§2. Estimation of the Heat Flux Peaking Factor in the Helical Fusion Reactor FFHR

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In the helical reactor FFHR, the liquid first wall composed of the Flibe has been proposed. (1) Therefore, the heat flux estimation is very important during the steady fusion burn operation and the transient phase such as abnormal condition including thermal quench and discharge termination.

In general, as the outboard surface sees the larger volume of the plasma than the inboard side, the outboard surface receives the larger heat flux. This heat flux ratio is called the peaking factor. We have first estimated the peaking factor analytically for the infinitely long tube shape plasma for two-dimensional layout. We have next estimated them in the three-dimensional layout with a circular FFHR plasma.

[1] Two-dimensional layout

For an infinitely long plasma as shown in Fig.1-(a), the heat flux to the area ΔS is simply given by the formula:

$$Q=\frac{\Delta P}{\Delta S}=\int_{S_p} P_b(\mathbf{r})\frac{\cos\psi}{2\pi\ell}\,dS_p \tag{1}$$

Actual heat fluxs to the inboard and outboard sides are given by

$$\left[Q/P_b(\mathbf{0})\right]_{IN}=\int\!\!\int\left[\frac{\left(x-\rho_{outw}\right)}{\left(x-\rho_{outw}\right)^2+y^2}\left(1-\left(\frac{R-R_o}{a}\right)^2\right)^{\left(2\alpha_n+0.5\alpha_T\right)}\right]\frac{Rd\varphi dR}{2\pi} \tag{2}$$

and

$$\left[Q/P_b(\mathbf{0})\right]_{OUT}=\int\!\!\int\left[\frac{\left(\rho_{outw}-x\right)}{\left(\rho_{outw}-x\right)^2+y^2}\left(1-\left(\frac{R-R_o}{a}\right)^2\right)^{\left(2\alpha_n+0.5\alpha_T\right)}\right]\frac{Rd\varphi dR}{2\pi} \tag{3}$$

respectively. Here, $P_b(0)$ is the peak bremsstrahlung loss, and the radiation profiles is given by $P_b(r)\propto n(r)^2T(r)^{0.5}$ with $R=(x^2+y^2)^{0.5}$, $n(r) = n(0)(1-\{(R-R_0)/a\}^2)^{\alpha n}$, $T_e(r) =T_e(0)(1-\{(R-R_0)/a\}^2)^{\alpha T}$. The integration regime is taken as shown in Fig.1-(b).

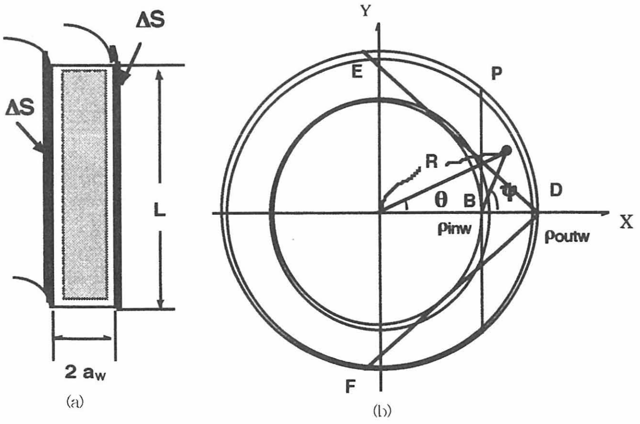

Fig. 1 Two-dimensional layout for the calculation

Average heat flux is given by

$$\left[Q/P_b(\mathbf{0})\right]_{AVE}=\int\!\!\int\left[\left(1-\left(\frac{R-R_o}{a}\right)^2\right)^{\left(2\alpha_n+0.5\alpha_T\right)}\right]\frac{RdR\,2\pi L}{S} \tag{4}$$

with $S=2\pi R_o(2L+4a_w)\sim 2\pi R_o 2L$ for infinitely long plasma (a_W<<L). For FFHR parameters of R_o = 10 m, a=1 m, a_W=1.2 m, ρ_{inw} = 8.8 m and ρ_{outw} = 11.2 m, peaking factors are $Q_{out}/Q_{in}\sim 1.5$ and $Q_{out}/Q_{av}\sim 1.2$ which are shown in Fig. 2 as a function of the resolution (dR) along the major radius.

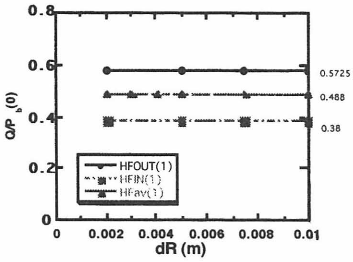

Fig. 2. The peaking factor for two-dimensional layout

[2] Three-dimensional layout

The heat flux to the area ΔS is given by the formula:

$$Q=\frac{\Delta P}{\Delta S}=\int_{V_p} P_b(\rho)\frac{\cos\psi}{4\pi\ell^2}\,dV_p \tag{5}$$

which is derived based on Fig. 3.

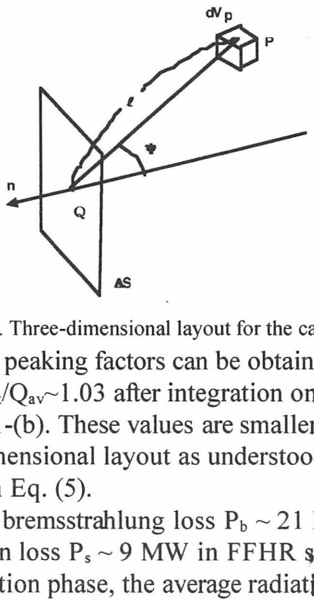

Fig. 3. Three-dimensional layout for the calculation

The peaking factors can be obtained as $Q_{out}/Q_{in}\sim 1.1$ and $Q_{out}/Q_{av}\sim 1.03$ after integration on the similar regime in Fig.1-(b). These values are smaller than that in the two-dimensional layout as understood from the solid angle in Eq. (5).

For bremsstrahlung loss $P_b\sim 21$ MW and synchrotron radiation loss $P_s\sim 9$ MW in FFHR steady state subignition phase, the average radiation wall loading is Γ_r ~30 MW/434 m^2 ~ 0.07 MW/m^2. Therefore, the heat flux to the outboard surface is given by Γ_r ~0.07x1.1~0.08 MW/m^2 which is lower than the allowable limit of 0.1 MW/m^2 for the liquid first wall. We should note that although the synchrotron radiation profile is different from the bremsstrahlung profile, the same profile is assumed for simplicity.

References

(1) A.Sagara et al., Fusion Technology, Vol.30, Part2, (2001) 753