NEW RESONATOR FOR THE ISRAELI FEL

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Abstract

The Israeli FEL resonator (W-band 75-110 GHz) was re-designed in order to reduce the overall round-trip losses and to control the radiation out-coupling.

In its new configuration, the resonator consists of an overmoded corrugated rectangular waveguide and two radiation mode splitters, separating the high-energy e-beam from the mm-wave radiation. The electron input splitter is based on Talbot effect in an overmoded rectangular waveguide. The radiation out-coupling takes place in the output splitter. The splitter is based on a novel design. It combines Talbot effect between two parallel plates with free space propagation and with focusing by two curved cylindrical mirrors in a confocal imaging scheme.

The waveguide and the splitters were tested, showing improved performance in comparison with the former resonator. The measured unloaded Q-factor of the new resonator is increased by a factor of ~3, up to Q=25,000. Accordingly, the round-trip losses are ~23%. Rotating grids control the radiation out-coupling, allowing optimization of the radiation power and the extraction efficiency. The design layout and the testing results are presented.

NEW RESONATOR DESIGN

The Israeli FEL with Curved Parallel Plate (CPP) waveguide-based resonator was reported earlier [1-2]. Only a small part (~5%) of the generated RF energy was coupled out in these configuration. In order to minimize the total round-trip losses of the resonator, it was re-designed. The previously used CPP waveguide was substituted by a two-corrugated-walls rectangular waveguide. To separate the laser RF radiation from the electron beam and to out-couple the desired part of the RF energy, the beam output confocal splitter was also designed.

General Layout

The resonator consists of several waveguide sections of different profiles. It is integrated into

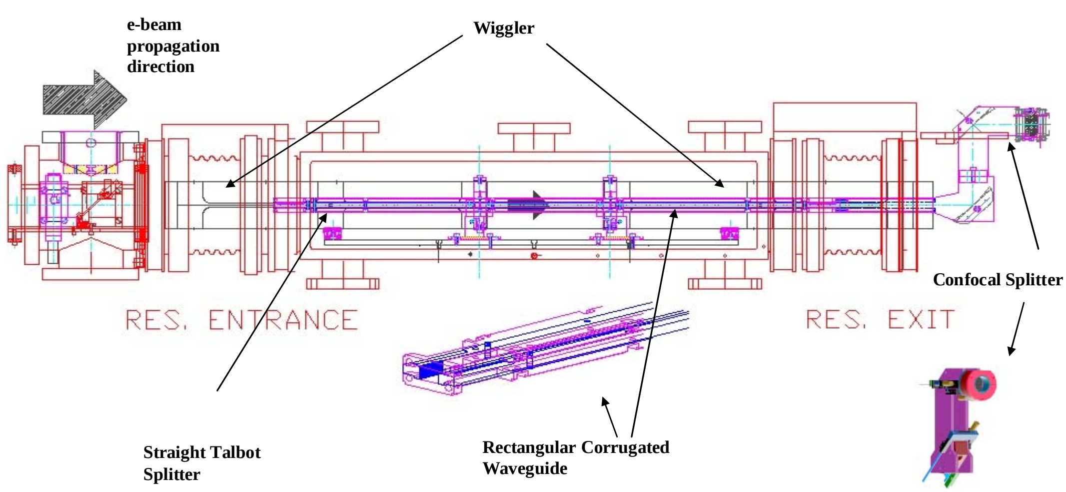

Fig. 1. The resonator lay-out and the scheme of installation of the resonator into the wiggler system.

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the wiggler system, so that the interaction between the electron beam and the wiggler magnetic field of takes place inside the waveguide cavity - rectangular corrugated waveguide. The latter is assembled from 4 separate walls, 2 smooth and 2 mill-machined corrugated. This waveguide was designed in such a way that the electron beam at the design energy (1.4 MeV) can interact only with the fundamental mode TE_{01} according to the dispersion relation. The resonator layout installed into the wiggler system is schematically shown in Fig. 1.

In order to obtain positive feedback from the resonator mirrors, two wave splitters were placed at both terminations of the corrugated waveguide. These splitters are reflectors, based on overmoded rectangular waveguides shorted with a mirror at one end.

Confocal Splitter

The confocal splitter is a quasi-optical mm-wave component that based on a novel design. The splitter consists of an overmoded rectangular waveguide and two curved metallic mirrors. The splitter scheme provides the continuous waveguide propagation and Talbot effect in one dimension, and free-space propagation of the radiation in the other dimension (both orthogonal to the direction of propagation). The two parabolic (shaped in the plane of free space propagation) mirrors provide the dispersion-free focusing. The splitter prototype design and the manufactured model photo are shown at fig. 2. Computer simulation of the radiation propagation through the confocal splitter was also performed. The round-trip losses in the splitter were theoretically estimated as 12%, and later measured experimentally to be about 15 %.

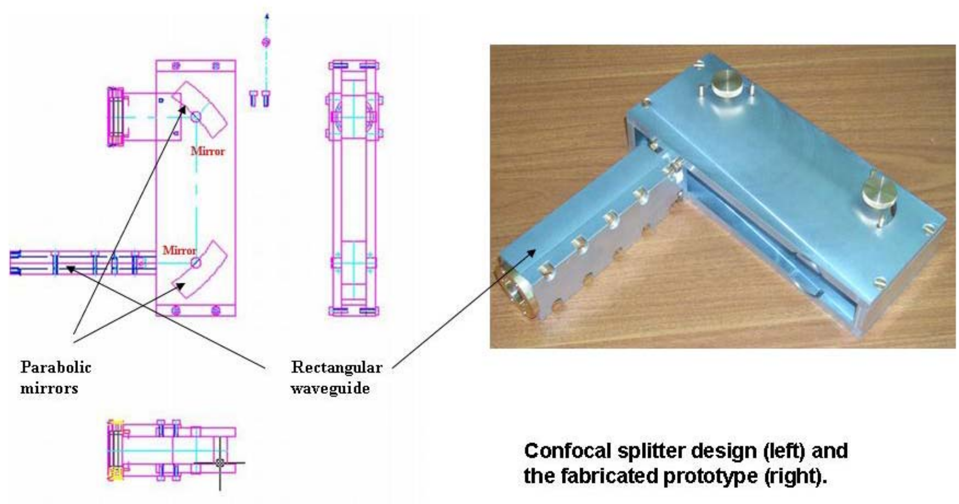

Fig. 2. Confocal splitter design (left) and the fabricated prototype (right).

The length of the input splitter equals to half of the Talbot-effect-optical-imaging length. At this distance, the overmoded (oversized) rectangular waveguide provides splitting of the original field distribution at the termination plane of the waveguide, where the reflecting mirror is placed. This effect allows to make a hole in the metallic mirror (as there is no field in the center), therefore to pass the electron beam through this hole.

The output confocal splitter is of the Talbot-effect-optical-imaging length and it provides the fundamental mode's field reconstruction at the plane of coupling grids that terminate the resonator.

MEASUREMENTS RESULT

After manufacturing of the resonator components, the whole resonator was assembled in the laboratory in order to enable experimental investigation outside the FEL tank. The round-trip reflectivity of the resonator was measured using excitation by special designed corrugated horn mode exciter through the 3-grid tuneable coupler system. In this experiment, the reflected signal from the excited resonator cavity was measured directly and the round trip reflectivity was calculated according to the theory presented in [2], [3].

Calculation of the round trip reflectivity

The algorithm of the round trip reflectivity is based on measurement of the reflection coefficient resonance curve and uses "optical" formulation. The reflection coefficient of the shorted Fabri-Perot resonator is

$$\Gamma = 1 - \frac{(R_1 - R_{rt})(1 - R_1)/R_1}{\left(1 - \sqrt{R_{rt}}\right)^2 + 4\sqrt{R_{rt}}\sin^2(\delta/2)} \qquad (1)$$

were Γ is the power reflection coefficient, R_1 – reflection of the entering mirror (coupling condition), R_{rt} is the total round trip reflectivity and δ is a phase. On the other hand, choosing the Q factor definition as the ratio between the frequency f_0 (resonant wavelength λ_0) and bandwidth of the resonator mode $\delta f_{1/2}$ (or $\delta\lambda_{1/2}$):

$$Q = \frac{f_0}{\delta f_{1/2}} = \frac{\delta\lambda_{1/2}}{\lambda_0} \qquad (2)$$

As it shown in [2], one can derive:

$$Q = \frac{2\pi L}{\lambda}\frac{\sqrt[4]{R_{rt}}}{1 - \sqrt{R_{rt}}} \qquad (3)$$

were L is the resonator length and λ is wavelength. It should be noted that in Eq. 3 above, Q is the loaded Q-factor since both internal and external (coupling mirror) losses are included. Finally, the round trip reflectivity (or total losses, since R_{rt} = 1-Loss) can be found in terms of Q_{loaded} or directly in terms of FWHM ($\delta f_{1/2}$) of the measured resonator peaks:

$$R_{rt} = \left[-\frac{2\pi L}{\lambda_g Q_{loaded}} + \sqrt{\left(\frac{2\pi L}{\lambda_g Q_{loaded}}\right)^2 + 1}\right]^4 \qquad (4)$$

$$= \left[-\frac{2\pi L\delta f_{1/2}}{v_g} + \sqrt{\left(\frac{2\pi L\delta f_{1/2}}{v_g}\right)^2 + 1}\right]^4$$

were λ_g and v_g are the wavelength and velocity of wave propagation inside the resonator accordingly. The total round-trip reflectivity R_{rt} of the FEL resonator was calculated in the present work based on Eq. 4 and the direct measurement of the FWHM linewidth $\delta f_{1/2}$ of the resonant peaks. This linewidth was obtained from measurement of the power spectral reflection pattern.

CONCLUSIONS

The Israeli FEL resonator was re-designed in order to decrease the internal round-trip losses and thus to achieve threshold current reduction. The novel reflector and splitter based on the quasi-optical confocal scheme, were designed, manufactured and characterized. The round trip losses of the confocal splitter are about 15% (in good agreement with the theoretical limit estimation of 12%). The round trip losses of the overmoded corrugated waveguide and straight Talbot section were measured to be about 8 % for both waveguides. The total losses of the whole resonator system are therefore about 23%.

REFERENCES

[1] A. Faingersh, A. Gover, A. Eliran, and B.Kapilevich "Concluding report: measurements and calculation of round-trip reflectivity in the FEL waveguide resonator before and after modification and estimate of threshold current improvement", Internal report of the FEL group, 25-Aug-06, Tel-Aviv University.

[2] A. Gover, A. Faingersh, at al. "Radiation measurements in the new tandem accelerator FEL", Nuclear Instr. And Methods In Physics Research, A 528 (2004), pp. 23-27.

[3] B. Kapilevich, A. Faingersh, and A. Gover, "Accurate determination of Q-factor of a quasi-optical resonator", Microwave and Opt. Tech. Lett., vol.36, No.4, (2003).