Development of lithium and tungsten limiters for test on T-10 tokamak at high heat load condition

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Abstract. Application of a complex of powerful (up to 3 MW) ECR plasma heating in T-10 tokamak is pulled down with a problem of the strong plasma pollution at power input more than 2 MW. For the solution of these problems the new W and Li limiters is developed and prepared to implementation. As it is supposed, application of W as a plasma facing material will allow excluding carbon influx into vacuum chamber. An additional Li limiter arranged in a shadow of W one will be used as a Li source for plasma periphery cooling due to a reradiation on Li that will lead to decrease in power deposition on W limiters. Parameters and design of limiters are presented. Plasma facing surface of a limiter is made of capillary-porous system (CPS) with Li. Porous matrix of CPS (W felt) provides stability of liquid Li surface under MHD force effect and an opportunity of its constant renewal due to capillary forces. The necessary Li flux from a Li limiter surface is estimated for maintenance of normal operation mode of W limiters at ECRH power of 3 MW during 400 ms. It is shown, that upgrade of limiters in tokamak T-10 will allow providing of ECR plasma heating with power up to 3 MW at reasonable Li flux.

1. Introduction
The main undermined problem in the tokamak reactor is the problem of plasma interaction with the reactor wall. Graphite diaphragms and divertor plates was used in the tokamak reactors for many days long. However high physical and chemical erosion and tritium accumulation in the graphite powder are made to refuse of using this material. Tungsten was offered as an alternative of graphite. Tungsten doesn’t interact with hydrogen by chemical way and it has low sputtering ratio. Jet experiments had shown the falling of the hydrogen sorption by an order of magnitude. However tungsten has the big nuclear charge, what leads to significant radiation loss, even its small concentrations. Main radiation loss proceed from hot zone because of neoclassical tungsten ions accumulation in the centre. That’s why it’s desirable to develop the method of reduction for the tungsten entrance into the plasma. It is the target of the T-10 experiment. Tungsten ring diaphragm (with ring’s radius 30 cm) and the mushroom rail limiter (with limiter radius 30 cm) will be the main diaphragms at the experiment. Lithium mobile diagram which is made at the capillary structure base is introduced of tungsten reduction into the T-10. It’s assumed to choose the optimal position of lithium diaphragm for tungsten...
prevention into the discharge. It can happen as a result of two processes: the closing of tungsten surface by the lithium and the cooling of cord’s periphery cause of its intake. As expected, tungsten application as a material turned to plasma will allow excluding the graphite intake and the cooling of plasma periphery [1-4] will lead to energy flux reduction at the tungsten diaphragms. Nowadays it’s difficult to assess the efficiency of these movements. It’s the aim of the future T-10 experiments.

2. Lithium limiter
Lithium limiter – is the source is located in the top vertical port of tokamak’s chamber T-10. It can move relatively last closed magnetic surface (LCMS). Limiter’s moving in the SOL plasma region allows to regulate energy flux into the plasma. Surface limiter that faced to plasma is manufactured from capillary pore system (CPS) with lithium. CPS material (tungsten felt with radius of pores of 30 microns) provides lithium limiter surface stability under MHD forces influence and surface opportunity on account of capillary forces. The main limiter technical characteristics list is at the table 1.

| Parameter                                      | Value       |
|-----------------------------------------------|-------------|
| Max heat load, MW/m²                          | 5           |
| Diaphragm overall dimension H×L×W, mm         | 95×450×48   |
| The length of working section, mm             | 323         |
| The diameter of working section, mm           | 34          |
| The area of opened lithium surface, cm²       | 324         |
| The movement range of the lower diaphragm (r1-r2), mm | 150     |
| Working temperature, °C                       | 200-550     |
| The heater power, W                           | 1000        |
| The lithium mass, g                           | 50          |

The lithium limiter construction (figure 1) includes the system of mount/movement and receiving element. The receiving element represents the tubular construction with lithium supply tank. The receiving element forms by supporting tube 1, which manufactured from molybdenum and plays the heat accumulation role.

Figure 1. Lithium limiter
The CPS 2, which has hydraulic connection with liquid lithium at the tank 3, installs at the receiving element outer surface. The molybdenum mesh with the pore’s radius of 75 microns – is the foundation of the CPS limiter. The elements of pored tungsten additionally installed in direct contact places of receiving surface with the plasma. The limiter’s heating to the lithium melting temperature is carried out by electric heater 5, which located inside the tube. The receiving element electrically isolated from the tokamak structure, what allows to change its electric potential relatively plasma.

The receiving element’s construction lithium mobile limiter operability estimated magnitude ratings of the lithium surface temperature at adjusted temperature coming heat flow no more than 5 MW/m$^2$. If the element is located at the LCMS position at the ECRH heat power 3 MW, that max flow is ~ 9MW/m$^2$, and the heat load distribution at the surface takes the form that represents at the figure 2.

For the provision of the heat load magnitude 5 MW/m$^2$ top mobile limiter must be at the shadow of low mobile tungsten limiter. The temperature stabilization at the receiving element surface at the 500-550 °C level reaches on account of the heat removal from the surface to the internal construction elements at these conductions. Temperature evolution of lithium limiter surface at plasma discharge with heat flux 5 MW/m$^2$ presented on figure 3. The effect of shielding layer lithium steam formation and reradiation in it the part of coming energy didn’t take in account in the calculation.

![Figure 2. Heat load distribution on lithium limiter surface at power input 3 MW](image)

![Figure 3. Temperature evolution of lithium limiter surface at plasma discharge with heat flux 5 MW/m$^2$](image)
3. Complex of tungsten limiters

The tungsten limiter’s complex (figure 4) includes fixed circular and mobile “mushroom” (rail) limiter. The circular limiter is the ring with external diameter of 760 mm and internal diameter of 660 mm. The ring plate is perpendicular to the direction of the longitudinal tokamak T-10 magnetic field. The ring strengthens at the wall of vacuum chamber T-10 with the keeping electrical contact. 50 removable tungsten elements with the sizes 50×70×20 mm, that have profiled surface with the optimum tilt angle to magnetic field, forms the receiving limiter surface.

The lower mobile limiter is the “mushroom” construction that sets the radius of the last closed magnetic surface (the boarder of plasma filament) with an opportunity of changing this radius in the range r = 200-300 mm. The construction consists of fixed foundation which fixed at the flange of low vertical nipple and the mobile cap. The cap is lined by tungsten elements and electrically isolated from the foundation and the section T-10. The cap’s top operating surface is made gable with the incline’s line of separation which locates perpendicular to longitudinal magnetic field. The incline slope angle to longitudinal magnetic field is 10-15°. The cap’s overall dimensions are 300×300 mm at plate, parallel to magnetic field and 50 mm at radial dimension. The overall dimension of tungsten elements are 150×50×20 mm.

The diagnostic system of limiters includes: quick-detachable diagnostic tungsten elements for fast analysis of changing the surface states of tungsten limiters; Langmuir probes are established in the holes at the surface of tungsten elements and represented the information about contact plasma parameters; thermocouples, which measure heat state the limiter complex.
4. Conclusion
The executed values required lithium flow from the lithium limiter surface into the plasma for providing conditions for normal operation tungsten limiters at ECRH power heating 3 MW for 400 ms are shown that required flow reaches at the temperature of 500-550 °C. In this case $Z_{\text{eff}}$ of plasma won’t exceed the magnitude 2. Moreover, the lithium flow estimated at the base of researching tokamak T-11M results at the tokamak wall doesn’t exceed $\sim 10$ g at 1000 plasma shots, what comparable with lithium influx at using lithium evaporator for the wall T-10 conditioning at the previous experiments. In this way are shown that the limiters modernization at the tokamak T-10 will allow to provide ECRH heat modes with power to 3 MW at moderate lithium fluxes.

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