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DEVELOPMENT OF THE X-BAND MEGAWATT-CLASS COAXIAL MAGNETRON*

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Abstract

X-band coaxial magnetrons are preferred for industrial and medical accelerators owing to the compact size, low cost and high efficiency. A conditioning and high power test stand for X-band magnetrons has been built in Tsinghua University. Two X-band magnetrons named "MGT-1#" and "MGT-2#" were tested at this stand. The maximum anode currents of both magnetrons reached 100 A after the conditioning process. At the duty cycle of 1‰, maximum peak output power of 1.71 MW and 1.89 MW was achieved for "MGT-1#" and "MGT-2#", respectively. The efficiencies of two magnetrons are both about 50%.

INTRODUCTION

Low energy electron linear accelerators (linacs) have been increasingly applied in the non-destructive testing, radiation therapy and radiation processing [1]. Compared with S-band and C-band linacs, X-band ones have the advantages of compact size, light weight and higher shunt impedance to meet the requirements of portable and high-precision system [2]. A challenge of the development of X-band technologies is the X-band high-power microwave source. Magnetron is one of the preferable candidates owing to the advantages of compact size, low cost and high efficiency [3].

The R&D of X-band coaxial magnetron is ongoing over the past decade in the Accelerator Laboratory of Tsinghua University [4]. Recently, a conditioning and high-power tests stand was built in Tsinghua University. An automatic conditioning approach was studied and realized. The layout of the stand is described in this work.

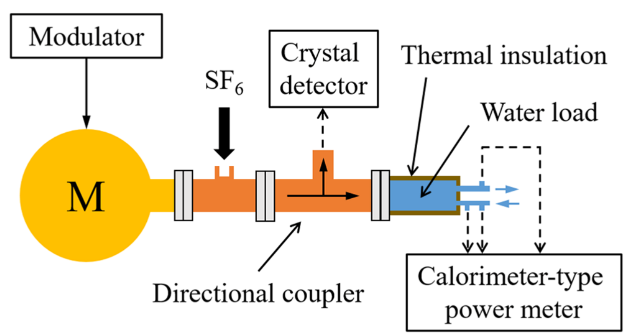
Two X-band coaxial magnetrons named "MGT-1#" and "MGT-2#" have been designed, fabricated and tested in Tsinghua University. The conditioning processes and high-power tests of these two magnetrons are presented in this paper.

TEST STAND

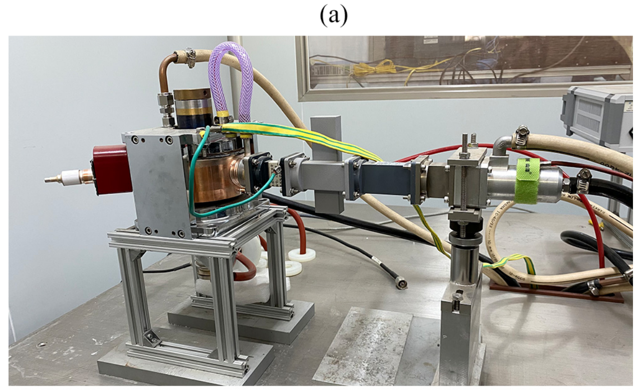
The systematic diagram of the conditioning and high-power test stand is shown in Fig. 1(a). The tested magnetron is driven by a line-type modulator (CEMV Electronics Co). The anode voltage and anode current of the magnetron are sampled by oscilloscope. The automatic conditioning process conducted before the high-power test is controlled and realized by the PLC system in the modulator to improve the power capacity of the magnetron. The high voltage of the pulse forming network (PFN) in the modulator automatically increases if there is no detected breakdowns (BDs) within 10 seconds. When breakdown happens, the high voltage of the PFN decreases immediately to protect the magnetron. The number of pulses per second (PPS) is gradually raised up to 300 Hz.

The test data (e.g., date, time, anode voltage, anode current, number of breakdowns, PPS) are recorded once per second in the database management system. The output power of the magnetron can be measured by two methods. One is via the directional coupler and crystal detector, and the other is via the water-loading calorimeter type power meter. The latter is adopted in this work because of the higher credibility.

Two X-band magnetrons named "MGT-1#" and "MGT-2#" have been tested at this stand, as shown in Fig. 1(b).



(a)



(b)

Figure 1: (a) The systematic diagram of the test stand. (b) The layout of the test.

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CONDITIONING PROCESSES

The conditioning histories of "MGT-1#" and "MGT-2#" are shown in Fig. 2. The black, red and blue dots in Fig. 2 represent the anode current of the magnetron, cumulated number of breakdowns (Cum. BDs) and PPS as a function of the number of pulses, respectively.

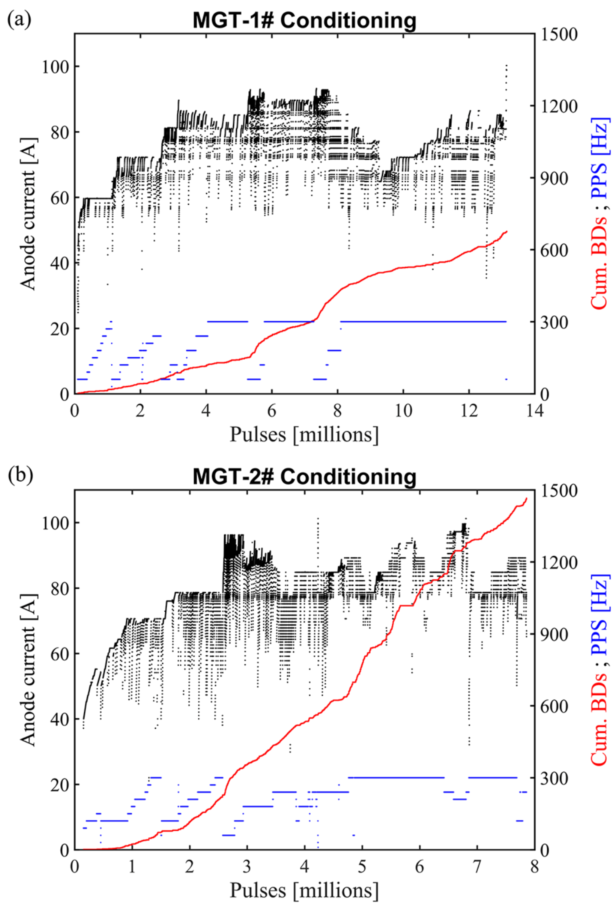

Figure 2: Conditioning histories of (a) "MGT-1#" and (b) "MGT-2#".

Table 1: Conditioning of Two Magnetrons

Magnetron	MGT-1#	MGT-2#
Pulse width [μs]	3.37	3.34
Pulses [million]	13.15	7.86
Cum. BDs	676	1465
Max. anode current [A] @ PPS	100 @ 60 Hz 90 @ 300 Hz	101 @ 210 Hz 95 @ 300 Hz

The pulse width was kept constant as approximately 3.3 μs in the conditioning. After 12.15 millions pulses with 676 cumulated breakdowns, the maximum anode current of "MGT-1#" reached 100 A with the PPS of 60 Hz. Less pulses but more numbers of the breakdown occurred in the conditioning process of "MGT-2#" compared with that of "MGT-1#", as summarized in Table 1. The statuses of the magnetrons were similar after the conditioning. The maximum anode current of "MGT-2#" reached 101 A with the PPS of 210 Hz. Given by the maximum PPS of 300 Hz and the pulse width, the maximum duty cycle was 1‰. Under this condition, the maximum anode currents of "MGT-1#" and "MGT-2#" reached 90 A and 95 A, respectively.

HIGH-POWER TESTS

The water-loading calorimeter type power meter utilized in the high-power test is coated by the thermal insulation material, which is not adiabatic and will absorb a small part of the power. Consequently, the power meter needs to be calibrated to acquire the accurate power.

In our experiment, the water-loading calorimeter type power meter was calibrated by an L3Harris magnetron (L6170). Figure 3 presents the calibration results. It can be derived from slope of the curve that the measured power is 93% of the nominal power.

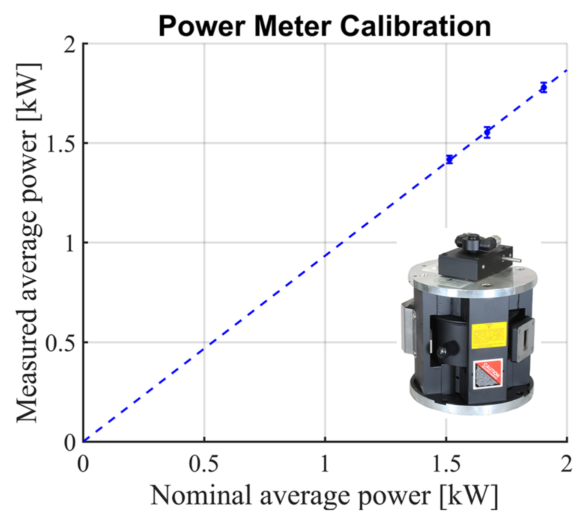

Figure 3: Calibration of water-loading calorimeter type power meter by the L3Harris magnetron [5].

Table 2: Performance Characteristics of Two Magnetrons with Duty Cycle of 1‰

Magnetron	MGT-1#	MGT-2#
Peak output power [MW]	1.71	1.89
Peak anode voltage [kV]	42.4	41.8
Peak anode current [A]	80.8	89.2
Efficiency [%]	50.0	50.7
Pulse width [μs]	3.37	3.36
PPS [Hz]	300	300

The output power of two X-band magnetrons were tested at the duty cycle of 1‰ (pulse width of 3.36 μs and PPS of 300 Hz) at first. The peak output power of "MGT-1#" reached 1.71 MW with the peak anode voltage of 42.4 kV and the peak anode current of 80.8 A. After the operating at 1.71 MW for 20 minutes, continuous breakdowns occurred in "MGT-1#". So we reduced the duty cycle in the later experiments of "MGT-1#". The maximum peak output power of "MGT-1#" finally reached 1.92 MW and

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2.08 MW at the duty cycle of 0.8‰ and 0.4‰, respectively. As for the MGT-2#, all the measurements were conducted at the duty cycle of 1‰. The maximum peak output power of MGT-2# finally reached 1.89 MW with the peak anode voltage of 41.8 kV and the peak anode current of 89.2 A. The efficiencies of "MGT-1#" and "MGT-2#" were 50.5% and 50.7%, respectively. The performances of "MGT-1#" and "MGT-2#" with the duty cycle of 1‰ are summarized in Table 2.

The performances characteristics including the voltage-current curve and power-current curves of "MGT-1#" and "MGT-2#" obtained from the conditionings and high-power tests are shown in Fig. 4.

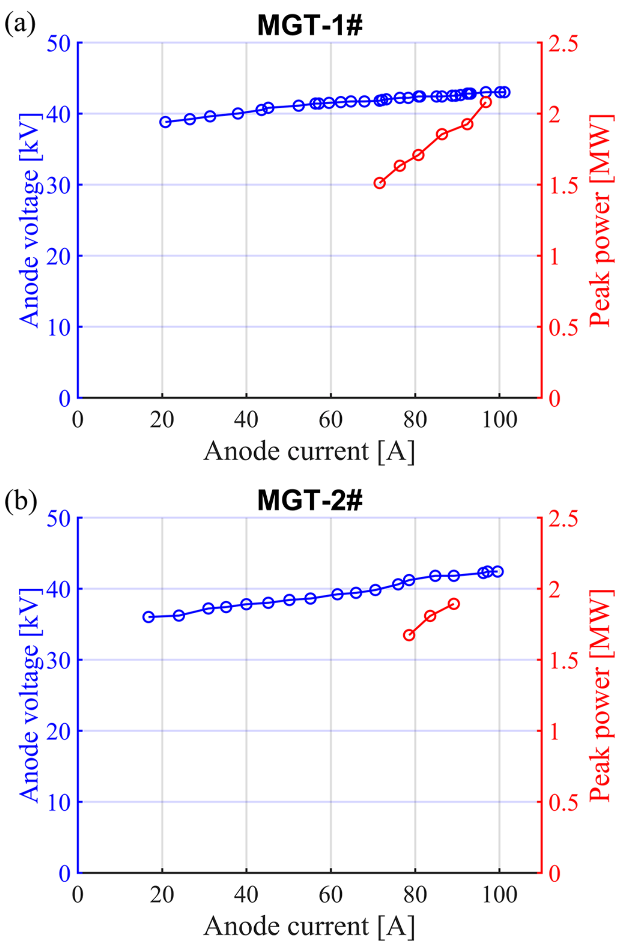

Figure 4: Performance characteristics of (a) "MGT-1#" and (b) "MGT-2#".

CONCLUSION

A conditioning and high power test stand for X-band magnetrons has been established in Tsinghua University. The conditioning and high power tests of two X-band megawatt-class coaxial magnetrons showed good results. At the duty cycle of 1‰, maximum peak output power of 1.71 MW and 1.89 MW were achieved for "MGT-1#" and "MGT-2#", respectively. The efficiencies of two magnetrons were 50.5% and 50.7%, respectively.

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