

Abstract

A new capacitive vibration sensor using an array of laterally moving mass-spring systems is being developed at Chemnitz University of Technology. The sensor operation is based on narrow-band resonance of the mass-spring elements. The natural frequency of each element can be tuned electrically. The sensor is intended for application in wear state recognition on highly stressed machine components. The poster is focussing on high abstraction level CAD modeling of the sensor array. A new design approach, efficient choice of physical domains, resolving problems and their solutions will be shown in connection with the design of both sensor and analog signal processing models.

The experimental Prototype „Vibration Sensor Array“

The sensor system consists of a sensor array containing eight individual mass-spring resonators, with an electrically tunable natural frequency each, an analog signal processing unit and a high voltage amplifier. The system is controlled by a micro controller and will also include a fuzzy pattern classification system.

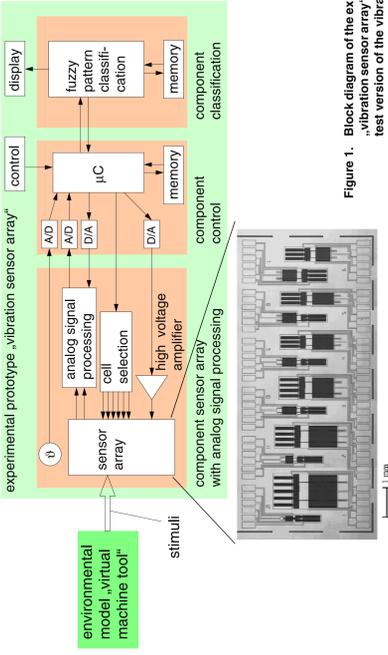


Figure 1. Block diagram of the experimental prototype „vibration sensor array“ and photograph of a test version of the vibration sensor

Frequency Tuning

The laterally moving mass-spring resonators of the sensor work in a frequency-selective resonant mode. To allow measurements at variable frequencies the spring constant and, therewith the natural frequency is tuned by an electrostatic force.

Tuning by stress-stiffening

Tuning by stress-stiffening has two disadvantages. • Fabrication of this structure is difficult because of stress in the layers.

• Lever mechanism is causing non-linearities in the behavior. So an alternative approach was tested. In this approach the spring constant is kept constant. The tuning of the natural frequency is done by a curved comb structure where the attraction force is a linear function of the displacement.

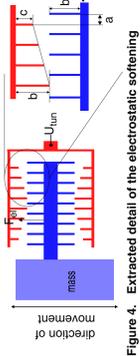


Figure 4. Extracted detail of the electrostatic softening. • Curve was optimized by FEM simulation. • For system simulation it was assumed to be a linear function.

Figure 5. shows the structure of the VHDL-AMS sensor array model with this kind of tuning the natural frequency:

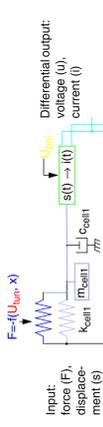


Figure 3. Schematic of the sensor array. The stress-stiffening unit is driven by an electrostatic force F_e . This force is caused by the voltage U_{in} and can be calculated as follows:

$$F_e = \frac{dW}{dx}, \quad dW = \frac{1}{2} \cdot U_{in}^2 \cdot dC$$

The capacitance of the comb structure can be calculated by the simplification of a homogeneous field of a plate capacitor:

$$C = 2n \cdot \epsilon \cdot \frac{x \cdot d}{a}, \quad dC = 2n \cdot \epsilon \cdot \frac{d}{a}$$

$$F_e = U_{in}^2 \cdot n \cdot \epsilon \cdot \frac{d}{a}$$

The capacitance of this comb structure can be calculated by the simplification of the homogeneous field of a capacitor without the simplification $-(b-x) \leq x \leq (b-x)$:

$$C = 2 \cdot \epsilon \cdot \frac{d}{a} \cdot \frac{x}{b-x} \cdot n \cdot \frac{1}{2}, \quad C = \epsilon \cdot \frac{d}{a} \cdot \frac{x}{b-x} \cdot n$$

$$\frac{dC}{dx} = 2 \cdot \epsilon \cdot \frac{d}{a} \cdot \frac{n}{b-x}$$

$$F_e = U_{in}^2 \cdot \epsilon \cdot \frac{d}{a} \cdot \frac{n}{b-x}$$

Because F_e and the force of an ordinary spring are acting in opposite directions, the following can be written:

$$F = k \cdot x, \quad k = \left(U_{in}^2 \cdot \epsilon \cdot \frac{d}{a} \cdot \frac{n}{b-x} \right)$$

And in the range $|x| > (b-x)$ applies:

$$C = 2n \cdot \epsilon \cdot \frac{(x-(b-x)) \cdot d}{a} + C_0, \quad \frac{dC}{dx} = 2n \cdot \epsilon \cdot \frac{d}{a}$$

$$F_e = U_{in}^2 \cdot n \cdot \epsilon \cdot \frac{d}{a} \quad \text{for } x > (b-x)$$

$$F_e = -U_{in}^2 \cdot n \cdot \epsilon \cdot \frac{d}{a} \quad \text{for } x < -(b-x)$$

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