Slot Effect in Electret Devices

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Abstract

An expression for the force exerted on electrets by slot-type electrodes is derived.

ONE obvious application of electrets is the construction of devices which can be used for transforming electric energy into mechanical energy and vice versa. In the past, such devices were of little practical importance essentially because of two deficiencies; first, the mechanical force available from electrets with traditional electrode arrangements was very small; second, the electrets were losing their polarization as a result of the absence of shielding.

The slot effect allows one to eliminate both these deficiencies by providing almost complete shielding combined with adequate mechanical force.

Consider an electret of thickness t, dielectric constant ϵ, and effective surface charge density σ_e resting on a conducting plate, as shown in Figure 1. Let there be another conducting plate with a slot of width w and length l at a distance d above the electret. As we shall show, if a voltage V is applied between the two halves of the upper plate, the electret will experience a horizontal force

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

We call this phenomenon the "slot effect."

To obtain Equation (1), let us apply the basic electrostatic force equation in the form

$$F_x = {}^\circ \int \rho E_x dv \tag{2}$$

to the upper surface of the electret under consideration. Replacing ρdv by $\sigma_{et} dS = \sigma_{et} l dx$, where σ_{et} is the total effective surface charge of the electret, we have

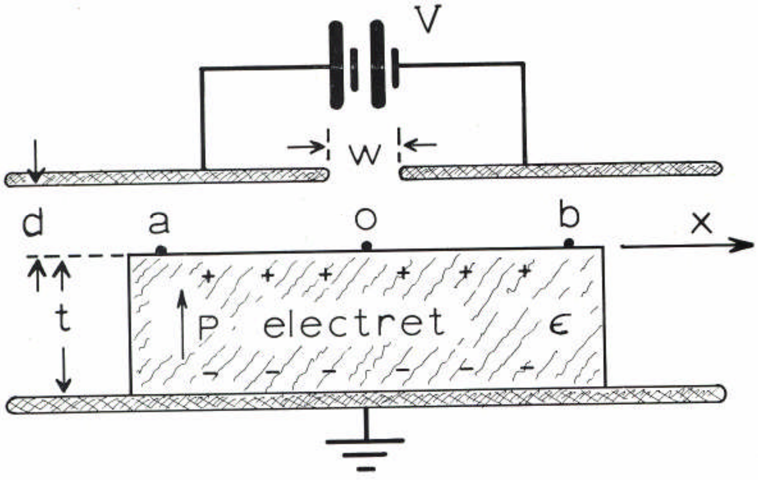
$$F_x = {}^\circ l \int \sigma_{et} E_x dx \, . \tag{3}$$

The charge σ_{et} is given by $\sigma_{et} = \sigma - P_o + P_i$, where σ is the real surface charge, P_o is the normal component of the polarization outside the electret, and P_i is the normal component of the polarization inside the electret, both measured at the upper surface of the electret. However, $P_o = 0$ and

$$P_i = P_r - \epsilon_0 (\epsilon - 1) E_i \, , \tag{4}$$

where P_r is the remanent polarization of the electret, and E_i is the normal component of the electric field in the electret. We can write therefore for σ_{et}

$$\sigma_{et} = \sigma + P_r - \epsilon_0 (\epsilon - 1) E_i = \sigma_e - \epsilon_0 (\epsilon - 1) E_i \, , \tag{5}$$



Length of electrodes or electret (into the page) is ℓ

FIGURE 1. Slot-type electrodes above an electret resting on a grounded conducting plate.

where $\sigma_e = \sigma + P_r$ is the effective surface charge of the electret. Equation (3) becomes then

$$F_x = {}^\circ l \int \sigma_e E_x dx - {}^\circ l \int \epsilon_o (\epsilon - 1) E_i E_x dx \ , \tag{6}$$

where the integrals are extended over the entire upper surface of the electret. Since σ_e is constant, it can be factored out from under the integral sign. The first integral is then

$${}^\circ l \int \sigma_e E_x dx = {}^\circ l \ \sigma_e \int E_x dx = {}^\circ l \ \sigma_e V_s \ , \tag{7}$$

where V_s is the voltage measured along the x-axis between the extreme points of the upper surface of the electret. If the electret is sufficiently thin, which we assume to be the case, the end effects of the electret may be neglected, and this voltage may be replaced by the voltage V_{ab} between the points a and b lying in the regions of the homogeneous electric field. The force is then

$$F_x = {}^\circ \sigma_e \ l \ V_{ab} - {}^\circ l \int^b_a \epsilon_o (\epsilon - 1) E_i E_x dx. \tag{8}$$

If the slot is sufficiently narrow, which we also assume to be the case, E_i may be considered constant throughout the entire left half and the entire right half of the electret, so that we can write, using subscripts "l" and "r" for "left" and "right",

$$F_x = {}^\circ \sigma_e l \ V_{ab} - {}^\circ l \ \epsilon_o \ (\epsilon - 1) \ E_{il} \int^o_a E_x dx - {}^\circ l \ \epsilon_o \ (\epsilon - 1) \ E_{ir} \int^b_o E_x dx,$$

or, since $\int^o_a E_x dx = \int^a_o E_x dx = \frac{1}{2} V_{ab}$,

$$F_x = {}^\circ [\sigma_e - \frac{1}{2} \epsilon_o (\epsilon - 1) \ (E_{il} + E_{ir})] \ l \ V_{ab} \ . \tag{9}$$

The fields E_{il} and E_{ir} can be found as follows. At the upper surface of the electret we must have

$$D_i - D_o = \sigma \ , \qquad (10)$$

where D_i and D_o are the normal components of the displacement at the upper surface inside and outside the electret. Since $D = P + \epsilon_o E$, we have from Equations (4) and (10) (remembering that $P_o = 0$, and $\sigma + P_r = \sigma_e$)

$$\epsilon_o \ \epsilon \ E_i - \epsilon_o E_o = \sigma_e \ . \qquad (11)$$

Since the voltage between the upper and lower plates is $-\frac{V}{2}$ for the right half and $\frac{V}{2}$ for the left half, we have

$$E_{il} \ t + E_{ol} \ d = \frac{1}{2} V \ , \qquad (12)$$

and

$$E_{ir} \ t + E_{or} \ d = -\frac{1}{2} V \ . \qquad (13)$$

From Equations (11), (12), and (13) we obtain

$$E_{il} = \frac{2 \ \sigma_e d + \epsilon_o V}{2\epsilon_o (\epsilon d + t)} \ , \qquad (14)$$

and

$$E_{ir} = \frac{2 \ \sigma_e d - \epsilon_o V}{2\epsilon_o (\epsilon d + t)} \ . \qquad (15)$$

Combining Equations (9), (14), and (15), we obtain for the force equation

$$F_x = \frac{^\circ(1 + d/t)}{1 + \epsilon d/t} \ \sigma_e \ l \ V_{ab} \ . \qquad (16)$$

Now, the potential at the point a with respect to the lower plate is, by Equation (14),

$$\phi_a = \frac{2 \ \sigma_e d + \epsilon_o V}{2 \ \epsilon_o (\epsilon d + t)} \ t \ , \qquad (17)$$

and the potential at the point b is, by Equation (15),

$$\phi_b = \frac{2 \ \sigma_e d - \epsilon_o V}{2 \ \epsilon_o (\epsilon d + t)} \ t \ . \qquad (18)$$

Hence the voltage $V_{ab} = \phi_a - \phi_b$ is

$$V_{ab} = \frac{V}{1 + \epsilon d/t} . \qquad (19)$$

Combining Equations (16) and (19), we finally obtain Equation (1).

It must be pointed out that Equation (1) is subject to the assumption of a sufficiently thin electret and a sufficiently narrow slot. The extent of the validity of this equation must be verified, therefore, by experiments. Such experiments are reported in the paper by Jefimenko and Walker [1].

LITERATURE CITED

1. Jefimenko, O., and D. K. Walker. 1968. Force measurements on electrets. Proc. W. Va. Acad. Sci. **40**: 338-344 (this issue).