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On losses and spatial mode characteristics of a wide-aperture Fabry – Perot resonator upon a periodic spatial perturbation of the field phase at one of the mirrors

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***Abstract*. The losses and spatial mode characteristics of a wide-aperture Fabry – Perot resonator are studied upon a periodic spatial perturbation of the radiation-field phase in a thin layer adjacent to one of the resonator mirrors. It is shown that two regions with different perturbation scales, which affect the losses and distortions of the spatial characteristics of the first modes, are formed for a given perturbation amplitude in the general case.**

Keywords: *Fabry – Perot resonator, mode composition.*

Several methods have been worked out at present for determining in most cases the mode characteristics of empty optical resonators [1 – 3], as well as those filled with an active medium [4]. These methods are used to determine the characteristics of the highest-Q modes of a resonator upon a periodic modulation of the absorption coefficient at one of the mirrors [5]. It is also interesting to study the effect of periodic field phase perturbation on mode characteristics. Such a situation may arise due to a deformation of mirrors or in the presence of optical inhomogeneities in the resonator.

In this work, we study the dependence of losses and spatial mode characteristics of a Fabry – Perot resonator on sinusoidal phase perturbations having a small amplitude (insufficient for attaining the point of degeneracy by the system). The perturbations were localised in a thin layer of the medium adjacent to one of the mirrors. The effect of these perturbations was studied in the cross section coinciding with the second mirror. The period l_0 of a certain perturbation was chosen as the unit of measurements in mirror planes. The mirrors were set apart at a distance $L = 0.5z_{\rm T}$, where $z_{\rm T} = kl_0^2/\pi$ is the Talbot spacing and k is the wave number. The radius a of the mirrors was chosen in such a way that the Fresnel number $N_{\rm F1} = (a/l_0)^2$ had the following values: $N_{\rm F1} = 4, N_{\rm F2} = 16$ and $N_{\rm F3} = 64$, i.e., 2, 4 and 8 perturbation periods l_0 fit on radius a.

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Calculations were made by using perturbations with a varying period l, whose dimensionless wave numbers $w_{\rm u} = l_0/l$ were in the range 0 – 8. The complex eigenvalues $\gamma_j(\varepsilon)$ of mode j were determined for each value of the perturbation scale in this range, and were subsequently used to determine the losses $L_j(\varepsilon) = 1 - |\gamma_j(\varepsilon)|^2$ for this mode (ε is the perturbation). We calculated the complex spatial distributions $U_j(x;\varepsilon)$ of eigenvectors and the normal distributions of their moduli:

$$|U_{{\rm norm}j}(x;\varepsilon)| = \frac{|U_j(x;\varepsilon)|}{\max\limits_x |U_j(x;\varepsilon)|}.$$

Fig. 1 shows the dependence of losses L_j for the first four modes on the dimensionless wave number w for N_{F1}, N_{F2} and N_{F3}, respectively, and for an odd phase perturbation $\sin(2\pi x/l)$. One can see from the figure that there are two regions of the perturbation scales, separated distinctly from one another for $N_{\rm F} = N_{\rm F2}, N_{\rm F3}$, where the fundamental mode losses oscillate upon a variation of scale. Let us denote these regions as A and T from left to right. Region A has a range $w_{\rm u} = 0 - 0.5$ for $N_F = N_{F1}$ and narrower ranges adjacent to the origin for large values of N_F. Region T begins at the peak L_0 for $w_{\rm u} = 1$ and extends towards increasing values of $w_{\rm u}$. These two regions are separated by region Z in which there are no oscillations.

One can see from Fig. 1 that the number L_j of oscillations of the losses in region A increases with mode number. Moreover, the amplitude of oscillations of L_j also increases somewhat with mode number. Such behaviour of losses is common for all the perturbations considered by us and for all values of $N_{\rm F}$. Perturbations of the type $\sin(2\pi x/l)$, $-\cos(2\pi x/l)$ and $\cos(2\pi x/l)$ lead to dependences $L_j(w_{\rm u})$, which differ in the number and phase of oscillations. In addition, the nature of deformation of distributions $|U_{{\rm norm}j}(x;\varepsilon)|$ depends on the type of perturbations. In particular, asymmetric perturbations induce asymmetric deformations of spatial distributions (Fig. 2).

Perturbations of the type $\sin(2\pi x/l), -\cos(2\pi x/l)$ and $\cos(2\pi x/l)$ lead to close dependences $L_j(w_{\rm u})$ in region T. The maximum of losses for the fundamental mode is achieved in the region $l \approx l_0$ (for $N_{\rm F} = N_{\rm F1}$, the deviation of the period l corresponding to the maximum of losses from l_0 is of about 3 % and decreases to zero for $N_{\rm F} = N_{\rm F3}$). The number of peaks in region T increases with the Fresnel number, and the peaks themselves become narrower (see Fig. 1). It follows from the results of calculations that the arrangement of peaks on the $w_{\rm u}$ axis in region T corresponds to $\sqrt{n}$ for the

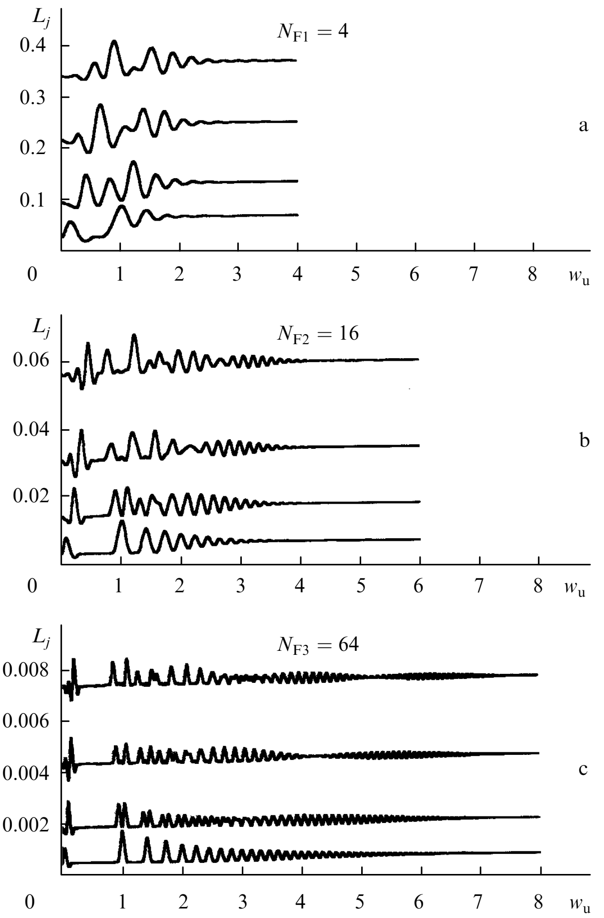

Figure 1. Dependences of losses L_j in the fundamental and the first three modes (the curves are arranged in ascending order) on the dimensionless wave number w_u of spatial perturbation for different Fresnel numbers upon a phase perturbation $\sin(2\pi x/l)$.

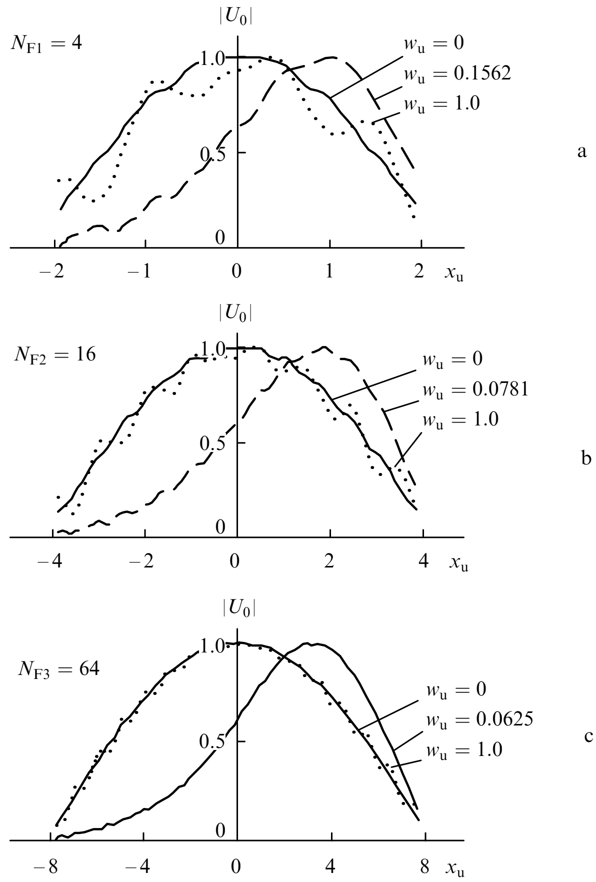

Figure 2. Dependences $U_0(x_u)$ of the distribution of the modulus of the fundamental mode on the Fresnel number N_F for initial distributions ($w_u = 0$), distributions at the maximum of losses peak in region A ($w_u = 0.0625, 0.0781, 0.1562$) and distributions at the beginning of region T ($w_u = 1$); $x_u = x/l_0, w_u = l_0/l$, and $\sin(2\pi x/l)$ is the phase perturbation.

fundamental mode in region T, where n is peak number, the peak at $w_u = 1$ being treated as the first one. Such an arrangement of peaks corresponds to the Talbot multiple effect because n intervals of size $l = l_0/\sqrt{n}$ fit in the spacing $z_T/2 = l_0^2/\lambda$ for a cell size l^2/λ. With increasing mode number, the loss peaks split off (Figs 1b, c). The fundamental mode profile at the points $\sqrt{n}$ in region T proves to be distorted, the period of distortions being equal to the scale of perturbations (Fig 2).

In region Z, the distributions $|U_{\mathrm{norm}j}(x;\varepsilon)|$ are less deformed than in regions A and T.

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