§23. 1.8 MW/1 s Operation of a 77 GHz Gyrotron with Flexible Anode Voltage Control


Since 2006, the installation of 77 GHz gyrotrons with each output power of over 1 MW has progressed in the Large Helical Device (LHD). In the present state, three 77 GHz gyrotrons are operational for plasma experiments.

The anode voltage \(V_A\) of the 77 GHz gyrotrons can be flexibly controlled using the preset waveform and the improvement of the electric efficiency was successfully achieved by applying stepwise \(V_A\). Figure 1 shows the time evolution of (a) the applied voltage for collector \(V_C\), for body \(V_B\) and for anode \(V_A\), (b) the beam current \(I_C\), the anode current \(I_A\) and the body current \(I_B\) and (c) the MOU output power for the latest-installed 77 GHz gyrotron. In this operation, enough low \(V_A\) not to start oscillation was applied for 100 ms. After that, \(V_A\) was increased to ~40 kV and the output power of 1.8 MW was stationary obtained for 1 s.

The charge neutralization of the gyrotron electron beam due to the ionization of the residual gas in the tube is a key for the improvement of the electric efficiency by the stepwise \(V_A\) applying. Figure 2 shows the dependence of the MOU output power on (a) \(V_B\), (b) \(T_1\) and (c) \(I_C\), where \(T_1\) denotes the duration of the first step of the stepwise \(V_A\). The electric efficiency \(\eta\) is also plotted in fig. 2 (c). The circles and triangles in fig. 2 (a) and (c) represent the results of the operations with the stepwise \(V_A\) and the regular \(V_A\) (rectangular waveform), respectively. \(T_1\) was fixed at 100 ms for the case of the stepwise \(V_A\) and \(V_B\) in fig. 2 (a) and (c). In fig. 2 (b), the gyrotron operation parameters were kept unchanged except for \(T_1\). The oscillation duration \(T_p\) was set at 10 ms for all these operations in fig. 2 (a)-(c).

As can be seen from fig. 2 (a), the operation with the regular \(V_A\) required 5~6 kV higher \(V_B\) to generate the similar output power with the stepwise \(V_A\) case. This means that the drop of the beam accelerating voltage occurred for the regular \(V_A\) case due to the space charge effect of the electron beam. Figure 2 (b) shows that the output power increased with the increase of the first step duration and was saturated for the longer duration than 50 ms. This indicates that the drop of the accelerating voltage recovered through the charge neutralization process in the \(T_1\) phase and the space charge was fully neutralized for ~50 ms in the operation. These results suggest that the gyrotron operational parameters are able to be optimized for the fully accelerated electron beam by applying the stepwise \(V_A\) with the adequate \(T_1\) duration, leading to the improvement of the output power and the electric efficiency as shown in fig. 2 (c).


**Fig. 2.** The dependence of the MOU output power on (a) \(V_B\), (b) \(T_1\) and (c) \(I_C\).