FIRST EXPERIENCES WITH THE PITZ PLASMA CELL FOR ELECTRON BEAM SELF-MODULATION STUDIES

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Abstract

The self-modulation of long particle beams in a plasma has recently gained interest in light of the ongoing preparation for the plasma wakefield acceleration experiment of the AWAKE collaboration at CERN. Instrumental to the experiment is the self-modulation of a proton beam to generate bunches short enough for producing high acceleration fields. As electron bunches are easier to handle and the underlying physics is identical, it is judicious to first gain insight into the experimental conditions of the self-modulation of long particle beams in plasma by using electron bunches before progressing to the experiment with proton bunches.

The experimental demonstration of self-modulation of an electron bunch is in preparation at the Photo Injector Test facility at DESY, location Zeuthen (PITZ). In this contribution the fabrication and first experimental tests towards a Lithium plasma cell are highlighted. The distinctive feature of this plasma cell is the addition of side ports for insertion of the ionization laser beam and for diagnostics purposes.

INTRODUCTION

Plasma wakefield acceleration (PWFA) works by manipulating the charge distribution in a volume of plasma, either with a strong laser pulse or a particle beam. A beam following this disturbance can then be accelerated with gradients that are orders of magnitude higher than what can be achieved with common RF technology.

In an experiment, which is in preparation by the AWAKE collaboration at CERN, high-energy SPS proton beams will be used to drive a plasma wave that is able to transfer its energy to accelerate electron beams to the TeV-energy scale in a single plasma stage [1]. To minimize the length of the plasma stage it is important to have a high acceleration gradient. This necessitates a high plasma density, therefore a short proton bunch length, on the order of 100 µm or less [2]. The problem now is that the SPS proton bunches are much longer, about 12 cm. To solve this problem it was proposed to use a plasma-beam instability to modulate the long proton beam at the plasma wavelength to produce a bunch train that is able to resonantly drive large plasma waves for acceleration [3].

So far, this concept of self-modulation was mostly shown analytically and in simulation [4, 5], first experimental hints using electron bunches were published recently [6]. It is well worth conducting such self-modulation experiments before attempting the main plasma acceleration experiment with proton bunches to study characteristics such as dephasing, hose-instability, etc. Consequently, a self-modulation experiment is in preparation at the Photo Injector Test facility at DESY, location Zeuthen (PITZ), which offers a unique possibility to study and demonstrate experimentally the self-modulation of long electron bunches in plasma [7]. In this contribution we report the current status of the plasma cell which will be used in these experiments.

FABRICATION OF PLASMA CELL

The central device of the self-modulation experiments is the plasma cell [7]. The design of the cell was driven mostly by two factors; first to provide a plasma volume of specified size and density for the experiments, and second its compatibility for insertion into the PITZ beam line.

The basic principle of the plasma cell is that of a heat pipe oven [8] where a substance (in this case Lithium) is evaporated in the centre of the cell. At the ends of the pipe, which works also as the electron beam pipe, a cooling mechanism (in this setup a water cooler) condenses the vapour back to liquid form. This liquid is transported back to the hot middle region by capillary forces in a mesh, thereby closing the cycle. The particle density of the gas is defined by the pressure of a buffer gas (Helium here). The beam pipe is capped with thin windows to isolate the plasma cell atmosphere from the surrounding accelerator vacuum. On one hand the windows have to be thick enough to withstand the pressure differential, on the other hand the windows thickness must be small to minimize scattering of beam electrons.

To create the desired plasma region, the gas in the centre of the cell has to be ionized, which, at PITZ, will be done by laser ionization. Typically the ionization laser is axially coupled into the plasma cell. This is not possible at PITZ because of space restrictions. Therefore, the existing design concept of the heat pipe oven [9] was modified to a cross-shaped structure, as shown in Fig. 1, where the electron beam travels through one pipe and the

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ionizing laser is coupled into the oven through the orthogonal pipe. The four buffer gas regions are connected like the two regions in the original design at both ends in the beam direction. The orthogonal pipe is terminated with optical windows to couple the laser in. An advantage of this configuration is the availability of side ports for optical characterization methods, e.g. interferometry for density measurements. Another advantage is the precise control of the geometry of the plasma column that is seen by the electron beam, especially entry and exit.

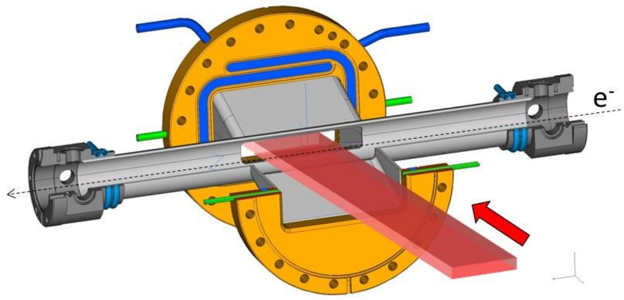
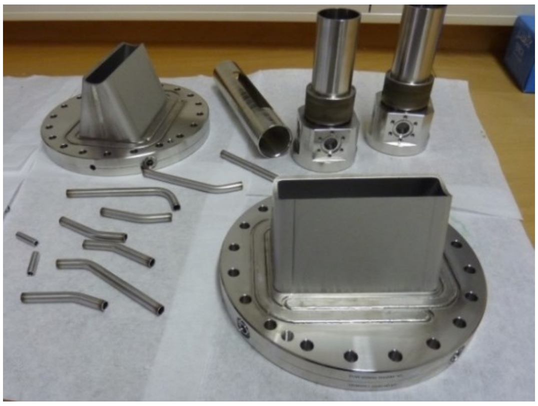


Figure 1: Concept sketch of PITZ plasma cell.

The plasma cell body was fabricated from non-magnetic stainless steel in the mechanical workshop at DESY, location Zeuthen. The beam pipe, flanges, connection tubes, etc. were manufactured separately (Fig. 2a) and welded together (Fig. 2b).

a)



b)

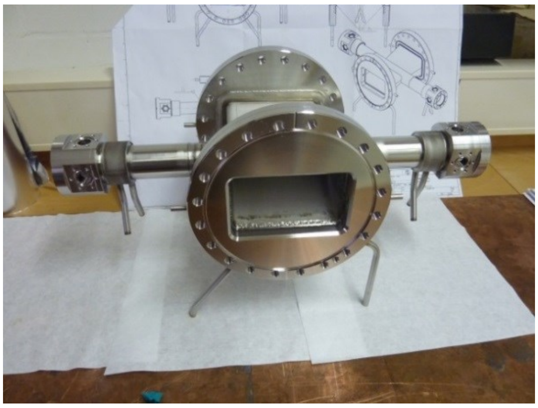


Figure 2: Fabrication of plasma cell body. a) fabricated parts. b) finished cell body, welded together.

The next parts to be fabricated were the copper heat conductors. The copper parts which are shown in Fig. 3 surround the plasma cell core and have grooves to fit heating elements. These are electrically driven, resistive heating elements. The heat will be transported via the copper elements into the plasma cell. Four heating wires (Thermocoax) will be used, two in the centre (above and below the middle plane) and two on each side around the beam pipe. This will allow for adjustment of the temperature profile by distributing heating power among the elements along the beam pipe accordingly.

Figure 3: Copper heat conducting elements.

Finally, the plasma cell is encompassed within a thermal insulation to maximize the heater function. For the PITZ experiments, heat insulation was chosen in the form of solid foam bricks. The shape of the plasma cell was formed by shaving the material, leading to an insulating cage closely enveloping the cell, as shown in Fig. 4. One opening for the beam pipe can be seen to the right, one opening for the laser port to the left.

Figure 4: Heat insulation for the plasma cell.

INITIAL RESULTS

As mentioned above, one critical point in the design of the plasma cell is the beam pipe windows, which keep the plasma cell interior pressurized against the accelerator vacuum. The plasma cell pressure is given by the design plasma density of 10^{15} cm^{-3}, resulting in a pressure of about 0.3 mbar. Therefore it is desirable to use window material as thick as possible to minimize the danger of breaking the windows. This thickness is restricted by the increasing scattering of the electron beam by the window material. This is especially critical on the upstream side since the beam has to be tightly focused into the plasma to maximize self-focusing.

ASTRA [10] simulations were conducted where the scattering of the electron beam at the window was reproduced by increasing the opening angle of the beam by a given amount at the window position. Using this procedure it was found that the maximal acceptable divergence introduced by scattering at the window is 0.2 mrad.

The best window material is polymer for two reasons: first, polymers are flexible so that they bend and only later break under pressure differences; second, these materials, especially polyethylene and polypropylene, have long radiation lengths, therefore a low amount of scattering. Three approaches were taken to estimate the maximal permissible thickness:

- An analytical estimation assuming multiple Coulomb scattering of the electrons [11].
- Simulation of the scattering using the FLUKA Monte Carlo code assuming a transverse Gaussian particle distribution.
- Experimental measurement of the electron scattering by the window material at the PITZ facility.

All results are summarized in Fig. 5, which shows reasonable agreement between all three methods.

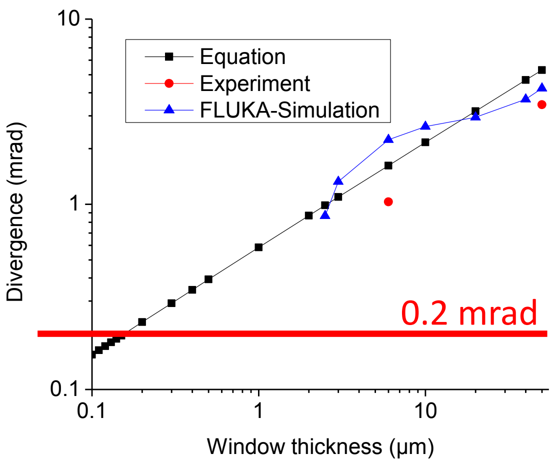


Figure 5: Scattering of electron beam at a polymer window.

All methods show an exponential trend with similar slopes but different offsets. The thick red line indicates the maximal acceptable divergence of 0.2 mrad. Taken together, the results lead to a maximal allowable window thickness of about 100 to 200 nm. But even such thin windows are commercially available, e.g. at [12].

CONCLUSION

We report about the fabrication of the plasma cell for self-modulation experiments at PITZ. The plasma cell body is made from stainless steel, surrounded by copper heat conductors for the resistive wire heater and mounted into heat insulating foam. As a result from simulations and preliminary experiments it was found that the optimal thickness of the windows between plasma cell and accelerator beam pipe is 100 to 200 nm.

ACKNOWLEDGMENT

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