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Progress in development and application of lithium based components for Tokamak

A.V. Vertkov[a,*], I.E. Lyublinski[a], M.Yu. Zharkov[a], V.V. Semenov[a], E.A. Azizov[b], V.B. Lazarev[b], S.V. Mirnov[b]

[a] *JSC "Red Star", Moscow, Russian Federation*
[b] *SRC TRINITI, Troitsk, Moscow, Russian Federation*

HIGHLIGHTS

- Porous materials from W fibers filled with lithium applied as structural material of PFC in tokamaks.
- Tests of lithium PFC prototypes for steady-state operation are in progress in FTU and KTM tokamaks.
- Concept of lithium closed loop circulation for protection of PFC has been realized and confirmed experimentally in T-11M tokamak.
- Methods for PFC lithium surface cleaning and rehabilitation, lithium removal from tokamak wall has been demonstrated experimentally.

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ABSTRACT

Experiments with lithium plasma facing components (PFCs) show promising results for the operation of hot plasma facilities and the general improvement of plasma parameters. The design and development of new tokamak plasma facing material (PFM) based on lithium capillary porous systems (CPS) are described in this paper.

The recent progress in the development of limiters with different kinds of CPS is relevant for protection of tokamak PFCs from damage under normal operation, ELMs and disruptions. New PFM eliminates the lithium flux into plasma, its pollution and lithium accumulation.

Here we present an overview of the design and the experimental tests of the liquid lithium limiters. These limiters are based on CPS with hard matrix from stainless steel mesh, molybdenum and tungsten. Different types of limiter have been taken into account: the horizontal and vertical rail type limiters with passive and active cooling for investigation the possibility to provide the closed lithium circulation in tokamak chamber; the ring CPS-based limiter for investigation of lithium behavior in limiter scrape-off layer (SOL).

Here we also present the preliminary results of the application of the cryogenic techniques for lithium removal from the chamber wall after operation in hot plasma.

1. Introduction

The new lithium plasma facing materials (PFM), based on capillary porous systems (CPS) in which liquid lithium fills a porous matrix can be used for a manufacturing of a plasma facing component (PFC) for current plasma devices and for the future DEMO type steady-state tokamak reactor [1,2].

We have developed such PFCs as the application of different kinds of limiters with lithium CPS and have tested them in plasma experiments in T-11M, T-10, FTU tokamaks, stellarator TJ-II and plasma accelerators QSPA, MC 2000-UG. All these experiments demonstrated the clear visible protection of tokamak PFCs from damage under normal operation, ELMs and disruptions. The use of lithium improved the plasma operation parameters and advertised a self-renewal of PFC surface with elimination of plasma pollution.

2. Progress in development of lithium CPS

The key problems of long-term tokamak PFC are surface damage, property degradation, plasma pollution and tritium retention. They may be overcome by the usage of liquid lithium, showing low Z and low neutron activation.

* Corresponding author. Tel.: +7 499 6138311; fax: +7 499 6138311.
E-mail address: avertkov@yandex.ru (A.V. Vertkov).

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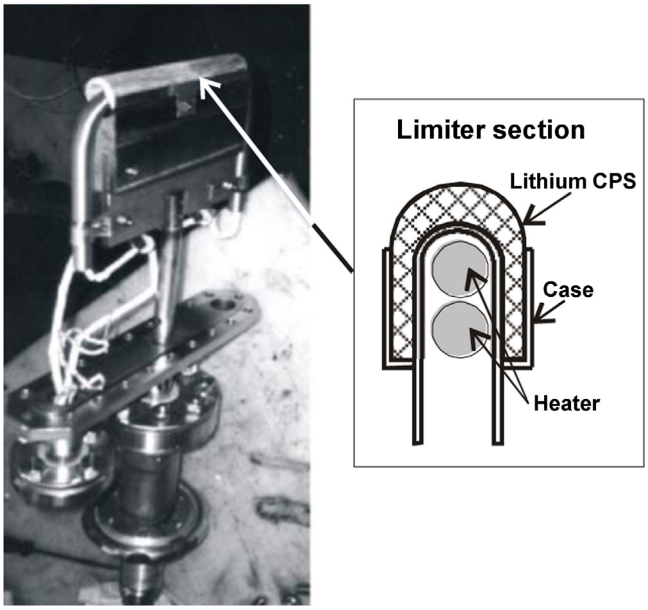

Fig. 1. Lithium limiter of T-11M tokamak.

Different matrix materials may serve as a basis for lithium CPS, but there are constraining, and sometimes contradictory, engineering and physical requirements [1,2], which have to be taken into account before the realization of PFCs. That reduces the actual number of potentially useful matrix materials.

We performed a comparative analysis of physical properties of ferritic, austenitic steels, vanadium, molybdenum and tungsten alloys used as CPS hard basis (sintered powder or fiber).

The analysis showed that the fiber based materials like mesh or felt from tungsten (W) are the most preferable.

For example, we compared the tungsten felt (wire 30 μm in diameter, pore size 20 μm and porosity of 0.4) with felt from stainless steel, and showed that the first has higher properties in terms of thermal shock parameter (3 orders of magnitude), thermal conductivity (factor 5.5), corrosion resistance (temperature limits for W and stainless steel are 800–900 °C and 550–600 °C respectively).

The powder based CPS has not been taken into account because of its low plasticity and strength resulting in low available power flux to the surface (thermal shock parameter) and problems with banding to supporting structure.

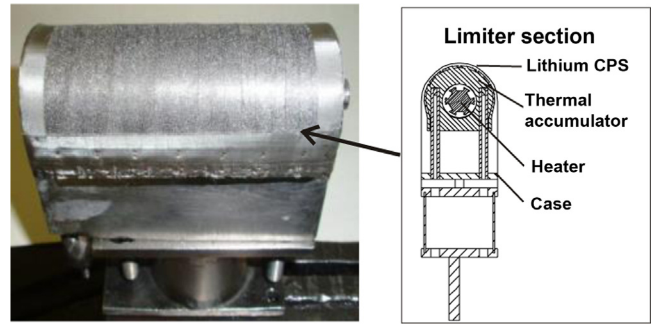

Fig. 3. Lithium limiter with thermal accumulator.

The promising CPS design has been developed in the aim of the guaranteed surface self-renewal [3]. It consists of an outer layer (with pore size 20–100 μm) and an inner layer (with arteries of 200 μm in diameter). Such structure of CPS provides high capillary pressure, sufficient low hydraulic and hydro-magnetic resistance for lithium flow in comparison with homogeneous CPS.

3. Progress in PFC design

The maximal temperature for plasma facing surface, in order to ensure a reasonable level of lithium atom flux to the plasma is estimated to 550 °C. Therefore PFC design should provide surface temperature stabilization below this maximum threshold level.

The first series of lithium limiters for T-11M tokamak [4] represent a line intended for plasma device with plasma discharge duration up to 0.1 s and power flux up to 10 MW/m^2. The distinctive feature of this line was passive mode of surface temperature stabilization using the heat capacity of a thick mat of CPS (Fig. 1). The surface temperature of actual structure of CPS from stainless steel exceeds 700 °C as it follows from the experimental results (infrared measurements) at condition specified above. The estimated behavior of surface temperature as a function of the power flux and the discharge duration (Fig. 2) demonstrates lack of ability of operation below specified level for CPS with such design at discharge duration more than 0.1 s.

The next version of the limiter structure (Fig. 3) with thin (1 mm) CPS and thermal accumulator from molybdenum allowed

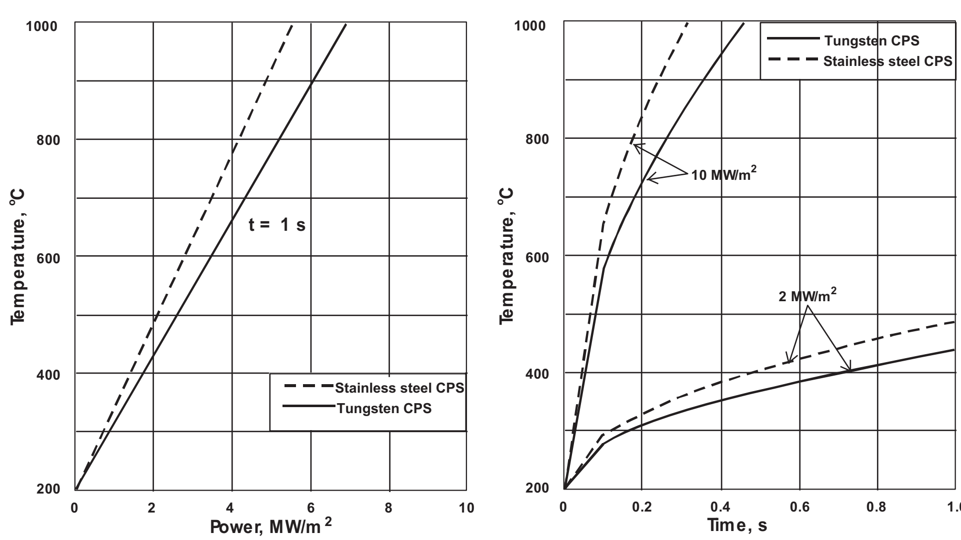

Fig. 2. Surface temperature of thick lithium CPS from stainless steel and tungsten for discharge up to 1 s [8].