Complex of Lithium and Tungsten Limiters for 3 MW of ECR Plasma Heating in T-10 Tokamak. Design, First Results

I.E. Lyublinski[1,2], A.V. Vertkov[1], M.Yu. Zharkov[1], S.V. Mirnov[2,4], V.A. Vershkov[3], Ya.V. Glazyuk[1], G.E. Notkin[3], S.A. Grashin[3], A.Ya. Kislov[3]

[1]JSC "Red Star", Moscow, Russian Federation

[2]NRNU MEPhI, Moscow, Russia Federation

[3]NRC "Kurchatov Institute"

[4]JSC "SRC RF TRINITI", Troitsk, Moscow, Russian Federation

E-mail contact of main author: lyublinski@yandex.ru

Abstract. The complex of W and Li limiters is developed. 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 tungsten 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 provides stability of liquid Li surface under MHD force effect and an opportunity of its constant renewal due to capillary forces. The necessary lithium 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 Z_{eff} of plasma would not exceed of 2 in this case. Thus, 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 lithium flux.

1. Introduction

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. As it has been determined, the reason of it is the strong local overheat resulting in high physical and chemical erosion of existing graphite limiters. The use of graphite limiters leads to formation of carbon films and dust on a tokamak chamber wall essentially increasing of impurity flux and hydrogen recycling. Now it is a common situation for tokomaks with graphite based plasma facing elements (PFE). Tungsten was offered as an alternative decision for PFE to overcome this problem. In JET it permitted decrease of the hydrogen sorption by an order of magnitude. However tungsten application leads to significant radiation losses owing to neoclassical ions accumulation in the plasma center. It is supposed that reduction of tungsten flux to the plasma can be achieved by lithium deposition on tungsten PFE surface [1-4]. In this case the main power flux is coming to the main tungsten limiter but the flux of lithium atoms provides screening of impurity influx to the plasma column. In this way with the use of tungsten and lithium based limiters will allow to provide ECR heating with power to 3 MW. It's the main goal of the experiments in T-10.

2. Tungsten limiters of T-10 tokamak

The complex of tungsten limiters (Fig. 1) includes a fixed circular and a movable "mushroom" (rail) limiters armored by tungsten tiles. The circular limiter is the ring with external diameter of 760 mm and internal diameter of 660 mm. The removable tungsten tiles with sizes of 50×70×20 mm forms the plasma facing surface and have profiled surface with the optimum tilt angle to magnetic field.

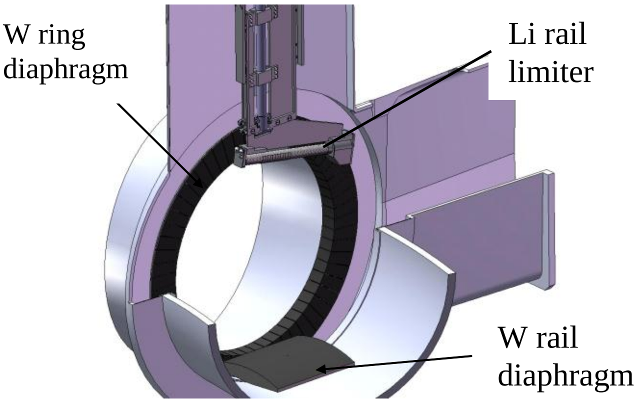

FIG. 1. Complex of W and Li limiters of T-10

The lower movable limiter has the "mushroom" form and sets the radius of the last closed magnetic surface (LCMS) with an opportunity of radius changing in the range of r=200-300 mm. It consists of fixed support that installed on the flange of low vertical port and the movable tungsten cap with dimensions of 300×300×50 mm formed by tungsten tiles with dimensions 150×50×20 mm. Tiles braised to bronze substrate in Efremov Institute by ITER-like technology.

The diagnostic system of limiters includes: quick-detachable diagnostic tungsten elements for fast analysis of surface states change; Langmuir probes installed in the holes of the tungsten elements for plasma measurements; thermocouples of thermal monitoring of the limiters.

3. Liquid lithium limiter of T-10 tokamak

Lithium limiter serves as the source of lithium emission to the plasma and is located in the top vertical port of T-10. It is moved relatively last closed magnetic surface (LCMS) and allows regulating of incoming power flux and, as consequence, a lithium influx into the plasma. Plasma facing surface of the limiter is made of **c**apillary-**p**orous **s**ystem (CPS) with lithium. Porous matrix of CPS (tungsten felt with radius of pores of 30 microns) provides stability of liquid lithium surface under MHD force effect and an opportunity of its constant renewal due to capillary forces.

The lithium limiter structure (Fig. 2) includes the system for mount/movement and W-Li plasma facing element. This element represents the tubular structure with lithium supply tank. The plasma facing surface is covered with capillary – pore system (*2*), which has hydraulic contact with liquid lithium in the lithium tank *3*. The molybdenum mesh with the pore radius of 75 microns is the base of the CPS limiter. The elements (*4*) of porous tungsten is additionally installed in region of strong plasma interaction with limiter. CPS is instaled on the supporting tube (*1*) made from molybdenum. In addition it plays the role of heat accumulator for surface temperature stabilization on the level of 500-550 °C. The limiter heating up to the lithium melting temperature is carried out by electric heater *5*, which is inserted inside the tube. The plasma facing element is electrically isolated from the tokamak structure, that allows to change its electric potential relatively to plasma. Main parameters of lithium limiter are presented in Table I.

TABLE I: MAIN PARAMETERS OF LITHIUM LIMITER

Parameters	**Value**
Maximal power flux, MW/m^2	5
Limiter size H×D×L, mm	95×450×48
Length of lithium element, mm	323
Diameter of lithium element, mm	34
Area of lithium surface, cm^2	324
Limiter radial moving (r1-r2), mm	150
Operation temperature, ^oC	200-550
Heater power, W	500
Lithium amount, g (cm^3)	~50 (100)

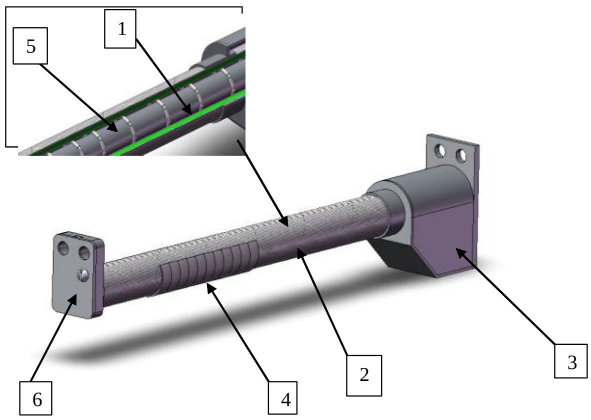

FIG. 2. Lithium limiter of T-10 tokamak

The proper operation of the plasma facing element is possible at the power flux not exceeding of 5 MW/m^2 because it will operate principally in the shadow of low movable tungsten limiter.

The necessary lithium flux from the lithium limiter surface is estimated for maintenance of normal operation mode of tungsten limiters at ECRH power of 3 MW during 400 ms. It is shown, that Z_{eff} of plasma would not exceed of 2 in this case. Besides the lithium flux to the tokamak wall was estimated on the basis of experimental results on investigation of lithium behavior in tokamak T-11M. It is shown, that about 13 g of lithium deposit will be on the wall for the campaign of 1000 discharges, that it is close to lithium amount used for T-10 conditioning by evaporator in the previous experiments.

Thus, 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 lithium flux. The first results of plasma campaign on T-10 tokomak with new limiters are presented and discussed.

4. Main results of W-Li experiment on T-10 tokamak

Effect of lithium limiter on plasma discharge was studied by comparison of plasma parameters with results of reference experiments only with W based limiters.

It should be noted, that lithium limiter could operate in two ways. The first is long enough exposition of limiter heated up to 450^{o}C before the plasma discharge which led to thin Li film formation on internal elements of the tokamak chamber owing to evaporation. This way of lithium gettering is corresponded to conditions of the previous experiments on T-10 [5]. In the second way lithium limiter was heated up to the Li melting point and was inserted into the plasma SOL.

In the reference experiments the high concentration of impurities (W, C, O) in plasma have been observed. Insertion of the lithium limiter into SOL led to significant purification of plasma and increase in intensity of LiI, LiII spectral lines. These results allow assuming, that there are two mechanisms of plasma pollution prevention by lithium. The first is reduction of impurity level proportionally to lithium flux in SOL when limiter is introduced. But this effect disappeared after limiter removal. The second mechanism is related to lithium flux increase owing to lithium accumulation on the chamber wall and W based limiters by shot to shot or by previous lithization (limiter operated as evaporator). As a result both of the mechanism led to growth of lithium flux in SOL and effect of lithium is related to lithium flux. It have been shown that growth of the lithium lines intensity in 9 times result in AXUV signal (indication of W concentration) from plasma center region falls in 40 times and spectral lines intensity of O and C falls at 10-15 times. However the radiative losses on periphery related to light impurity fall only in 4 times. Thus reduction of W concentration is related to lithium screening effect instead of reduction of its sputtering owing to decrease in plasma temperature on periphery. According to Langmuir probe data on a rail W based limiter the temperature has increased from 20-30 to 50-60 eV.

The same effect detected in experiments with ECR plasma heating at 1.4 MW. Radiative losses and AXUV profiles before and after lithization are presented in Fig. 3. The strongest effect of lithium takes place in the central region of plasma for W concentration decrease. The radiative losses on plasma periphery increase.

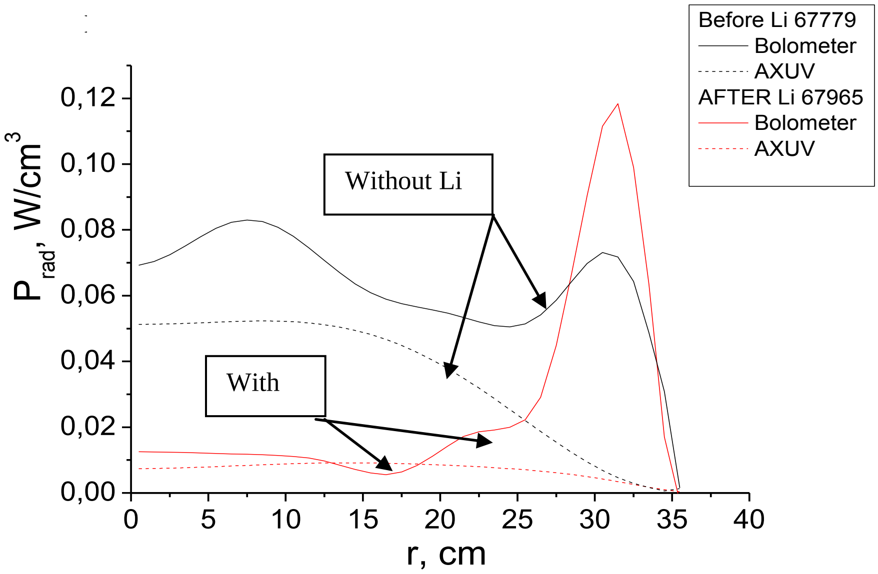

FIG. 3. Radial profile of radiative losses before and after Li insertion to discharge

Despite of strong changes in impurity concentration in plasma with Li insertion Li penetration to plasma center not indicated within the limits of measurement accuracy. It indicates that limiters very effectively catch the lithium flux in SOL. This is resulted in reduction of concentration of lithium in the center, effective covering of tokamak in-vessel surfaces with Li and impurity shielding. Also it is possible that lithization of the W based limiters and other parts of tokamak chamber work as effective sorbent and reduce impurity flux to plasma. High efficiency of impurity screening with use of lithium limiter completely confirms early experiments with lithium gettering [5]. The results of experiments on DIII-D [6] with introduction of lithium as microgranules are very close to our results. Apparently, lithium introduction in SOL of tokamak plasma is optimum.

5. Conclusion

Taking into account mentioned above possibility of lithium to provide pure plasma it is possible to offer the following scheme of lithium limiter use in a reactor-tokamak with the closed cycle of lithium circulation [7]. Schematically it is shown in Fig. 4.

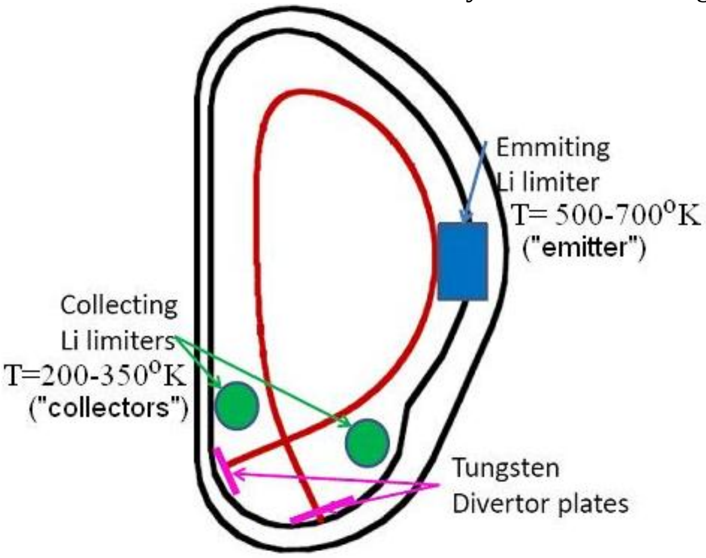

FIG. 4. Scheme of lithium limiter use in a reactor-tokamak with the closed cycle of lithium circulation

As in ITER, the divertor can be made of tungsten and the wall from berillium. The divertor will receive a full energy flux from plasma. However lithium will be used for reduction of W spattering and influx to the plasma. In this case the emitting lithium limiter on the base of lithium CPS is entered deeply in SOL. The mentioned facts indicate that lithium propagates mainly along magnetic lines and is effectively captured on limiters and is not reaching the wall. Therefore it is possible to arrange limiters collecting lithium for prevention of its accumulation on a reactor wall. These limiters are also located in SOL, but moved less deeply to plasma and collect lithium. In these conditions the protection of tungsten against sputtering with use of lithium and application of central ECR heating should prevent accumulation of tungsten in the central areas of plasma. The collecting limiters will exclude accumulation of lithium on the wall that will exclude tritium sorption. It will provide significant improvement of conditions of plasma confinement and to promote to achievement of practically stationary modes of plasma burning.

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