INVESTIGATION OF MULTIPASS MODES OF A COAXIAL LASER FOR LIDARS

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The paper presents some results of the investigations of coaxial lasers with the cavity, which consists of a flat and aspherical mirrors. Estimation of the dependences of admissible angles at the vertex of a conoid on the cavity length and on radius of the output radiation circle on the flat mirror and slopes of output beams on the cavity length is presented. These dependences allow one to choose parameters of the coaxial laser cavities in order to obtain necessary characteristics of the output radiation.

Active elements of a circular cross section for the development of lasers with a large radiation energy have been proposed in a number of references.[1,2] Increase in the energy in the given case is reached due to an increase of the cross dimensions of the cavity (and active medium) while keeping the longitudinal dimensions.

Theoretical investigations of coaxial lasers are too a complex problem. Preliminary estimations, which were carried out within the scope of a flat model, are presented in Ref. 3. However, the flat model describes only one "ideal" type of oscillations, which is never realized in practice. Experimental investigations of output characteristics of similar lasers show that multipass modes (M-modes)[2] are the predominant type of oscillations.

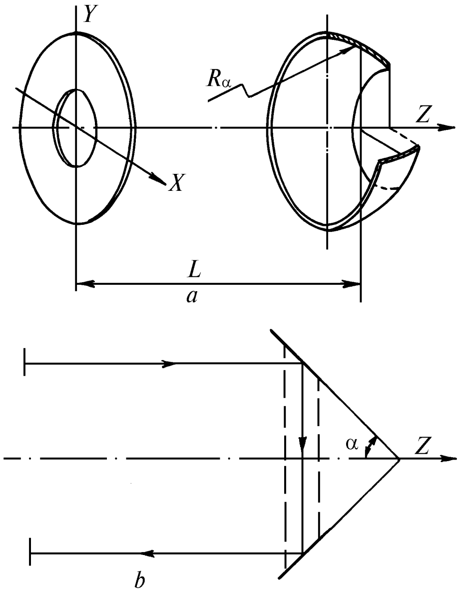


FIG. 1. The geometry of a cavity (a) and plane model of the cavity (b).

This paper presents some results of the analysis of M-mode in a coaxial laser with a cavity comprising flat and aspherical mirrors. The aspherical mirror is made in the form of axially symmetric conoid, which is formed by an arc with radius R_a (Fig. 1*a*).

Figure 1*b* shows the cavity section by a plane, which passes through the symmetry axis. As it follows from this figure, the normal incidence of optical beams on the flat mirror is fulfilled only for one angle $\alpha = 45°$. In this case only, the optical beam does not escape the cavity at the multiple pass.

For a simplification of the three-dimensional problem, the aspherical mirror was replaced with an equivalent conic mirror with the angle 2α at vertex of a cone. We consider ray path in the cavity in a ray approximation.

In our analysis we have assumed that

– optical beams in aspherical mirror must lie in the plane, which is parallel to the flat mirror plane of the given cavity;

– at the incidence of optical beam on the conic surface of mirror the reflected beam lies in the plane, which is formed by the incident beam and a normal to the conic surface;

– because of the cone symmetry the normal to its surface passes through the symmetry axis.

Figure 2 shows the path of rays in the three-dimensional cavity model. The upper circle corresponds to the section of the cone by the plane, which is perpendicular to the symmetry axis OO'. The bottom circle is the place of points of the beam reflection from the flat mirror M_2. The beam $A'C'$ is parallel to X axis and it is at a distance $O'A'$ from it, R is the radius of working section of the cavity on a cone, R_{fl} is the circle radius of output radiation on the flat mirror.

From obvious considerations it follows that in a steady regime beams in the conic mirror must lie in the plane of circle with O' center. The beam reflected from the cone lies in two planes; the first one is the plane $A'C'B'A$, the second is perpendicular to the mirror plane

M_1, the plane $C'BB'$. If the beam in the plane of the cone passes over at a distance $\Delta h = O'A'$ from the symmetry axis, then the distance $\Delta H = AO$ is found from the relation

$\Delta h/\Delta H = 1/k$.

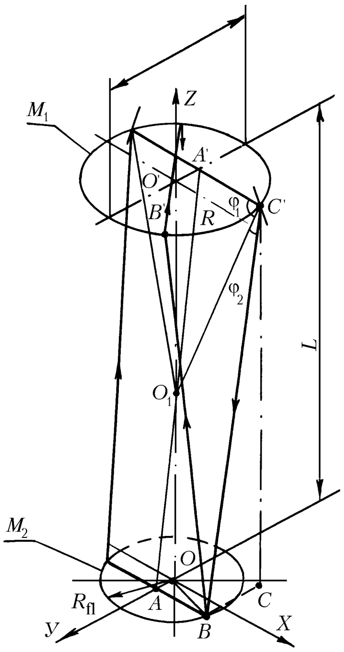


FIG. 2. The beam path in the three-dimensional model of the cavity.

The point O_1 is an intersection point of the symmetry axis of the cavity with the plane $A'C'BA$. In addition it is also intersection point of all normals to the conical surface at a given R. From Fig. 2 it also follows that the plane $C'BB'$ is perpendicular to the mirror plane and the beam reflected from the cone is in it. Besides, plane $C'BB'$ is perpendicular to OB. Since the reflected beam belongs to both these planes, then the point of its reflection from the flat mirror also must belong to planes $A'C'BA$ and $C'BB'$. Detailed analysis of the beam path in the three-dimensional model of the cavity determines the coordinates of the following reflection points:

point A' ($X_{A'} = 0$, $Y_{A'} = -\Delta h$, $Z_{A'} = L$);

point C' ($X_{C'} = \sqrt{R^2 - \Delta h^2}$, $Y_{C'} = -\Delta h$, $Z_{C'} = L$);

point B ($X_B = \sqrt{(R^2 - \Delta h^2)/2}\ +$

$+\sqrt{(R^2 - \Delta h^2)/4 - k(k+1)\Delta h^2}$, $Y_B = k\Delta h$, $Z_B = 0$).

The condition of self-reproduction of the paths in the multipass modes in the aspherical cavity takes the form:

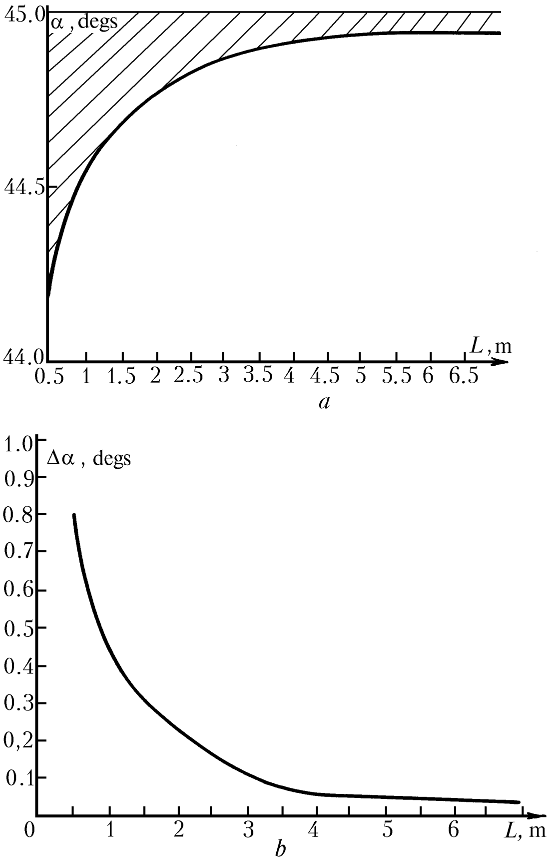
$$\cos\varphi_1 = \cos\varphi_2. \qquad (1)$$

This condition can be met not for an arbitrary relations between the cavity parameters L, R, and α.

Figures 3–5 show the results of calculational estimates of the cavity parameters, from which one can determine the values L, R, and α, which make the Eq. (1) valid.

Figure 3*a* presents the dependence of allowable angles α at vertex of a cone on the cavity length L at constant value R. The shadowed area in the figure designates the area of possible values of the angle at vertex of the cone of the aspherical mirror, at which the existence of multipass modes is possible. From the analysis of these curves it follows that at increase of the cavity length the angle 2α at the cone vertex tends to 90°, at the decrease of cavity length the existence of M-modes is provided at angles 2α less than 90°. The minimum value of this angle is determined by the specific structural parameters of the cavity. Hence it follows that the flat model of the cavity well describes the aspherical cavity properties only at large L values.

Figure 3*b* shows variation over a range of possible angles $\Delta\alpha$ of the cone vertex for various cavity lengths L. From this figure follows that at small cavity length the requirements to accuracy with respect to angle at the vertex of the cone become less stringent.



a

b

FIG.3.

Figure 4*a* presents the dependence of admissible angles α at the conoid top on the ring radius of the output radiation in the flat mirror R_{fl} at a fixed value R. From curves the range of angles at the conoid top can be determined for a gap in spark discharge cell of the laser ($R - R_{fl}$).

Multipass modes show that their output beams go at various angles with respect to the mirror M_2. For some practical applications this property may be very interesting.[4] The above-mentioned procedure allows one to estimate the values of angles of output beams depending on various structural parameters of the cavities.

Figure 4*b* presents the dependence of output beam slopes on the length of the cavity L at a fixed value R. There is a possibility to work with M-modes in a wide range of slopes at small lengths of the cavity. This range is set by the increase in the cavity length. Figure 5*a* shows the dependence of slopes of output beams on the ring radius of radiation on the output mirror R_{fl}. These dependences can be used for determination of the gap in the discharge cell, which provides the oscillation of M-modes with the given parameters.

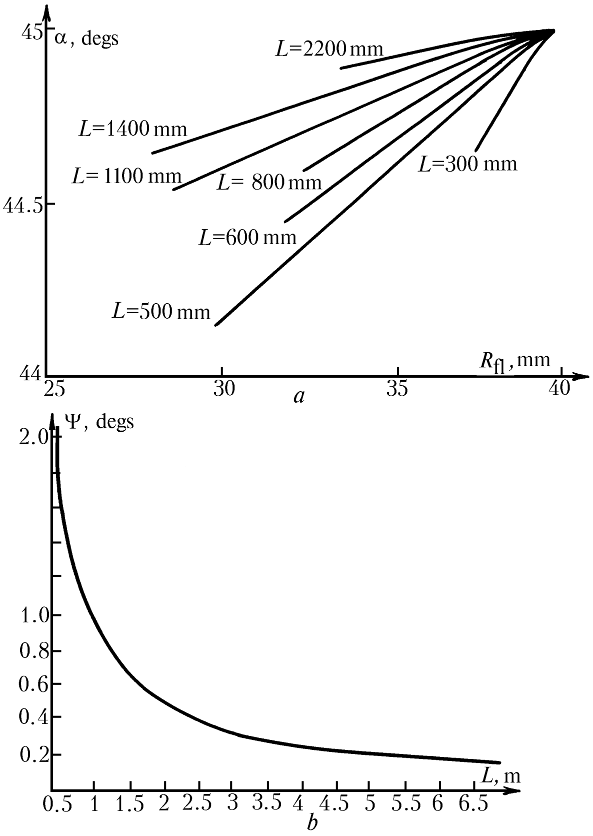


FIG. 4.

Figure 5*b* shows the dependence of the output beams slopes ψ on a displacement of beams, which pass over within the cone and on the symmetry axis of the cavity Δh. If it is necessary to work on M-modes with large slopes, the absorption rod can be introduced into the symmetry axis region. The dimensions of the rod are to be determined from this figure in order to provide the oscillation at the given slopes.

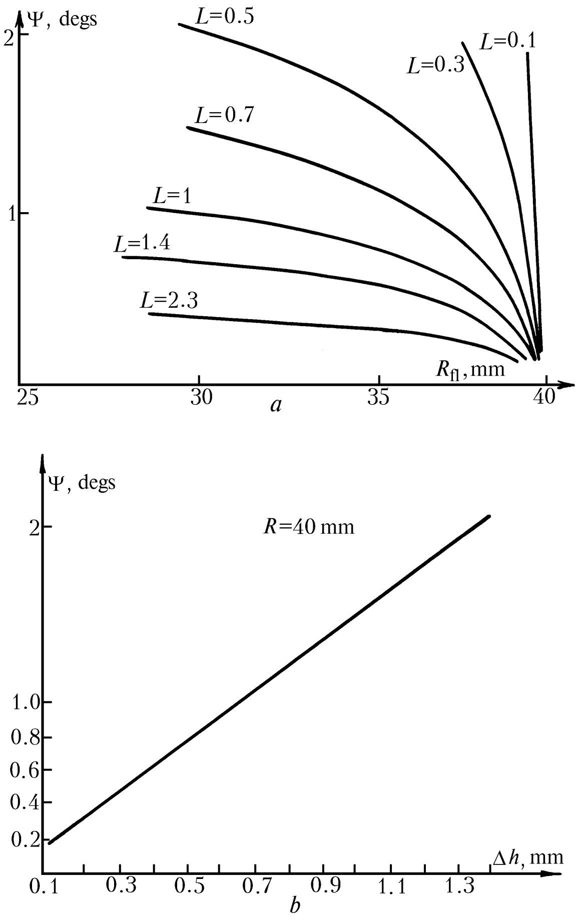


FIG. 5.

The above dependences obtained in this paper allow one to determine basic constructive parameters of the coaxial laser cavities for the given group of multipass modes. It is shown, that multipass modes can exist only in cavities with angles 90° at the vertex of the equivalent cone and less. The minimum value of this angle is determined by the concrete structural cavity parameters.

The results of theoretical investigation presented here are in agreement with experimental data, obtained in Ref. 2.

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