It is shown that by increasing the distance between the external mirrors of a ruby laser it is possible to reduce the angle of divergence of the radiation at the expense of energy alone. There is an optimal distance at which the light sum of the axial luminous intensity is maximum.

In [1-4] it was shown that by increasing the distance between the external mirrors of a ruby laser one can produce generation in a small number of modes. The authors anticipated that this would tend to reduce the angle of divergence and to increase the axial luminous intensity of the laser radiation. These problems were the subject of the present study.

In contrast to [1-4], our experiments involved a powerful laser and intense pumping: with the mirrors positioned near the crystal, the generated energy amounted to 20 J per burst.

Description of the Experiment

The ruby crystal in the shape of a rod (length: 75 mm; diameter: 16 mm) with a 90° orientation of the optic axis had a chromium ion concentration of about $10^{15}$ cm$^{-3}$. The crystal was pumped with filament-type xenon lamps. The pumping conditions (except those involved in the measurement of the threshold) remained the same in all experiments. The plane, dielectrically coated mirrors had a diameter equal to that of the crystal. The exit mirror with a reflectivity of 77% at 694 nm was mounted at a fixed distance from the nearest end face of the crystal. The non-transparent mirror could be moved as far as 20 m away. All of the measurements were made on the exit mirror side. The angular divergence of the laser radiation was measured photoelectrically. In this case, the radiation was directed into a long-focus objective ($f = 975$ mm for measuring large divergence angles and $f = 2440$ mm for measuring small divergence angles). Interchangeable calibration apertures of various diameters were placed in the focal plane of the objective. Behind these apertures was placed a piece of milk glass. The light scattered by the milk glass struck the cathode of a F-5 photocell coupled to an integrating circuit whose signal was displayed on an oscilloscope screen. The amplitude of the signal was proportional to its energy.
Results of the Experiment

Figure 1 shows the dependence of the relative signal energy $W/W_0$ on the angular diameter of the calibrated aperture. The angle $\phi_{0.5}$ to which one half of the total radiated energy was confined was arbitrarily assumed to be the angle of divergence of the light beam. The curves in Fig. 1 were used to obtain the angular distribution $B_\phi/B_0$ of the laser radiation (Fig. 2), where $B_\phi = dW/dS_\phi$ ($dS_\phi$ is the area of an annular element with angular diameter $\phi$).

![Oscillogram of the radiation of a laser with a resonator base of 13 m.](image)

It is notable that the angle $\phi_{0.5}$ to which 50% of the total radiated energy was confined was somewhat larger than the angle along whose circumference the luminous intensity fell to 50% of its axial value. With a resonator base of 13 m, generation was observed to take place in a small number of modes with an angular divergence on the order of 1-1.5°. The temporal character of the vibrations became simpler (Fig. 3). The groups of bursts adjacent in time corresponded to modes with different directions, which made it difficult to measure accurately the angular distribution of the radiation using the conventional procedure. The area of the generating portion of the crystal end face diminished as the non-transparent mirror was moved further away. With a base of $L = 13$ m generation was confined to two small areas. These areas coincided geometrically with the points of minimal wave front curvature in the interferogram of the crystal. The threshold changed little as the base was varied from 0.65 to 6.5 m, and then increased rapidly, becoming 2.7 times larger at a length of 13 m than it was at the minimal $L$. At a distance of 20 m between mirrors, the losses in the resonator were so large that generation could not be produced, even at the maximum permissible pumping energy. Figure 4 shows the energy $W_H$, divergence angle $\phi_{0.5}$, and the light sum $B$ of the axial luminous intensity as functions of the distance $L$ between resonator mirrors. The radiation energy and divergence angle diminish as the base becomes larger, while the light sum grows, attaining its maximum at a base of 6-8 m.

Discussion of the Results

Increase in the base is accompanied by selection of the simplest modes for which the resonator "Q" increases. This resulted in a reduction of the divergence angle, increased the light sum, and simplified the relaxation pattern. In order to prevent the generated energy from diminishing substantially with increasing base it would appear to be necessary to improve substantially the quality of ruby crystals. According to [5], a crystal 16 mm long and 75 mm in diameter with $L = 13$ m would operate in the fundamental mode if it were homogeneous to within 0.02 of a band, taking account of thermal deformations during bursts. Ruby crystals of this degree of homogeneity have not yet been produced. The greatly increased thresholds associated with large bases can apparently be attributed to the effect of microinhomogeneities in the crystal, which scatter the parallel beam at small angles. This scattering increases aperture losses in the resonator as the base becomes larger.