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Force Measurements on Electrets

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Abstract

Force exerted on electrets by slot-like electrodes was measured. The dependence of this force on the width and length of the slot as well as on the electrode-electret distance was investigated. The results were found to be in good agreement with theory.

ONE possible application of electrets is the construction of electret devices which can be used for transforming electrical energy into mechanical energy. These devices must combine a sufficiently large force with an adequate shielding of the electret, because electrets lose their polarization when not shielded.

Three possible types of electrode arrangements in such devices are shown in Figure 1. In the first arrangement (top, left), the electret is well shielded, but its motion is restricted by the electrodes, and the force is relatively small. In the second arrangement (top, right), the electret can move freely, but it is not well shielded, and the force, again, is not very large. A much more satisfactory arrangement is shown at the bottom of the figure. There, two pairs of electrodes, each pair forming a slot, are placed above and below the electret. This arrangement combines a nearly complete shielding of electret with an essentially unrestricted motion and a relatively large force. It is this latter electrode arrangement which will be the subject of the present paper.

Theory

From the symmetry, the force exerted on the electret by the top pair of electrodes in the arrangement under consideration is the same as that exerted by the bottom pair. Therefore, in analyzing this arrangement, it will suffice to discuss the force associated with only one pair of electrodes. Such a single pair of electrodes, with the other pair replaced by a grounded conducting plate, is shown in Figure 2.

The theoretical expression for the force exerted on the electret in the arrangement shown in Figure 2 ("slot effect" force), as derived in the paper by Jefimenko [1], is

$$F = \frac{{}^\circ(1 + d/t)}{(1 + \epsilon d/t)^2} \sigma_e l V, \qquad (1)$$

where σ_e, ϵ, and t are the effective surface charge, dielectric constant, and the thickness of the electret, respectively, l is the length of the electrodes (length of the slot), and V is the voltage applied to the electrodes. This equation was obtained under certain simplifying assumptions, so that its experimental verification is of considerable interest.[1]

[1]These assumptions were: (1) the electret was sufficiently thin, and (2) the slot was sufficiently narrow. The derivation involved also the use of the widely accepted although not yet directly verified postulate for electret polarization: $\mathbf{P} = \mathbf{P}_r + \epsilon_o(\epsilon-1)\mathbf{E}$, where $\mathbf{P}_r$ is the remanent polarization and $\epsilon_o(\epsilon-1)\mathbf{E}$ is the induced polarization.

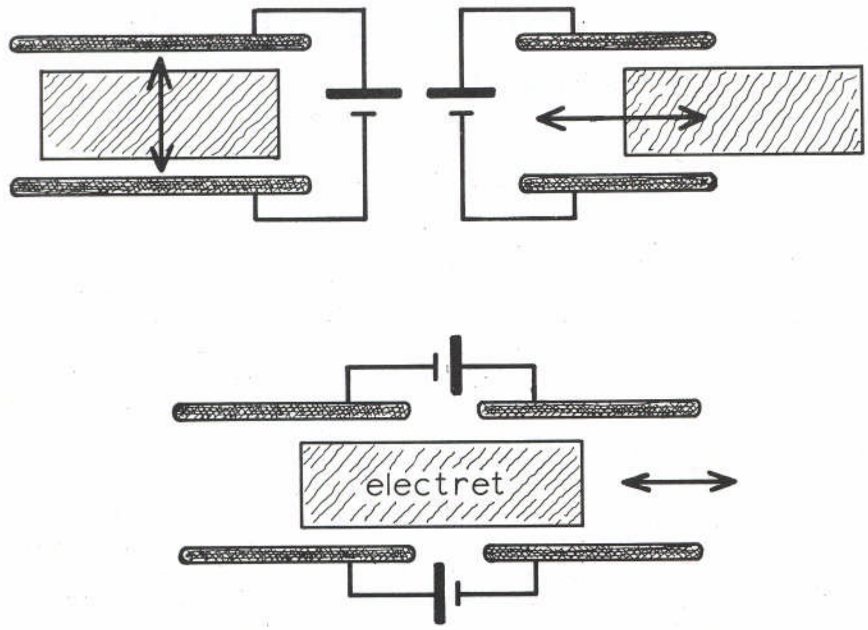

FIGURE 1. Various types of electrode arrangements.

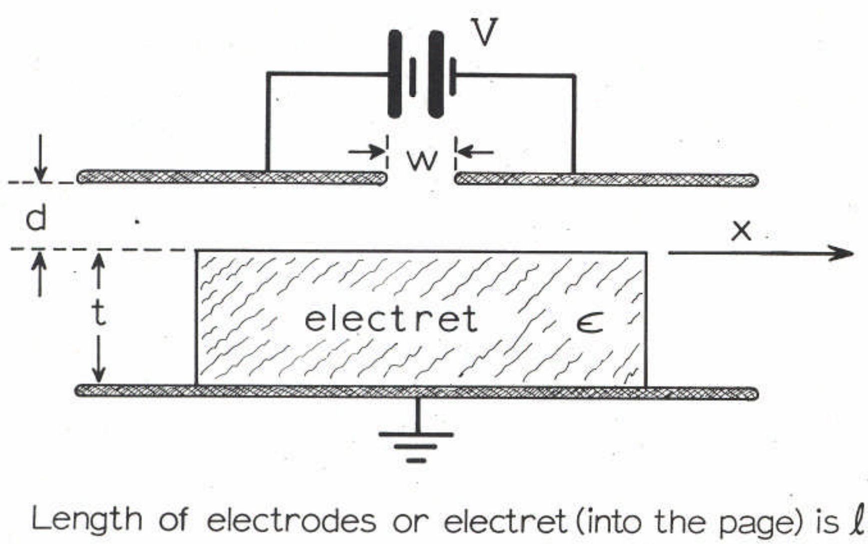

FIGURE 2. Slot-type electrodes above an electret resting on a grounded conducting plate.

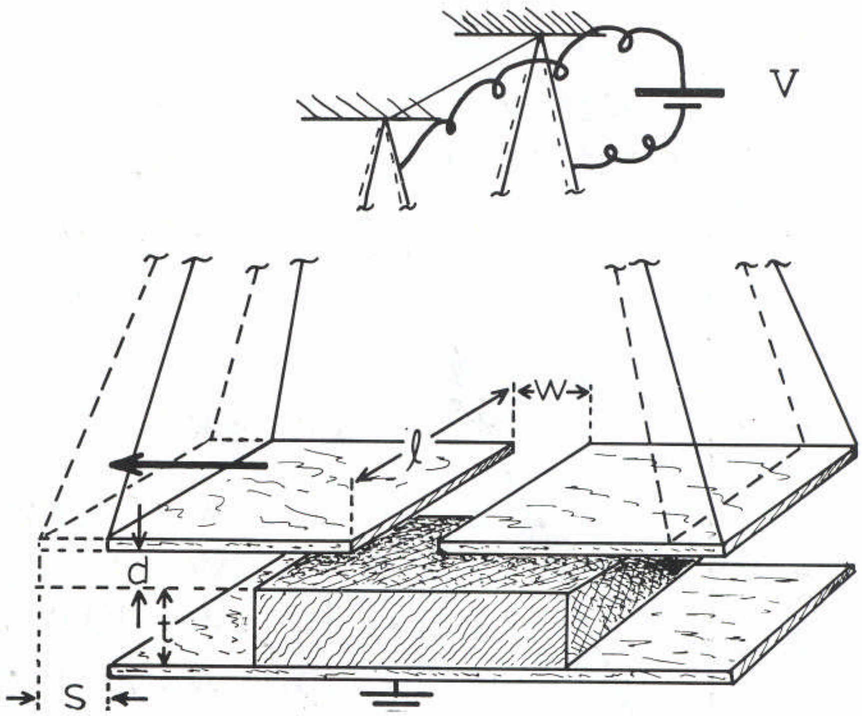

FIGURE 3. Diagram of the force measuring apparatus.

Experiment

A diagram of the apparatus used for the force measurement is shown in Figure 3. The electret was kept at rest and the force that it exerted on the electrodes was measured by means of a pendulum-like device. The electrodes were painted with india ink on very thin mica plates 5 cm wide and 15 cm long mounted in Balsa wood frames. The mass of the electrode assembly was between 5.4 and 6.2 g. The assembly was suspended above the electret by four very light wires so forming a pendulum of length L = 2.89 m. To prevent air currents, the entire device was enclosed in a plastic shield.

When a voltage V, ranging from 200 to 900 v, was applied between the electrodes, the pendulum deflected through a distance S. The deflection was measured by a traveling microscope and did not exceed 3 cm. The maximum deflection corresponded to a force of $\approx$ 60 dynes, as calculated from the well-known pendulum formula

$$F = \frac{mgS}{L} . \qquad (2)$$

Four different distances d between the electrodes and the electret were used: 1 mm, 3 mm, 8 mm, and 16 mm. These distances were adjusted by lowering or raising the electret with the aid of spacers.

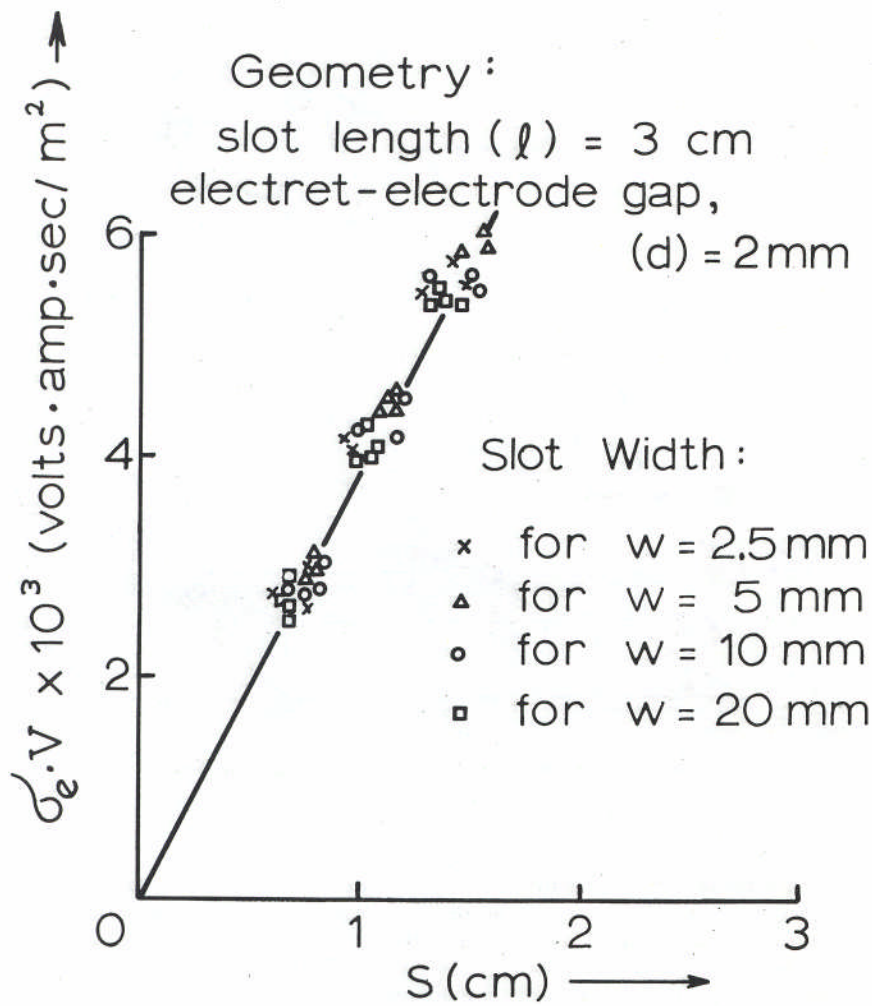

FIGURE 4. The slot width has no effect on the force.

The electrets were disks of thickness t = 12 mm and diameter 70 mm. They were made from mixture of 45 per cent carnauba wax, 45 per cent colophonium, and 10 per cent white beeswax. The details of their preparation are given elsewhere [2].

Results

According to Equation (1), the force should depend on V, l, and d, but not on the slot width w. Our first experiments were designed, therefore, to determine the effect of the slot width on the force.

The results of the corresponding measurements are sumarized in Figure 4. As it follows from Equation (1), the deflection of the pendulum should be proportional to the product $\sigma_e V$ for all electrode-electret arrangements with the same ϵ, d, and l.

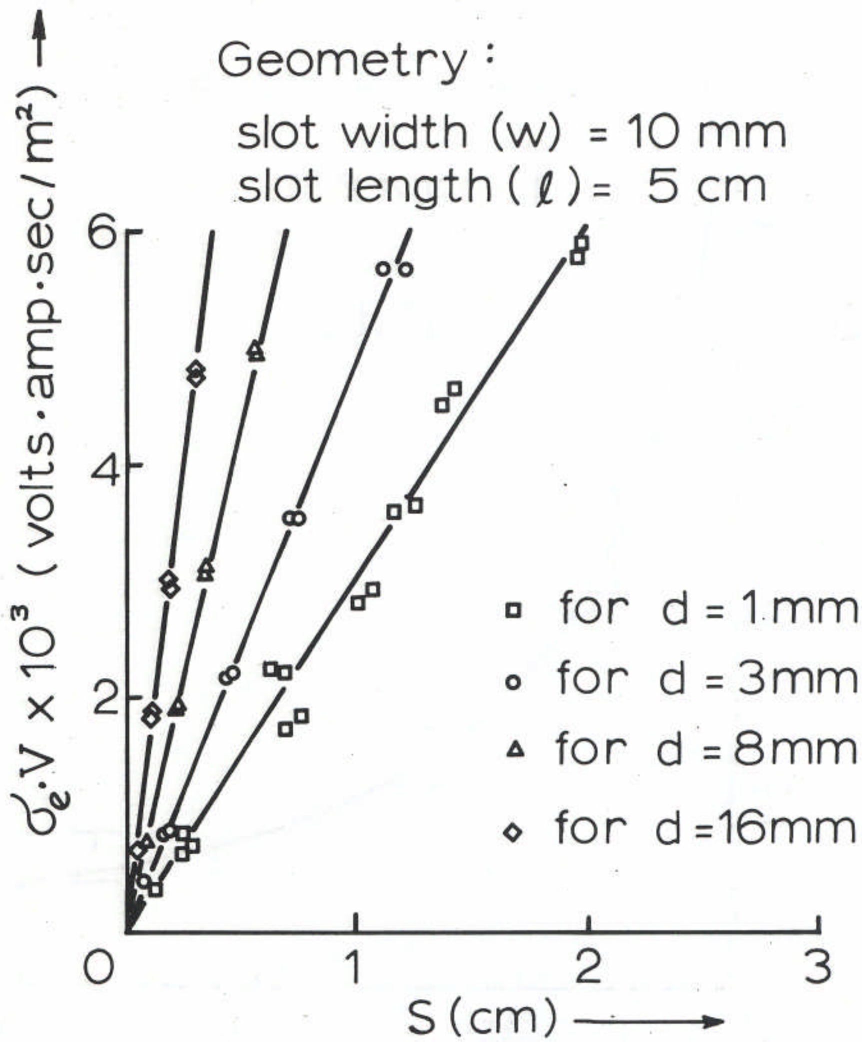

FIGURE 5. The force depends on the electret-electrode distance.

We have, therefore, represented our results as a plot of $\sigma_e V$ against the deflection S. As can be seen from Figure 4, the variation of the slot width had no effect on the deflection, as was predicted by Equation (1).

Our second experiments were designed to determine the effect of the variation of electret-electrode distance d on the force. An example of the results of the corresponding measurements is shown in Figure 5. These measurements were analyzed as follows. According to Equation (1), the ratio of the force associated with a given d to the force associated with d = 0 ("reduced force") is

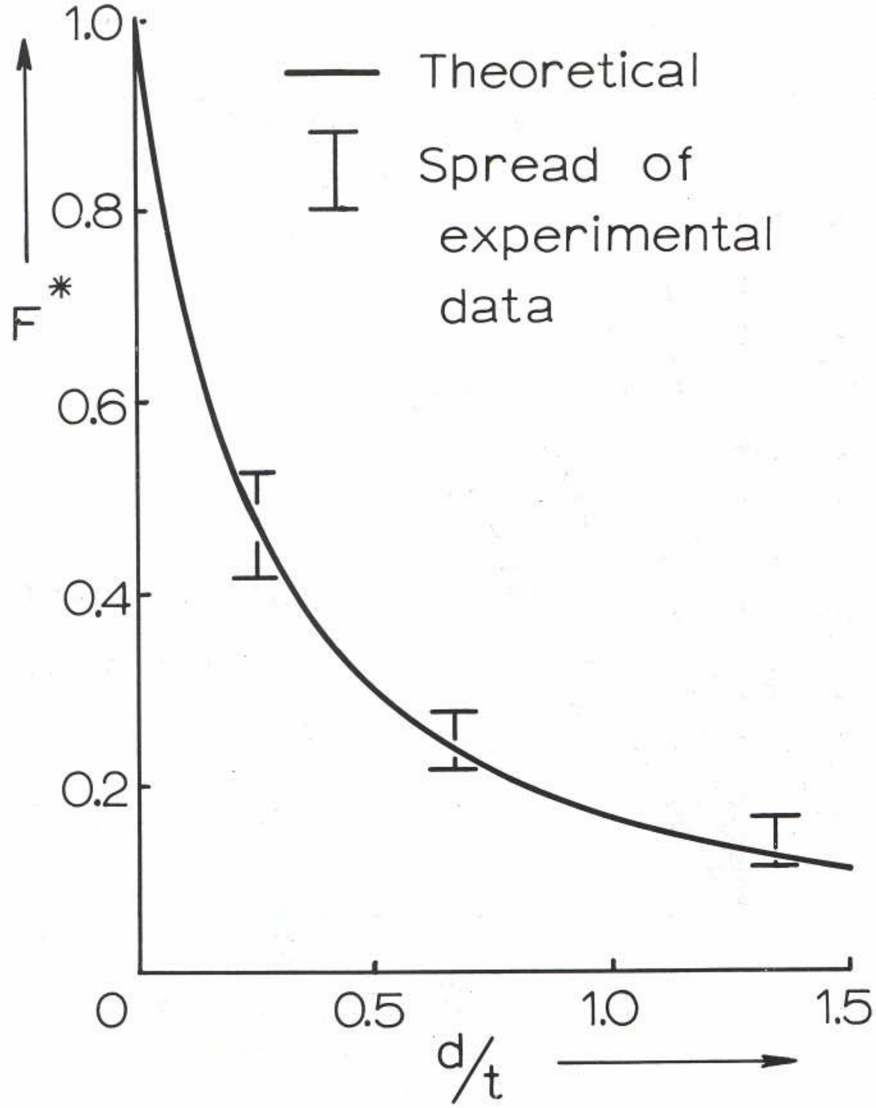

FIGURE 6. The measured forces are in good agreement with the theoretical expression.

$$F^{\circ} = \frac{1 + d/t}{(1 + \epsilon d/t)^2} . \qquad (3)$$

Therefore, one can verify or disprove Equation (1) by comparing the theoretical and the experimental values for F°. Such a comparison is shown in Figure 6. The theoretical curve is that given by Equation (3) with $\epsilon = 2.5$, which was the dielectric constant of our electrets [2]. As can be seen from this figure, the experimental data are again in good agreement with theory.

Our final experiment was a direct measurement of force for $d = 0$. The measured force was within 5 per cent of the value predicted by Equation (1).

DISCUSSION

The measurements described above show that electrodes utilizing the slot effect constitute a very satisfactory arrangement for electret devices transforming electrical energy into mechanical energy.

The force obtained by means of such electrodes is correctly represented by Equation (1). This force is independent of the slot width but depends very strongly on the electret-electrode distance, rapidly decreasing with an increase in this distance. For practical applications, therefore, it will be desirable to make the slot width and the electret-electrode distance as small as possible. They will assure both a maximum force and a maximum shielding. Furthermore, by using many electrodes with narrow slots, one will be able to produce many times larger forces than those obtained with a single wide slot.

We have already constructed electrometers and motors based on the foregoing considerations. The preliminary results obtained with them are very satisfactory.

LITERATURE CITED

1. Jefimenko, Oleg. 1968. Slot effect in electret devices. Proc. W. Va. Acad. Sci. **40**: 345-348 (this volume.)
2. Walker, David K. 1968. External field and stability of carnauba wax electrets. M.S. Thesis, West Virginia Univ., Morgantown.