DESIGN OF THE ELECTRON CYCLOTRON HEATING EXPANSION SYSTEM ON EAST

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ABSTRACT

Electron Cyclotron Resonance Heating (ECRH) expansion system on EAST is in development. This expansion system includes two gyrotron systems. It will enhance the total ECRH's power output capability at the 140 GHz frequency to 4.5MW for up to 1000 seconds.

INTRODUCTION

- The Phase I long-pulse high-power electron cyclotron resonance heating (ECRH) system has been developed on EAST. This system consists of four sets of gyrotrons. After years of development and optimization, it has achieved an operational capability of 3.2 MW for 100–1000 seconds during EAST experiments, providing a crucial heating method for EAST's high-parameter long-pulse operation[3].
- To further enhance EAST's plasma parameters, the electron cyclotron wave power needs to be increased to over 4.5 MW. Therefore, plans are underway for a Phase II ECRH upgrade for EAST.

OVERALL SYSTEM ENGINEERING DESIGN

To accommodate the entire operational range of EAST's toroidal field, the two additional systems, i.e., #5 and #6 systems, will primarily operate at 140 GHz but can switch to a secondary frequency of 105 GHz to adapt to EAST's low toroidal field operations. The layout diagram of the ECH expansion system is shown in the red rectangular area in Fig. 1.

The expanded ECRH system consists of two subsystems: #5 system and #6 system. Similar to the Phase I ECRH system, each subsystem includes the gyrotron system, the high-voltage power supply system, the transmission line and antenna system, the control and protection system, and the active cooling (water-cooling and oil-cooling) system. Each gyrotron system includes one gyrotron, a superconducting magnet and its refrigerator, and auxiliary power supplies for the gyrotron (such as the superconducting magnet power supply, ion pump power supply, collector coil power supply, and filament power supply).

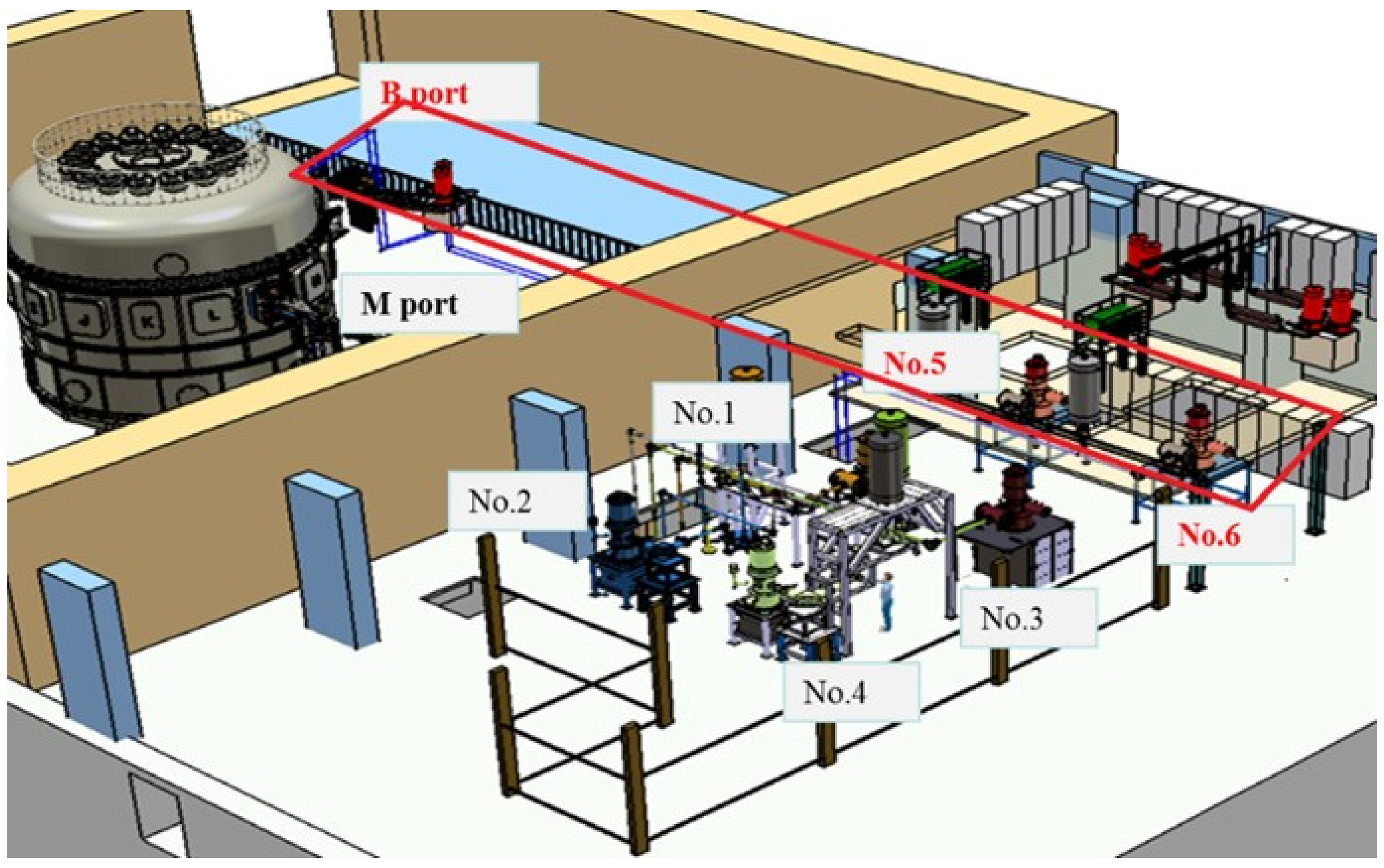


Fig. 1. The layout diagram of the EAST ECRH system, where the extended #5 and #6 systems are in the red rectangular area.

TRANSMISSION LINES AND ANTENNA

The corrugated circular waveguides are the main parts of the transmission lines for Phase I ECRH system. To maintain system compatibility, the upgraded #5 and #6 systems will also utilize this type of waveguide. The gyrotrons of the ECRH expansion system are located in Hall 8-1, with antennas positioned at the B port of the EAST device.

As shown in Fig. 2, each line undergoes 10 directional changes, and the combined total length of both lines is approximately 120 meters. Each transmission line has a power capacity of 1 MW and operates at frequencies of 140/105 GHz, meeting the requirements for continuous-wave operation.

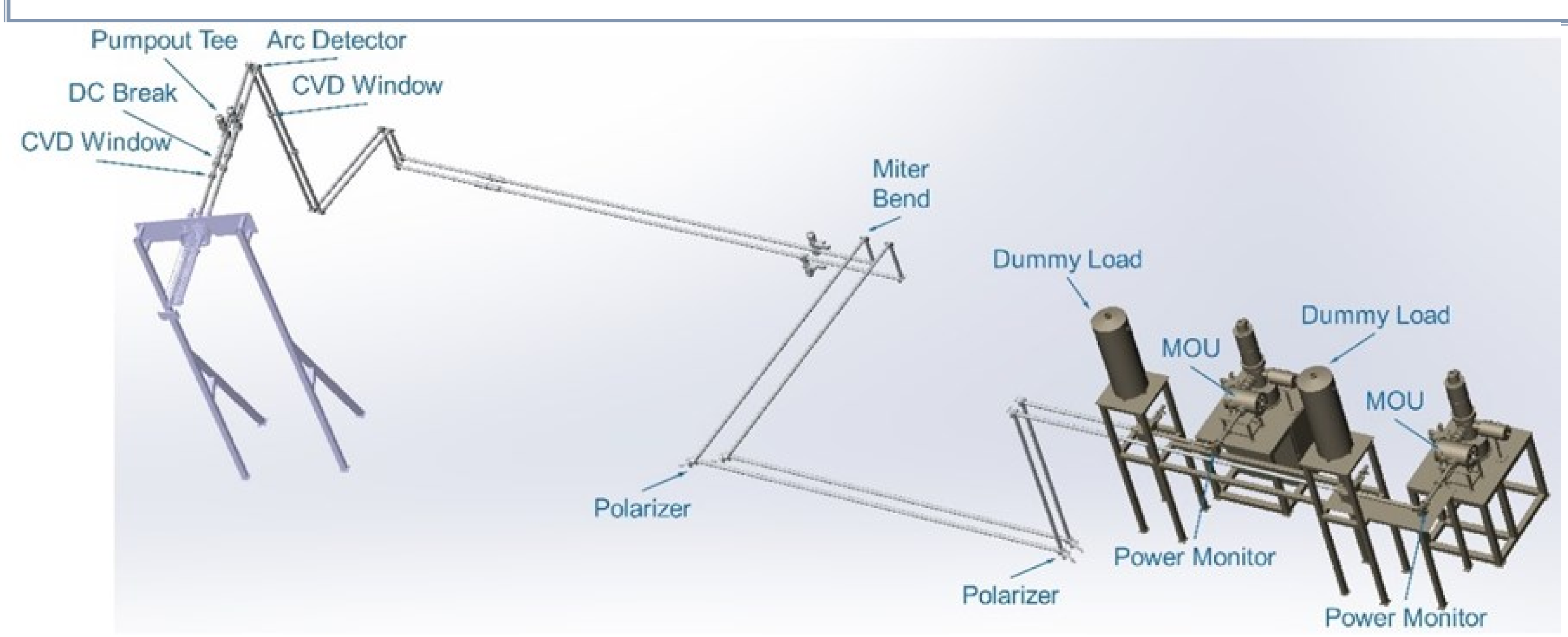


Fig. 2. The layout of the transmission lines for the electron cyclotron heating expansion system.

TRANSMISSION LINES AND ANTENNA

The upgraded systems #5 and #6 share horizontal Port B with the upgraded 4.6GHz Lower Hybrid Wave (LHW) system. The quasi-optical transmission and emission unit shown in Fig. 3 is the core component of the antenna. There are two independent transmission and emission units. Each unit utilizes two metal mirrors based on the quasi-optical characteristics of millimeter waves to achieve microwave power injection. Each unit consists of a 2.6-meter-long 63.5 mm stainless steel waveguide, a focusing mirror, and a rotating mirror with a drive mechanism. The stainless steel waveguide connects to the external transmission system of the antenna, enabling microwave feed into the antenna interior. The focusing mirror and rotating mirror form a quasi-optical emission mirror set, which constrains the beam characteristics and adjusts the emission angle to achieve precise microwave power deposition. The emission centers of the two beams are 350 mm apart from the central horizontal plane of EAST. The major radius R of the emission point is 2750 mm, and the optimal current drive poloidal angle is 111°. The incident distance of the focusing mirror is the distance from the waveguide port to the reflective center of the focusing mirror, denoted as z_1 = 240 mm. The angle θ between the incident beam and the reflected beam of the focusing mirror is 118.6°. The distance from the center of the focusing mirror to the center of the rotating mirror is z_2 = 125 mm, and the distance from the center of the rotating mirror to the plasma resonance layer is z≈1200 mm. To balance the conflict between minimizing the beam waist of the ECW within the plasma resonance layer and the engineering constraint that the focusing mirror size, optimization calculations yielded the following results: The ellipsoidal surface has a semi-major axis a = 1.311 m and a semi-minor axis b = 0.674 m; The equivalent focal length is 0.653 m; The beam radius at the resonance layer position wzp ≈ 43.5 mm, as shown in Fig. 4.

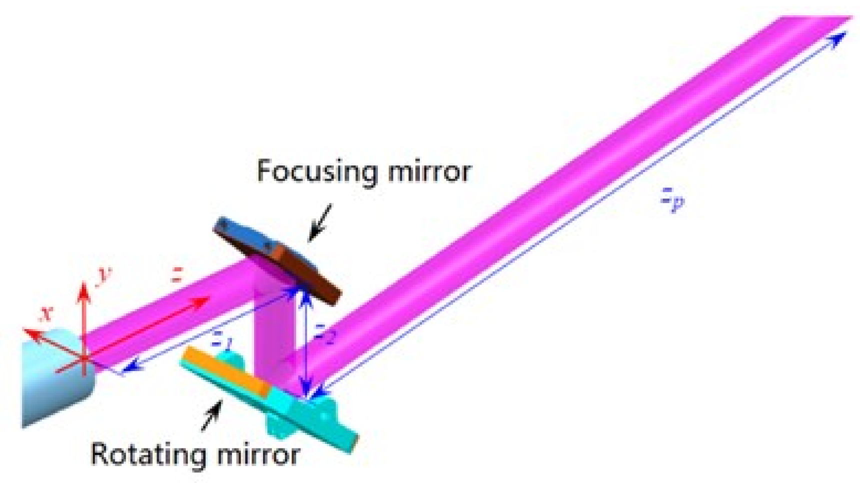


Fig. 3. The quasi-optical transmission and emission unit.

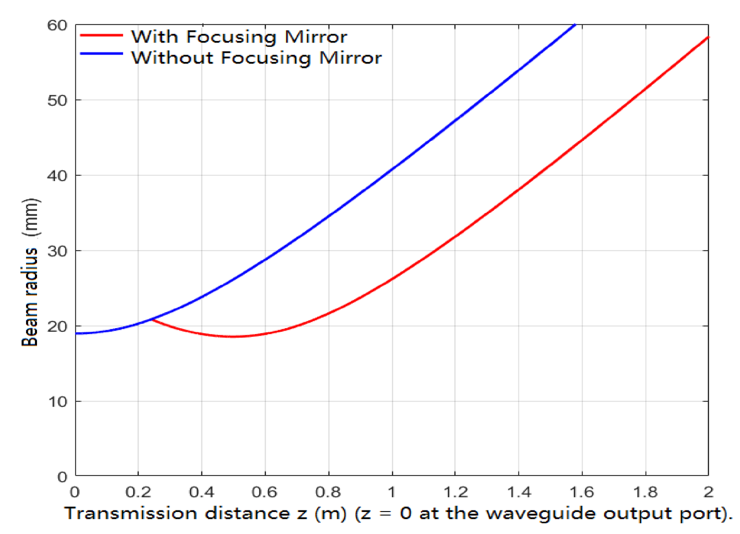
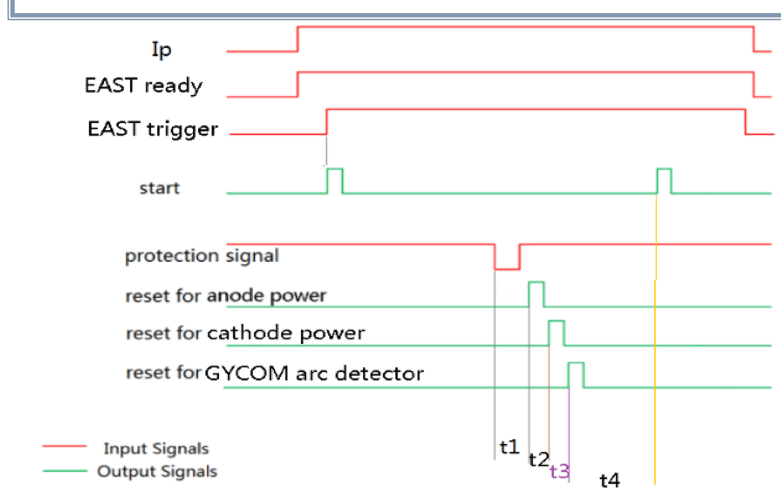


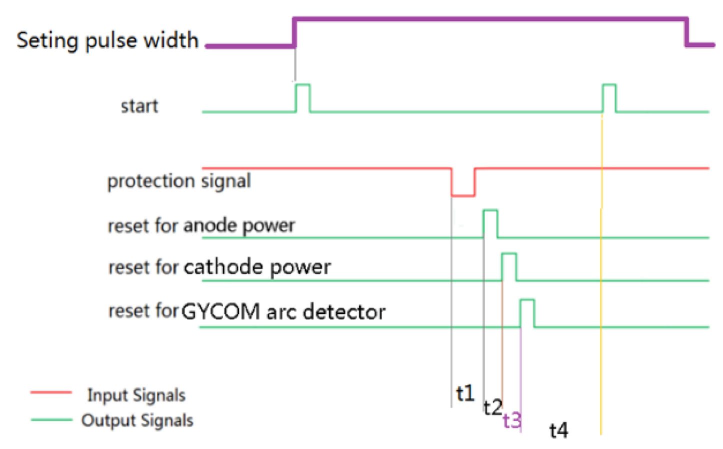
Fig. 4. The evolution of beam radius with transmission distance.

CONTROL SYSTEM

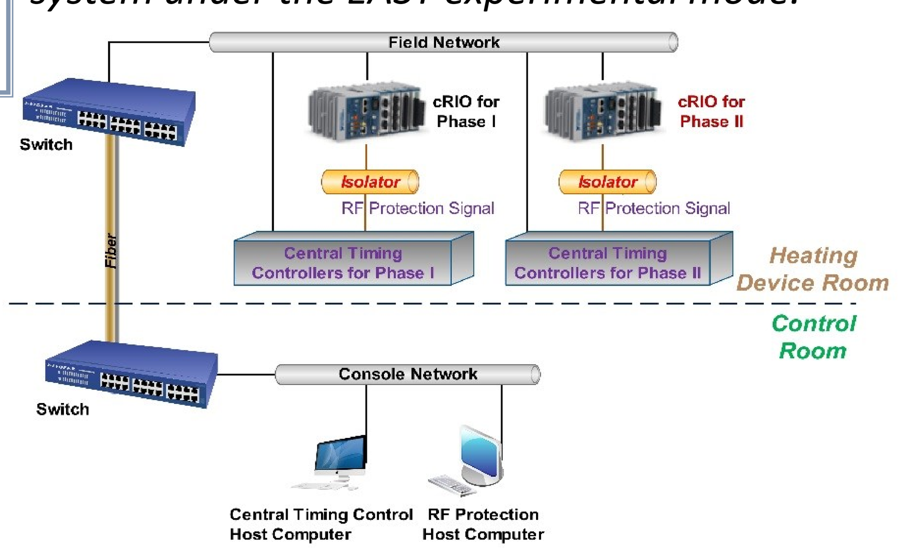
The independent control system for the #5 and #6 systems was designed, including a new automatic restart control system and a new real-time power control system. The real-time power control system is designed to receive power demand signals from the Plasma Control System (PCS) and output the corresponding power to meet the more flexible power requirements of EAST experiments. A new central timing controller has been designed with three operating modes: system self-check mode, test mode, and EAST experiment mode. In test mode and EAST experiment mode, the automatic restart function can be enabled, allowing the gyrotron to restart automatically in the event of a fault interruption.



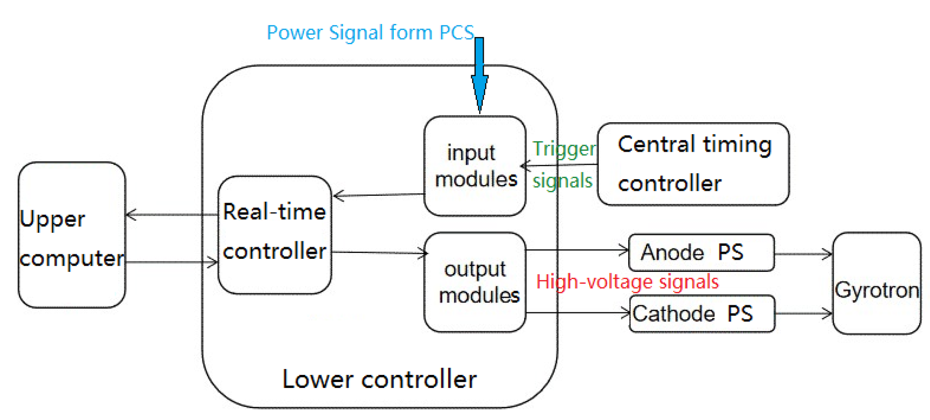
The automatic restart logic for ECRH expansion system under the EAST experimental mode.



The automatic restart logic for ECRH expansion system under gyrotron test mode.



The architecture diagram of the RF protection system (including both Phase I and Phase II).



The architecture diagram of the real-time power control system for ECRH expansion system.

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