ENHANCED HIGH VOLTAGE HOLDING UNDER VACUUM BY FIELD INDUCED ADSORPTION OF GAS ON METAL SURFACES*

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Abstract

The energy of future neutral beam injector heating systems of fusion power plants ranges from 1 to 2 MeV. They are based on powerful hydrogen negative ion electrostatic accelerators where electrodes are polarized by high-voltage DC power supplies. The bushing is a high-voltage feed-through that allows supply of the accelerator electrodes. In this paper, a new high-voltage bushing concept is presented. The main advantages of the concept are a likely reduction of the electron field emission by the field induced gas adsorption effect in the inner part of the bushing where the electric field intensity is highest. This effect also yields to a reduction in size, and mechanical simplification of the device.

INTRODUCTION

In order to provide initial plasma heating to enter the burn phase on Fusion reactors an additional heating system based on the injection of high-power (~150 MW) high-energy (from 1 to 2 MeV) neutral particles (D°) into the plasma core is required [1,2]. Such neutral beams will be provided by high-voltage electrostatic accelerators for the acceleration of several tens of amperes (~40 A) of D^- up to 1-2 MeV [3]. The ion acceleration is performed by the polarization of large electrodes (~1 m^2) at the required DC high voltage (~1-2 MV). The NBI electrostatic accelerators are supplied by DC high-voltage (HV) power supplies, connected to the injector via a transmission line pressured under SF6 gas (~ 0.5 MPa) and a high-voltage feedthrough (called bushing) crossed by HV electrical bus bars and water-cooling lines of the accelerator. The bushing is thus a major component of the beam line, as it can affect the HV holding of the injector under vacuum in many ways. The bushing acts as a barrier between the SF6 insulated HV line and the primary vacuum of the NBI tank; its major purpose is to withstand the HV on both sides (vacuum and SF6) and to supply the injector with electrical power, water cooling, and gas.

In this paper, we propose a new bushing concept, the goal of which is to reduce the electron field emission current (so-called dark current) by the field induced adsorption process which screens the "micro-tips" emitters by localized atom sticking. The bushing concept has been designed on the basis of experimental results on high-voltage holding previously obtained on the MV-testbed at CEA Cadarache

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HIGH VOLTAGE HOLDING

As the HV breakdowns can strongly affect the reliability of a high-energy injector, a dedicated study has been performed on the MV-testbed at Cadarache (see Fig. 1) in recent years [4] in order to address studies on HV holding under vacuum at a high electric field intensity (up to 60 kV/cm).

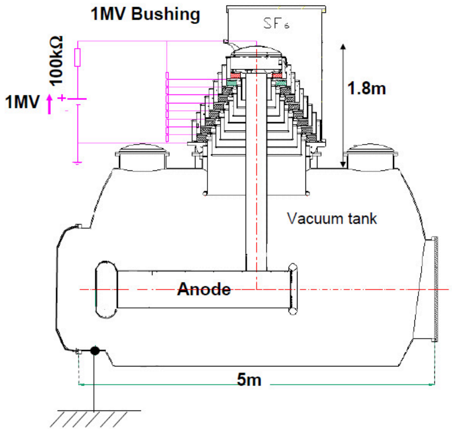

Figure 1: MV test bed at CEA Cadarache.

The first experimental finding was of a large amount of the stray electron current (called dark current) resulting from the field emission process under vacuum between the grounded cathode (the tank metal walls of ~50 m^2 surface) and the anode (the central electrode at HV). The electron current is strongly correlated with the anode voltage and the background tank pressure (see Fig. 2). We note that, at low hydrogen pressure, p_1~ 1.7E-3 Pa, a maximum HV of 500 kV has been obtained after a "current" conditioning process, where the applied voltage is increased in small steps keeping the same overall dark current value (I~ 100 mA). On the other hand, 970 kV dark current free (I<10 mA) was achieved with p_{he}= 35 E-3 Pa of helium filling pressure. The Fowler–Nordheim (FN) equation (1) describes the field emission of electrons by quantum tunneling due to the presence of a high electric field E= V/d.

$$I = \frac{A_e.C}{\phi}\left(\frac{\beta V}{d}\right)^2 \exp\left(-A_2\phi^{3/2}\frac{d}{\beta V}\right) \quad (1)$$

The total current **I** is function of several parameters: the area $\mathbf{A_e}$ of the field emitting surface, this area is usually not known and is much smaller than the total area of the typical cathode employed in our field (cathode surface of about $50m^2$ on the MV-testbed); the field enhancement factor β which is due to the local reinforcement of the electric field on the micro-tips and, the work function ϕ of the emitter.

A2 and C are physical constants. The fitted curves on figure 2 have been performed by the Fowler-Nordheim law supposing that only the hydrogen or helium tank pressure (p_i) modifies the work function Φ. Under this assumption, the fits exhibit an increase of the work function with the pressure of up to 33% in hydrogen and up to 68% in helium. The increase in work function consequently leads to an increase in HV holding capability.

This observation suggests that a physisorption (or chemisorption) mechanism occurs between the gas and the metal surfaces.

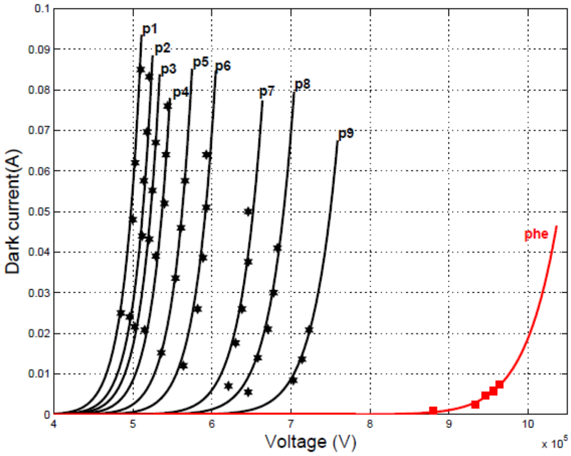

Figure 2: Electron current vs high voltage for different tank pressures.

Hydrogen: p_1=1.7E-3Pa, p_2=2.5E-3Pa, p_3=3.0E-3Pa, p_4=3.8E-3Pa, p_5=5.7E-3Pa, p_6=8.0E-3Pa, p_7=13.3E-3Pa, p_8=19.8E-3Pa, p_9=28E-3Pa.

Helium : p_{he}=35 E-3Pa,

FIELD INDUCED ADSORPTION

A calculation of helium deposition at 0.03Pa on a metal surface (at 300 °K) without any electric field gives ~10^{-8} monolayer of coverage; such low value is explained by the combination of a low pressure (low atom flux on the surface) and high desorption rate at 300 °K [5].

On the other side, a field enhanced gas adsorption onto metal by an intense electric field (several tens of V per nm) was discovered by Muller [6]; this property results from an important increase of the atom binding energy (more than one order of magnitude) [7] with the external electric field. At 300 °K, the atom (helium) kinetic energy is 36 meV, its binding energy at zero-field is only 6 meV; at high E-field (~50 V/nm) it can increase up to 300 meV on a tungsten metal surface due to covalent and polarization effects [7], yielding to a sticking of atoms near the micro-tips, and a change of the emitter parameters.

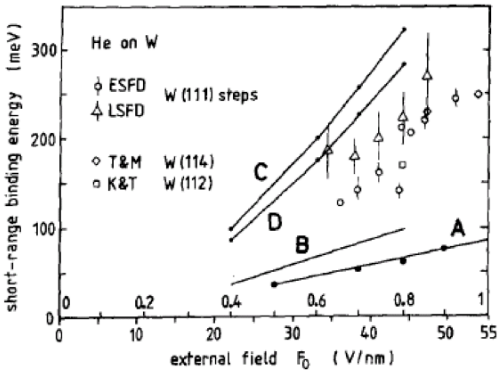

Figure 3: Helium binding energy on metal vs external electric field [7].

The electric field on the cathode surface inside the MV testbed ranges between 20 to 50kV/cm, the enhancement factor β is not known, but on the leading edge of the micro-tips, β could reasonably be as high as 10^3-10^4, yielding to a local very high electric field (~5-50 V/nm) enough to trigger this screening effect. The physisorption process (work function variation) is function of the adsorbate (the metal surfaces) and gas polarizabilities: it is shown [8] that adsorption of hydrogen and helium gas on tungsten or stainless steal surfaces increases the work function, ie, decreases the field emission, while water (H_2O) enhances field emission.

NEW BUSHING CONCEPT

Figure 4 shows the bushing concept; it is a reverse bushing geometry, where the HV (1 MV) surface under vacuum conventionally located on top of all bushings (see Fig. 1) is now in the tank centre where the electric field is lower. The bushing is a sealed stack of insulators that has the inner part filled with low-pressure (helium) gas. Thanks to the field-induced absorption of gas, this inner region would remain without electron field emission, despite a very high electric field intensity (E> 50kV/cm). Owing to the low pressure (p< 0.03Pa) within the stack, the bushing is subject to a compression by the external pressure on the upper part (0.6 MPa of SF6 in the transmission line). Alumina insulators in the lower part of the bushing (in the tank) are sustained by a nut screwed on the central column, which compresses the insulators to seal the entire stack. Insulators on the upper part support the SF6 pressure (~0.6 MPa), the bushing weight, and the central channel, which sustains the HV (1MV) accelerator electrode. The central channel which contains the water-cooling pipes or

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electrical bus bars coming from the transmission line and supplying the accelerator below is a metal tube with a flange and feed-throughs (SF6-vacuum) on the top; it crosses the equipotential central column at 1 MV. Note that there is no mechanical contact between the central channel and the stack of insulators. The stack of insulators is 2 x 1.7 m in height (five insulators under vacuum and five insulators under SF6); the insulator diameter is a function of the central column diameter, ie, 0.15 m for the central column would yield an insulator diameter of 0.7 m on a 1MV Bushing.

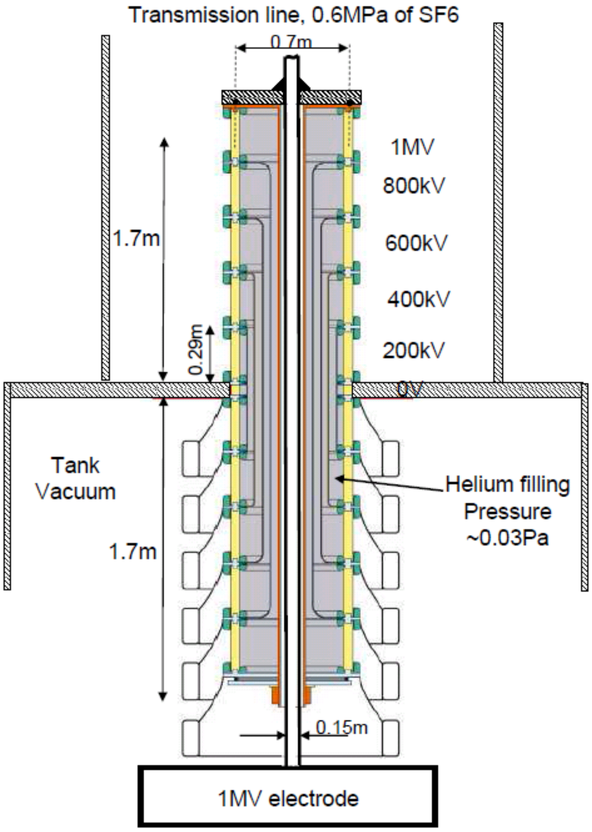

Figure 4: 1MV new Bushing concept.

CONCLUSION

This new Bushing concept based on the field induced adsorption process, ie, low electron field emission under high electric field in the presence of gas, should increase the HV holding performances of large physics instruments, such as particle accelerators. A dedicated R&D focussed on this process will be launched between CEA and French Universities, the goal being to find specific physical conditions which exhibit very high metal work function under very high electric field (E~50-100 kV/cm).

ACKNOWLEDGMENTS

This work, supported by the European Communities under the contract of Association between EURATOM and CEA, was carried out within the framework of the European Fusion Development Agreement. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

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