Status of the EU 170 GHz/2 MW/CW Coaxial Cavity Gyrotron for ITER: The Dummy Gun Experiment

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***Abstract*—A mock-up gun has been manufactured as exact replica of the refurbishment first prototype EU 170 GHz/2MW/CW coaxial cavity gyrotron, but without emitter ring in order to validate the voltage standoff stability. The experimental results of the mock-up gun tests are presented.**

I. Introduction And Background

The refurbishment of the first prototype of the EU 170 GHz/2MW/CW coaxial cavity gyrotron is being carried out by Thales, in a collaborative effort between the European Gyrotron Consortium (EGYC) and Fusion for Energy (F4E) [1]. The new gyrotron design has been improved compared to the first prototype. In particular, (i) the gun design has been significantly modified [2] in order to optimize the beam quality at the cavity, and to avoid the build-up of trapped electrons populations which were identified as one of the possible causes for the first prototype poor voltage stand-off, (ii) the beam-tunnel characteristic has been modified in order to prevent the excitation of parasitic oscillations [3], and (iii) a new launcher based on an improved design technique leading to a Gaussian content in excess of 95% will be used [4]. Experiments with the refurbished tube are expected to start during the forth quarter of 2010. In the mean-time, in order to validate the voltage stand-off stability of the new gun, as well as to study the correlation between the voltage stand-off and the existence of trapped electrons, a dummy gun device has been manufactured.

II. The Mock-Up Gun Design

The mock-up gun device (see Fig. 1) reproduces exactly the gun design of the first prototype refurbished tube, except for the coaxial insert internal parts and the absence of emitter ring. It has been made flexible, so that magnetic wells can be created by an appropriate modification of the external magnetic field, and the mechanisms leading to the formation of a population of trapped electrons can be studied. A negative potential is applied on the cathode structure while the coaxial insert and the anode, which consists of five insulated parts, are grounded. The current carried by each grounded part can be recorded separately.

The tube was (i) not sealed, and (ii) not baked so that it can be opened and internal parts can be changed. This affects significantly the vacuum quality, i.e. the pressure is more than two orders of magnitude higher than in the real gyrotron. In the future, a window will be put on the top part of the gun in order to get a viewport allowing the user to connect a camera or a spectrometer.

III. Main Results

The tests planned within this work were dedicated to the validation of the gun design for the refurbished tube. They were limited to the verification that the voltage stand-off would be compatible with gyrotron operation in the absence and in the presence of the nominal magnetic field.

As a minimal effort was needed to create a magnetic potential well, it was decided to make some initial tests to estimate the effect of a well on the stand-off properties, and to further validate the new gun design criterion aiming at the avoidance of any electron trapping mechanism. Details about the physics of electron trapping mechanisms in gyrotrons, such as the magnetic potential wells and the magnetic mirror, have been presented in the 34^{th} IRMMW 2009 in Busan [2].

The voltage was provided by a high impedance power supply with a current limiter. The power supply provides a rectified voltage, i.e. the AC component is still significant.

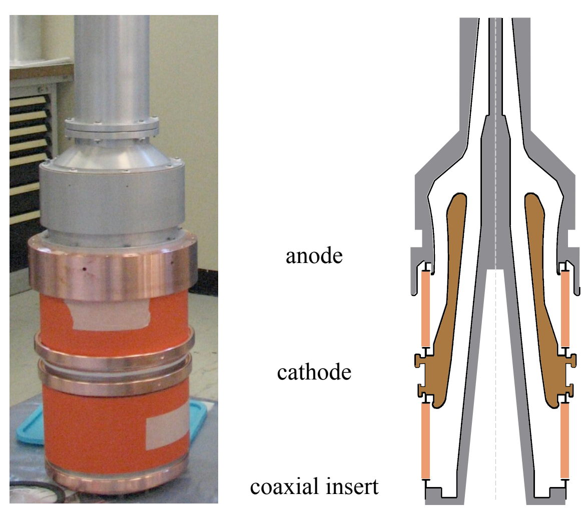

Fig. 1. The mock-up gun device.

A. At zero magnetic field

The mock-up gun had already been conditioned at zero field at the factory. The voltage could directly be increased up to 80kV, in one step. After a few conditioning arcs, a voltage of 90kV was reached without any problem. Voltages up to 106 kV were applied, with some intermittent arcs. The main result is that the system was very stable and no field emission current could be detected (i.e. it was less than 5 μA). As a consequence, it was not possible to record a Fowler-Nordheim curve.

B. At the nominal magnetic field

The application of a high voltage in presence of the nominal magnetic field necessitated a surprisingly short conditioning period. The voltage could be increased up to 100kV in less than 2 hours. The main features of the voltage stand-off at the nominal magnetic field are:

- The system is very stable up to the nominal voltage, in contrast to the first prototype experiments where an ergodic/chaotic behavior was observed for voltages above a threshold of the order of 60kV.
- The leakage current remains below the power supply detection threshold.
- A clear conditioning curve is observed. However, increasing the voltage stand-off to 125kV would probably require a long conditioning time and/or a better vacuum.
- No Fowler-Nordheim curve could be recorded. This is most probably a positive result of the design effort to minimize the electric fields inside the gun.

The best voltage stand-off recorded so far (limited by conditioning time and working pressure) are 90kV/32' and 100kV/11'.

C. In presence of a magnetic potential well

The simplest way to create potential wells of various depths was to modify the bucking coil current of the superconducting magnet by a few amperes. In particular, a potential well similar to the first prototype tube, was formed for coil current values less than 6.2 A (nominal value 6.95A). Its depth increases as the coil current is lowered , as it is shown in Fig. 2. The main observation was that the voltage stand-off is strongly affected in a negative way by the existence of a potential well, even is this latter is shallow (a few kV only). In more detail:

- Above a certain threshold, micro-discharges appear. Their duration is of the order of 1 ms and their frequency is 1-10KHz, possibly determined by the voltage power supply.
- The current is mainly measured in the body, in the halo shield, and on the coaxial insert in 10% of the cases.
- The voltage stand-off decreases down to 2-20kV instead of 100kV, depending on the well depth (see Fig. 2).
- A strong pressure increase is noticed when micro-discharges appear. A stationary state can eventually be reached.
- There seems to be an hysteresis: once the micro-discharges have appeared, the voltage must be decreased to almost zero to suppress them.

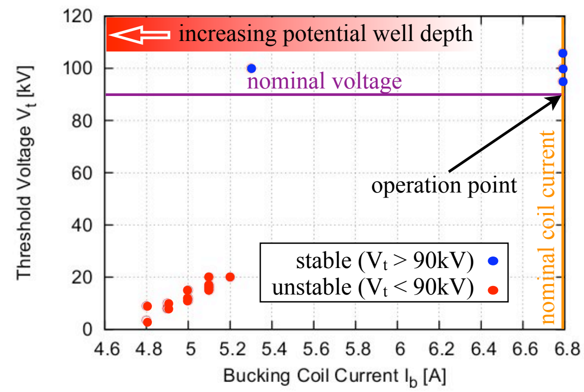

Fig. 2. The threshold voltage is corellated with the existence and the depth of the potential well.

- Using the micro-leak, it was possible to control the pressure by letting some Argon gas in. Some very preliminary test indicates that the micro-discharges threshold goes down when the pressure increases.

All these observations are compatible with the hypothesis of a reduced voltage stand-off due to the existence of potential wells.

VI. Conclusions

The main objective which was the validation of the gun stand-off for the refurbished electron tube was successfully reached. The correlation between the voltage stand-off stability and the existence of a potential well in the tube has been verified. More experiments are needed to understand the underlying physics, such as a better identification of currents, spectroscopy, inspection of the gun, etc.

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