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Effect of the electrode form on the MEMS structure parameters

***Abstract**. Electrostatic systems with linear and angular movements are compared in this paper. Variants with rectangular and rounded up comb fingers are considered. A field analysis is performed using the 3D models of the relevant comb structures. Calculations and comparison of results show an insignificant effect of the change in microstructure form on the parameters of the system.*

Streszczenie**. Artykuł przedstawia porównanie układów elektrostatycznych grzebieniowych o ruchu liniowym i kątowym. W przypadku ruchu liniowego rozpatrywano przypadki zębów prostokątnych i zębów zaokrąglonych. Przeprowadzono analizę polową z wykorzystaniem modelu 2D i 3D wymienionych konstrukcji grzebieniowych. Obliczenia i porównanie wyników wykazują nieznaczny wpływ zmiany kształtu mikrostruktury na parametry układu. **Wpływ kształtu struktury MEMS na jej parametry

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Keywords: MEMS, combdrive, optical switches.
Słowa kluczowe: MEMS, napędy grzebieniowe, przełączniki optyczne.

Introduction

The Micro Electro Mechanical Systems (MEMS) are miniature system made most often by micromachining of silicone. Many devices contain MEMS microchips which are perfect components of the nowadays domains of technology.

The applications of Microsystems are first of all:

1. sensors:
   - accelerometers: in cars – air bags, seatbelts etc., in photo cameras – detection of vibrations (picture stabilization), in computers – detection of free falls (protection of the hard disc form damage when it is falling) , in modern toys,
   - pressure sensors (chemical reactors, containers of substances)
   - vibration sensors
   - flow meters
   - gyroscopes
   - magnetic field sensors (using Hall effect)
2. optical switches
3. video projectors
4. ink printer heads
5. electrodes for brain examination
6. endoscopes
7. atomic clocks
8. chemical microreactors (Lab-On-Chip)

The MEMS systems have many interesting properties which can be very easily modified when changing the form or dimensions of the device itself. The effects connected with the change of finger form are shown in the description of the tunable resonators. The design of resonators is based on electrostatic comb systems with linear movement 0.

Design and mathematical model

Two types of electrostatic MEMS combs systems are considered, the first design with linear movement and the other one with angular movement. In both cases the same dimensions of the comb design are considered.

They differ only by thy methods of changing the movement direction.

The first case – linear movement

The formula for the capacitance of a flat capacitor at a change in position of one of the electrodes is:

$$C = \frac{\varepsilon}{d} \cdot \frac{dS}{dx} \tag{1}$$

where: S – surface area of the electrodes, d – air gap between the electrodes, ε – permittivity of the surrounding where the electrodes are placed.

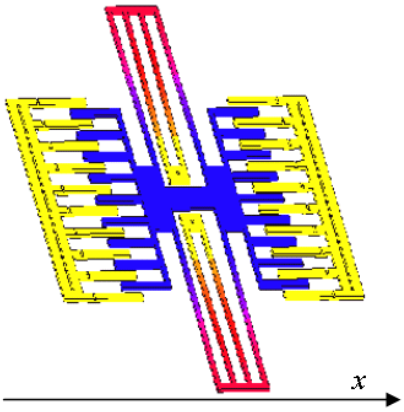

Fig. 1. View of the MEMS combdrive actuator with linear movement in x direction.

The energy accumulated in the system can be expressed by the formula:

$$W = \frac{1}{2} CU^2 = \frac{U^2 \varepsilon}{2d} S_{total} \tag{2}$$

The electrostatic force produced by the actuator in the x axis direction:

$$F_x = \frac{\partial W}{\partial x} = \frac{\varepsilon \cdot U^2}{2d} \frac{\partial S_{total}}{\partial x} \tag{3}$$

where: U – voltage applied across the capacitor electrodes, C – capacitance of the capacitor, ε – permittivity, d – air gap between electrodes.

The second case

A combdrive system with an angular movement around the axis of comb suspension is considered in the other case 0.

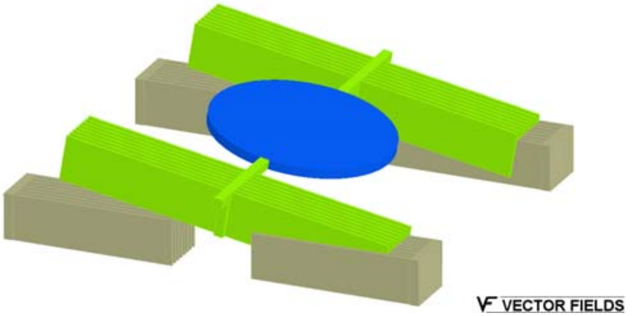

Fig. 2. A schematic diagram of an electrostatic MEMS actuator with angular movement 0

The formula for the capacity of a flat capacitor 0,0 with rotating electrodes is:

$$C = \frac{\varepsilon}{d} \cdot \frac{dS}{d\alpha} \tag{4}$$

where: S – surface area of the electrodes, d – air gap between the electrodes, ε – permittivity of the surrounding where the electrodes are placed.

The energy accumulated in the system can be expressed by the formula:

$$W = \frac{1}{2} C U^2 = \frac{U^2 \varepsilon}{2d} S_{total} \tag{5}$$

The electrostatic torque produced by the actuator according to the rotation α angle is:

$$M_\alpha = \frac{\partial W}{\partial \alpha} = \frac{\varepsilon \cdot U^2}{2d} \frac{\partial S_{total}}{\partial \alpha} \tag{6}$$

where: U – voltage applied across the capacitor electrodes, C – capacitance of the capacitor, ε – permittivity, d – air gap between electrodes.

Field model

Two models of electrostatic MEMS microstructures were constructed using the finite element method (FEM). Computer calculations in the FLUX 2D/3D environment were made. Dimensions of the analyzed structures are in Table 1.

Table 1. List of parameters of the electrostatic system

Item	Parameter	value [μm]
1	Lower finger length	125
2	Upper finger length	170
3	Finger width	3
4	Finger height	50
2	Yoke thickness	5
5	Air gap	1
6	Number of fingers	100

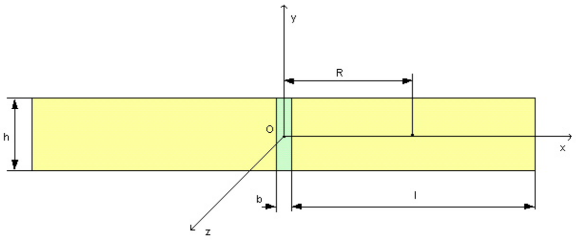

Fig. 3. A schematic diagram of an electrostatic MEMS moving comb 0

A MEMS structure showing a mechanism performing a linear movement in the range of 0 to 100 μm was shown in the foregoing chapter. A 3D model was constructed for computations. Twenty six thousands of equations with Dirichlet boundary conditions were used for computations.

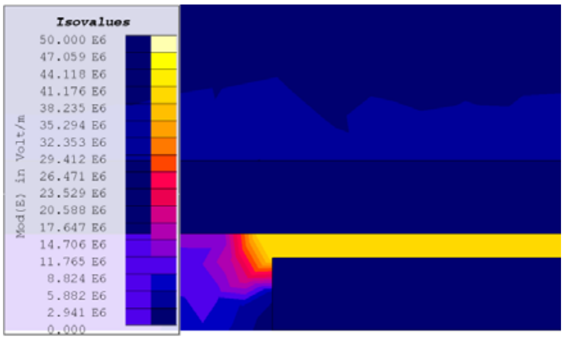

Fig. 4. Distribution of the electrostatic field in a microstructure with linear movement with rectangular comb fingers

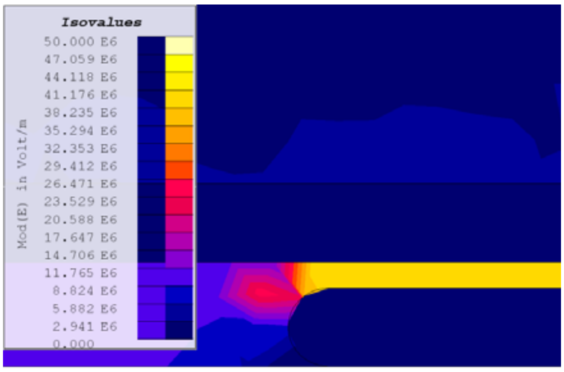

Fig. 5. Distribution of the electrostatic field in a microstructure with linear movement with round fingers

The computations of the electrostatic field shown in Fig. 4 and 5 were performed across the surface cutting the microstructure at the height equal to the finger height.

The effect of the finger shape on the value of the electrostatic field is shown on the maps of field distribution.

The electrodes with rectangular shape produce a visible border effect, which in the later case is eliminated by the rounding up.

The other case considered is a system with an angular movement in the range of deflection angles α of 0° to 10°.

The 3D modeling was used for describing the microstructure, as it the previous case with Dirichlet boundary conditions.

Thirty four thousand equations were used for calculations.

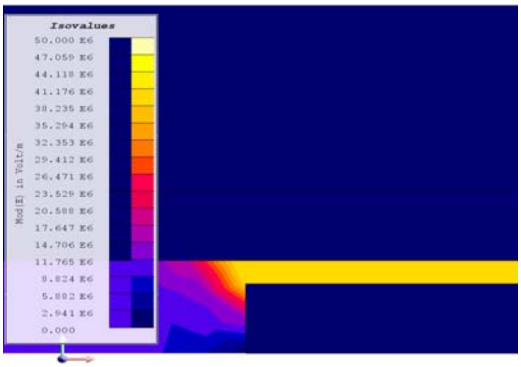

Fig. 6. Distribution of the electrostatic field in a microstructure with angular movement with rectangular fingers

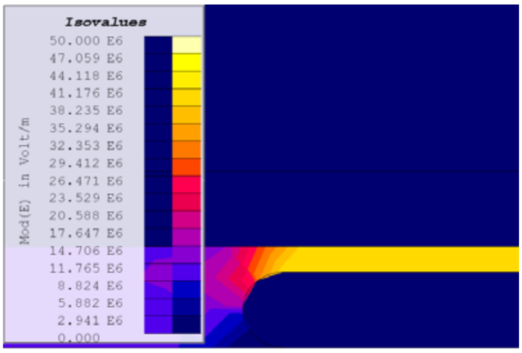

Fig. 7. Distribution of the electrostatic field in a microstructure with angular movement with round fingers

Fig.6 and Fig.7 show the obtained results of 3D field calculations for a system of angular movement.

The effect of the electrodes shape on the distribution of the electrostatic field in the air gape between electrodes is also visible in this case.

Calculation

A field analysis is carried out in the case of a system with linear movement in connection with the symmetry of both at the width as well as at the height of the comb. Two cases of finger forms are considered: rectangular fingers and rounded fingers with the radius of the rounding equal to half of the finger width. The voltage applied across the stationary and moving electrodes is 40 V.

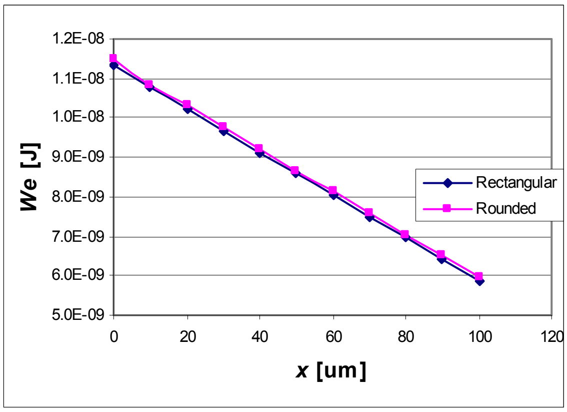

Fig. 8. Energy accumulated in the electrostatic field of a system with rectangular fingers (blue color) and with rounded up fingers (pink color) for model 1

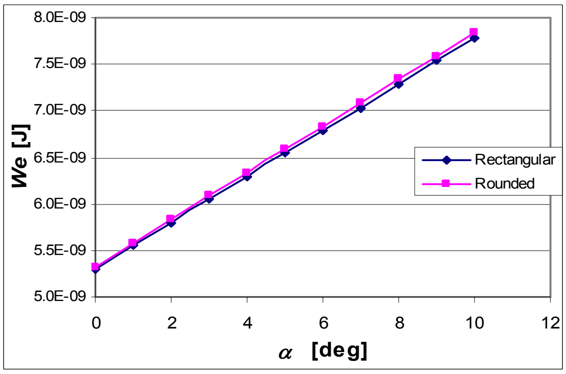

Fig. 9. Energy accumulated in the electrostatic field of a system with rectangular comb fingers (blue color) and with rounded up fingers (pink color) for model 2

An significant effect of electrode form on the finite result in the shape of the energy produced in the microstructure visible form the field analysis of two MEMS structures with rectangular and round fingers. The effect of the shape of finger tips would be significantly bigger if their length were shorter. The boundary effects can be neglected in this case, especially in a structure with linear movement.

Conclusions

Calculations of the electrostatic field were performed in MEMS microstructures of two types with linear and angular movement. The effect of the finger shape of the cooperating electrodes was analyzed in both cases.

Two basic finger shapes the rectangular and round ones were analyzed.

The radius of rounding up was the half of the finger width. From the analyses performed it results that there is an insignificant effect of finger rounding on the electrostatic field distribution; the field is more uniform. In respect to physical values used in that type of devices, the effect is not high. The energy stored in MEMS microstructures is higher for in the case of fingers with rounded edges in both models but only up to 1%. Therefore in this case changes of electrode shapes in MEMS structure don't produce any important advantages.

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