STRAY RF EVALUATION AND DESIGN IMPROVEMENT ON THE ITER EQUATORIAL EC H&CD LAUNCHER

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1. INTRODUCTION

ITER Equatorial EC H&CD Launcher (EL) has been designed in QST, aiming for 170 GHz / 20 MW continuous millimeter wave injection (Fig. 1). Unlike other EC H&CD launchers in the world's major tokamaks, EL is carefully designed for neutron shielding against nuclear reactions during the ITER lifetime. However, such shielding restricts the internal space and thus RF transmissivity. Therefore, stray RF can be a new risk on the overall EL thermal design, and hence, any evaluation method should be established.

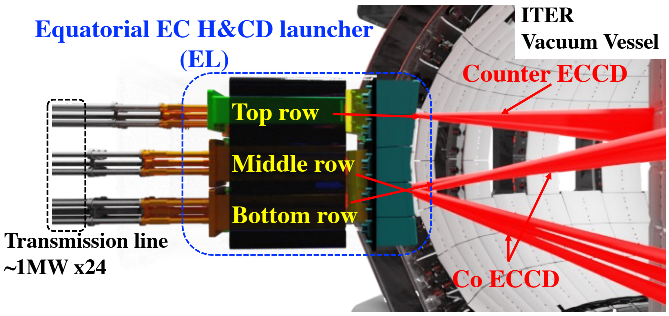

Fig. 1 EL design concept. RF power transmission up to 20 MW is divided into 3 rows (Top, Middle, and Bottom)

2. DESIGN ACTIVITY

The EL optical design is optimized in 2020, as described in ref [1]. Fig. 2 shows the schematic view of the internal optics of EL. As shown in Fig. 2, the dog-leg structure with two mirrors prevents a direct neutron path. EL can inject 20 MW EC power into the vacuum vessel, and there are three rows (Top, Middle, and Bottom row) with similar internal optics to deliver each 6.7 MW EC power. After the internal optics optimization under thermal and radiation limits, the maximum transmission efficiency is 99.0%. This suggests at least 1.0 % of RF input (200 kW) experiences EL internal reflections and becomes stray RF. Though there is a chance for such stray RF to come out from EL, the mockup experiment in ref [2] suggests that only 20~40% of expected stray RF is emitted from the EL output. Therefore, the remaining 60% (120 kW) should be taken into account in the EL thermal design.

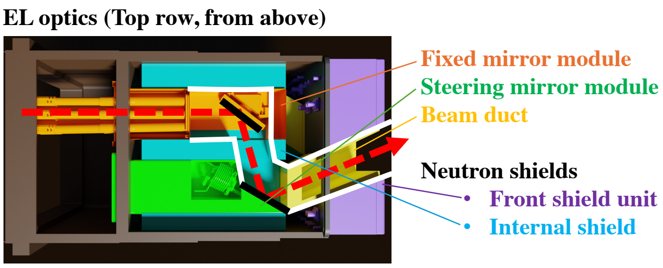

Fig. 2 Internal optics of the EL. The second mirror is steerable so that the output beam angle can be controlled.

3. STRAY RF HEAT LOAD EVALUATION

Stray RF heat load should be evaluated precisely. However, since the size of EL (~2 m) is much larger than the wavelength (1.8 mm), a full-wave calculation is impossible due to computational resource problems. Physical optics (PO) is another low-cost but precise approach for single beam tracing, but it has poor capability to trace all highly-split and multi-reflected beam fragments. Therefore, as a feasible approach for stray RF simulation, geometric optics (GO) was considered. A fundamental issue is that GO cannot represent coherence or diffraction effects, but GO can be a proper approximation since coherence is not important for stray RF, and the EL internal structure is so large compared to the wavelength that diffraction is not significant.

To obtain the heat flux distribution using GO, a numerical toolkit was developed according to the following steps: (1) create a ray bunch that statistically simulates the beam width and spread angle of the waveguide mode LP_{01}, (2) execute GO calculations on the EL surface (made of 2×10^6 triangle mesh), (3) calculate the Fresnel reflection coefficient R for each reflection by an incident angle and a wall conductivity to find the RF absorption coefficient ($1-|R|^2$), (4) create a heat load distribution [W] by counting the RF absorption per cell, and (5) find the EL surface area [m^2] per cell to obtain the heat flux distribution profile [W/m^2]. The simplest way to search which cell contains an EL surface mesh is to judge if a cell contains a mesh or not for all combinations of the cells and the surface meshes. However, it would take years to perform such a calculation to obtain a sufficiently fine (10 mm) grid profile even with ~20 CPU cores if all combinations are considered between the EL surface mesh and grid elements (10^7 cells) in calculation (5). To avoid computing such all combinations, the evaluation step has been improved based on a bisectional search, i.e., by successively narrowing the computational grid resolution as follows: 640→...→40→20→10 mm. This approach is efficient because, for example, when determining the EL surface area contained in a 10 mm grid element, it is unnecessary to scan the entire EL surface but only the EL surface contained in a 20 mm grid element. In the same way, a 40 mm grid is useful in the calculation for the 20 mm grid elements. Finally, the whole calculation process on the entire EL structure has been completed in a week with 3×10^7 rays. Here, GO in calculation (2) has also been accelerated by loading the minimum necessary mesh in passing grid elements to find a collision point instead of scanning all the EL surface.

4. RESULTS AND CONCLUSION

According to the optical design, a major hot spot of more than 200 kW/m^2 is found in the fixed mirror module in the Middle row due to an obstacle on the internal aperture [Figs. 3(a), 3(b)]. After the recalculation with an extended internal aperture, such a peak is eliminated [Fig. 3(c)]. Furthermore, it is found that stray RF can penetrate unexpected regions, such as the steering mirror rotary actuator [Fig. 3(d)]. For some springs and bellows in the rotary actuator, cooling water cannot approach, and thus, radiant is the only cooling mechanism, which can emit ~1 kW/m^2 at 300ºC on alloy 718 surfaces. To reduce heat load to such a level, an RF shield is designed, and the effectiveness is proven in the calculation, as shown in the comparison between Fig. 3(d) and Fig. 3(e). After design improvements, the risk of stray RF is significantly mitigated, which finalizes the EL design.

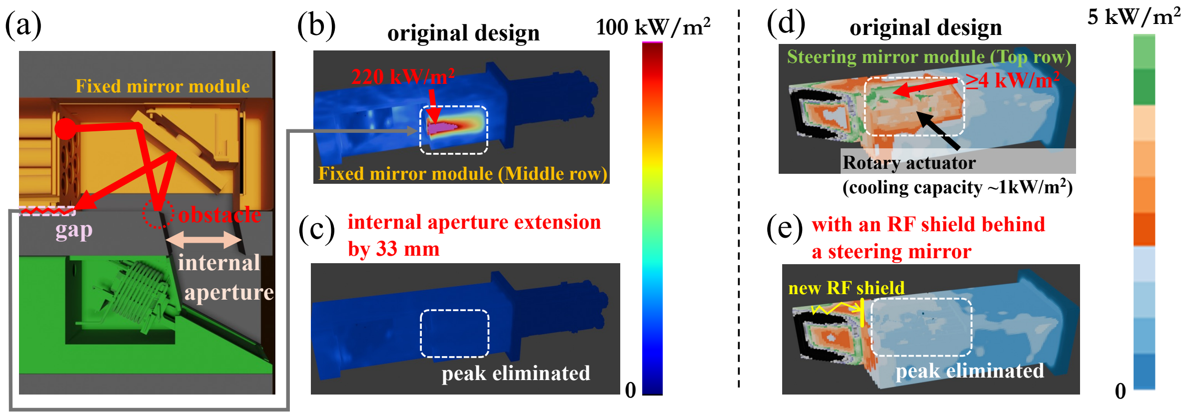

Fig. 3 Calculated heat load profiles and EL design improvement. Removing an obstacle in (a) eliminates a peak in (b) as shown in (c). Another peak in (d) is eliminated by a new RF shield in (e).

REFERENCES

[1] KAJIWARA, K., et al., 29th IAEA Fusion Energy Conference, preprint, 2023
[2] YAJIMA, S., et al., Fusion Eng. and Des., 194, 113690, 2023