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ROTATIONAL PONDEROMOTIVE INSTABILITY

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We consider in this paper the effect of rotational ponderomotive instability, the gist of which is as follows: We assume that a spherically symmetrical body is exposed to a homogeneous light flux. We assume also that the absorption coefficient η of the body surface depends on the surface temperature in such a way that $\partial\eta/\partial T > 0$. It is easy to see that this body will be rotationally unstable relative to any axis perpendicular to the flux. Indeed, if we impart to this body an initial angular momentum about an axis perpendicular to the light flux (see Fig. 1), then the parts of the surface that are symmetrical relative to the flux will have different temperatures (at the chosen direction of rotation we have $T_B > T_A$), owing to the finite time of heating of the surface (the part of the body CFD, which is in the "shadow," is cooled). Since by assumption $\partial\eta/\partial T > 0$, the absorption coefficient is larger in the vicinity of B than in the vicinity of A, and consequently the body acquires an additional mechanical moment about 0; this moment coincides in direction with the initial moment. Thus, the angular velocity ω of the body will increase. For most metals and many dielectrics, $\partial\eta/\partial T > 0$ in a wide range of temperatures and wavelengths. We note that in this effect the "choice" of the initial rotation axis is analogous to the "choice" of the initial phase of a Thomson oscillator: the initial rotation axis and the phase are determined by the initial impulse. It is clear that any body with $\partial\eta/\partial T > 0$, having an axial symmetry, will be rotationally unstable relative to the symmetry axis in a homogeneous light flux.

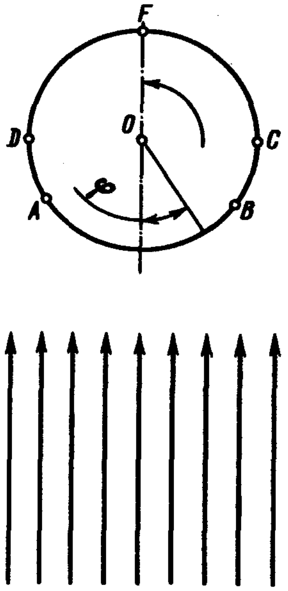

Fig. 1. Cylinder in homogeneous light flux (explaining the principle of rotational instability).

An exact solution of the problem of the rotational ponderomotive instability is a rather complicated matter. To estimate the magnitude of the effect, let us confine ourselves to a simplified model, viz., a cylinder whose axis is perpendicular to the direction of the light flux. We assume that ω is specified. Then the absorption coefficient η is a function of ϕ and ω only, namely $\eta = \eta(\phi,\omega)$. Obviously, $\eta(\phi,0)$ is an even function of ϕ, $\eta(\phi,\infty) = \text{const}$, and $\eta(\phi,\infty) < \eta(\phi,0)$ at all points of the illuminated part of the surface ($-\pi/2 < \phi < \pi/2$), for when $\omega \to \infty$ the entire surface has on the average a lower temperature than the illuminated part of the cylinder at rest. When $0 < \infty < \infty$ the function $\eta(\phi,\omega)$ is asymmetrical relative to ϕ, so that $\eta(+\phi,\omega) - \eta(-\phi,\omega) > 0$. Taking these circumstances into account, we put for a rough estimate of the effect

$$\eta(\phi, \omega) = a(\omega) + b(\omega)\phi . \tag{1}$$

The functions $a(\omega)$ and $b(\omega)$ should have the following properties: $a(\omega)$ is positive and decreases monotonically when ω increases from 0 to ∞; $b(\omega)$ is also positive (since $\partial\eta/\partial T > 0$ and $b(0) = b(\infty) = 0$ and $b(\omega)$ has a maximum at a certain value ω_0 such that the time of thermal relaxation of the surface is of the order of ω_0^{-1}.

If a light flux of density W is incident on a cylinder of radius and height R, then the moment of the light-pressure forces about the cylinder axis is

$$\int_{\pi/2}^{\pi/2} \frac{W}{c} \eta R^3 \sin\phi \cos\phi \, d\phi = \frac{W}{c} \frac{\pi}{2} R^3 b(\omega) . \qquad (2)$$

Assuming that b(ω) is a slowly varying function (in analogy with the procedure used to solve nonlinear problems in oscillation theory), the change of the cylinder rotational velocity Δω within a time Δt is equal to:

$$\Delta\omega = \frac{\pi}{2} \frac{W}{c} R^3 \frac{1}{I} b(\omega) \, \Delta t \quad , \qquad (3)$$

where I is the moment of inertia of the cylinder. By way of illustration we present an estimate for an artificial earth satellite. Assuming its radius to be R = 3 m and its mass ∿300 kg, we obtain Δω ≃ 0.1 rad/sec after Δt ≃ 1 year, if $b(\omega) = 1 \cdot 10^{-2}$.

The effect considered here can be observed with relative ease under laboratory conditions. We present below a brief description of a setup used to observe this effect. A cylinder 1.5 cm high and of 1 cm radius, made of tin foil 15 μ thick, was mounted on a diamagnetic suspension [1] in an evacuated volume (pressure $P = (2 - 4) \times 10^{-6}$ mm Hg). The cylinder could rotate freely on this suspension about a vertical axis, with a damping time on the order of a day. A flux with power density $W \simeq 5 \times 10^6$ erg/cm²sec was incident on its lateral surface.

The initial rotation period imparted to the cylinder was 3 - 3.5 sec (the time of thermal relaxation of the cylinder was 1 - 2 sec). The measurements consisted of observing the time change of the period of the cylinder rotation with the illumination source turned on and off. To exclude the influence of asymmetry of the light flux relative to the cylinder, the measurements were made with the cylinder rotating both clockwise and counter clockwise. (More intense illumination of one side of the cylinder also leads to the appearance of a mechanical moment about its axis .)

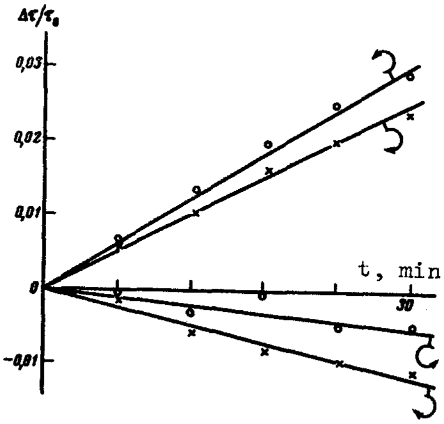

Fig. 2. Results of one measurement series. When the illumination source is turned on (lower half-plane), the period of cylinder rotation decreases.

The results of one series of measurements are shown in Fig. 2. The ordinates represent the relative change of the cylinder rotation period, $\Delta\tau/\tau_0$, and the abscissas represent the time. The arrows show the rotation direction. The angular velocity of the cylinder increases when the illumination source is on (lower half-plane) regardless of the rotation direction. Some discrepancy is observed for the cases when the cylinder rotates clockwise and counterclockwise, and is attributed to the change of pressure P in the volume and to the asymmetry of the light flux relative to the cylinder. The observed change of the angular velocity due to the effect under consideration amounts to $\Delta\omega_{\text{meas}} \simeq 2.5 \times 10^{-2}$ rad/sec; after Δτ = 1800 sec. The approximate formula (3) yields a value of Δω of the same order. The approximate value of b(ω) that can be obtained knowing the temperature drop at a given rotation velocity and knowing the dependence of η on the temperature [2] is $(2 - 3) \times 10^{-2}$.

When precision physical experiments are performed with test bodies, it is essential to take into account the effect of ponderomotive rotational instability. If the body is not free but constitutes a torsional pendulum illuminated by an electromagnetic flux, then the presence of a temperature dependence of the absorption coefficient leads to additional stiffness and friction in the system; their signs and magnitudes depend on the thermal inertial properties of the body.

In conclusion, let us note one interesting circumstance. The angular velocity of a body having the dimensions of the earth would change after 5 billion years, as a result of the foregoing effect, by an amount $\Delta\omega \simeq 2 \times 10^{-5}$ rad/sec (assuming $b(\omega) \simeq 10^{-1}$), under the condition that the flux density of the solar radiation, averaged over 5 billion years, is larger by approximately one order of magnitude than the presently observed value. (At the present time, ω of the earth amounts to 7.3×10^{-5} rad/sec.)

[1] V.B. Braginskii and V.I. Osika, PTE No. 4, 196 (1969).
[2] Teplotekhnicheskii spravochnik (Heat Engineering Handbook), Gostekhizdat, 1963.

STRUCTURE OF SPECTRA OF SOLID-STATE LASERS IN THE FREE GENERATION REGIME

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We have observed in an earlier study [1] that the emission spectra of free-generation spikes of solid state lasers without mode selection have an irregular structure. The cause of this structure may be the spatial inhomogeneity of the field in the laser resonator, which leads to an uneven burning out of the inversion [2]. Such a situation obtains in a laser operating in the "standing" wave regime.

To verify the correctness of the assumption that spatial inhomogeneity of the radiation field plays a role in the formation of the irregular structure of the spectra, we have investigated the emission spectra of lasers operating in the "traveling" wave regime. The active elements of the lasers were ruby and neodymium glass, in which, as is well known, the luminescence-line broadening occurs in different ways.

To obtain the "traveling" wave regime, we chose two widely used resonator systems (Fig. 1): a - a ring resonator with a Faraday cell as a nonreciprocal element [3], and b - a ring resonator with a return mirror [4]. The resonator length length was $L \simeq 170$ cm.

The emission spectra in the setup of Fig. 1a were carried for a ruby laser (AR) of 10 mm diameter and 110 mm length. The mode selection in the resonator was eliminated by using nonselective elements. The diaphragms D_1 and D_2, of 2 mm diameter, suppressed the non-axial modes. The spectra were registered with the aid of a Fabry-Perot interferometer (SP) with a resolution $\delta\nu = 0.015$ cm^{-1}. The picture of the spectrum was projected on the input slit of a high-speed scanning camera (SFR) operating in the slit-sweep regime. The reduction of a large number of spectrograms has shown that the spectra of the emission spikes of the described laser always have a structure that is irregular from spike to spike. A typical microphotograph of the spectrum of the first generation spike is shown in Fig. 2a.