Fusion Engineering and Design xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Progress in magnet design activities for the material plasma exposure experiment☆

Robert Duckworth[a], Arnold Lumsdaine[a,*], Juergen Rapp[a], Tom Bjorholm[a], Jonathan Demko[b], Dean McGinnis[a], John Caughman[a], Rick Goulding[a], and the MPEX team

[a] Oak Ridge National Laboratory, Oak Ridge, TN, USA
[b] LeTourneau University, Longview, TX, USA

HIGHLIGHTS

- A new linear plasma facility is proposed, requiring a superconducting magnet system.
- Magnets are designed in order to meet field requirements for helicon source and electron and ion heating.
- A superconducting magnet and cryogenic system has been planned in order to achieve steady-state operation and mitigate risk.

ARTICLE INFO

Article history:
Received 3 October 2016
Received in revised form 26 May 2017
Accepted 30 May 2017
Available online xxx

Keywords:
Plasma facing components
Plasma-material interactions
R&D facilities
Linear plasma experiments
Superconducting magnets

ABSTRACT

One of the critical challenges for the development of next generation fusion facilities, such as a Fusion Nuclear Science Facility (FNSF) or DEMO, is the understanding of plasma material interactions (PMI). Making progress in PMI research will require integrated facilities that can provide the types of conditions that will be seen in the first wall and divertor regions of future fusion facilities. To meet this need, a new linear plasma facility, the Materials Plasma Exposure Experiment (MPEX), is proposed. In order to generate high ion fluence to simulate fusion divertor conditions, a steady-state plasma will be generated and confined with superconducting magnets. The on-axis fields will range from 1 to 2.5 T in order to meet the requirements of the various plasma source and heating systems. Details on the pre-conceptual design of the magnets and cryogenic system are presented.

1. Motivation

One of the largest technology gaps for the development of next step fusion facilities is in the area of plasma material interactions (PMI) [1,2]. The field of plasma material interactions occurs at the intersection of plasma physics, materials science, and engineering, and requires expertise and research and development in each of these fields. The Materials Plasma Exposure Experiment (MPEX) is a proposed linear plasma experiment that will begin to close this technology gap [3,4]. Fig. 1 shows a model of the pre-conceptual design of MPEX. The plasma source will be a helicon antenna, with heating provided by electron Bernstein wave and ion cyclotron heating systems totaling up to 800 kW of input power. This will produce heat fluxes of up to 10 MW/m^2 and ion fluxes of up to 10^{24}/m^2-s over a 75 cm^2 area at the target. In order to provide long-pulse conditions, plasma will be confined with superconducting magnets with on-axis fields from 1 to 2.5 T, and all plasma facing components will be actively cooled. In order to examine the plasma interactions with neutron damaged materials, MPEX will have the capability to handle low activation irradiated samples. A vacuum cask which can be disconnected from the high field environment in order to execute in-situ diagnostics is planned for the facility as well. Details on the pre-conceptual design of MPEX [5] and the

---

☆ This manuscript has been authored by UT-Battelle, LLC under Contract No. DE-AC05-00OR22725 with the U.S. Department of Energy. The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes. The Department of Energy will provide public access to these results of federally sponsored research in accordance with the DOE Public Access Plan (http://energy.gov/downloads/doe-public-access-plan)

* Corresponding author.
E-mail address: lumsdainea@ornl.gov (A. Lumsdaine).

http://dx.doi.org/10.1016/j.fusengdes.2017.05.137
0920-3796/© 2017 Elsevier B.V. All rights reserved.

Please cite this article in press as: R. Duckworth, et al., Progress in magnet design activities for the material plasma exposure experiment, Fusion Eng. Des. (2017), http://dx.doi.org/10.1016/j.fusengdes.2017.05.137

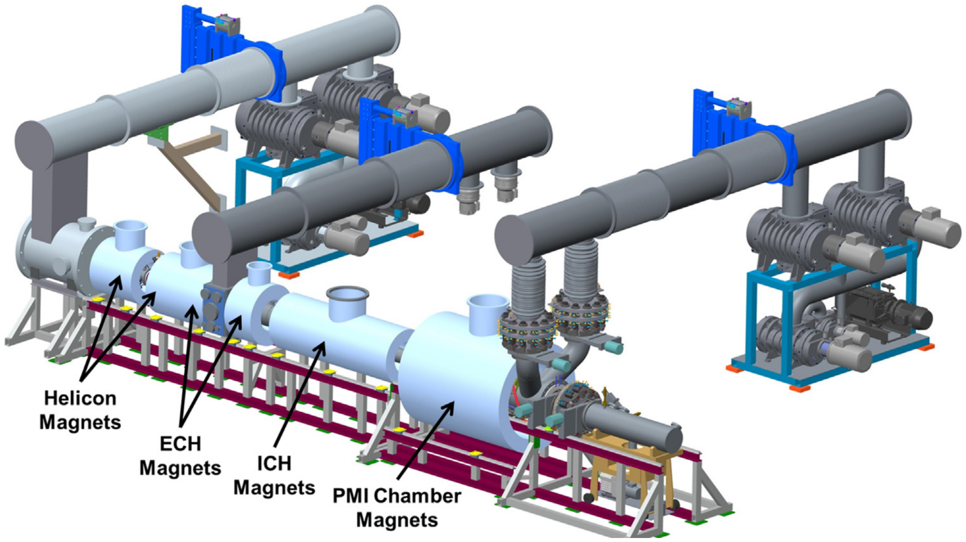

Fig. 1. MPEX pre-conceptual design.

operations of the prototype experiment, Proto-MPEX, can be found elsewhere [6,7].

2. Design of magnet system

2.1. Specifications

Superconducting magnets are under consideration in order to provide the operating fields to confine the plasma and enable heating to the required fluxes and temperatures. As shown in Fig. 1, the magnets are divided into four different systems, which are placed into five different cryostats. The magnets systems are:

- Helicon magnets, placed fore and aft of the helicon antenna, which is the plasma source;
- Electron cyclotron heating (ECH) magnets, placed fore and aft of an EC heating area, where microwave power will be launched into a 1 T resonant zone;
- Ion cyclotron heating (ICH) magnets, extended over two IC antennae;
- Plasma material interaction (PMI) chamber magnets, placed over a 50 cm diameter PMI chamber, where the plasma will terminate onto a target, and where most of the machine diagnostics will be placed.

The dimensional requirements on the magnet systems are determined based on the size of the vacuum vessel and the need for diagnostic space. As much as possible, the magnets are made with the same inner diameters in order to reduce cost and risk in the serial production of the magnet systems. The inner diameter of the warm bore of the helicon, ECH, and ICH magnets will be 43.2 cm (17 inches) while the warm bore of the PMI chamber magnets will be 131 cm (51.5 inches). The length of the device from the center of the ECH heating chamber to the target is 5 m. Finally, separations between systems like the ECH/ICH and ICH/PMI were minimized to 30 cm and 25 cm respectively to permit utility (water, electrical) access while minimizing the divergence of field along the length.

The magnetic field specifications are based on the requirements of the various heating systems. The peak field in the helicon antenna region should be less than 0.5 T with no more than 10% variation over the 40 cm length of the antenna window. The ECH field should be no greater than 1.0 T and no less than 0.6 T in the heating region. The ICH field should be 1.8 T over the 60 cm IC antennae length, with a 1.6 T beach area downstream of the antennae for ion normalization. The PMI chamber field should be 1.0 T over the 1 m length of the chamber.

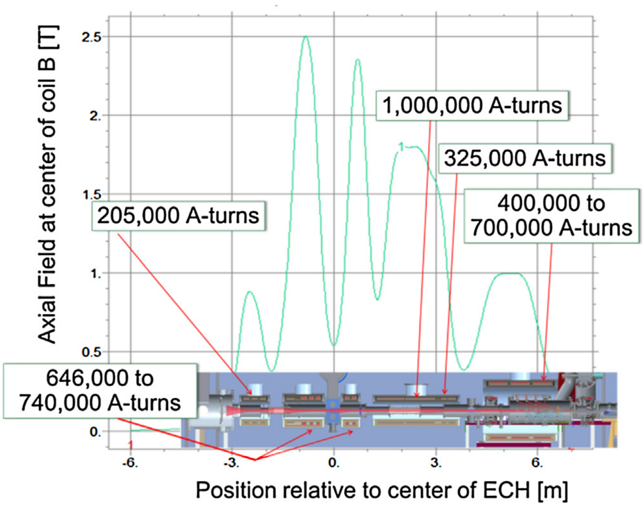

Fig. 2. Field profile along length of MPEX.

Given the dimensional and field requirements, the amp-turns along the length were grouped together to create the target magnetic field profile for each of these areas simultaneously. Fig. 2 shows the breakdown of the amp-turns along length of MPEX along with a cross section of the device.

2.2. Conductor

In order to determine the feasibility of superconducting coils for the amp-turns, the effective engineering current density, J_e, and the winding area, $A_{winding}$, was found from the expression:

$$N * I = J_e A_{winding} \quad (1)$$

where N is the number of turns and I is the current of the individual conductor or turn. For a given winding, the number of turns was calculated using the conductor cross sectional area and assuming a 30% insulation packing factor.

While several different conductors have been considered previously [8], a commercial available NbTi Wire-in-channel conductor

Please cite this article in press as: R. Duckworth, et al., Progress in magnet design activities for the material plasma exposure experiment, Fusion Eng. Des. (2017), http://dx.doi.org/10.1016/j.fusengdes.2017.05.137