Evaluation of Optical Resonator for the JAERI Far-Infrared Free Electron Laser

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Abstract

The performance of optical resonator with output coupling for the JAERI far infrared free electron laser is evaluated by numerical calculating of mode profile, diffraction loss and output coupling efficiency. The optical resonator is in near concentric geometry and 14.4 m length. The evaluated configurations are output coupled by a center hole and ring-shaped mirror at downstream side mirror of optical resonator. It is found that the ring-shaped mirror output coupler is more efficient than the center hole, mode degeneracy in both of them is not so much and the output coupler can provide satisfactory performance at JAERI far-infrared free-electron laser.

1. Introduction

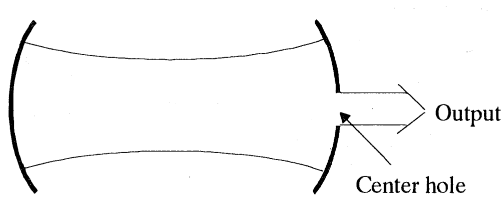
A free electron laser based on a superconducting rf linac has been lased in far-infrared region and achieved 100 W class lasing at JAERI (Japan Atomic Energy Research Institute)[1]. Improvements for the 1 kW class lasing of the FEL system are under progress. To realize a high power and high efficiency FEL system, output coupling of the optical resonator is done efficiently. In infrared region, FEL optical beam is output coupled by cutting away of a part of the optical beam of inside the resonator. Diffraction loss may rise up due to cut away of the optical beam. For the high power far-infrared region FEL, diffraction loss of the optical resonator is one of the most important parameters. The FEL system performance is degraded by the diffraction loss at the mirror edges and apertures. Dominant part of the loss is based on distortion by the output coupling. So, reducing of the distortion by the output coupling has an effect on improvement of the FEL system performance.

In the first lasing experiment at JAERI FEL[2-5], the optical resonator system of the FEL was near concentric geometry with an insertable scraper mirror output coupler. This coupler allows easy adjustment of the output coupling but the mode quality of inside the resonator can be poor. In case of over a few percent output coupling, there is a lot of mode degeneracy[6]. So, this coupler is not adapted for high power and high efficiency FEL system. Then a center hole and a ring-shaped mirror output coupling configurations are investigated in this study.

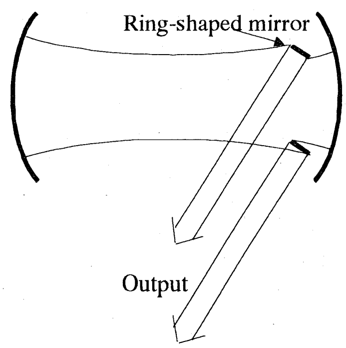
In the output coupling configurations, the mode profile of inside the resonator and diffraction loss at the mirror edges and apertures are calculated by using the iterative calculation procedure used by Fox and Li[7].

2. Calculations and results

A dominant eigenmode in the JAERI FEL optical resonator is calculated using Fox-Li procedure at optical wavelength 30 μm. The total loss per round trip and output coupling efficiency are also evaluated. The total loss means an amount of the diffraction and output coupling, not contains reflection loss of the mirror. The output coupling configurations and the nominal configuration of the JAERI FEL optical resonator are shown schematically in fig.1 and 2. The Calculation model contains two perfectly refrecting mirrors and four apertures. The effect of the undulator duct and bending magnet ducts is taken into account by the four apertures at both end of the undulator and outer side of the bending magnet ducts. The optical resonator for the JAERI FEL is in near concentric configuration, with the parameters listed in table 1.



(a) Center hole output coupling



(b) Ring-shaped mirror output coupling

Fig. 1. Output coupling configurations.

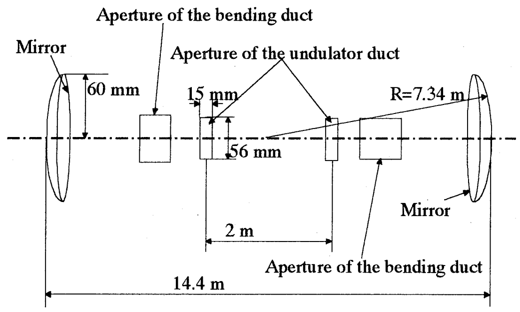


Fig. 2. The nominal configuration of the JAERI FEL optical resonator.

Table 1. Resonator Parameters for JAERI FEL

Length of the resonator	14.4 m
Mirror radius	120 mm
Courverture of the mirror	7.34 m
Undurator duct length	2 m
Aperture of the undulator duct	15×56 mm
Aperture of upstream bending duct	45.5×35.5 mm
Aperture of downstream bending duct	35.5×45.5 mm
Distance of the undulator aperture to upstream bending aperture	1.11 m
Distance of the undulator aperture to downstream bending aperture	1.25 m
Distance of the bending aperture to upstream mirror	5.09 m
Distance of the bending aperture to downstream mirror	4.95 m

Typical results of the transverse intensity profile calculated for each output configuration are shown in fig.3 and 4 at the location of output coupling side mirror. As shown in fig.3 and 4, the mode degeneracy due to output coupling is not so much for the each output configuration. In fig.5, the total loss per round trip and the amount of power coupled through the center hole on downstream side mirror are shown as a function of the center hole radius. In fig.6, the total loss per round trip and the amount of power coupled through the ring-shaped mirror in front of downstream side mirror are shown as a function of the inner radius of the ring-shaped mirror. The round trip loss and the amount of output coupling are monotonously varied in fig.5 and 6. So, the mode degeneracy due to output coupling is not so much. If there is a lot of mode degeneracy, output coupling is discontinuously varied in fig.5 and 6.

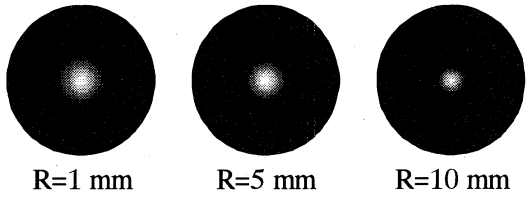


Fig. 3. Typical results of the transverse intensity profile at the output coupling side mirror for center hole output coupling resonator.

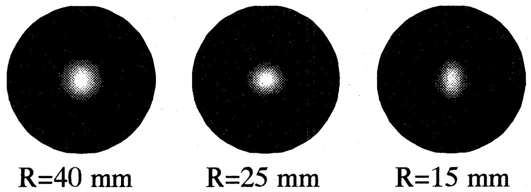


Fig. 4. Typical results of the transverse intensity profile at the output coupling side mirror for ring-shaped mirror output coupling resonator.

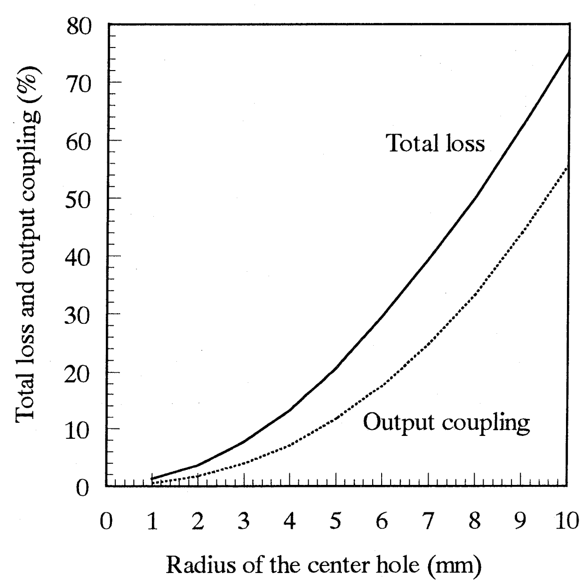


Fig. 5. Total loss per round trip and the amount of power coupled through the center hole on downstream side mirror are shown as a function of the center hole radius.

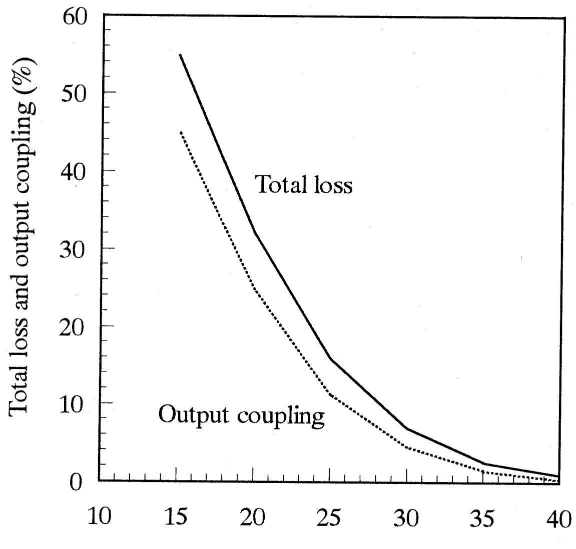


Fig. 6. Total loss per round trip and the amount of power coupled through the ring-shaped mirror in front of downstream side mirror are shown as a function of the inner radius of the ring-shaped mirror.

Output coupling efficiency defined to be the ratio of the power through the output coupler to the total loss is shown as a function of the total loss in fig.7. The output coupling efficiency of the ring-shaped mirror coupler is better than the center hole coupler.

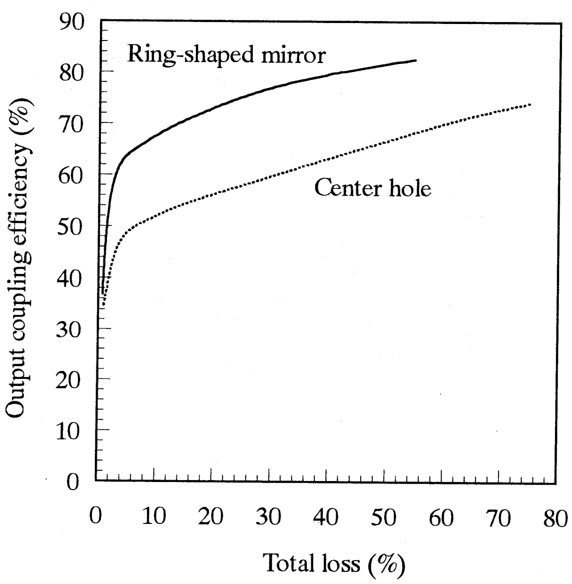


Fig. 7. Output coupling efficiency defined to be the ratio of the power through the output coupler to the total loss is shown as a function of the total loss.

3. Conclusion

The performances of center hole and ring-shaped mirror output coupler optical resonator have shown that the resonator can provide satisfactory performance at JAERI far-infrared free-electron laser. Because of there is not so much mode degeneracy in the both case. It is found that the ring-shaped mirror output coupler is more efficient than the center hole.

References

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