A composite open resonator for compact X-ray source

E.G. Bessonov\textsuperscript{a} R.M. Fechtchenko\textsuperscript{a}

\textsuperscript{a}P.N. Lebedev Physical Institute RAS, 117924, Leninsky prospect 53, Moscow, Russia

The results of calculation of the finesse of a composite open resonator for compact X-ray source are presented. The region of the resonator parameters has been found where the finesse is changed unessentially.

1. Introduction

Currently there has been considerable progress in the development of super-reflection mirrors, high-finesse optical resonators (super-resonators) and frequency stabilized high power cw and pulsed mode-locked lasers. Optical resonators can be used as a photon storage to accumulate a very high laser power. By this method, a finesse of the optical resonators of $10^6$ can be achieved, which means the laser power can be enhanced by this order \cite{1}. The high reactive power stored in the super-resonators can be used in gravitational experiments in astrophysics, Laser-Electron Storage Rings \cite{1} - \cite{3}, gravitational analogue of lasers (grasers) \cite{5} or other applications.

The main reason for mirror degradation of high finesse dielectric open resonators of free-electron lasers based on storage rings is the deposition of chemical components on the mirror surface by X-ray synchrotron radiation \cite{6}. The same degradation can occur in Laser-Electron Storage Rings \cite{1} - \cite{3}, gravitational analogue of lasers (grasers) \cite{5} or other applications.

The intensity of the Gaussian laser beam is distributed by the law

$$I_L = \frac{P_0}{2\pi\sigma_L^2} e^{-\frac{r^2}{2\sigma_L^2}},$$

where $P_0 = \int I_L dS$ is the initial power of the laser beam stored in the resonator; $dS$, the element of the area; $\sigma_L = \sigma_{L,0}\sqrt{1 + s^2/l_R}$, the dispersion of the laser beam in a point $s$; $\sigma_{L,0} = \sigma_L(s = 0)$; the point $s = 0$ corresponds to the waist of the laser beam; $l_R = 4\pi\sigma_{L,0}^2/\lambda_L$, the Rayleigh length; $\lambda_L$, the laser wavelength.

In a composite resonator a part $P_1 = P_0R_1$ of the laser power is reflected by the first mirror. A part $(P_1 - \Delta P_1)R_1$ of this power is reflected by external part of the second mirror and

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{fig1}
\caption{A composite open resonator.}
\end{figure}
the other part $\Delta P_1 R_2$ by the internal one, where $\Delta P_1 = P_1[1 - \exp(-a^2/2\sigma_{Lm}^2)]$ is the energy incident upon the insertion part of the second mirror. The round trip reflected power $P_2 = (P_1 - \Delta P_1)R_1 + \Delta P_1 R_2$ can be presented in the form

$$P_2 = P_0 R_1^2 [1 - \frac{R_1 - R_2}{R_1} (1 - e^{-a^2/2\sigma_{Lm}^2})].$$  \hspace{1cm} (2)

After $n$ round trips the laser light power can be presented in the form

$$P(t) \approx P_0 (\frac{P_2}{P_0})^n = P_0 e^{n \ln(P_2/P_0)} = P_0 e^{n \ln[\frac{R_2^2 [1 - \frac{R_1 - R_2}{R_1} (1 - e^{-a^2/2\sigma_{Lm}^2})]}{R_1^2 [1 - \frac{R_1 - R_2}{R_1} (1 - e^{-a^2/2\sigma_{Lm}^2})]}]},$$  \hspace{1cm} (3)

where $n = ct/2L$; $L$, is the resonator length. The finesse of the open resonator can be determined by the equation

$$F = \frac{-2\pi}{\ln\{\frac{R_2^2 [1 - \frac{R_1 - R_2}{R_1} (1 - e^{-a^2/2\sigma_{Lm}^2})]}{R_1^2 [1 - \frac{R_1 - R_2}{R_1} (1 - e^{-a^2/2\sigma_{Lm}^2})]}\}}.$$  \hspace{1cm} (4)

where $F_0 = F|_{R_1 = R_2} = -\pi/\ln R_1 \simeq \pi/(1 - R_1)$. According to (4), in the approximations $(1 - R_1)/(1 - R_2) \ll 1, 1 - R_1 \ll 1$, $1 - R_2 \ll 1, a/\sigma_{Lm} \ll 1$, the finesse of the resonator will be decreased $F_0/F$ times when the radius $a \simeq \sqrt{2}\sigma_{Lm}\sqrt{\frac{1 - R_1}{1 - R_2} \frac{F_0}{F} - 1}$. \hspace{1cm} (5)

Example. The relativistic factor of electrons $\gamma = 10^3$, $\lambda_L = 10 \text{ mkm}$, $\sigma_{L0} = 50 \text{ mkm}$, $L = 2m$, $F/F_0 = 0.5, (1 - R_2)/(1 - R_1) = 10^2$.

In this case, according to (1), (5), the Rayleigh length $l_R = 3.14 \text{ mm}$, the mode size $\sigma_{Lm} = 15.9 \text{ mm}$, the radius of the X-ray beam at the mirrors $\sigma_{X-ray} \simeq L/2\gamma = 1 \text{ mm}$, the radius of the insertion $a = 0.1\sqrt{2}\sigma_{Lm} \simeq 2.25 \text{ mm} > \sigma_{X-ray}$. The magnification $M$, defined as the ratio of the mode size on the mirrors to the mode size at the waist in the resonator, must be chosen to be high ($\sim 10^2 \div 10^3$) as a compromise between mirror degradation, resonator finesse and source issues.

3. Conclusion

We have considered a composite open resonator. One of its mirrors has a small circular insertion at the axis of the resonator made from another much lower finesse material. It was shown that if the dimension of the insertion is larger than the effective transverse dimension of the X-ray beam and much less than the diameter of the fundamental mode the mirror degradation time can be increased to a great extent and the finesse of the resonator is decreased unessentially. Such conditions can be fulfilled when the magnification $M \gg 1$.

This work was supported partly by the Russian Foundation for Basic Research, Grant No 02-02-16209.

REFERENCES

1. J.Chen, K.Imasaki, M.Fujita, et al., Nucl. Instr. Meth. A341 (1994), p.346.
2. Zh. Huang, R.D.Ruth, Phys. Rev. Lett., v.80, No 5, 1998, p. 976.
3. E.G.Bessonov, Proc. of the 23d Int. ICFA Beam Dynamic WS on Laser-Beam Interactions, Stony Brook, NY, June 11-15, 2001; physics/0111084 physics/0202040 (http://atfweb.kek.jp/icfa/2001/box/index.html).
4. J.Urakawa, M.Uesaka, M.Hasegawa, et al., Proc. of the 23d Int. ICFA Beam Dynamic WS on Laser-Beam Interactions, Stony Brook, NY, June 11-15, 2001 (http://atfweb.kek.jp/icfa/2001/box/index.html).
5. E.G.Bessonov, Proc. of the Int. Advanced ICFA Beam Dynamic WS on Quantum Aspects of Beam Physics, Monterey, CA, Jan. 4-9, 1998, World Scientific, p.330, USA; physics/9802037
6. M.Yasumoto, T.Tomimasu, S.Nishihara, N.Umesaki, Proc. of 21st Internat. Free Electron Lasers Conf., Aug.23-28, 1999, Hamburg, Germany, p.II-109.