New Vacuum Chamber for the Plasma Density Transition-Trapping Experiment

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INTRODUCTION

Plasma density transition trapping is an experiment designed to capture an electron beam and modify its quality via a plasma wake-field [1]. The Particle Beam Physics Laboratory (PBPL) transition-trapping plasma experiment requires a chamber to support the confined plasma source, in-vacuum diagnostics and associated hardware. Initial measurements on the plasma source utilized a chamber initially created for an underdense plasma lens experiment [2]. However, current research and future positioning of the plasma source required drastic improvements of nearly all facets of the chamber design. The initial plan was to rearrange the plasma source to move the interaction box onto the opposite side of the pumping-Tee (see picture below). This proved successful to measure plasma densities at or above the required value to carry out the plasma transition-trapping experiment. However, because the original design of the interaction box did not have an exit port for the beamline, a new box design became necessary. A decision was made to redesign the plasma chamber from scratch. The proposed design and specifications are described in this note.

Figure 1 Current plasma source
GROUND FOR A NEW CHAMBER

Technical demands on the new chamber included the following:

A: Testing on the Fermilab MeV photo-injected particle beam line
B: Current beamline interaction issues
C: Reusing the internal structure of the existing plasma source.

Requirement A was imposed by PBPL personnel to insure higher charge beam quality than currently available at the Neptune laboratory. Hence, drastic revisions of the vacuum became necessary to satisfy the technical requirements at Fermilab.

Requirement B was imposed by the transition trapping experiment. The existing interaction box lacks both precise instruments for plasma density measurements and an exit port for the electron beam, both of which are necessary to begin the experiment. Thus, a new interaction box was required.

Requirement C was imposed by the success of current plasma density measurements. By keeping the current plasma’s source as similar as possible to its current state, we will eliminate numerous, uncontrollable variables that the new chamber might create in the future.

DESIGN CHARACTERISTICS

Of the many requirements needed for a new interaction chamber, the design specifications and peripherals/diagnostics described below were the major considerations used in designing the new chamber.

Design Specifications

Plasma Characteristics

In order to carry out the plasma density transition-trapping experiment, a few characteristics of the old plasma source need to be kept consistent with the new design. Since we are able to achieve densities above the necessary value of $2 \times 10^{13} \text{ cm}^{-3}$ with the original plasma source, the minimum value required for the trapping experiment to work, the internal parts of the system as well as similar solenoids used to confine the plasma will be reused. Thus, 1) the distance from the plasma production region to electron beam path must be similar, 2) the back conflat-style flange needs electrical feedthroughs at the same locations for the thermionic cathode’s heater, and 3) the magnetic field, which currently produces a maximum value of ~120 Gauss, needs to be around the same magnitude at the center of the beam path.
**Fermilab Requirements**

Because a decision was made to run the experiment at Fermilab National Laboratory, many changes were necessary to improve the integrity of the plasma source’s vacuum as well as raise the plasma source’s center to Fermilab’s beamline height. The direct cause of the vacuum upgrade was the sensitivity of the Fermilab super-conducting linac to contamination by zinc or particles. Because the current plasma chamber is constructed from brass, a high zinc metal, this presented a major dilemma. Several options were presented to prevent contamination, including a window and/or an all-metal gate valve, but these were determined to be an insufficient amount of quality control. These issues, in addition to other difficulties with the current plasma chamber listed above (see “Grounds for a New Chamber”), a newly designed plasma chamber was deemed necessary that would a) create a higher vacuum, b) constructed from stainless steel, and c) rest at 48.425” above the floor to the center of the chamber— the exact height as Fermilab’s beamline.

**Peripherals/Diagnostics**

**Linear Stages**

Experimental demands require that the plasma density be measured in two axes. For the transverse axis (perpendicular to the beam) a range of motion of ~1.25 cm (~0.5 inches) and high precision is required. However, for the z axis (beam path), a range of motion of ~6 cm (~2.36 inches) with only low precision is necessary. Thus, a varying dual axis stage is needed to meet these requirements. Careful thought and design showed that the best solution would be a combination of a Newport 443V6 (5.08 cm/2” of total travel) vacuum compatible linear stage with a Newport 423V6 (2.54 cm/1” of total travel) vacuum compatible linear stage.

Because the need for absolute positioning is mitigated by the necessity to realign the beam and apparatus between runs, two New Focus Picomotors (models 8301-V and 8303-V) would be sufficient to move the linear stages. These two vacuum compatible Picomotors give 1.27 cm (0.5 inches) and 5.08 cm (2.0 inches) of travel, respectively, with less than 30nm of incremental motion. These, in turn, will be controlled by a New Focus 3-axis driver, model 8753. The combination of these three items will give enough precision and range of motion to position the current probe and the trapping screen for the proposed transition trapping experiment.
YaG Screens/ Miscellaneous Pop-ins

YaG screens and other pop-ins will be required to measure the effects of the plasma on the beamline during the transition-trapping experiment. Hence, several ports in various places on the plasma chamber are necessary for their future addition.

MECHANICAL ENGINEERING AND FINAL DESIGN

Chamber

After all the above items were considered, the final design was made via CAD software. One of the main problems with creating a plasma chamber with such a large inner diameter to house the Newport linear stages (3” x 6”) was getting large enough solenoids to create a magnetic field of approximately 120 Gauss near the center of the beam path. The solution to this problem was finding another solenoid of the same size as the larger of the two original solenoids (10” inner diameter) to replace the smaller one. After preliminary tests at different distances, we were able to confine a magnetic field of approximately 110 Gauss with a distance of 8” between the set. Thus, we were able to go with the standard 10” conflat-style flange, whose inner diameter of 8” is more than large enough to insert and set-up the linear stages with their support stand (see fig 2).

The length of the plasma producing chamber was kept around the same distance of the original chamber (~eleven inches) to minimize the amount of variables that may cause plasma production problems later on (i.e. the distance from probe tip to heater, etc. see “Design Specifications”). At the end of the 11 inch section lies a 4-way cross for the actual interaction with the beamline. The top flange is made from a 10” standard conflat-style flange in order to accompany any peripherals (i.e. YaG screens and other pop-ins).
that may be later required. The input of the beamline is also made from a standard 10” conflat-style flange to allow room for the movement of the dual axis linear stages. The output, however, shrinks down to a 2-3/4 inch conflat-style flange to mate with the spectrometer. The final arm of the 4-way cross is a 6” conflat-style flange that connects the chamber to a Leybold mechanical roughing pump and turbo fan. On the other side of the 4-way cross lies a short tube of seven inches to a 10” conflat style flange for the feedthroughs of the Picomotors, current probe, and any other peripherals that might be added (see fig. 6).

**WATER COOLING**

Plasma production requires 4kW of power, virtually all of which is absorbed by the chamber (radiatively and conductively). Hence, the chamber and end flanges must be designed with water cooling in the areas of greatest heat absorption. (see figs 3, 4, 6).

**CUSTOM FLANGES**

The inner diameter of the large solenoids used to confine the plasma are big enough to fit around the chamber’s tubing, but too small to fit over the 10” flanges at the ends of the chamber (see figures 6 and 7). Thus, a decision was made to split the 10” flanges along the main tube of the chamber to give way to the confining solenoids. Additionally, because of spatial hindrances that the second solenoid will create, the 10” flange attached to the shorter side of the main tube must be tapped.

The diagnostics required to measure the plasma density and future beam fluctuations after interactions with the plasma require several feedthroughs for their control. These feedthroughs will initially be put on two, custom 10” conflat flanges, with a third, 10” blank-flange available for extra feedthroughs (designed by Christopher Muller). The first (front) flange will have two, 1-1/3” flanges, which will be used as electrical feedthroughs for the heater, and 2 swagelock feedthroughs for water cooling.
The second (back) flange will feature four, 2-3/4 flanges and a 1-1/3 conflat flange for various feedthroughs (Picomotor control, current probe, etc.), as well as 2 swagelock fittings for water cooling.

![Figure 4 Front flange](image)

**STANDS**

Because of the solenoids’ positioning and the height of the Fermilab beamline height, a new stand design was needed to support the new chamber. The main supporting stand will be used from the original plasma source. It is a 2” nipple with 6” conflat style flanges on both ends and 4, 1 square inch wings, 90° apart from one another, welded to one of the flanges that bolt to the tabletop. In order to put the center of the beam line at 10” above the tabletop (the same height of the beamline at Neptune), a 0.05” bore was cut around the vacuum pump hole in the table that this nipple will rest on. This, in combination with a support stand on the 10” flange from the 4-way cross, will be the two main supports for the new chamber. After the solenoids have been positioned, 2 other stands will be placed on the ends of the main tube (see fig 7 below).

Since the current table sits 30” high, and the center of the new chamber will only be 10” above the table (the beamline height from the table top at Neptune), the new design demanded a booster stand to increase the height from the center of the beamline to the floor to 48.425 inches. An aluminum support that would add 8.175” between the bottom of the 3/8” thick tabletop and the floor gave the best solution. Below (fig. 5) is a drawing of this additional stand with a couple of supports to prevent bowing from the weight of the new Plasma Chamber.
Figure 5 Stand for table height-increase
Figure 6 Dimensions of the new chamber. Shown above are computer generated isometric drawings with outer dimensions, and 2 3-D models.
CONCLUSION

Several options for modifying the plasma source were heavily discussed, and a complete redesign provided the best solution. Final designs have been approved for the new chamber, and are currently being manufactured by MDC Vacuum Products Corporation. Additionally, all peripherals and support stands listed above have either been ordered or are currently being produced by the UCLA Physics and Astronomy machine shop. Final assembly and completion is projected to be January, 2003.

REFERENCES

1. Thompson, M.C., Rosenzweig J.B., AAC proceedings (2002)