

INVESTIGATION OF DISSIPATIVE PONDEROMOTIVE EFFECTS OF
ELECTROMAGNETIC RADIATION

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An experiment is described in which a variation in the decrement of mechanical oscillations of a mobile wall of an ultrahigh frequency resonator was observed in the presence within the resonator of a powerful electromagnetic field (the effect of electromagnetic damping). The coefficient of electromagnetic damping introduced into the mechanical oscillator changes both in magnitude and in sign depending on the tuning of the resonator. The measured numerical values of the damping coefficient agree satisfactorily with a theoretical estimate.

THE present paper is devoted to an experimental verification of the dissipative ponderomotive effects of electromagnetic radiation. In ^[1] it has been noted already that a body which reflects or absorbs electromagnetic radiation and which oscillates in the direction of the source experiences additional electromagnetic damping. Utilization of resonant electromagnetic systems makes the magnitude of the effect much greater, and this enables one to observe the effect under laboratory conditions.

We attach one of the walls of mass m of a resonator (this may be either a Fabry–Perot resonator or a UHF volume resonator) to the laboratory by a means of a mechanical stiffness K_{mech} thereby converting it into a mechanical oscillator. We adjust the frequency of the electromagnetic generator which induces oscillations in the resonator in such a way that the equilibrium position of the mechanical oscillator corresponds to a steep region of the slope of the resonance curve of the resonator.

In the case of small oscillations of the mechanical oscillator an electromagnetic damping H_{em} appears in addition to H_{mech} and also an additional stiffness K_{em} . The sign of the quantities H_{em} and K_{em} depends on the choice of the slope of the resonance curve:^[1]

$$[H_{\text{em}}]_{\text{max}} = \pm \frac{W}{c^2} \frac{4\pi L}{\lambda(1-R)^3}, \quad [K_{\text{em}}]_{\text{max}} = \mp \frac{W}{c} \frac{2\pi}{\lambda(1-R)^2}, \quad (1)$$

where λ is the wavelength in the resonator, L is the length of the resonator, R is the coefficient of reflection of the mirrors of the resonator, W is the power supplied to the resonator, c is the velocity of light.

From formulas (1) it can be seen that by choosing the ratio λ/L and $(1-R)$ to be sufficiently small one can observe this effect under laboratory conditions and, what is of particular interest, one can observe the change in the sign of H_{em} and K_{em} (cf., ^[1] for greater detail).

An experimental set-up was constructed in which a section of a rectangular three-centimeter wave guide of length $L = 10$ m served as the resonator. The resonator was excited by means of electromagnetic waves passing through the coupling slit. A CW source of UHF was used as the generator. At one end of the waveguide

a movable piston was installed by means of which the resonator could be tuned. At the other end of the waveguide the wall of the resonator consisted of a metallic plate suspended by a thin quartz fiber (Fig. 1). The frequency of the proper pendulum oscillations for this oscillator was $f_{\text{mech}} = 3$ Hz. The plate was made of aluminum foil of thickness 1μ (the depth of the skin-layer is $\delta = 0.67 \mu$). The foil was glued to a rigid frame made of a quartz fiber of thickness 40μ . The quartz fiber from which the plate was suspended of 7μ diameter but thicker at the ends was welded to the frame. The mass of such an oscillator amounted to a few milligrams. This enabled us to reduce considerably the time constant of the mechanical oscillator $\tau^* = 2m/H_{\text{mech}}$, thereby reducing the time for measurement. The friction in the suspension is comparable to the friction due to a rarefied gas at a pressure of $p \approx 5 \times 10^{-9}$ mm of Hg, and its effect is practically eliminated since the measurements were carried out at a pressure of $p \approx 7 \times 10^{-6}$ mm of Hg. The time constant τ_{mech}^* was in this case equal to ~ 80 min. A system for photoindication of the amplitude of the oscillations of the oscillator was utilized. A narrow beam of light (a gas laser was used as the source of illumination) on being reflected from the mirror attached to the pendulum fell on a photographic film. The optical level provided a magnification of the amplitude of the oscillations of the pendulum by a factor of 300.

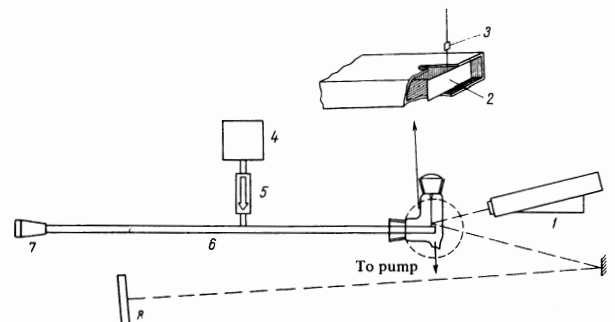


FIG. 1. Schematic diagram of the experimental arrangement: 1—laser, 2—plate-oscillator, 3—mirror, 4—magnetron, 5—ferrite valve, 6—resonator, 7—mobile piston, 8—photographic film.

The measurement of H_{em} reduced to the measurement of the time constant of the oscillator τ^* , which must vary depending on the chosen slope of the resonance curve of the waveguide resonator. After the resonator has been tuned by means of the mobile piston an initial amplitude for the oscillations of the pendulum was provided. Photographs were taken spaced by definite time intervals Δt . The length of one exposure amounted to 4 sec. On running the films through a photometer and thereby knowing the amplitudes of the oscillations of the pendulum and the time intervals Δt one can easily compute the time constants τ_{left}^* and τ_{rt}^* (depending on the chosen slope of the resonance curve). Knowing τ_{left}^* and τ_{rt}^* one can obtain H_{em} :

$$H_{em} = m \frac{\tau_{rt}^* - \tau_{left}^*}{\tau_{rt}^* \tau_{left}^*} \quad (2)$$

The introduction into the system of an additional electromagnetic stiffness $+K_{em}$ was observed by the change in the proper frequency of the oscillator f_{mech} .

We now give an estimate of the value of H_{em} for the system under investigation. The formulas (1) are somewhat altered as a result of the fact that one of the walls of the resonator is "static," with a coefficient of reflection of the plate R close to unity. In this case

$$[K_{em}]_{max} \approx \pm \frac{W}{c} \frac{32\pi}{\lambda(1-R)^2}, \quad [H_{em}]_{max} \approx \mp \frac{W}{c^2} \frac{128\pi L}{\lambda(1-R)^3} \quad (3)$$

The quality factor of the UHF resonator was measured: $Q = 19\,000-22\,000$; with such a quality factor $(1-R) = 0.135-0.15$; $\lambda = 4$ cm, $W \approx (0.6-1.0) W$. Substituting these values into (3) we obtain

$$H_{em} \approx (2.0 - 4.12) \cdot 10^{-7} \text{ g/sec.} \quad (4)$$

For a mass of the plate $m \approx 4 \times 10^{-3}$ g the time constant determined only by H_{em} is $\tau_{em}^* \approx 6 \times 10^4$ sec (approximately 16 h).

Measurements were made of the level of seismic background which amounted for the amplitude of the oscillations of the pendulum on the average to 20-30 μ . Thus, the scatter in the results of the measurements is determined primarily by seismic effects. (The initial amplitude of the oscillations of the pendulum usually amounted to 120-150 μ).

A calculation of the influence of the radiometric effect showed that the additional radiometric damping is $H_{rm} \approx 1 \times 10^{-13}$ g/sec. In order to decrease the coupling of the UHF resonator with the generator the power from the source was supplied through a ferrite valve with a directional coefficient of 20 dB. Measurements were carried out first with one, and then with two ferrite valves connected in series. No changes in the measured values were observed in this case. This fact enables us to assert that "pulling" effects have been eliminated.

In the course of the experiment several series of measurements were carried out. Two series are shown in Fig. 2. The circles denote the time constants of the oscillator when the resonator is tuned to the left slope of the resonance curve τ_{left}^* . In this case additional damping must be introduced into the mechanical system.^[2] The dots denote the values of τ_{rt}^* . Calculations of the confidence intervals for the average values were carried out by means of the Student criterion.^[3]

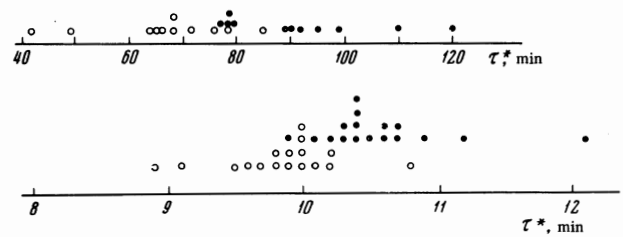


FIG. 2. Two series of measurements: ●— τ_{rt}^* , ○— τ_{left}^* .

An estimate of the discrepancy between the average values of τ_{left}^* and τ_{rt}^* enable us to establish that τ_{rt}^* and τ_{left}^* are significantly different with a level of confidence of 0.999.

The average value of H_{em} (evaluated according to the data of Fig. 2a) is equal to $H_{em} = (2.95 \pm 1.39)_{0.95} \times 10^{-7}$ g/sec; $H_{em} = (2.95 \pm 2.8)_{0.999} \times 10^{-7}$ g/sec. It is necessary to note that the true average value of H_{em} calculated according to formula (2) has a meteorological error of 30-40% due to the inexact knowledge of the mass of the pendulum m (in gluing the foil of the pendulum to the quartz frame it is impossible to take into account exactly the mass of the droplets of glue), and also due to the inaccuracy in determining the absolute value of the power of electromagnetic radiation entering the resonator.

The values of τ_{left}^* and τ_{rt}^* shown in Fig. 2b were obtained on measurements with another pendulum and for a somewhat different value of the power. In this case the pressure is $p \sim 1.5 \times 10^{-5}$ mm of Hg; $(1-R) \approx 1.3 \times 10^{-1}$; $m \approx 3.5 \times 10^{-3}$ g; $W \approx (0.4-0.8)W$; $H_{meas} = (3.0 \pm 2.3)_{0.999} \times 10^{-7}$ g/sec.

The measured values of H_{em} agree satisfactorily with the calculated estimate (4).

The results of the experiments that we have carried out, and also the theoretical estimates of the values of H_{em} and K_{em} show that the effects of the ponderomotive interaction of electromagnetic radiation with a mechanical oscillator must be taken into account in designing certain sensitive experiments with test bodies.

In conclusion we note that the effect of electromagnetic damping must basically determine the lifetime of micrometeorites revolving around the earth. (The lifetimes of micrometeorites of diameter of the order of 1 μ amounts to tens of years.)

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¹ V. B. Braginskiĭ and A. B. Manukin, Zh. Eksp. Teor. Fiz. **52**, 986 (1967) [Sov. Phys.-JETP **25**, 653 (1967)].

² V. B. Braginskiĭ and I. I. Minakova, Bulletin Moscow State University, Ser. III, **1**, 83 (1964).

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