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Progress on the Frequency Stabilization of MW-Class 140 GHz Gyrotrons at W7-X with a Phase-Locked Loop

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At Wendelstein 7-X (W7-X), a first proof-of-principle frequency stabilization system for megawatt-class 140 GHz gyrotrons was implemented with an off-the-shelf Phase-Locked Loop (PLL) [1]. To overcome the limitation of this first basic PLL system, a new digital PLL system was implemented, which allows a much more flexible change in operating parameters and can be easily integrated into the W7-X system. The gyrotron output frequency can be controlled with the accelerating voltage, which is applied between the anode and cathode of the gyrotron diode-type Magnetron Injection Gun. For the PLL system, the accelerating voltage is varied through the body voltage power supply [2]. Experiments with the new PLL system were conducted at W7-X with a high-power 140 GHz gyrotron from manufacturer CPI at different pulse lengths (short pulses at 5 ms and long pulses ranging from 5 s to 30 s) and at different operating points.
During the short pulses, the free-running gyrotron frequency drops significantly due to the gyrotron cavity expansion caused by heating and electron beam space charge neutralization. To counter the frequency drop, a change in the body voltage of 5 kV was used during the experiments. The gyrotron frequency was locked within a time shorter than 1 ms and was stabilized for 3 ms after which the frequency drop is too high to be kept stable. For longer pulses, the initial frequency drop ceases after 1 s; however, during the free-running operation, frequency variations in the 1 MHz range still appear afterwards. With the PLL system, the change in body voltage to counter these frequency variations was below 1 kV and the gyrotron frequency could be stabilized after 1 s until the end of the pulse. In the frequency spectrum of the stabilized gyrotron output, a full -20 dB linewidth of below 20 kHz was measured. Still sidebands arise in the frequency spectrum, the most significant ones appear at harmonics of 3.2 kHz and 135 kHz from the main peak. Those frequencies were also observed in the noise of the cathode power supply and could not be suppressed sufficiently enough by the body power supply. Future investigations will be conducted to reduce the noise of the accelerating voltage.
The new PLL system paves the way for applications that need a stable frequency output of high-power gyrotrons at W7-X, such as Collective Thomson Scattering (CTS) Diagnostic [3] or experiments to directly heat ions with beat waves generated by two gyrotrons operated at a difference frequency equal to the ion cyclotron resonance frequency.

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