THE CONSTRUCTION AND COMMISSIONING OF THE ELECTRON BERNSTEIN WAVE HEATING AND CURRENT DRIVE SYSTEM FOR MAST-U

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1. INTRODUCTION

The UK's Spherical Tokamak for Energy Production (STEP) programme was established to design and build a prototype powerplant with the aim of achieving net energy production [1]. Heating and Current drive (HCD) is a key driver for a fusion power plant design and it has been concluded that the optimum HCD system for STEP is microwave-based, using a combination of the Electron Cyclotron and Electron Bernstein Wave (EBW) approaches [2]. However, EBW Current-Drive (EBCD) has a lower readiness level, having not been demonstrated at high power (MW scale or above) in spherical tokamaks. Therefore, to progress the readiness level, an ambitious development programme has been initiated to integrate a 1.8MW EBW system on the MAST-U tokamak [3]. In addition to enhancing the experimental capabilities of the MAST-U device, the EBW system aims at validating theoretical predictions of enhanced current drive capabilities (relative to conventional electron cyclotron current drive) [4]. Microwave coupling to the EBW mode has been demonstrated on other devices [5][6] and the MAST-U EBW experiments aim to provide an experimental test of the EBCD technique in a Spherical Tokamak [7]: to examine open issues regarding the Low Field Side coupling scheme (O-X-B mode conversion), examine effects of density fluctuations (driven by MHD, ELMs, etc), collisional damping and non-linear effects, verify current drive capabilities (compare experimental versus modelled Current-Drive efficiencies ~ 0.1-0.14 A/W) and extend the original MAST experiments on EBW-based solenoid free start-up [8].

2. SYSTEM OVERVIEW

The MAST-U EBW system [3] includes the following main sub-systems (Fig. 1): high voltage power supplies; two dual frequency gyrotrons and Matching-Optics Unit and their ancillaries; evacuated transmission lines; a long pulse dummy load; control and instrumentation system; services such as water cooling and vacuum pumping. The Gyrotrons are dual frequency devices (34.8 GHz 1.5-1.6 MW delivered to plasma for HCD, 28 GHz 650-750 kW delivered to plasma for non-inductive start-up or HCD) [9]. The microwave power travels to the MAST-U vessel through evacuated hybrid (HE11, 88.9 mm dia.) corrugated waveguides and mitre bends. The microwave power can also be directed into a long pulse dummy load located in the EBW area for local Gyrotron conditioning. Inside the MAST-U vacuum vessel, a steerable in-vessel launching system provides flexible options via separate launchers: off-axis, on-axis and high field side start-up [10]. Stray microwave power detectors (sniffer probes) and protection components (interceptor plates) in the path of the first reflection will also be installed in the MAST-U vessel.

3. SYSTEM STATUS AND PLANS

The detailed design of the MAST-U EBW system is completed, and the project has now entered the installation and commissioning phase, the details are below:

Completed as of January 2025: The gyrotrons Factory Acceptance Test (FAT) [9] is complete, and gyrotrons were delivered to site as well as most of the gyrotron auxiliary equipment. The gyrotron area preparation work is complete. The High Voltage Power Supplies (HVPS) installation is complete. Gyrotrons base and Super-Conductor Magnet installation is completed. The long pulse dummy-load Factory and Site Acceptance Tests (SAT) is complete. The FATs for the transmission-line components are partly completed. The design of the launcher is complete, and a prototype of the steering mechanism was tested (Fig. 2). The launcher is in final manufacturing stage. Prototypes for the in-vessel mirrors (copper-coated graphite) were produced; the mirrors are in the final manufacturing stage. The Control and Instrumentation (C&I) and Personal Protection Safety System (PASS) design are finalized.

Plans for 2025: The first 2025 objective for the MAST-U EBW project is to commission the gyrotrons in a short pulse dummy load (few tens of ms), then in the long pulse test load (few seconds pulses). This requires installation and commissioning of the HVPS, gyrotrons and all their ancillary systems. The PASS system and C&I are also required for commissioning activities. The long pulse dummy load and transmission line elements (in the EBW area) required for Gyrotron commissioning will also be installed. The second objective is the installation of in-vessel components at the start of a long MAST-U engineering break, devoted to the installation of the EBW system and additional neutral beam heating capabilities: the launcher, steering mechanism and in-vessel protection components will be installed in the MAST-U vessel. In parallel, we will finalise the C&I design for launch control (steering mechanism, polarisers), the machine protection system based on sniffer probes and IR cameras, and the integration of the EBW system in the MAST-U machine control (MC) environment.

Plans for 2026-2027: The EBW system will be commissioned in MAST-U after the 2025-2026 MAST-U engineering break. Prerequisites are the following: the installation of the transmission lines between the EBW area and the MAST-U vessel and commissioning of C&I system for launch control and sniffer probes. For safe (machine safety) application of EBW into MAST-U plasmas, Real-Time control and protection based on plasma parameters will be used.

4. OUTLOOK

The MAST-U EBW system project is in the installation and commissioning phase. The gyrotrons SAT and commissioning in short and long pulse dummy load are scheduled in 2025. The system will be available for MAST-U experiments in 2026-2027 to assess EBW-Heating and Current Drive Capabilities on spherical tokamaks. Progresses in the system installation and commissioning will be highlighted along with lessons learned from a technical and project management point of view.

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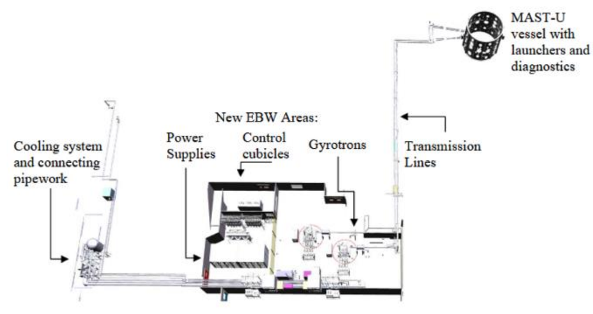

Figure 1. Overview of the MAST-U EBW system layout

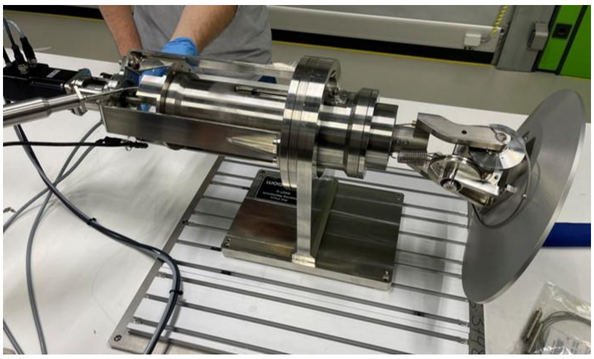

Figure 2. Prototype of the MAST-U EBW launcher steering mechanism.