Thermal noise estimation in bio-inspired hair flow sensor

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In micromachining technology, the reduction in the size of the moving structures has many advantages in different applications. However, these moving structures are subjected to mechanical noise resulting from the molecule agitation. In this abstract, we investigate the thermal-mechanical noise in our artificial hair-flow sensor. The realization of such sensors with high sensitivities requires designs with both low thermal-mechanical noise and high-resolution of angular displacement.

The fluid damping element in the hair sensor, when modelled as a resistor, has a noise source associated with it. For a rectangular membrane with a hair-shaft, the coefficient of the damping torque is related to the gap size, hair-shaft and membrane geometry. The damping coefficient (*R*) can be related to the quality factor by:

$$R = \sqrt{S.J}\,/Q \qquad (1)$$

where *J*: the moment of inertia and *S*: the spring stiffness. The average torque due to the damping coefficient becomes:

$$\bar{T}_{drag\_noise} = \sqrt{4k_{\mathrm{boltz}}TRBW} \qquad (2)$$

where k_{boltz} is Boltzmann's constant = 1.38 ×10^{-23} Joul/Kelvin, *T* is the absolute temperature and *BW* is the bandwidth of the sensor. The average angular displacement due to the thermal noise becomes:

$$\bar{\alpha} = \bar{T}_{drag\_noise}\,/S \qquad (3)$$

Once the average angular displacement is determined, the hair capacitance (due to the thermal noise) can be calculated. Recalling the input parameters to calculate the damping in each hair element (Quality factor of 1.96, $J = 2.5 \times 10^{-16}$ kg.m^2, $S = 7.8 \times 10^{-9}$ Nm/rad with hair length of 1 mm and *BW* of 1 kHz), the damping coefficient (from equation 1) is 0.55×10^{-12} Nm.s/rad. The correspondence average hair angular displacement is 0.65×10^{-6} rad. This generates 2.7 aF capacitance change in each hair-sensor. These values correspond to a detection limit of about 49 μm/s flow in our current hair-sensors.

In conclusion, the thermal noise will influence the design of high sensitivity sensors. Hence, the hair-sensor optimization (FoM [2]) has to be adapted to include the effect of the thermal mechanical noise, in addition to the bandwidth and sensitivity. We present a theoretical study in the thermal noise for our artificial hair sensor. Mathematical models for the damping coefficient originated from the hair-shaft and membrane geometry will be investigated further in our conference contribution.

References

[1] T. Shimozawa, et al., Cricket wind receptors: thermal noise for the highest sensitivity known. In: F.G. Barth, J.A.C. Humphrey and T. Secomb, Editors, Sensors and Sensing in Biology and Engineering, Springer, Berlin (2003) pp. 145–157.

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