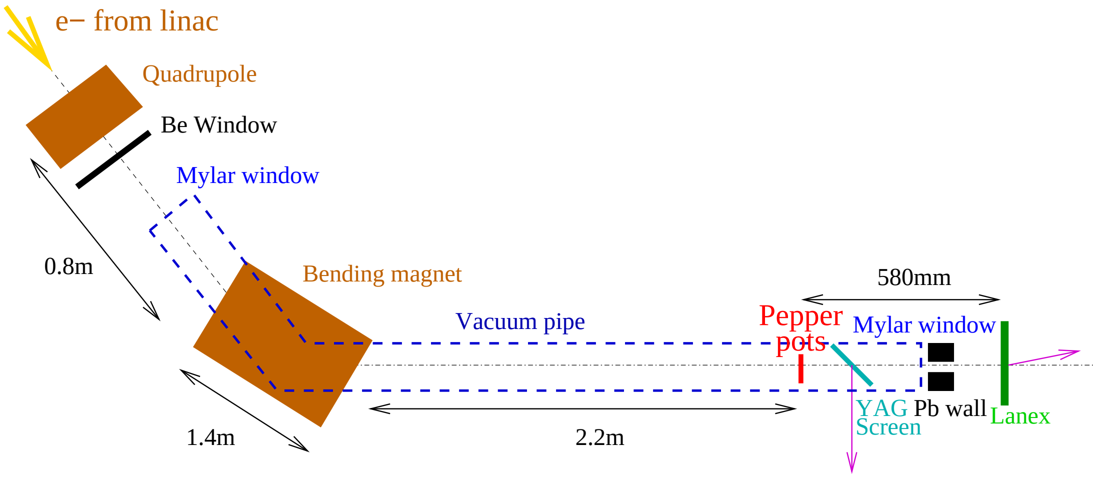

Figure 2: Experimental layout at the DAFNE BTF.

were being made or retracted to allow for other studies to take place. A YAG screen located 230 mm after the pepper-pots was used to ensure proper alignment. The test facility vacuum ended 380 mm after the pepper-pot with a 50 µm mylar window. The electrons were detected by a gadolinium doped screen ("Lanex regular") produced by Kodak located 200 mm beyond the mylar window. The photons emitted by the lanex screen were reflected by a 45 ° mirror and recorded by a "flea2" camera located 672 mm away from the screen. The lens fitted on this camera was focussed on the lanex screen. This arrangement allowed the camera to be out of the accelerator plane and shielded from the radiation by lead bricks. The layout of the experiment is shown on figure 2.

The sandwich pepper-pot used in this experiment was made of several plates of tantalum separated by air gaps (steel shims) as described in table 1 and illustrated in figure 1. The length of the tantalum plates along the beam axis was 50 mm, corresponding to 12.2 radiation lengths; simulations show that most electrons entering the tantalum are significantly scattered in propagating over this distance. To ensure mechanical stability the stack was held in a custom made holder. Figure 3 shows a picture of the sandwich pepper-pot stack viewed along the electron beam axis.

Figure 3: Picture of the sandwich pepper-pot used for our measurement.

Layer	Material	Thickness
1	Aluminium	1×10 mm
2	Gap (Al shims)	1×1 mm
3	Gap (steel shims)	5×100 µm
4	Tantalum	1×1 mm
5	Gap (steel shims)	5×100 µm
6	Tantalum	2×1 mm
7	Gap (steel shims)	5×100 µm
8	Tantalum	2×1 mm
9	Gap (steel shims)	5×100 µm
10	Tantalum	2×1 mm
11	Gap (steel shims)	5×100 µm
12	Tantalum	2×1 mm
13	Gap (steel shims)	5×100 µm
14	Tantalum	2×1 mm
15	Gap (steel shims)	5×100 µm
16	Tantalum	2×1 mm
17	Gap (steel shims)	5×100 µm
18	Tantalum	2×1 mm

Table 1: Layout of the stack used to build our sandwich pepper-pot

RESULTS

Figure 4 shows a cropped section of the raw image recorded on the lanex screen after firing a pulse of 508 MeV electrons with a charge of approximately 500 pC.

Figure 5 (left) shows the same image after background subtraction and rotation of the image to ensure that the beams transmitted by the slits are perfectly horizontal. The profile shown on figure 5 (right) is the horizontal projection of this image. To avoid including areas of the image where the signal saturated or where the signal is too low, only the pixels located between column 230 and 235 have been considered.

This profile can be analysed using the method proposed by Min Zhang [6]. By using this method the average squared position ($\langle x^2 \rangle$) is $16\,\mathrm{mm}^2$, the average squared divergence ($\langle x'^2 \rangle$) is $2.8\,\mathrm{mrad}^2$, and the cross

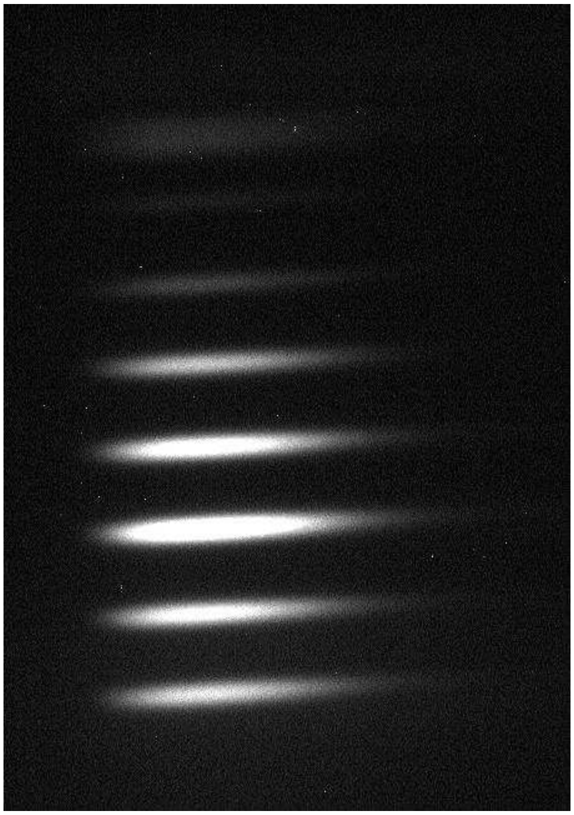

Figure 4: Cropped section of the image recorded on a lanex regular screen after firing in a single shot of approximately 500 pC of 508 MeV electrons. The wider bright band that can be seen at the top of the picture corresponds to the large gap created by layers 2 and 3. The thinner black band below is layer 4 which is made of only 1 mm of tantalum.

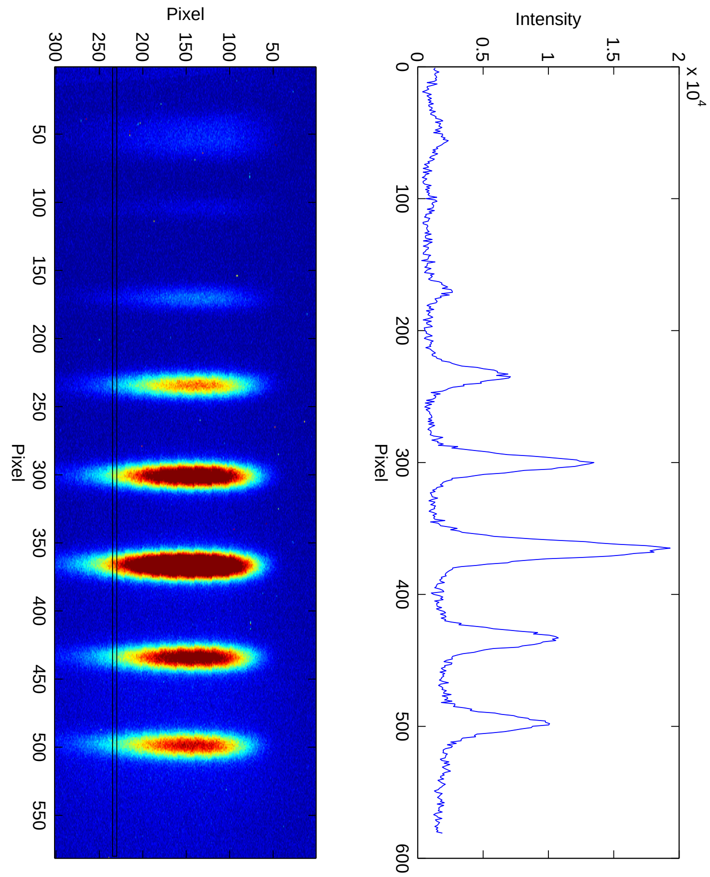

Figure 5: Left: False colour cropped pepper-pot image after rotation and noise substraction. Right: Horizontal projection of the image (sum of the pixels of column 230 to 235).

product ($\langle xx'\rangle$) is $5.3\,\mathrm{mm.mrad}$. This gives a geometric RMS emittance of $\epsilon_{\text{rms}} = \sqrt{\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle^2} = 4.0\,\mathrm{mm.mrad}$.

By using the measured position of each slit, it is also possible to measure the shearing of the emittance ellipse. Our measurements indicate a shearing (β/γ) of 0.32 $\frac{\mathrm{mrad}}{\mathrm{mm}}$. This suggests that the last vertical beam waist is located approximately 3.1 m upstream from the pepper-pot.

CONCLUSION

We have developed a sandwich type pepper-pot that allows the single-shot measurement of the emittance of a high energy electron beam. In tests performed at the Beam Test Facility of the Frascati National Laboratory we were able to measure the RMS emittance of a 508 MeV electron beam in a single shot. This geometric RMS emittance was found to be 4.0 mm.mrad. We expect that this design of pepper-pot could be used to measure in a single shot the emittance of the beam produced by a laser-driven plasma accelerator.

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