2005 JET WORK PROGRAMME

PLASMA FACING COMPONENTS

TASK: JW5-FT-JET-A Fusion Technology

***JW5-FT-3.26:** Assessment of detritiation with Ar plasma torch*

G. Dinescu, E. R. Ionita

National Institute for Laser, Plasma and Radiation Physics, Magurele, Bucharest

1. Introduction

Tritium retention inside the walls of vacuum vessel was proved during Joint European Torus (JET) machine operation. In the ITER case, due to its larger size the tritium inventory will increase faster and can reach critical values only after hundreds of pulses. So, tritium accumulation in the plasma facing components can strongly limit the operation time of the fusion machine. The investigations showed that this accumulation is related to erosion and re-deposition of materials on the divertor tiles and a significant fraction of the tritium remaining in the machine is immobilized in flakes and co-deposited layers localized in the sub-divertor region.

Various techniques were approached aiming to detritiate the walls, as example laser and flash lamp via ablation of co-deposited layers and H/D thermal desorption. Nevertheless the access of such techniques in the shadowed regions of the divertor, where the formation of thick and fuel-rich carbon films occurs is limited. The present task aims to approach this problem, by designing and realization of a small size plasma torch, able to be handled in the shadowed regions and which should have the capability to stimulate the detritiation.

The activities during 2005, after the start of task JW5-FT-3.26, have been devoted to aspects related to the fulfillment of the deliverable D1, as was specified in the Summary Sheet, i.e. “Realization of a movable small size plasma torch, with 2 cm diameter”.

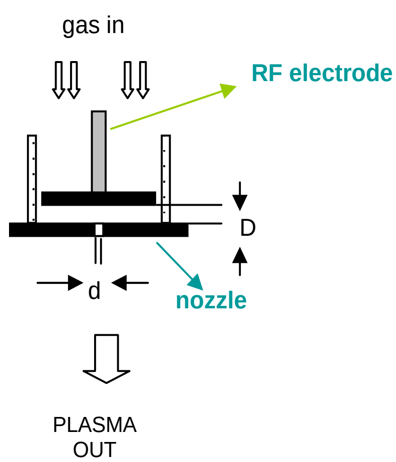


Figure 1. The schematic of the plasma torch discharge.

2. Results

Principle of operation of plasma torch

The schematic of a standard plasma torch discharge, elaborated at NILPRP is presented in Figure 1. Plasma is generated in the discharge chamber, which is a small size (18-36 mm diameter), diode type RF (radiofrequency) discharge, having as powered active electrode a metallic disk. The wall of the discharge chamber is made from quartz or ceramics, excepting a drilled base plate (hole diameter d = 1-5 mm). A distance (D) of 1-15 mm can be set between the disk and the plate. The gas is admitted in the system through the discharge, goes in the plasma state, and transfers as an expanded plasma jet outside the inter-electrodic space. The base plate separates the discharge chamber from the expansion, which in the case of low pressure plasma torches occurs into a vacuumed chamber.

This system was proved as operating stable at pressure values up to atmospheric; on its basis atmospheric pressure plasma torches can be built-up [1].

The smallest atmospheric plasma torch developed previously at the National Institute for Laser, Plasma and Radiation Physics (NILPRP) had a diameter of 40 mm. It was used, as example for processing contours on selective processing flat surfaces on predetermined contours [2]. The plasma beam shape and volume strongly depend on the working parameter values (discharge geometry, pressure in expansion, power, gas mass flow).

Scaling down the plasma torch dimensions

There were a number of difficulties identified in the process of scaling down the plasma torch dimensions from 40 mm to 20 mm. The main problem is that, additional to the small size, there is a strong requirement to produce energetic plasma, which should activate the desorption and material removal from surface. For the current project a lower limit of 200 W was imposed to the plasma torch operation. This power is transported via radiofrequency currents and dissipated in the limited volume of the discharge. The power dissipation is accompanied by strong heating of the torch parts in contact with plasma (the RF electrode, the nozzle and of the insulator wall) that will damage them. To avoid the parts damage active heat removal is necessary, which in is realized by water cooling circuits. The water has to flow around the discharge limiting parts, and all the pieces, i.e. the water jackets, the RF electrode, the nozzle and the insulator have to be arranged into a cylinder of maximum 20 mm diameter. In addition, the coupling of the gas inlet and pipes inlets has to be included. The torch operation at convenient power levels asks for not too small internal diameter of the discharge chamber; all these restrictions let very low space for the cooling circuits. In order to overcome these problems, extensive studies were performed and it was first realized, as intermediate stage, a plasma torch that fulfils only a part from the requirements

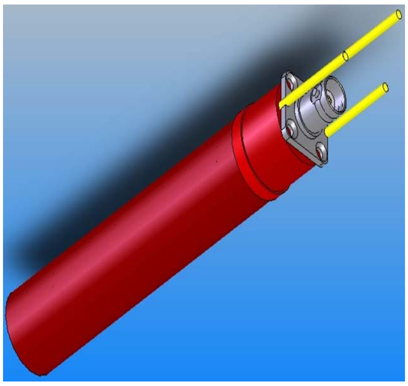
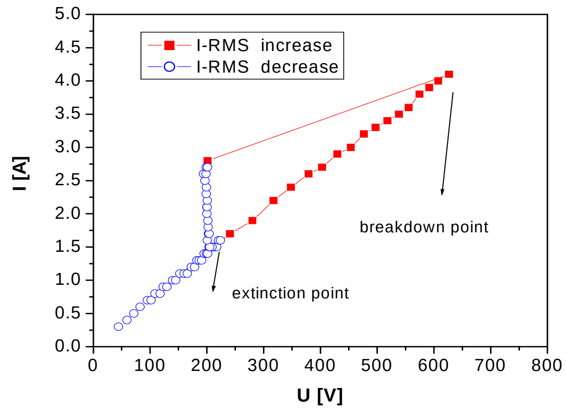


Figure 2. Schematic views of the 22 mm plasma torch in copper with one water circuit.

Intermediate stage: 22 mm plasma torch in copper with one cooling circuit

In an intermediate stage a plasma torch of 22 mm diameter with a cooper made body was designed and realized. A schematic view of the 22 mm plasma torch in copper is presented in Figure 2. Starting from the left bottom corner to the right upper corner, along the inner part of the body are distributed the nozzle, the RF electrode, the holder of the RF electrode, the RF electrical feedthrough and the RF coupling. In the same direction along the outer part of the body the water jacket is seen: at its end it is in contact with the nozzle, while along the internal diameter it is in contact with the insulator. In this approach one water circuits cools both the nozzle and the discharge wall: the water inlet and outlet are observed at the other end the water jacket. The measured water flow for the system was 400 cubic centimeters per minute.



Fiaure 3. I-V characteristics

Breakdown studies

A study of the breakdown was realized: an example of I-V characteristic of the torch discharge is shown in Figure 3. It was obtained from adequate voltage and current probes, assisted by home made Labview software.

The software controls a gradual increase of the RF voltage from zero until the breakdown point is reached, followed by the gradual decrease, passing through the extinction point until the zero power is attained again . The linear I-V part of the characteristic describes the passing of the displacement current through the capacity of the inter-electrodic space, in absence of discharge. The curve show that breakdown can be reached in flowing argon at atmospheric pressure, at Urms of about 600 V; moreover after breakdown due to the discharge hysteresis the torch can be kept in operation for voltages much lower than the breakdown voltage.

Temperature field

The temperature of the ionized argon gas was measured by inserting a small thermocouple head at different positions in the jet. The temperature increases with the decreasing the distance from nozzle, with the increasing of the mass flow and increasing of power.

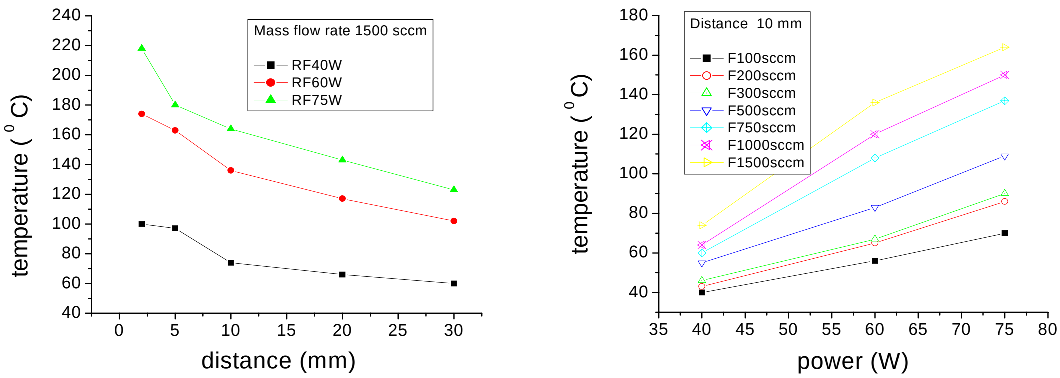


Figure 4. Temperature attained in the torch, intermediate design

The limitations observed and the conclusions obtained from the experiments with the intermediate 22 mm plasma torch, with one cooling circuit, were:

a) The source is flexible and hand held; it can be used as a plasma pencil; this accomplishment shows a step forward for a possible mounting on a robotic arm;

b) The plasma jet (obtained with a nozzle of 1.5 mm in diameter) in argon, as observed visually, is 10-15mm long; this is related to the gas nature (argon); experiments of injecting in the plasma low excitation elements (Na from NaCl solution) shows a higher length (25 mm) proving that plasma in argon exists, in the scale length, beyond the observed luminosity;

c) The breakdown of the discharge sustaining the torch operation is possible directly at atmospheric pressure;

d) The source operates well up to 80 W. The limitations are related to heating and to the RF coupling: the chosen coupling, of BNC type, was imposed by the size of 20 mm;

e) The power cannot be increased over 100 W for long term operation due to excessive heating of the internal RF electrode. For short periods (1-2 minutes) higher power values, up to 200 W were possible; nevertheless the operation at high power was accompanied by instabilities in the discharge and oscillations of the RF matching system, whose origin are not clear (could be involved: turbulent gas flow, too small discharge chamber, inadequate geometry of electrodes).

f) The quite linear increase of temperature with the power indicates that probably temperatures around 300 ^{0}C could be attained with this plasma torch in argon at 200 Watt; this was also proved by short time operation of the source at 200 Watt.

Solutions for plasma torch of 20mm and 200 Watt

The experiments performed with the intermediate plasma torch, revealed that in order to realize a plasma torch of 20 mm, working at 200 W power it is necessary to:

a) Insure more efficient cooling, not only with the external water jacket for the insulator wall and the nozzle, but also for the internal RF electrode;

b) Adopt a solution which allows the RF coupling for higher power: either a standard N type coupling, or a home made design for coupling appeared to be necessary;

c) Adopt a solution for larger discharge chamber;

According to these requirements a design based on two body torch was realized: the discharge body and the coupling body, as shown in Figure 5.

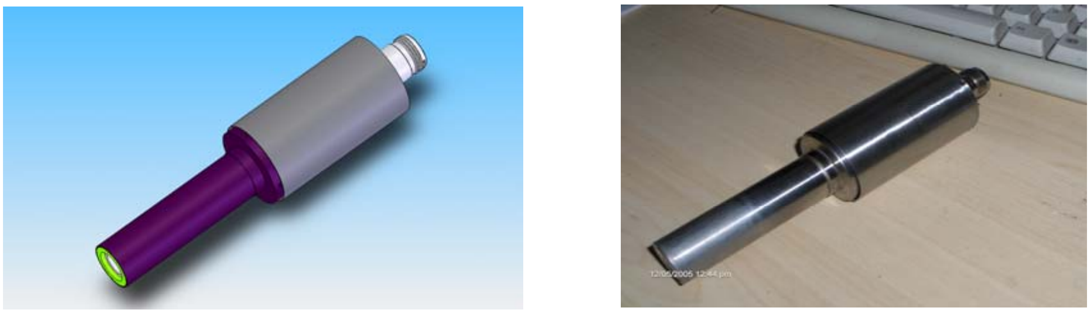


Figure 5. a) Schematic view(design) of the 20 mm stainless steel plasma torch(left) and a photograph of the manufactured torch (right)

The discharge body has 20 mm diameter and 70 mm length, and fulfils the dimensional conditions of the project. The coupling body has 38 mm diameter and 60 mm length, and fulfils the needs for adequate coupling of the water, gas, RF power, as follows:

- coupling of the RF power via a standard N type couple, allowing higher RF currents (up to 15-20 Amps)

- cooling by two water circuits, one for the nozzle and the insulator wall and one for the for internal electrode;

-convenient gas inlet management via the inside of the RF electrode, designed as a tube;

- larger discharge chamber of 10 mm diameter;

Photographs showing the plasma torch under operation are presented in Figure 6.

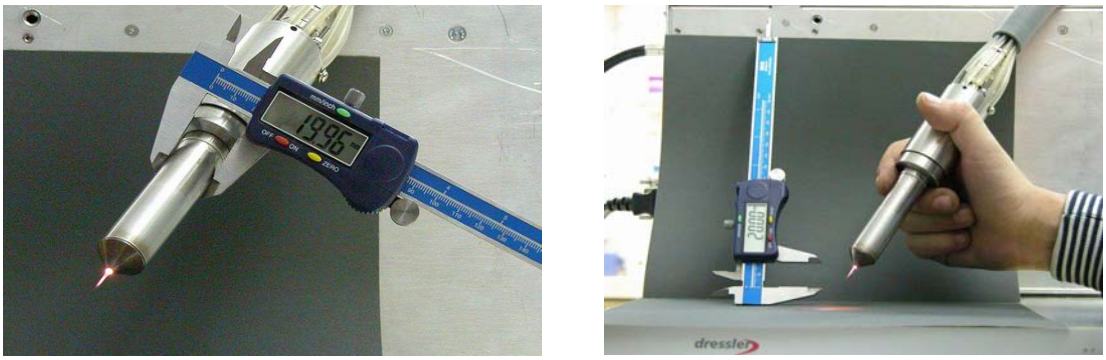


Figure 6. Plasma torch a) prove of 20 mm diameter b) hand held, prove of flexibility

The range of operating parameters for the realized plasma torch is presented in table I

Table 1. Range of operating parameters

Parameter and symbol	**Value**	**Parameter and symbol**	**Value**
gas type	argon	power (W)	50-300
nozzle	stainless steel	pressure (mbar)	760
electrode	tungsten	gas mass flow (sccm)	500-8000
d -nozzle diameter	1-3 mm	plasma jet length	15-20 mm
D -disk-plate distance	1-10 mm	plasma jet diameter	~ 2 mm

Temperature field for the plasma torch with 20 mm diameter

A parametric study of the heating capability of the plasma torch upon power was realized, by inserting a thermocouple in the jet at various distances from the nozzle. The measured temperatures are presented in Figure 7.

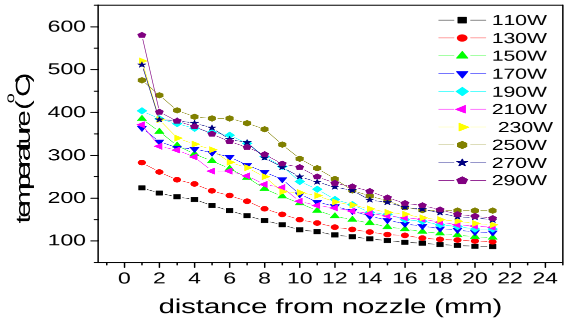


Figure 7. Temperature dependence on distance , for various forwarded power values (d=2mm, D=2mm, Ar, 2000 sccm)

Three regions can be identified along the plasma jet, one (at 1-2 mm, temperature up to 600 ^{0}C)) with rapid variation which describes the passing from discharge inside the inter electrodic space to the expansion, one with a middle temperature (3-9 mm, temperature up to 400 ^{0}C ; visually is seen as a bright zone) and a tail (temperature less that 200 C, visually is a faint zone). The promising part for cleaning the surface and stimulating desorption is the middle part, which carries out also excitation that can be transferred to other gases to form chemically active species. It is expected the observed temperatures to increase while working with a molecular gas, as example nitrogen, and experiments are envisaged in this direction.

3. Conclusion

A study of scaling down the dimensions of the plasma torch was realized. On the basis of this study plasma torches were designed aiming to reach the required dimension of 20 mm in diameter. An intermediate model of plasma torch, having 22 mm and one cooling circuit was realized. The model worked well with power up to 80 W. Finally, taking into account the results on experiments with the model plasma torch, a plasma torch of 20 mm was realized, in stainless steel and having two cooling circuits. This torch is working stable in argon at power values up to 300 Watt, with mass gas flows in the range 500-8000 sccm.

4. Future plans for 2006

According to the planned work, in 2006 the activities are distributed in two stages:

1) Test of the plasma torch on non-tritiated co-deposited CFC tiles

The goal is the assessment of the effectiveness of the plasma torch in modification/removal of material from co-deposited CFC surfaces. A scanning facility (15 cm x 15 cm) will be built up based on computer controlled stepper motors. The CFC coated surfaces will be submitted to plasma treatments. The source will be operated in argon but also experiments with other gases are envisaged (in nitrogen or with hydrogen or oxygen injection). The quantity of material removed will be assessing via surface and thin film characterization techniques.

2) Assessment on feasibility of detritiation tests at the JET Beryllium Handling Facility on activated tiles

The plasma torch will be optimized in terms of flexibility, length, arrangement of cables and cooling pipes in order to match the requirements for the experiments in the Beryllium Handling Facility. Possible in vessel applications will also be assessed.

References

[1] **Dinescu G.**, "*Radiofrequency discharge operating as a high pressure plasma jet*", Oral presentation, 16-th International Symposium on Plasma Chemistry (ISPC-16), section Plasma Sources, Taormina, Italy, June 22-27, 2003 (published in the Conference Proceedings, Full-Papers CD, eds. R. d'Agostino, P. Favia, F. Fracassi, F. Palumbo)

[2] **Vlad G., Ionita R., Ciobanu I, Petcu C., Dinescu G.**, "*Processing of Selective Contours on Flat Surfaces by Computer Assisted Beam Tracking*", in Plasma Polymers and Related Materials, eds. Mutlu M., Dinescu G., Forch R., Martin-Martinez J.M., Vyskocil J., ISBN 975-491-194-0, Hacettepe University Press, 2005, pp.84-90.