TW6-THHN-ASD3

Task Title: SINGAP NEGATIVE ION ACCELERATOR: STUDY OF THE BEAMLET HALO, DARK CURRENTS AND VERIFICATION OF ELECTROSTATIC WITHSTAND CAPABILITY AND TOLERABLE STORED ENERGY IN CASE OF ELECTRICAL DISCHARGES

INTRODUCTION

In the previous contract TW2-TPHN-NBDES1 (CEFDA01-645): "Support to neutral beam physics and testing 1", we demonstrated that the SINGAP accelerator concept is an attractive alternative to the ITER reference design, the so-called MAMuG (Multi-Aperture, Multi-Grid) accelerator. The best ITER-relevant shot displayed good beam optics (3.9 mrad divergence horizontally, 5.5 mrad vertically) and was performed at 727 keV, 120 A/m^2 D^- = 18.5 mA for one beamlet. The quoted current density is derived from the calorimetrically measured power on the graphite target with an infrared camera [1].

The experiments done in the previous contract confirmed some aspects of the design of the new "ITER-like" accelerator, but not all. In particular the experimental data showed that the beamlets had a bi-Gaussian power density distribution (70% of the power could be described by a beamlet divergence of ≈4-5 mrad and 30% was in a halo) as opposed to the single Gaussian with 2.5 mrad divergence of the simulation. The fraction of the total power that was seen as a halo varied between 15% while operating at low current densities without Cs to 30% during caesiated high current density operation. It has now been discovered that an undocumented instrumental effect of the Infrared camera had perturbed these measurements.

The new contract with EFDA was started in July 2006 in order to focus on three different tasks. The first task is to measure the beam halo and to find a method of how to mitigate it. The second task of the contract concerns the dark current at the SINGAP testbed. The last task is to study the electrical discharge and stored energy in a HV breakdown.

2006 ACTIVITIES

Halo measurements

In previous studies we presented evidence that pointed to the existence of large beam halos (≈30% of total beam power) during caesiated operation. Since then we found that the infrared camera we used to measure the power density profile on the beam target, exhibits an instrumental flaw. If a strong infrared light source shines into the camera (like a beam footprint), the signal in the entire picture increases, thus creating a spurious halo effect. The infrared camera can be operated with or without a filter. The filter is inserted between the objective lens and the infrared sensitive CCD array. The type of filter we used reduces the light intensity by a factor of 15. The instrumental halo effect has been calibrated and we found that its magnitude is linear with the amount of light entering the objective lens of the camera. Because the filter is between the objective lens and the camera, the instrumental halo effect is 15 times worse if the filter is used. Operation without filter is necessary and the calibration has allowed us to operate in such a way that the effect of this "instrumental" halo effect remains small and to quantify the real beam halos. We found:

- Real halo < 4% of the total beam power in volume operation
- Real halo up to ~10% of the total beam power in caesiated operation

It is well known (and indeed observed by us during cleaning) that caesium creeps out of the ion source into the accelerator. It is also known for some time that hot neutral H or D atoms (as produced inside the ion source) are converted to negative ions on caesiated surfaces. This means that production of negative ions must take place on these caesium-contaminated accelerator surfaces. Modelling clearly shows that we get wide beam halos if H^- or D^- trajectories are allowed to start from the accelerator grids. It is hypothesized that most of the halo would originate from the plasma grid, as this is the easiest to be reached by hot atoms from the source (atoms would cool down on their way to the downstream parts of the accelerator).

Using the hypothesis described above, it is possible to identify which parts of the plasma grid that transmit trajectories into a halo. These parts are the inside of the aperture (downstream of the meniscus). It is proposed to reduce the halo by machining away the plasma grid downstream of the knife-edge, where the meniscus resides, (see figure 1). Simulations give a good beam for this geometry and it is planned to carry out this experiment at CEA-Cadarache in the beginning of 2007.

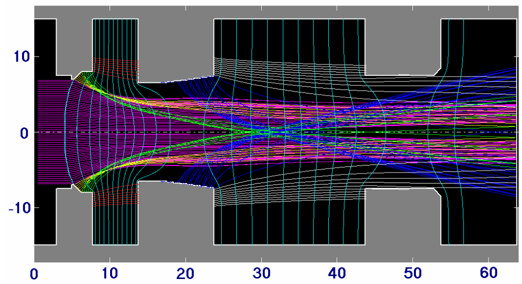

Figure 1: The beam (purple) is originating from the ion source on the left. The negative ions originating from the grid surfaces are shown as green, yellow and red from the plasma grid and blue and white from the extraction grid

Arc efficiency

In volume operation (before any caesium is introduced into the source) we typically obtain an extracted D^- current density of up to 2 mA /cm^2 using the plasma grid with the Ø14 mm aperture. As a part of the experiments done to minimise the beam halo we installed a plasma grid with a reduced aperture of Ø8 mm. With this reduced diameter of the aperture, we found that we could extract twice the current density (4 mA /cm^2 D^-). (Note however that the surface area of the Ø14 mm grid for one aperture is 1.54 cm^2 and 0.50 cm^2 for the Ø8 mm aperture).
In caesium operation we managed to obtain a current density of 27 mA /cm^2 with the Ø8 mm aperture, which is 70 % higher than is obtained with the Ø14 mm aperture plasma grid for the same arc power.

The reason for this increased current density while using smaller apertures is not known. It has however been seen previously.

Dark current

It is found that increasing the voltage in a recently pumped system is opposed by both the appearance of leakage (dark) currents and occasional high voltage (HV) breakdowns. We have identified 3 likely reasons why the SINGAP testbed has dark currents when applying high voltages. The present system has not got a symmetric electric field around the high voltage components, the surfaces have not been vacuum baked and the materials used are not appropriate. In order to address all these issues a new heated cathode structure will be installed inside the vacuum vessel.

This structure is made up of 7 segments where the stainless steel raw material has been polished and vacuum baked to 950 °C for 1 hour in order to obtain a surface that will outgas as little as possible. The segments will thereafter be assembled to one unit inside the vacuum tank. Heater elements will be attached to the outside of the cathode structure that will allow a moderate baking (<300 °C) after the structure has been assembled.

A new anode structure will also be installed. It is made of pre-polished stainless steel and it is installed symmetrically inside the cathode structure.

The electric field is in this way more uniform than with the present installation.

The already installed corona screens inside the bushing will be removed and vacuum baked in an external oven to 500°C for 5 hours.

A CAD drawing of the new components is seen in figure 2.

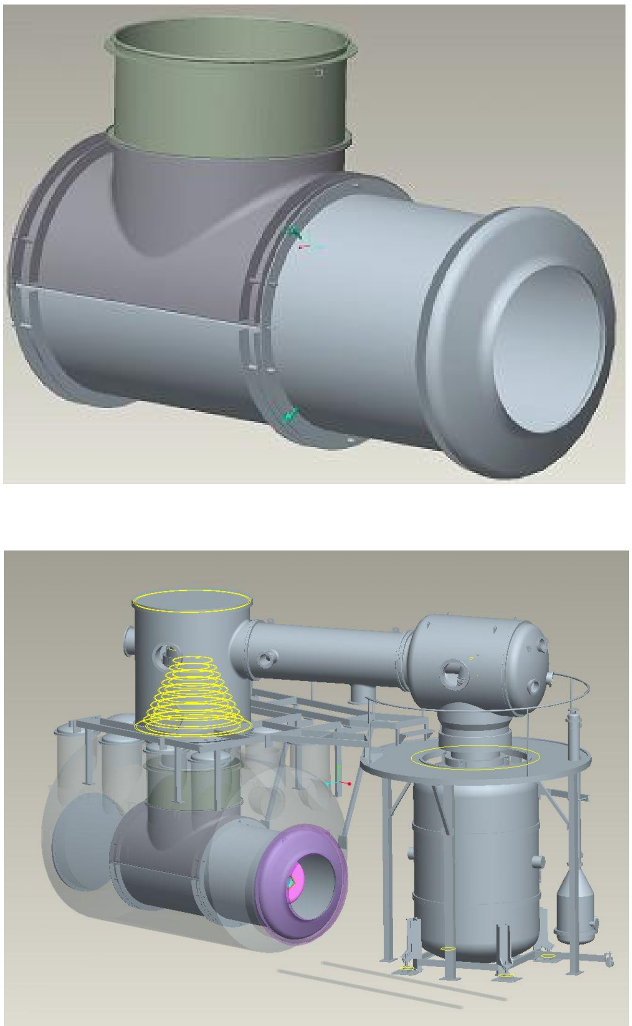

Figure 2: At the top the heated cathode is shown. At the bottom it is shown installed inside the vacuum vessel

A study of the electrical discharge and stored energy in a HV breakdown

The estimated energy that will be dissipated in a breakdown in the ITER neutral beam accelerator is estimated to be 500 J. This might degrade the voltage holding of the accelerator and cause damage to the acceleration grid surfaces. A new test set-up has therefore been designed to simulate the ITER SINGAP accelerator main accelerator gap in a simplified geometry. In order to obtain 500 J at 1 MV new capacitors will be added at the output of the 1 MV power supply. The voltage withstand before and after breakdowns at different stored energy levels will be assessed.

This test set-up is under construction and experiments will be done at the earliest December 2007.

CONCLUSIONS

Measurements of the beam halo have been done and we have established that the power fraction in the halo is <4 % when no caesium is used in the ion source and it increases to around 10 % when caesium is used to enhance the negative ion production. This is within the specifications for ITER.

During the beam halo experiments we discovered that by reducing the diameter of the aperture in the plasma grid from Ø14 mm to Ø8 mm we managed to increase the current density by 70 %.

A new heated cathode structure has been designed and will be installed during 2007. This structure will give a more uniform electric field around the accelerator than at present. It will be constructed of pre-polished stainless steel and vacuum baked to reduce the residual gas in the walls. It will also incorporate heating elements so that an in-situ baking can be done without breaking the vacuum.

A new test set-up for studying the electrical discharge between the acceleration grids in the ITER SINGAP has been designed. This test set-up will demonstrate the voltage withstand before and after a breakdown.

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