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Micro-angle tilt detection for the rotor of a novel rotational gyroscope with 0.47″ resolution

Key words: Micro-angle detection; Differential capacitive structure; Rotational gyroscope

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Introduction

- A differential capacitive detecting structure is presented to measure the tilt angle of the rotor of a novel rotational gyroscope. It has potential to obtain higher structural sensitivity than the detecting structures used in levitated rotational gyroscopes.

- Little has been reported on tilt angle measurement of the rotors of rotational gyroscopes using differential capacitive detection.

- An ASIC is designed to convert differential capacitance changes to voltage signals in this work.

Gyro and its detecting structure

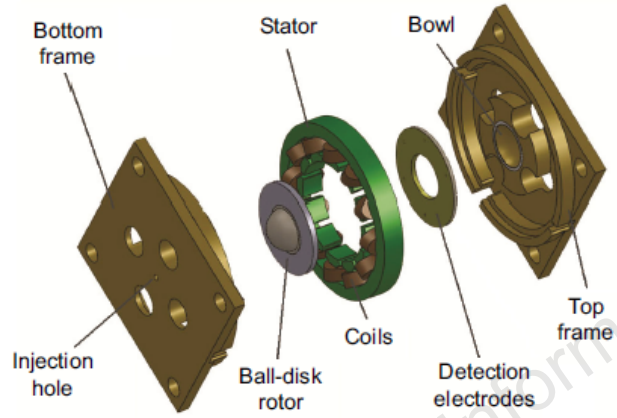

Fig. 1 Assembly drawing of the mechanical structure of the gyroscope

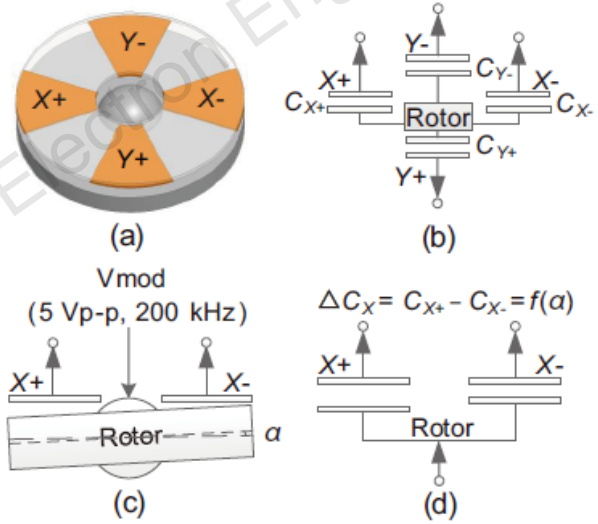

Fig. 2 Schematic of the micro-angle detecting structure (a) and its equivalent circuit (b), and schematic of the detection structure when the rotor tilts away from its null position (c) and its equivalent circuit (d)

Modeling of the detecting structure

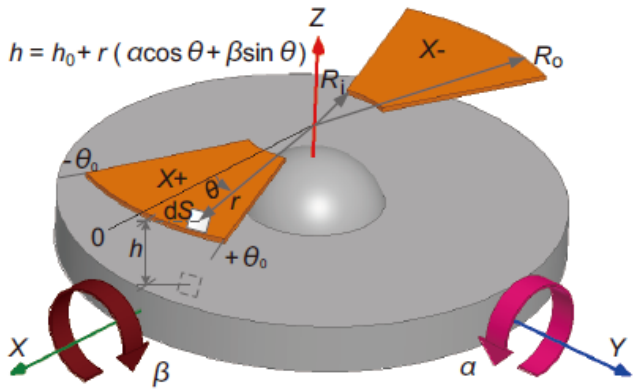

Fig. 3 The differential capacitor pair formed by electrodes $X+$ and $X-$ with the rotor where the capacitances are functions of the tilt angles of the rotor

$$\Delta C_X = -4\varepsilon \sum_{\substack{n=2M+1 \\ M=0}}^{M=\infty} \frac{R_o^{n+2} - R_i^{n+2}}{n(n+2)h_0^{n+1}} \sum_{\substack{k=2N+1 \\ N=0}}^{N=\frac{n-1}{2}} \binom{n}{n-k} \sin^{n-k+1}\theta_0 \cos^{k-1}\theta_0 \cdot \left[1 + \sum_{l=1}^{l=\frac{k-1}{2}} \left(\prod_{m=0}^{m=l-1} \frac{k-1-2m}{n-2-2m} \right) \cos^{-2l}\theta_0 \right] \alpha^k \beta^{n-k}.$$

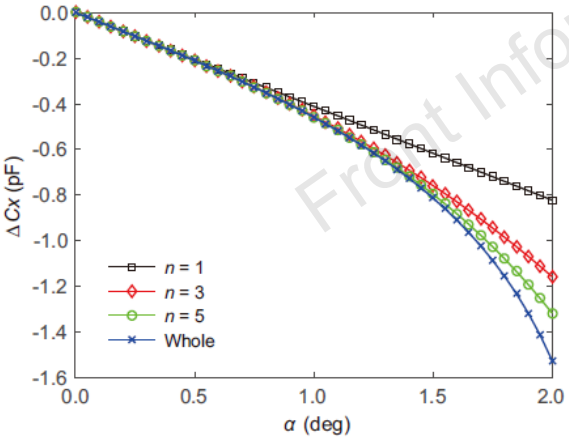

Fig. 5 Comparison of differential capacitances as functions of α between calculation results ($n = 1, 3, 5$) and numerical integration (R_i, R_o, h_0, and θ_0 are 2 mm, 5 mm, 200 μm, and 43°, respectively)

$$\Delta C_X = -4\varepsilon \frac{R_o^3 - R_i^3}{3h_0^2} \alpha \sin\theta_0 - 4\varepsilon \frac{R_o^5 - R_i^5}{15h_0^4} \cdot \left[(\cos^2\theta_0 + 2)\alpha^3 \sin\theta_0 + 3\alpha\beta^2 \sin^3\theta_0 \right] - \cdots$$

Optimization of the detecting structure

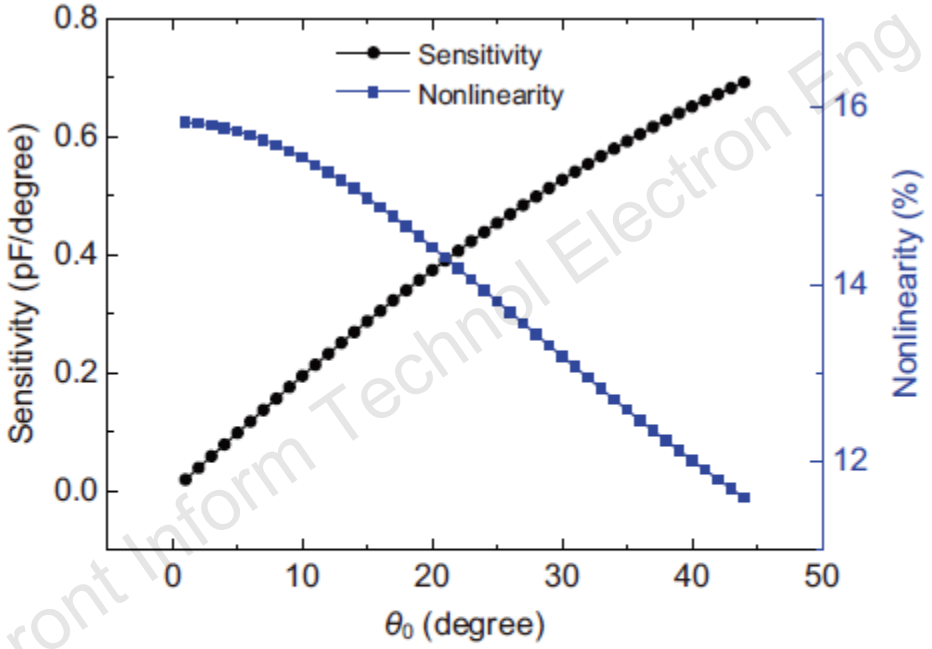

Fig. 4 Structure sensitivity and nonlinearity as functions of θ_0 when R_i, R_o, and h_0 are 2 mm, 5 mm, and 200 μm, respectively. The maximum tilt angle is 2° determined by the structure parameters

Detecting circuit

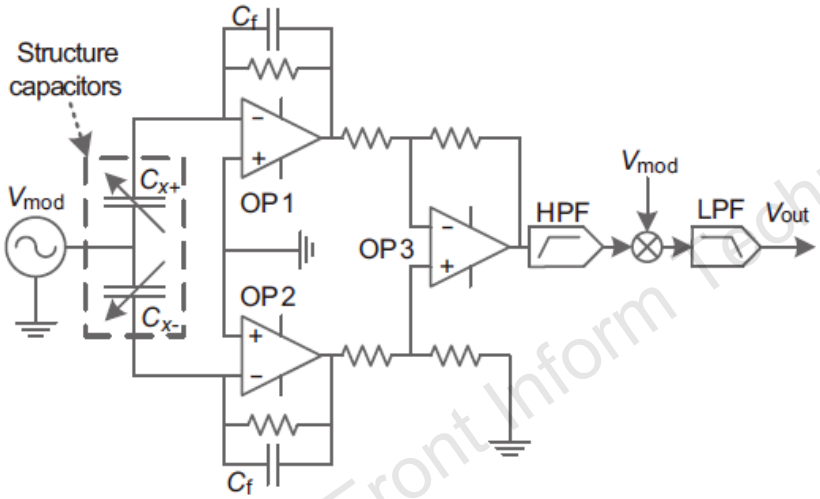

Fig. 6 Schematic of the detection circuit

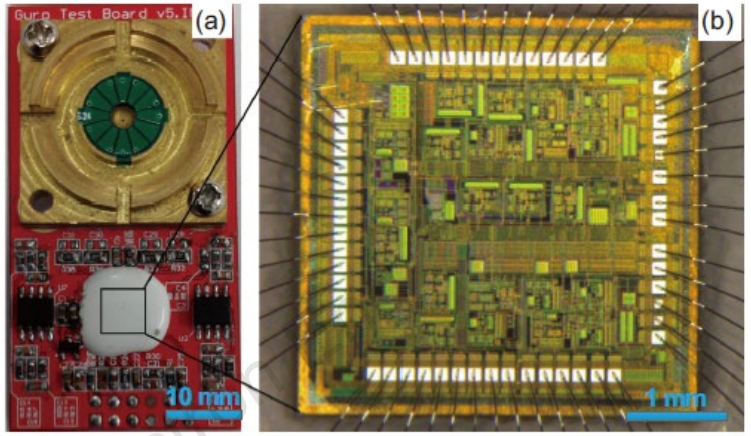

Fig. 7 Detection board (a) and micrograph of the readout ASIC (b)

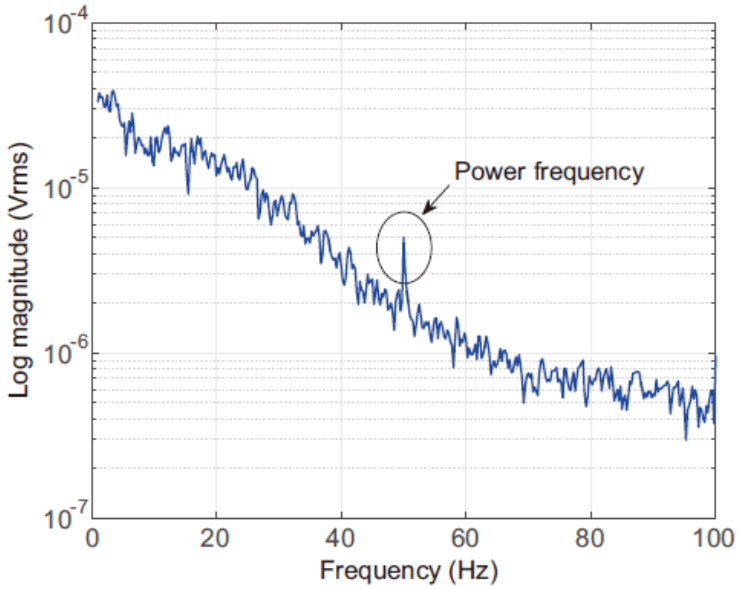

Fig. 8 Static output noise of the detection circuit

Measurement

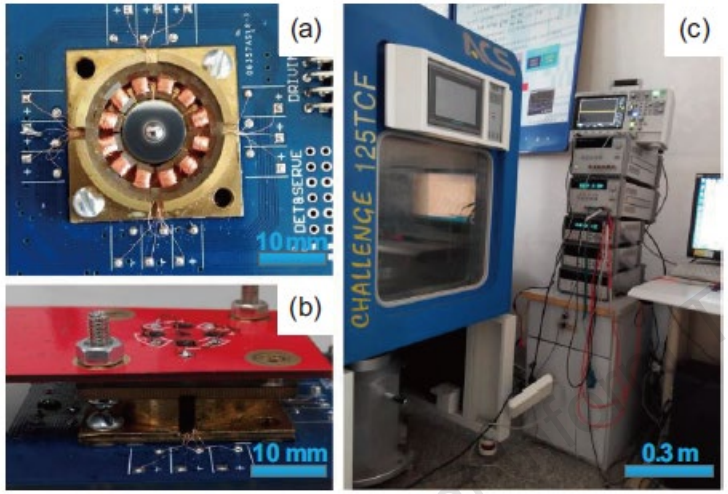

Fig. 9 Driving structure of the gyroscope with its rotor running at 7000 r/min (a), gyroscope structure (b), and the rate table test platform (c)

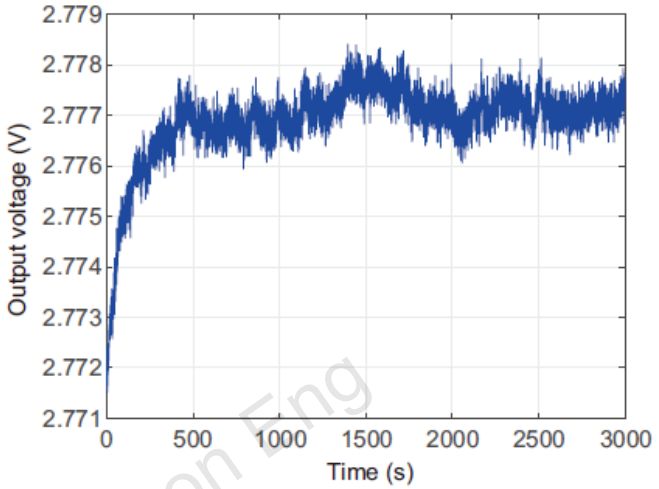

Fig. 10 Static output voltage of the detection circuit with the rotor rotating at 7000 r/min, measured for 50 min after the rotor reaches the speed

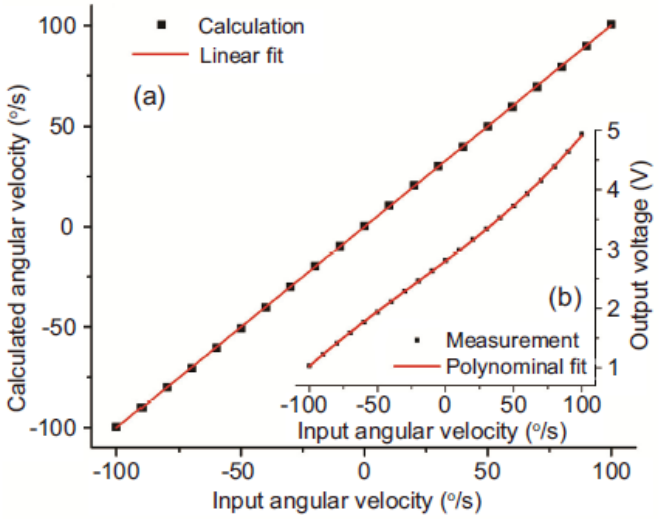

Fig. 11 Calculated angular velocity versus input angular velocity (a) and cubic polynomial fitting of the stable detection circuit output versus input angular velocity (b)

Performance comparison

Table 1 Comparison of this work and the literature

Reference	Circuitry	Resolution	Nonlinearity
Huang *et al.* (2007)	PCB	0.04°	2.3%
This work	ASIC	0.00013°	0.33%

Conclusions

- A special differential capacitive detection structure is presented to detect the tilt angle of the rotor of a novel rotational gyroscope.
- A detailed model of the differential capacitance of the detection structure is built and used to optimize the size parameters of the detecting structure.
- Test on the gyro shows that the smallest resolvable tilt angle of the detecting structure is less than 0.47″, which can be further improved.