INVESTIGATION OF DIVERTOR FIELD LINES IN THE NCSX STELLARATOR

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Divertor field lines calculations for NCSX stellarator are presented. The recommendations are given for the correction of the vacuum vessel and FW shape in order to perform an optimum arrangement of divertor system components.

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The paper is aimed to studying the divertor magnetic fluxes in the NCSX stellarator for the purpose to establish the optimum places for arrangement of divertor system components. The vacuum vessel and the first wall (FW) of the NCSX stellarator have a complicated spatial configuration that makes as a nontrivial problem of determining the regions where the divertor magnetic fluxes cross the first wall.

The vacuum configuration studied for NCSX was based on the LI383 magnetic system with a major radius of Ro=1.7 m and with M45 coils. The last closed magnetic surface (LCMS) is shown in Fig.1 at the V=0.5 cross-section. The location of the LCMS was determined by starting field lines on the midplane on the inboard and outboard sides of the v=0.5 cross-section for Rst=1.21-1.25m and Rst= 2.20 - 2.29m. In searching for the LCMS we usually used 200 field periods. The central iota was calculated to be 0.66. Iota drops below 0.6 and returns to 0.6 at the LCMS. There are the 3/5 islands inside of LCMS.

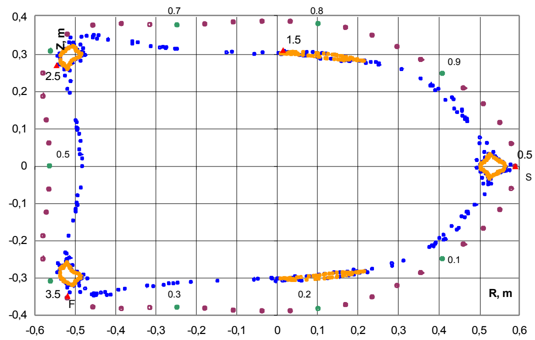


Fig.1. V=0.5,(Vst=0.5,U=0, Rst=2290 mm), Divertor line , L=±11.1, (Vf=3.517, Uf= 0.388)

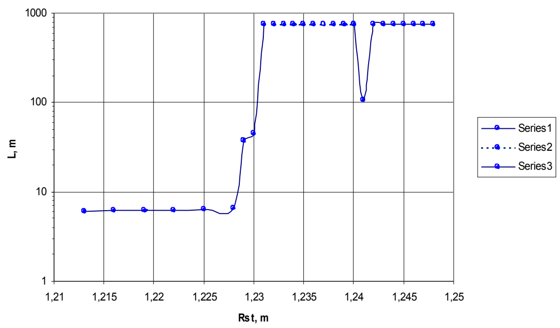
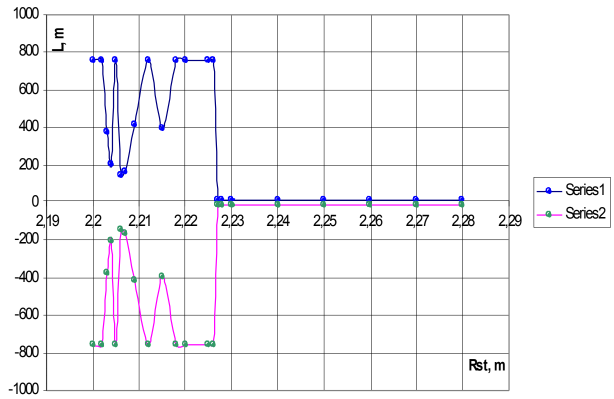


Fig.2. Divertor field line length dependence versus start radius, Vst=1.5

Connection lengths have been calculated as a function of starting point as shown in Figures 2 and 3. For starting points on the open field lines between the LCMS and the 3/5 islands outboard the plasma, the connection lengths are still long, more then 100m. For starting points outside the 3/5 islands, the connection lengths quickly become small, dropping from more than 750m (200 field periods) to less than 15m in only a few mm. The same steep drop may be seen for starting points inboard of the plasma where island structures are not apparent.

Fig.3. Divertor field line length dependence versus



start radius, Vst=1.5 (positive and negative directions)

An alternative method for following field lines is to actually start them on the first wall. This is practically true for non-vacuum configurations (with finite beta and plasma current), in which it is difficult to determine the precise location and geometry of the LCMS. By starting the field line on the first wall, we reduce the number of dimensions to scan from 3 to 2 and preclude following any field lines that do not intercept the first wall. We can also quickly determine where the longest field lines will intercept the first wall.

In Figs. 4 and 5 is seen that all of the long (>5m) field lines start and finish on points that connect the tips of the bean (u=0.3, 0.7) in the v=0 cross-section, and the nose with corners (u=0.4, 0.6) in the bullet-shaped (v=0.5) cross-section. The largest bubbles, which correspond to the longest field line lengths, are clearly clustered near the nose and corners of the bullet cross-section (Figs.6, 7). Away from these points, the field line lengths are quite small. These regions correspond to the places where the value of the poloidal field normal to the first wall surface is at a relative maximum, as shown in Figure 8. Minimum of field line lengths is observed in the regions where the poloidal field normal to the first wall surface is zero.

The longer field lines spend most of their transit time close to the LCMS. Only near the end of their transits they do depart from the close proximity to the LCMS and intercept the first wall away from the helical stripes (see Fig.9, 10). The field line starts in the upper tip of the bullet-shape cross-section (v=0.5, 1.5, ...) The field line proceeds along the thin line and is inside the all intermediate cross-sections (0,0.25, 0.5, 0.75, 1, ...) of the first wall.

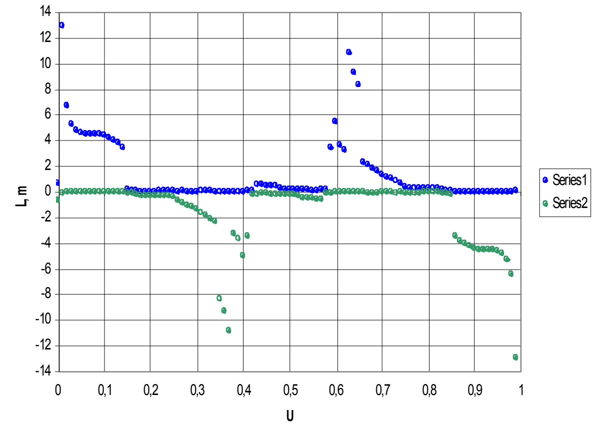


Fig.4. Divertor field line length dependence, Vst=1.5

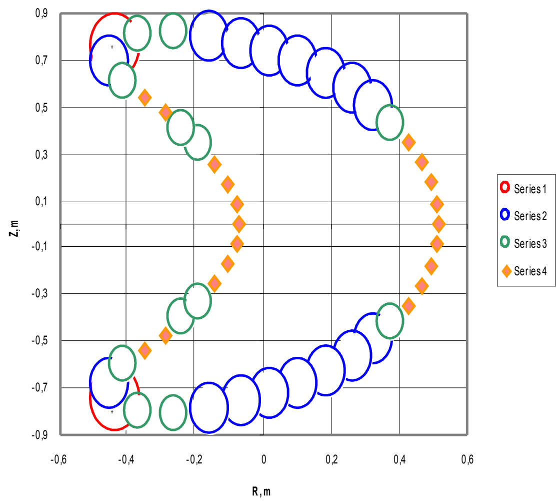
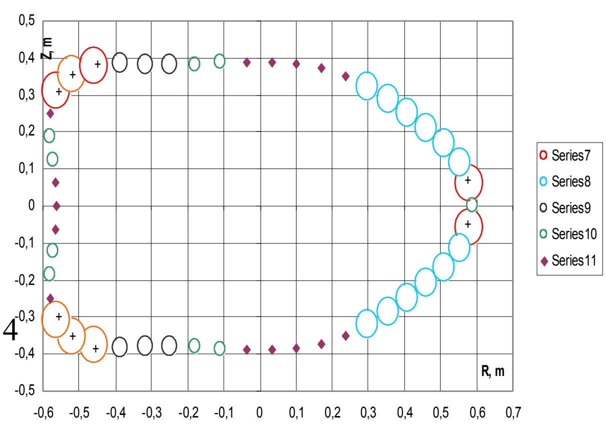


Fig.5. Divertor field line length dependence, Vst=2

To achieve a long field line length, it is necessary to ensure that field lines starting near the helical stripes do not prematurely intercept the first wall. By starting points near these helical stripes and following the field line, it becomes apparent where and by what extent the first-wall boundary should be move out to extend the length of the field line. Ultimately, the field line will stop wrapping around the plasma and begin wrapping around a coil, thus setting an upper bound on the maximum field line length.

As shown in Figure 11, the field line starts with a length (L) of zero and distance (DL) of zero. A value DL less than zero indicates that the field line is on the plasma



side of the first wall. Positive value of DL indicates that the field line has intercepted and is outside the first wall. The field line does few excursion inside and outside the first wall with deviation less than 10 cm and at a distance of 47 m along the field line, it intercepts the first wall and does not return. The lesson here is that by locally pushing out the first wall boundary by not more than 11cm, this field line length could be increased from 7m to 47m.

The other possibility to increase the divertor field line length is to use *bz* field correction and Kφ correction. We have studied a possibility of increasing the DFL length (Lmax) with the relatively small (≤10%) increase of the coefficient Kφ and selection of a suitable vertical correcting magnetic field Δb_Z.

Fig.6. V=0.5, first wall cross-section, divertor field line length dependencies L≥6 m (+)

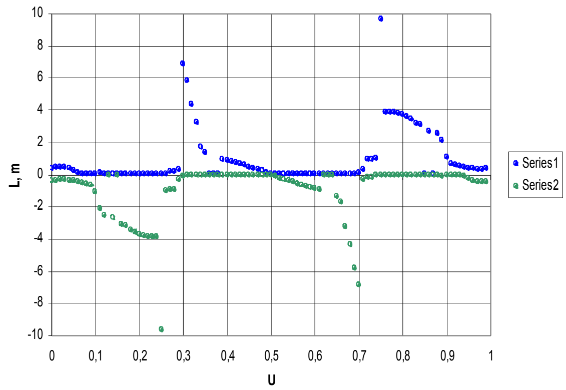


Fig.7. V=1, first wall cross-section, divertor field line length dependencies (L≥6 m -largest bubbles)

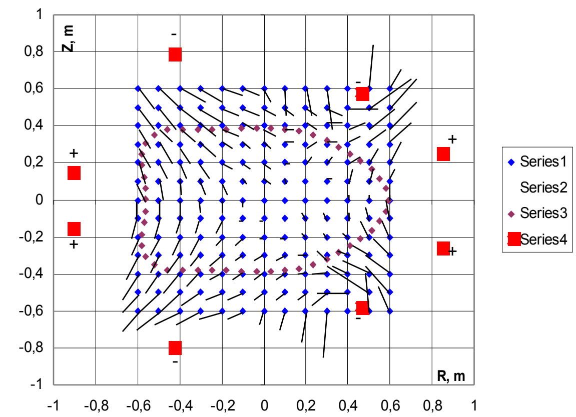
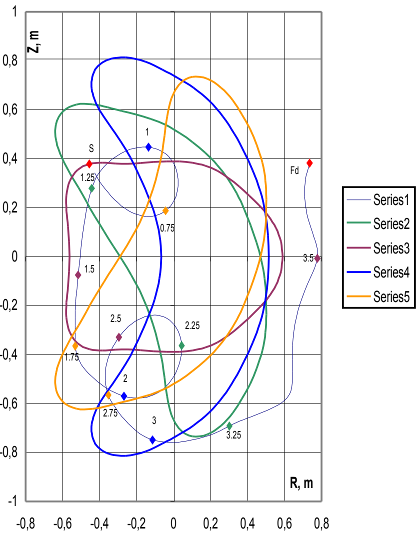


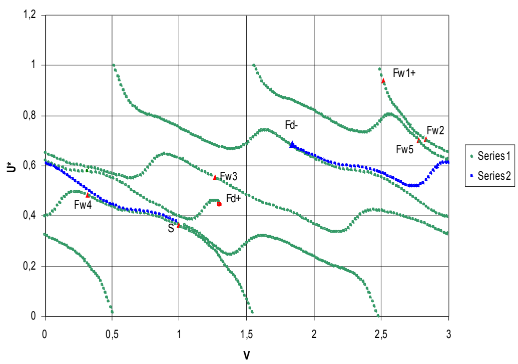
Fig. 8. Vector poloidal field, V=0.5, scale 0.11 T /cm

(Notice, that the value of Kφ equals to the ratio of the toroidal magnetic field (Bmc) in the modular coils (MC) to the total toroidal field (B_0) created by MC and coils of an additional toroidal field (TF)). It has been shown that the above-mentioned increase in Kφ leads to the significant (approximately in 2 times) increase of the DFL length



(maximum values of the length Lmax were increased from 12.6 m (for Kφ = 1.126) to 27 m (for Kφ = 1.2). Such an increase of Kφ leads to the insignificant (approximately by 10%) decrease of LCMS sizes and to the increase of values of rotational transform angles ***t***.

Fig.9. Field line path, (Vst=1.5,Ust=0.64), R,Z plane, Rcf=1.3Rfw, L=+11.3 m, First wall cross-sections: V=0.25,0.5, 0.75 , 1



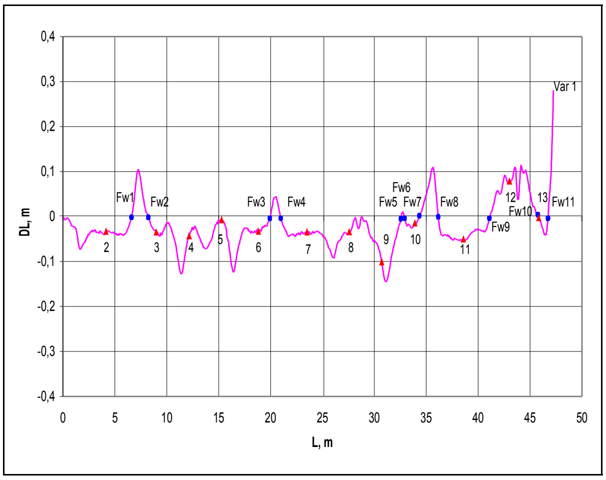


Fig.10. (Vst=1,Ust=0.3), (U =θ/2π, V) plane, Rcf=1.3Rfw, L=+47.22 m, positive direction L=-6.82 m, negative direction*

Fig 11. Field line deviations with respect to the first wall (Vst=1, Ust=0.3)

CONCLUSION

1. Parameters and behavior of divertor field lines in the gap between the LCMS and FW are studied. Magnetic surfaces in the edge region are not smooth surfaces. Isolated island structure is present. Long length field lines in the island's structure were observed. A steep drop in field line length was seen outside the region where long field line length were observed.
2. A new, comparatively simple method (method - starting from and finishing on the first wall) was proposed. The method allowed to determine the regions, where field lines have maximum length. These regions correspond to tips of the magnetic configuration.
3. It has been found that, because of the complicated spatial vessel configuration, the field lines crossing the first wall surface, before going out of the volume enclosed by the modular coils, make multiple crossings over the first wall. The recommendations are given for the correction of the vacuum vessel and FW shape in order to perform an optimum arrangement of deviator system components.

ДОСЛІДЖЕННЯ ДИВЕРТОРНИХ СИЛОВИХ ЛІНІЙ В СТЕЛАРАТОРІ NCSX

В.А. Рудаков, О.В. Георгієвський, У. Реєрсен

Представлені розрахунки диверторних силових ліній для стеларатора NCSX. Зроблені пропозиції щодо корекції вакуумної камери з метою оптимального розташування диверторних пристроїв.

ИССЛЕДОВАНИЕ ДИВЕРТОРНЫХ СИЛОВЫХ ЛИНИЙ В NCSX СТЕЛЛАРАТОРЕ

В.А. Рудаков, А.В. Георгиевский, У. Рейерсен

Представлены расчеты диверторных силовых линий для стелларатора NCSX. Сделаны рекомендации по коррекции вакуумной камеры с целью оптимального расположения диверторных устройств.