Operation of the Modular KIT 170 GHz - 2 MW Longer-Pulse Coaxial-Cavity Gyrotron with Pulses up to 50 ms

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***Abstract*—The KIT 170 GHz - 2 MW longer-pulse coaxial-cavity gyrotron is continuously upgraded with the goal to reach 1 s pulses with a modular construction. In this work, we present the latest experimental results that were achieved after modifications on the mirror-box, the collector and the cooling system of the gyrotron. In particular, it was possible to demonstrate pulses with output power up to 2 MW and pulse lengths up to 50 ms.**

I. Introduction

Currently, KIT is developing a longer-pulse coaxial-cavity gyrotron with the goal of generating 2 MW of power at 170 GHz with pulse duration of up to 100 ms in the first step and up to 1s after a second round of modifications. In order to support this goal multiple upgrades have been performed to the standard short-pulse pre-prototype construction of the gyrotron [1]. First, the key components of the tube, namely the beam-tunnel, the cavity and the launcher, have been equipped with cooling systems [2], [3]. Second, a new triode Magnetron Injection Gun (MIG) has been designed, manufactured and installed to the gyrotron [4].

During the previous experimental campaigns, various difficulties were faced and had to be carefully addressed in order to continue the development. In particular, it was difficult to maintain a good vacuum level during the bake-out process of the tube, and, most importantly, a significantly high body-current was observed during operation.

Various modifications have been performed on the gyrotron body in order to tackle these problems. To address the difficulties during the bake-out process of the tube, the interface flange between mirror box and collector was modified in order to be able to use a commercial type copper sealing. The previous implementation was using an adapter flange and an in-house copper-wire sealing. The unbalanced forces on the large-diameter adapter flange in combination with the temperature treating of the copper-wire in the nitrogen oven resulted to vacuum leakages. The relatively high body-current that has been measured during the previous experimental campaigns has been found to be related to the higher position of the collector with respect to the magnetic field, due to the use of a bigger (compared to the old pre-prototype) mirror box. This issue was partially addressed by the abovementioned adapted flange. In order to suppress the current even more, a compression coil was installed inside the water-jacket of the collector.

II. Experimental Results

After the modifications, the gyrotron was baked-out in the nitrogen oven at 350°C and then, the emitter was conditioned with a filament current of up to 24 A. As a result, the vacuum conditions in the tube are excellent and significantly better than those of the previous assembly. The main goal of the current experiments is to extent the pulse length as much as possible with the ultimate goal of 100 ms. With the current assembly (fused silica window, short-pulse collector, lack of a collector sweeping system), the maximum pulse length is limited to 50 ms. This relatively conservative limit is selected to protect the collector from failure, while there are ongoing studies to define the actual limit more precisely.

A. Short-Pulse Experiments

In the first stage of the experimental campaign, a second limit on the pulse length was set by the diagnostics and in particular by the short-pulse flow-through calorimeter used for the measurement of the generated RF power. The calorimeter can absorb ~ 10 kJ pulses, i.e. it is safe to absorb 1 MW-10 ms, 1.5 MW-7 ms and 2 MW-5 ms pulses. Considering that the coaxial gyrotron has been designed for output power 2 MW, alternative operating points have been determined in order to retain the electronic efficiency of the interaction as high as possible. In all cases the modulation anode of the triode gun is grounded. This means that for constant accelerating voltage the body voltage is used as a means to control the pitch factor of the electrons and in turn the body voltage cannot be set independently to control the depression voltage of the gyrotron. It should be noted that focusing on the pulse length extension and not on the maximization of the output power, no optimization of the operating parameters, in terms of the magnetic field angle on the emitter and the beam radius in the cavity, was attempted.

Fig. 1 presents the output power and the corresponding total efficiency with respect to the body voltage. As shown in the figure, it was possible to demonstrate 10 ms pulses with 1 MW power and 34 % total efficiency, 7 ms pulses with 1.5 MW power and 41 % efficiency, as well as 5 ms pulses with 1.9 MW power and 46 % efficiency. The total efficiency that has been obtained for the 1 MW operating point is relatively low due to the high operating current. On the contrary much higher efficiency has been achieved for high-power operating points. It is evident from Fig. 1(c) that we, essentially, achieved 2 MW pulses with pulse duration of 5 ms. The efficiency of these pulses is higher than 45 %, which is very encouraging for achieving the 50% specification after optimizing the operation of the tube. The slightly reduced output power of the 2 MW operating point is related to the capabilities of the short-pulse power supply, which when operated near its limit presents voltage instabilities (spikes). These instabilities can trigger mode competition and make difficult to operate the tube at the optimal accelerating voltage, which would result to higher output power and total efficiency. Note that the comparison of the experimental data to numerical results is currently ongoing.

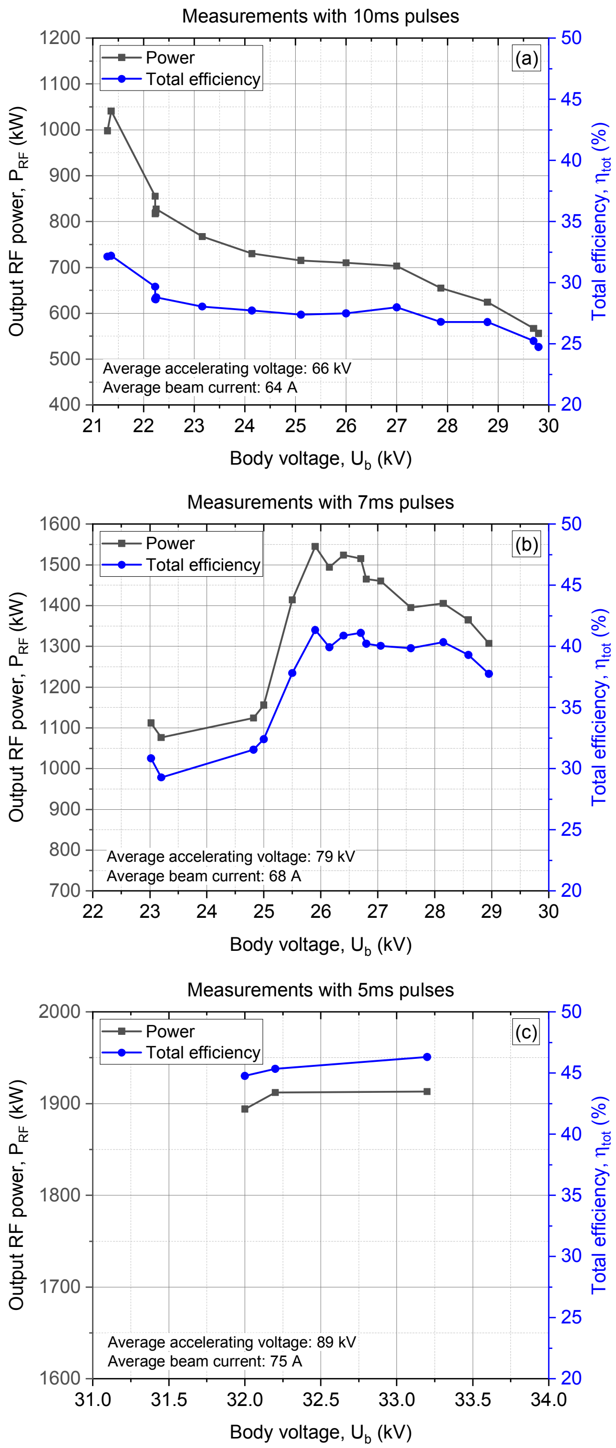

Fig. 1. Preliminary experimental results for three different combinations of output power and pulse length: (a) 1.0 MW – 10 ms, (b) 1.5 MW – 7 ms and (c) 2.0 MW – 5 ms.

B. Longer-Pulse experiments

In order to reach the 50 ms milestone, the short-pulse calorimeter was replaced by a longer-pulse flow-through load, which is expected to be able to dissipate 2 MW. In order to keep the risk of damaging the short-pulse collector as low as possible, the gyrotron was progressively conditioned by pulsing at the 1.5 MW operating point, which provides a good balance

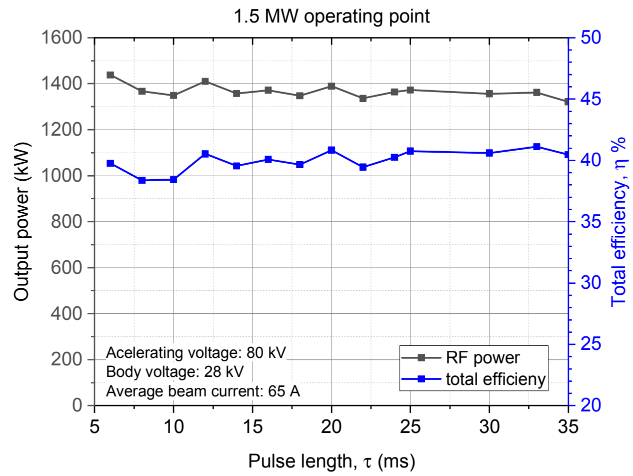

Fig. 2. RF power and total efficiency with respect to the pulse length for the 1.5 MW operating point.

of output power and efficiency. Fig. 2 presents the RF power and the corresponding total efficiency with respect to the pulse length for body voltage 28 kV. As shown in the figure it was possible to generate 1.4 MW with total efficiency 40 % and pulse length up to 35 ms. The further increase of the pulse length at this power level was difficult due to increased outgassing, which indicates that further conditioning of the collector is necessary. However, by reducing the input power of the electron beam it was possible to achieve multiple 50 ms pulses with output power higher than 1 MW. Regarding the 2 MW operating point, it was possible to achieve 11 ms pulses with output power 2.1 MW and total efficiency 47 %.

III. Conclusion

After the multiple upgrades that have been performed to the longer-pulse coaxial gyrotron it was possible to demonstrate stable 35 ms pulses with output power 1.5 MW and efficiency 40 %, while multiple 50 ms pulses have been achieved with output power above 1 MW. The conditioning of the tube will be continued in order to reach 50 ms at the 2.0 MW operating point. At the moment, 11 ms pulses have been achieved with output power 2.1 MW and total efficiency 47 %.

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