A comparison of two capacitive displacement transducer designs

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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 exibit 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

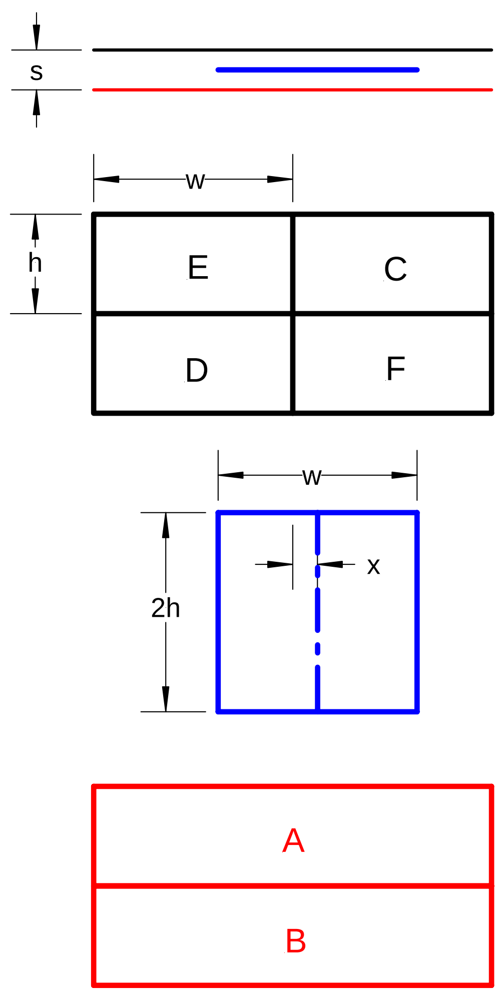
In the SDC array, sectors C & D are connected, and E & F are connected.
These sectors have dimensions h x w

The bridge is driven by a balanced signal applied to A and B.
A & B each have dimensions h x 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 to A ε_0 h (w/2-x)/s

CD to B ε_0 h (w/2+x)/s

EF to A ε_0 h (w/2+x)/s

EF to B ε_0 h (w/2-x)/s

Capacitance changes due to motion x:

CD to A $-\varepsilon_0 hx/s$

CD to B $\varepsilon_0 hx/s$

EF to A $\varepsilon_0 hx/s$

EF to B $-\varepsilon_0 hx/s$

Arranged in a full bridge, the total unbalance capacitance
due to motion, x $C_u = 4\varepsilon_0 hx/s$ Fd

Sensitivity: Total unbalance capacitance per unit motion $C_u/x = 4\varepsilon_0 h/s$ Fd/m

Sensitivity per unit area = $(C_u/x)/A_t = 4\varepsilon_0 h/(4hws) = \varepsilon_0/(ws)$ Fd/m^3

So, for maximun 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 assume w = 5s, making the sensitivity per unit area = $\varepsilon_0/5s^2$ 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 to C = $\varepsilon_0 h^2/(s/2-y)$

B to C = $\varepsilon_0 h^2/(s/2+y)$

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

$C_u = \varepsilon_0 h^2/(s/2-y) - \varepsilon_0 h^2/(s/2+y) = 2\varepsilon_0 h^2 y/(s^2/4-y^2)$

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.

Sensitivity = $8\varepsilon_0 h^2/s^2$ Fd/m

Sensitivity per unit area = $8\varepsilon_0/s^2$ Fd/m^3

Comparison

When compared with the SDC's sensitivity per unit area of $\varepsilon_0/5s^2$, given the stated geometry assumptions, we find that the gap-variable sensor has 40x the sensitivity.