

A comparison of two capacitive displacement transducer designs

Brett M. Nordgren

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brett3nt@bnordgren.org

I had always been under the impression that a gap-varying capacitance transducer would be more sensitive than a parallel-motion transducer, but I confess that I had little idea how they actually compared. This is an attempt to make some sort of quantitative comparison of the relative sensitivities to be expected from a modern capacitance transducer of the SDC design vs a Gap Varying Capacitance, *GVC*, design. It is in no way intended to suggest that one design is better than another but is simply a sensitivity comparison based on a particular set of constraints.

Assumptions:

For the sake of comparison, I have arbitrarily assumed that the air gaps in both examples would be the same. In practice, the *GVC* might need a larger gap, though, on the other hand, if employed in a tightly controlled feedback design, it might possibly require less gap.

The SDC is assumed to be operating in a full-bridge configuration and the *GVC* in a half-bridge.

The SDC results are calculated with the assumption that the shadow sectors can be made quite narrow, having width of only 5 x the total gap, or 10 x the air space on each side, although that may be optimistic and such narrow sectors may not exhibit the calculated sensitivity due to field fringing.

Since the sensitivity of either design is proportional to plate area, the comparison here will be based on sensitivity per unit area.

Other performance issues:

The *GVC* is non-linear in capacitance vs displacement whereas the SDC is generally linear. On the other hand, in a feedback application linearity might not matter much, whereas in a non-feedback system, the inherent linearity of the SDC would be advantageous.

The *GVC* would likely exhibit some squeeze-film damping which might require its moving plate to be perforated, possibly reducing its sensitivity slightly, whereas the SDC will be less affected by fluid flow issues. Again, in a feedback system, such damping might well be of no significance, while without feedback it could be important.

SDC Sensitivity Per Unit Area

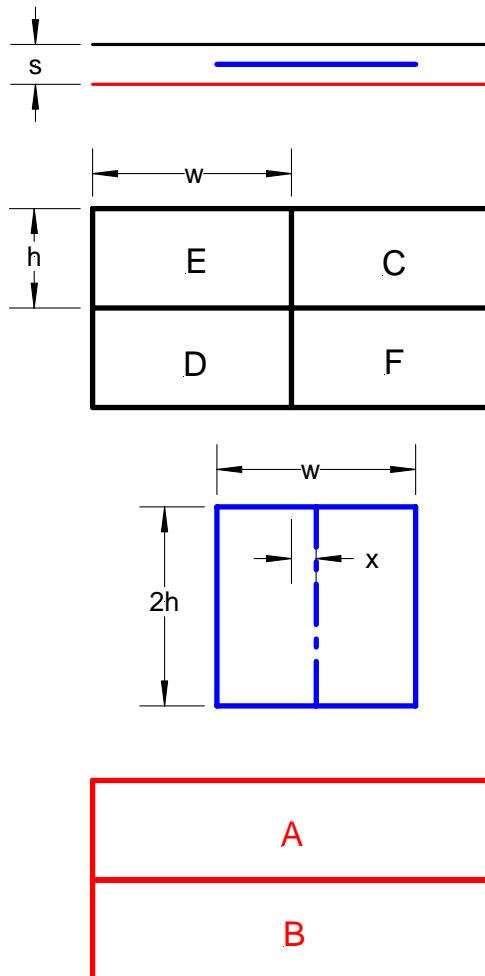
In the SDC array, sectors C & D are connected, and E & F are connected. These sectors have dimensions $h \times w$

The bridge is driven by a balanced signal applied to A and B. A & B each have dimensions $h \times 2w$

The static plates CDEF are separated from static plates AB by distance s .

Midway between the static plates is the moving shadow plate having width w and height $2h$ and having zero thickness.

So, the total area of the array, $A_t = 2h2w = 4hw$



We start by moving the shadow plate an horizontal distance, x .

Capacitances:

$$CD \text{ to A } \quad \epsilon_0 h (w/2-x)/s$$

$$CD \text{ to B } \quad \epsilon_0 h (w/2+x)/s$$

$$EF \text{ to A } \quad \epsilon_0 h (w/2+x)/s$$

$$EF \text{ to B } \quad \epsilon_0 h (w/2-x)/s$$

Capacitance changes due to motion x :

$$CD \text{ to A } \quad -\epsilon_0 hx/s$$

$$CD \text{ to B } \quad \epsilon_0 hx/s$$

$$EF \text{ to A } \quad \epsilon_0 hx/s$$

$$EF \text{ to B } \quad -\epsilon_0 hx/s$$

Arranged in a full bridge, the total unbalance capacitance

$$\text{due to motion, } x \quad C_u = 4\epsilon_0 hx/s \quad Fd$$

Sensitivity: Total unbalance capacitance per unit motion $C_u/x = 4\epsilon_0 h/s \quad Fd/m$

$$\text{Sensitivity per unit area} = (C_u/x)/A_t = 4\epsilon_0 h/(4hws) = \epsilon_0/(ws) \quad Fd/m^3$$

So, for maximum sensitivity/area we will want w to be as small as possible. If $w < 5s$ the sensitivity may decrease due to fringing effects, so for maximum sensitivity we will

$$\text{assume } w = 5s, \text{ making the sensitivity per unit area} = \epsilon_0/5s^2 \quad Fd/m^3$$

Note that if the number of shadow plates is increased, the area increases in proportion leaving the sensitivity per unit area unchanged.

Gap-Variable Sensor Sensitivity Per Unit Area

For a gap-variable sensor, assume two square fixed plates A & B, each having area h^2 and separated by distance s .

Midway between them is the square moving plate C, with zero thickness, also having area h^2 .

Plate C is assumed to move a distance y toward fixed plate A.

Capacitances:

$$A \text{ to } C = \epsilon_0 h^2 / (s/2 - y)$$

$$B \text{ to } C = \epsilon_0 h^2 / (s/2 + y)$$

Arranged as a half-bridge, the total capacitance difference as a function of $y =$

$$C_u = \epsilon_0 h^2 / (s/2 - y) - \epsilon_0 h^2 / (s/2 + y) = 2\epsilon_0 h^2 y / (s^2/4 - y^2)$$

Since this is non-linear, we will define the sensitivity as the magnitude of $dC_u/dy|_{y=0}$
Note that by evaluating at $y = 0$ we will obtain the minimum value for the sensitivity.

$$\text{Sensitivity} = 8\epsilon_0 h^2 / s^2 \text{ Fd/m}$$

$$\text{Sensitivity per unit area} = 8\epsilon_0 / s^2 \text{ Fd/m}^3$$

Comparison

When compared with the SDC's sensitivity per unit area of $\epsilon_0/5s^2$, given the stated geometry assumptions, we find that the gap-variable sensor has 40x the sensitivity.