



TOHOKU
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Design and Fabrication of Micro Force Sensor with Quartz Crystal Resonators

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水晶振動子を用いた力センサはどこまで薄くできるか？

I. Introduction

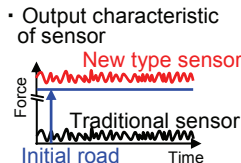
- Medical and nursing



Endoscope

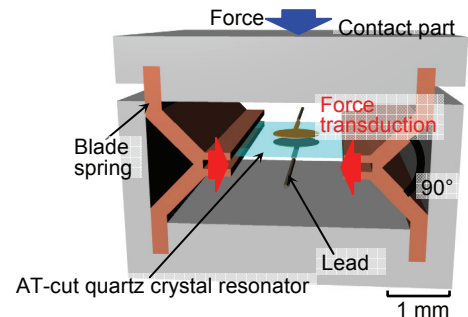


Biosignal



- High sensitivity
- Wide measuring range
- High-speed response
- Small size

Novel mechanism



II. Novel mechanism force sensor with quartz crystal resonator

水晶振動子を用いた力センサ: 外力により共振周波数が変化, デジタル化容易, 自己検知機能, 高感度, 優れた温度・周波数安定性.

水晶: 曲げ, 引っ張り, 衝撃に弱い.

What is new ?

- センサシステムの小型・薄型化, 水晶振動子の安定保持:
水晶振動子の水平保持機構, 力方向の変換機構(垂直→水平).
- 曲げ応力の低減: 上下二重構造の板ばねの導入.

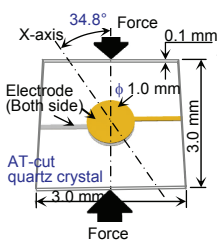
Comparison with traditional research and commercial products

(a) This study (b) KISTLER 9001A (c) KISTLER 9207 (d) Z. Wang et al. 2004

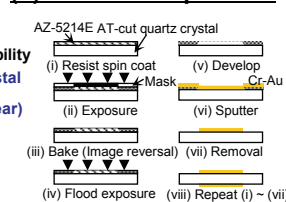
	Output	Measuring object	Sensitivity (Resolution)	Measuring range	Size [mm]
(a)	Frequency	Static ~Dynamic	15 Hz/N (Tens of grams)	~130 N (Theoretical)	6 × 5 × 4
(b)	Voltage (charge)	Quasi-static ~Dynamic	4 pC/N (1 g)	~7.5 N	φ 10.3 × 6.5
(c)	Voltage (charge)	Quasi-static ~Dynamic	115 pC/N (50 mg)	±50 N	φ 11.9 × 63.7
(d)	Frequency	Static	105 Hz/N	~100 N	31 × 30 × 35

III. Fabrication of quartz crystal resonator

(a) Design



(b) Fabrication process



- Improvement of sensitivity and stability
- AT-cut quartz crystal (Main vibration: Thickness-shear)
- Circular electrode
- Direction of 34.8° from X axis

(c) Frequency characteristics of quartz crystal resonator

Q: Quality factor

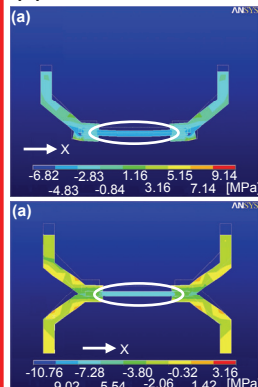
$$Q = \frac{2\pi f \cdot L}{R}$$

f: Resonant frequency
L: Inductance
R: Resistance

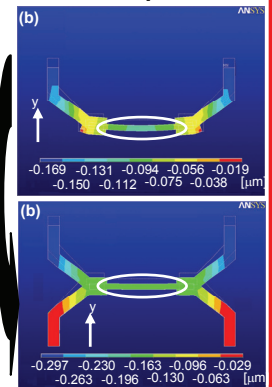
... Q = 16,000
Enough for the resonant value measurement.

IV. Stress analysis of sensor mechanism by FEM

(a) Distribution of stress



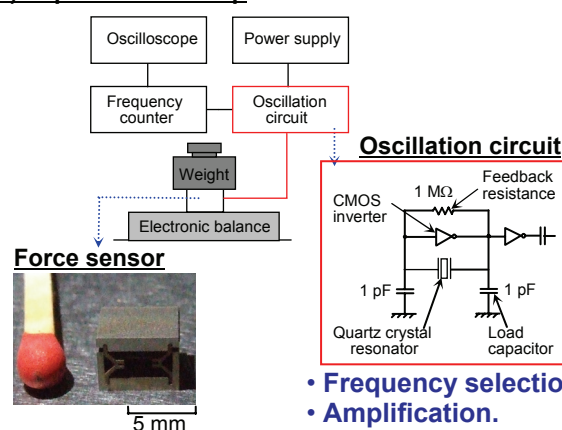
(b) Distribution of displacement



- Uniform compression stress.
- Bend is hardly generated.
- Maximum deformation: 0.297 μm (3.27 MPa)
- Conversion efficiency of force: 36.7%
- Allowable stress, Overload: 235 MPa, 130 N

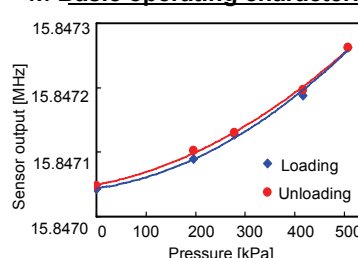
V. Experiments

(a) Experimental setup



(b) Experimental results

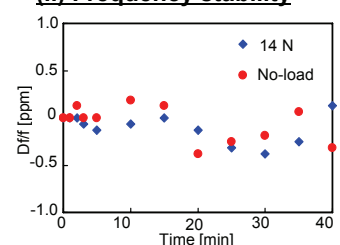
(i) Basic operating characteristic



Hysteresis: 5.78%
Nonlinearity: 12.59%

The quartz crystal resonator unit
Hysteresis: 2.47%
Nonlinearity: 2.88%

(ii) Frequency stability



Static load measurable.

(Temperature: 20.4°C, Humidity: 26%, Input: 4.0 V)

VI. Conclusions

- 微細加工技術により製作した水晶振動子を用いた超小型力センサ機構を提案.
- 従来より薄型で安定な構造であることをFEMによる解析により確認.
- 共振周波数と荷重に単調増加, 静的荷重の計測が可能であることを確認.



ロボティクス・メカトロニクス講演会 2007

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2007年5月10日(木)~5月12日(土) 秋田拠点センター ALVE (アルヴェ)
社団法人 日本機械学会ロボティクス・メカトロニクス部門主催