Published in the Proceedings of Transducers/Eurosensors

# A WIDE RANGE, CONFORMABLE, CAPACITIVE DISPLACEMENT TRANSDUCER

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We have developed a displacement transducer concept which successfully addresses the requirements of biomechanics, physiology and general engineering metrology:

- High sensitivity (eg. plethysmography, heart beat monitor, microstrain analysis).
- Large range of elongation (eg. monitoring of respiratory activity and body movements, large deformations of structures).
- Non invasive (e.g. nocturnal penile tumescence monitors).

The design has been validated in many biomedical, agricultural and engineering applications (Ref. 1-4). The European Space Agency has selected and successfully integrated our transducers in the ANBRE suit designed to capture human movements in space (Ref. 4. Pictures 1-2).

In its basic form the transducer consists of a bifilar helix of insulated conductive wires embedded in a tube of elastomeric material (Fig 1). This combination results in an extraordinarily large range of elongation. The range can be more than double its initial length. The flexibility permitted by the design allows the transducer to conform to the contour of objects to which it is attached ( eg. chest, joint, knee, heart) whilst monitoring their dimensional changes (Fig. 2).

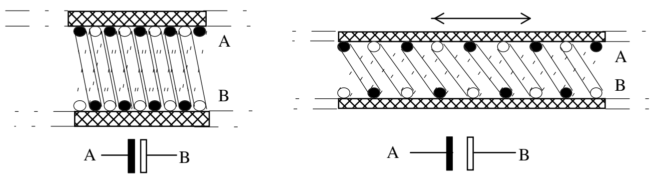



Fig. 1

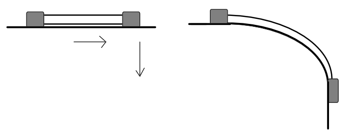
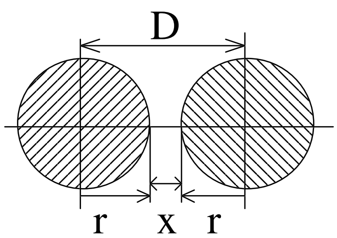


Fig. 2

The transducer is basically a spring: elongation and compliance are determined by the elastic properties of the covering elastomer and the double helix core dimensions.. As the transducer is stretched, the two wires of the double helix core separate in a uniform, reversible fashion, controlled by the silicone covering.

The transducer can be modelled as a multilayer capacitor or, by unwinding the double helix, as a parallel wires capacitor.

The capacitance per unit length c(x) for two parallel conductors of circular cross section of radius r and distance D = 2r+x between centres is:




$$c(x) = \frac{\pi\varepsilon}{\cosh^{-1}\frac{D}{2r}} = \frac{\pi\varepsilon}{\ln\left(\frac{D}{2r} + \sqrt{\left(\frac{D}{2r}\right)^2 - 1}\right)}$$

$$for \quad x << 2r \qquad c(x) = \frac{\pi\,\varepsilon\,r}{x} + c_{\infty}$$

$$C(x) \cong 2Lc(x) = \frac{\varepsilon\,A}{x} + C_{\infty} \qquad (1)$$

In (1) C(x) is the total capacitance, L is the uncoiled length of the electrodes, $A=2\pi rL$ is the effective area, and $C_\infty$, which includes end effects, is the asymptotic value of C(x). If n (>>1) is the total number of turns in the core, the elongation is given by $l = nx$ and the sensor capacitance can also be written as:

$$C(l)=\frac{\varepsilon nA}{l}+C_\infty \qquad l=nx \qquad (2)$$

Equation (1) and (2) encapsulate the essential features of the transducer:
(1) Very high sensitivity and resolution, typical of parallel plate capacitor displacement transducers.
(2) Very large range of elongation, owing to the multiplying effect resulting from the helical configuration , up to a limit set by the tensile strenght of the elastomer.
Another feature is the large capacitance achievable in a small size: a 100 mm long transducer with a core coil of 1 mm diameter and 0.1 mm gauge insulated wire, has an initial capacitance of ~ 300 pF.
If the transducer capacitance, compensated for end effects, is the timing component of a simple hysteretic RC oscillator, the output frequency F is directly proportional to the elongation l:

$$F(l)=\frac{k}{R\left[C(l+l_0)-C_\infty\right]}=\frac{k}{\varepsilon nAR}\left[l+l_0\right]=al+b \qquad (3)$$

In (3) k is an oscillator circuit constant, R is the timing resistance and $d_0$ is the residual core elongation in the relaxed state.
Fig 3 shows the extremely good fit ( to 0.1%) between the elongation data for a typical transducer and the simple model represented by equations (3).

Pic.1-2 ANBRE suit .The elastic transducers are inserted into the butterfly shaped guides.

Ref: 1) United States Patent 5,090,248
2) J.R. Brimacombe et al., Non-invasive monitoring of tidal volume with an extensometer:laboratory and clinical studies. Anaesthesia, 1991, **46**, p756-761
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4) F. Bagiana et al., EUROMIR 95 ANBRE project, ESA.ESAT3, 1994