Enhanced Transversal Collector Sweeping for High Power CW Gyrotrons

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***Abstract*—Amplitude modulation of the 50 Hz AC sweeping current of transversal sweeping systems reduces the maximum averaged power density on the collector wall as compared to an unmodulated system. This makes transversal sweeping a very attractive alternative to conventional longitudinal sweeping systems for high power CW Gyrotrons.**

I. Introduction

Efficient collector sweeping systems are mandatory for high power CW Gyrotrons. Due to eddy currents in the collector wall, conventional longitudinal sweeping is restricted to relatively low sweeping frequencies (5–10 Hz). This can be avoided by applying transversal sweeping, where the sweeping system consists of three pairs of elliptic or circular coils laterally mounted to the lower part of the collector. In this region of the collector stainless steel can be used (which is the case for the 140 GHz, 1 MW CW Gyrotron for W7-X), strongly reducing the effects of eddy currents and making it possible to apply 50 Hz three-phase AC current to the sweeping coils.

Both computer simulations and experiments show that this concept is very promising [1], [2], [3]. While the main advantages are the higher sweeping frequency and much simpler (and therefore cheaper) power supplies, simulations show that the critical averaged peak power densities on the collector wall will be not significantly reduced compared to longitudinal sweeping.

II. Unmodulated vs. modulated transversal sweeping

Fig. 1 shows the averaged power density on the unrolled collector wall for a sweeping current of 7 kAT (kA $\cdot$ turns) obtained with a 3D raytracing computer simulation. A pronounced maximum is seen at the lower part of the covered area. To spread out the maximum located at $z \approx 1.7$ m, one can apply a simple but efficient method: by modulating the amplitude of the applied 50 Hz three-phase current with a lower frequency in the range of 5–10 Hz, the critical maximum will be shifted up and down and the averaged power density at that position will be reduced.

Fig. 2 shows simulation results where the amplitude of the sweeping current has been modulated in the range of 4–7 kAT at a frequency of 5 Hz. The maximum at $z \approx 1.7$ m is spread out and the maximum power density is reduced to $\approx 280\,\mathrm{W/cm^2}$, compared to $\approx 450\,\mathrm{W/cm^2}$ in the unmodulated case.

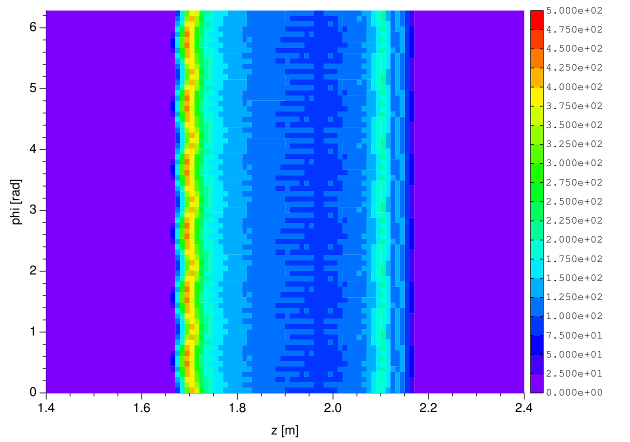

Fig. 1. Average power density on the unrolled collector wall, obtained for constant AC sweeping current of 7 kAT.

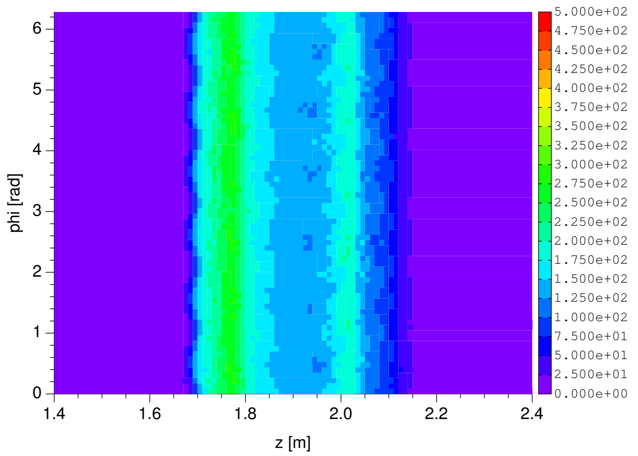

Fig. 2. Average power density on the collector wall, obtained for modulated 50 Hz sweeping current (4–7 kAT at 5 Hz).

III. Experimental Results

At IPP Greifswald experiments with modulated sweeping current have been performed using the TED Prototype Gyrotron from the ECRH plant for W7-X (140 GHz, 1 MW, CW). The cooling jacket and the conventional sweeping coil, which covers almost the entire collector of the Gyrotron, have been removed and the collector surface has been observed with an

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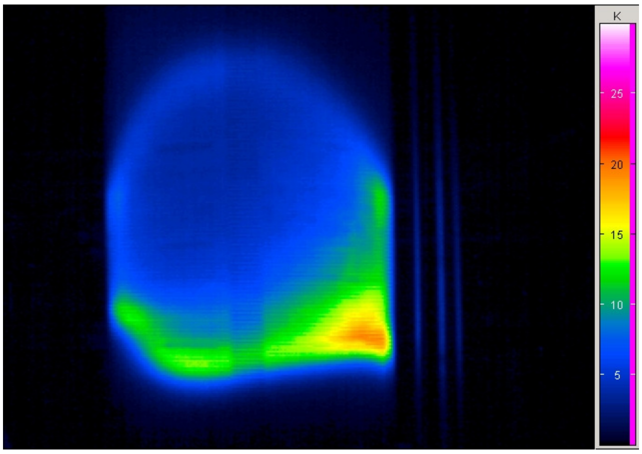

Fig. 3. Distribution of the temperature rise on the collector wall in the case of unmodulated sweeping with a sweeping current of 9.5 kAT.

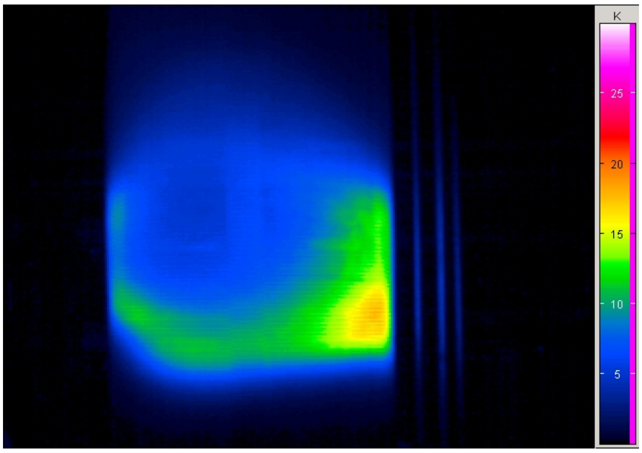

Fig. 4. Temperature distribution in the case of modulated sweeping in the range of 6.5–9.5 kAT.

infrared camera during pulsed operation. The power supply used to drive the three pairs of sweeping coils is a three-phase AC controller based on half controlled thyristor-diode modules. While it has the required capability to modulate the sweeping current, it is still a relatively simple and inexpensive device.

Fig. 3 shows a thermocamera snapshot for the case of an unmodulated sweeping current of 9.5 kAT after a 600 ms pulse. A strong deformation of the stray field of the superconducting magnet due to the steel in the surrounding concrete walls is seen. This results in a non-negligible focusing that can be observed in the lower right part of the thermocamera picture. Compared to the numerical simulation, a higher sweeping current is required to achieve a corresponding sweeping range. This is caused by the damping of the sweeping magnetic field in the stainless steel part of the collector due to eddy currents.

Applying a modulated sweeping current in the range of 6.5–9.5 kAT at a modulation frequency of 8 Hz gives the temperature profile depicted in Fig. 4 (again after a 600 ms pulse). While the result is still superimposed by the unwanted focusing effect, one can observe that the maximum temperature rise is somewhat lower than in the case of unmodulated sweeping.

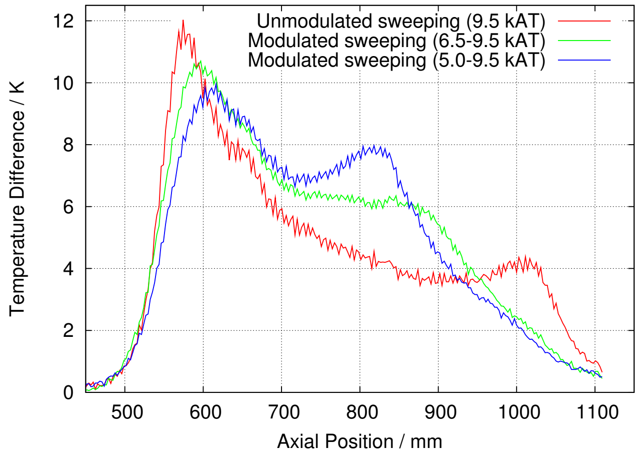

Fig. 5. Comparison of the axial distribution of the temperature rise in the case of unmodulated and modulated transversal sweeping.

A quantitative analysis of the infrared photographs is summarized in Fig. 5. Here the temperature profiles obtained in the center of the collector along the axial direction are plotted. Indeed the comparison shows that the modulation of the sweeping current lowers the maximum differential temperature from approximately 12 K to 10 K in the best case (5.0–9.5 kAT), while the total profile width is shrinking. A higher magnetic field in combination with an upward shift by a small vertical DC-field is expected to improve the profile further.

IV. Conclusion and Outlook

Both numerical simulation and experiments indicate that the maximum power density and temperature rise in critical areas of the collector will be reduced due to modulated transversal sweeping. These results confirm that modulated transversal sweeping is a promising option for future high power CW Gyrotrons.

A more detailed analysis of data obtained with thermocouples during long pulse operation (with water jacket) is presently under investigation.

Acknowledgements

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