Abstract

The design of ITER equatorial ECH/ECCD launcher (EL) is progressing toward the design finalization in 2020. The concept of the upper launcher (UL) steering mechanism for steering mirror is adapted to the EL for poloidal steering. The key of the concept is the torque balance between the bellows actuator, the coil springs and cooling spiral pipe. Because of the larger heat load of the steering mirror, the flow of the cooling water needs to be increased by larger diameter of the spiral pipe. The larger diameter pipe increases the torque, therefore it is compensated by improving the bellows and the coil spring design. The other issue is the thermal stress at the Blanket Shield Module (BSM). The thermal analysis shows the peak stress of the cooling pipe exceeds the limit. By separating the first wall from the integrated shield structure, the temperature gradient is decreased for the first wall part, which reduces the thermal stress of the cooling pipe. Another issue is the rectangular flange attached to the closure plate, which holds the mirror and waveguide unit. Because the surface pressure at the corner of the flange is high,
the introduction of the Inconel 718 bolt is being considered. The 8 RF beams radiated from 8 waveguides are injected to the large parabolic steering mirror and focused to plasma. Therefore, injection angles of each beam are slightly different, which gives distorted RF absorption profile compared to expected one. In order to improve this situation, a ray tracing code is integrated with the EL optical system optimization program.

1. INTRODUCTION

In 2014, the ITER organization (IO) decided to change the EL design from toroidal steering configuration to poloidal steering (-12°~+12°) at fixed toroidal angle (~60°) in order to increase the co-current drive efficiency at the peripheral region (normalized minor radius p~0.4). Because of this major change of the design requirement, the modifications have been performed for the BSM configuration and the optical system [1]. In 2017, further design change was decided, in which the double dogleg structure between the port plug and vacuum vessel was introduced to improve neutron shields, and the skids at the bottom and the pads at the side of the plug were introduced to adapt the modified port handling method. As a result, the inner volume of the port plug was reduced. Redesign of the EL according to these design change requests is progressing. Figure 1 shows the bird view of the EL.

![Figure 1. ITER Equatorial Launcher (EL).](image)

2. PROGRESS OF THE REDESIGN

2.1. Steering mirror assembly (SMA)

The concept of upper launcher (UL) steering mechanism [2,3] has been adapted for EL since the steering direction of beams of EL was changed from toroidal to poloidal. One of the differences between the EL and the UL is the number of injection beam per mirror. Since, the EL need to handle 8 beams which is doubled compared to the UL mirror (4 beams), the EL mirror should be larger than UL. Then, the weight of the EL mirror is about 1.6 times larger than the UL. Moreover, in order to remove larger heat load, the pipe diameter of the spiral-cooling water pipe must be larger to provide more cooling water to the mirror, which increases the torque of the spiral pipe (see Fig. 2). Therefore, the SMA should be redesigned for EL with different inertia and torque balance. One of the key designs is the torque balance among the bellows actuator, the coil springs and the spiral pipe as shown in Fig. 2. In order to compensate the increased torque caused by the increased diameter of the pipe, the reduction of the torque by coil spring or/and increasing the torque by bellows actuator is necessary. Both reducing the torque of the coil spring and strengthening the bellows are progressing. These redesigned components will be tested near future. It is also necessary to develop angle detection system in order to improve the plasma controllability. A direct angle detector, which consists of a rotary capacitor, stubs and RF circuits [4], has been developed and the detection accuracy of more than ±0.025 degree is successfully achieved.
The torque of the coil springs and the spiral-cooling pipe should be balanced with the bellows actuators.

2.2. Blanket shield module (BSM)

One of the design issues is the thermal stress at the BSM. The thermal analysis showed the peak stress of the cooling pipe was 820MPa, which exceeded the allowable stress limit. In order to decrease it, the separable first wall from the BSM is considered. The surface of the BSM is heated by plasma radiation and neutron, but the other part is relatively low temperature since there is no plasma radiation. Because of this situation, the temperature gradient becomes large. The other problem is the difficulty of the nondestructive inspection nearby the first wall. In order to relief the temperature gradient and difficulty of the nondestructive inspection, the first wall part is separated from the neutron shield module part as shown in Fig. 3. The temperature of the first wall part is high, but the gradient becomes low because the first wall part is independent from the other part. As a result, the thermal deformation becomes small and the stress of the cooling pipe is reduced from 820MPa to 454MPa. However, the design stress intensity of $S_m$ is 127MPa@150C, then the stress limit is 380MPa ($=3S_m$) for thermal deformation, i.e., the stress at cooling pipe still exceeds the limit. The optimization of the route and shape of the cooling pipe with separated first wall configuration is still under progressing.

2.3. Mirror unit

The mirror and waveguide unit are attached to the closure plate by flange (see Fig. 4) with double metal vacuum seal. This seal needs to assure an adequate leak tightness compliant with both vacuum and safety.
requirements. Vacuum condition in the interspace between metal seals is monitored for tritium leakage. Since the circular flange is not applicable because of the space limitation, the rectangular flange is adopted as shown in Fig.4. However, the surface pressure at the corner of the rectangular flange is high, the required bolt tension is higher than circular flange. In order to estimate the required bolt tension, a simulation of the vacuum seal compression is performed. The necessary load is calculated as 2440kN, which is sustained by 36 bolts. Therefore, the required bolt tension is 67.8kN, which exceeds the stainless steel bolt limit. In order to solve this problem, the introduction of the Inconel 718 bolt is considered. The simulation with this bolt shows the enough tension to sustain the pressure.

![Diagram of mirror unit bird view](image)

**FIG. 4.** Mirror unit bird view. The unit is attached to the closure plate by rectangular flange. Double metal seal assures both leak tightness and safety function. The tritium leakage is monitored through a hole between the seal.

### 2.4. Optical components

The 8 RF beams radiated from 8 waveguides are injected to the fixed mirror, then reflected to the steering injection mirror as shown in Fig. 5. Both fixed mirror and steering mirror is large parabolic mirror and the waveguide is slightly tilted. By adjusting the waveguide tilt angles and curvature of the parabolic mirrors, the RF beams can go through inside the launcher with high transmission efficiency. However, the injection angles of each beam into plasma are slightly different, which cause the electron cyclotron current drive (ECCD) profile come apart. In order to adjust the ECCD profile directly, a ray tracing code (EC-Hamamatsu code [5]) for the calculation of RF propagation and absorption in the plasma is integrated with the EL optical system optimization program [6]. The optimization program adjusts the curvatures of the parabolic mirrors and waveguide angles. Figure 6 shows the comparison of the ECCD profile before integrating the EC-Hamamatsu code (upper figure) and after integrating the code (bottom figure). The obsolete optimization (upper figure) is performed by using following condition

- The radius of 8 beam superimposed pattern at resonance layer is less than 250mm;
- Increase the transmission efficiency inside the EL as much as possible;

The adjustment was successfully finished. The obtained beam radius is 250mm and the transmission efficiency reached 99.3%. However, As shown in the upper image of Fig. 6, the ECCD profile was divided by three peaks. The bottom figure shows the result of the optimization by integrating the EC-Hamamatsu code. The optimization condition is as follows,

- Transmission efficiency is more than 99.0%;
- Minimize the ECCD width as much as possible;

The integrated optimization program successfully adjusts the parameters as indicated in the bottom figure. The ECCD profile becomes one peak and very narrow width (Δp=0.05) with high transmission efficiency (99.1%). This new optimization method will apply to the design of EL after the discussion with IO about the precise physics requirement of EL.
FIG. 5. Middle row sectional view of EL. Eight RF beams is delivered by waveguide and propagated through two mirrors to the plasma.

FIG. 6. Comparison of the ECCD profile before (upper figure) and after (bottom figure) optimization with EC-Hamamatsu code. Horizontal axis is the normalized minor radius $\rho$ and vertical axis is the 8 beam total current drive density. Two different injection angle cases (aiming to $\rho$~0.2 and $\rho$~0.5) are indicated.

3. SUMMARY

In order to finalize the EL design applicable to the recent design changes, the modification of the port plug, the improvement of SMA, BSM, mirror unit and waveguide unit are executed. Especially, the steering mirror assembly (SMA) design of EL was successfully performed which was the one of the key issue toward the design finalization. The fixation of the mirror unit to the closure plate is considered and concluded that the rectangular flange with double vacuum seal system can be applied. The problem of the high thermal stress at BSM close to get fixed by separating the first wall from BSM body. The optimization program of the optical component is improved by integrating a ray-tracing code (EC-Hamamatsu code) into the program. The design will be finalized near future.
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REFERENCES


