§2. Improvement of Electric Efficiency by Flexible Control of Anode Voltage for a 77 GHz Gyrotron

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In the LHD, seven gyrotrons with each oscillation frequency of 77, 82.7 and 84 GHz are operated in the present state.[1)] Excluding one 82.7-GHz tube, those are collector potential depression (CPD) type gyrotrons and a thyristor is used for each collector power supply to control the collector voltage (V_C). The response time of the thyristors are about ~100 ms and the slow response always causes the V_C drop at the RF start-up phase. The value of the V_C drop is not constant and vary by an oscillation even the other operational parameters are fixed. For example, the V_C drop is -8~-16 kV in the 1 MW operations for 77 GHz gyrotrons. The V_C drop means the excess CPD application and it limits the gyrotron operation range namely the other operational parameters must be suited to the excess depressed voltage. In 2009, we upgraded one of the anode power supplies to control the anode voltage (V_A) flexibly and tried to apply stepwise V_A in order to decrease the V_C drop at the oscillation start-up phase.

Figure 1 shows the schematic diagram of the flexible V_A control system. We transmit an arbitrary waveform from the control PC to the function generator through TCP/IP. The arbitrary waveform is inputted to the anode power supply as reference signal and applied as the anode voltage with the output-input ratio of 10 kV/ 1V.

Figure 2 shows the time evolution of (a) the V_C and the V_A, (b) the beam current I_C and (c) the output power P in the operation of 1 MW/ 0.3 s with stepwise V_A application for the second 77 GHz gyrotron. In this operation, the applied voltages of the collector and the body were fixed at V_C = 65 kV, V_B = 80 kV (the potential depression was 15 kV). The V_A was applied in two steps; the applied voltage in the first step was 23.9 kV, which was enough large to extract the beam current from the cathode and was enough small not to excite any mode and 37.7 kV required for exciting the main mode was applied in the second step after recovering collector voltage (~100 ms). As can be seen from the figure, the V_C drop could be reduced at the oscillation start-up phase by decreasing the rising I_C at that time. In this operation, the value of the V_C drop at the first V_A rising was 8.5 kV and that at the second V_A rising was 2.0 kV.

We carried out the property re-evaluation using stepwise V_A application and tried to extend the operational regime. The comparative results between normal V_A cases (rectangle waveform) and stepwise V_A cases are summarized in Table I, where I_M is the main coil current of the superconducting coil, T_p is the pulse duration and η is the output efficiency. We could successfully improve the output power and the efficiency by decreasing the main magnet field and increasing the anode voltage and the depression voltage for the stepwise V_A operations.

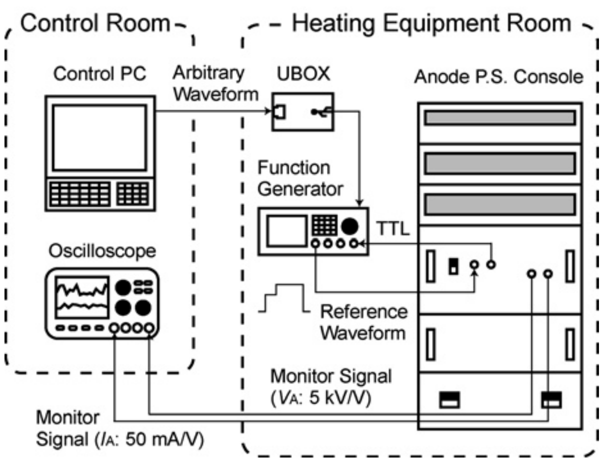

Fig. 1. Schematic diagram of the flexible V_A control system.

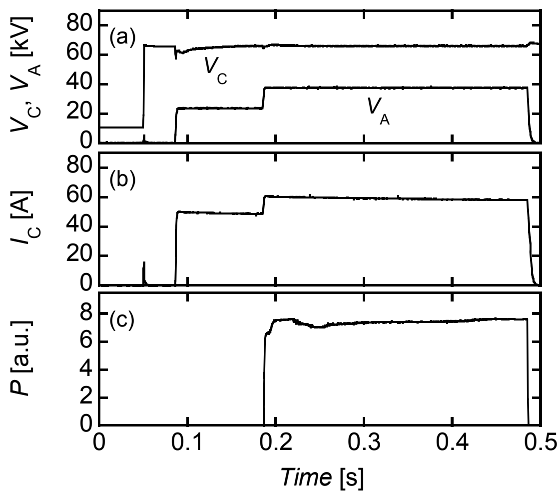

Fig. 2. Time evolution of (a) the V_C and the V_A, (b) the beam current I_C and (c) the output power in the operation of 1 MW/ 0.3 s with stepwise V_A application.

TABLE I. Comparative results between normal V_A cases (rectangle waveform) and stepwise V_A cases

Operation	Short pulse		Long pulse	
waveform	Rectangle	Stepwise	Rectangle	Stepwise
V_A [kV]	39.3	25->39.6	39.0	25->39.6
I_M [A]	102.3	102.08	102.4	102.08
V_C [kV]	62	56	65	65
I_C [A]	57.3	61.3	57.1	58.9
P [MW]	1.10	1.31	1.10	1.30
T_p [s]	0.1	0.1	1.2	1.0
η [%]	31.0	38.2	29.6	34.0

1) H. Takahashi *et al.*, Fusion Sci. Technol. **57**, 19 (2010).