FINITE ELEMENT SIMULATIONS FOR THE DESIGN OF MICRO ELECTRO-MECHANICAL SYSTEMS

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Abstract — Miniaturisation and integration are the key words for future technical developments. They imply to enable savings in space, material and energy. The accurate prediction of the physical behaviour of such micro devices is required to enable short development times and to be able to study their various working principles. To ensure a particular safety in predicting the behaviour of such microstructures, accurate and professional design tools are required. Such tools are using numerical models of the micro device and can simulate their physical behaviour. A field computation method with a very general application range is the finite element method (FEM). Various problems, such as magnetic, electric, mechanical and thermal fields can be studied with this numerical tool. In this contribution, the modelling of micro motors operated by the electrostatic field will be discussed. The variants of radial and axial field micro motors will be considered.

INTRODUCTION

Devices, such as micro motors and actuators are upcoming technical products in various areas. Since the fabrication and "know how" of the micro mechanical components nowadays is becoming cost-effective, applications in the areas of the medical micro surgery etc., micro mirror arrays for the communication techniques and various applications in the biological and chemical technique can be found. As a consequence of this growing market and next to the fabrication technology of such micro systems, an increasing interest can be stated in the simulation of micro devices.

By using finite element models, complicated shaped microstructures can be simulated. Novel developments of micro devices can be done by material innovations. In finite element models material properties can be changed and therefore it is possible to simulate devices with fictive materials to, for example, determine desired material properties for a particular geometrical shape or vice versa.

Different simulation strategies for the design of a micro device can be followed. To compute the force or the torque of an actuator the local field quantities are required. The complicated geometrical shape of a micro motor very often requires a three-dimensional FEM model. A FEM simulation can be distinguished in three steps, a pre-process, a solution process and a post-process. During pre-processing the model is geometrically defined, materials are introduced, field exciting sources and the physical type of problem is defined. The solution process is commonly started and controlled without large user interactions. From the obtained solution, local and global field quantities can be computed and the field distribution can be evaluated.

For the entire dynamic system simulation it is advantageous to construct an equivalent circuit model of the system out of the microscopic field solution to avoid time consuming transient field computations (Fig. 1). The parameters for the equivalent circuit can be extracted by using global quantities, such as the field energy. Lumped parameter models, consisting of concentrated elements, are important for the development of the control strategy of the micro actuator. If an appropriate equivalent circuit for the simulation is found to model the motor's behaviour accurately, various operating points can be simulated on the computer. This enables for example, to choose for an appropriate switching scheme to operate the micro motor in the desired way.

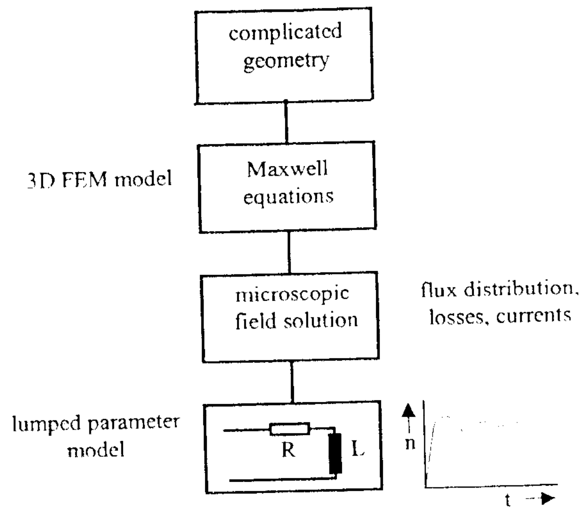

Fig.1 Analysis scheme using the FEM.

Electrostatic Micro-Motors

In devices scaled in the cm range, electromagnetic forces are dominant and applied to motors. Such motors are operated by a particular current density in their windings. The power of motors operated by the electromagnetic principle decreases significantly as such motor becomes small. Motors operated by electromagnetic forces are therefore not very good applicable in micro applications.

Electrostatic attractive forces scale with the area. The breakdown voltage increases in micro gaps by a factor of ten of the macroscopic limit. This makes the scaling of electrostatic motor principles advantageous. The electrostatic micro motors studied here are based on the principal of variable capacitance. The operation principle is very simple. A voltage on the stator electrodes induces a charge on a conducting rotor and in response the rotor moves to minimise the electrostatic field energy.

The most inexpensive fabrication technology of electrostatic micro machines is a thin film process for planar structures. Therefore, such rotating actuators are extremely flat and the generated forces are very low. The studied motor with its outer dimensions is shown in Fig. 2. This motor is an axial field type.

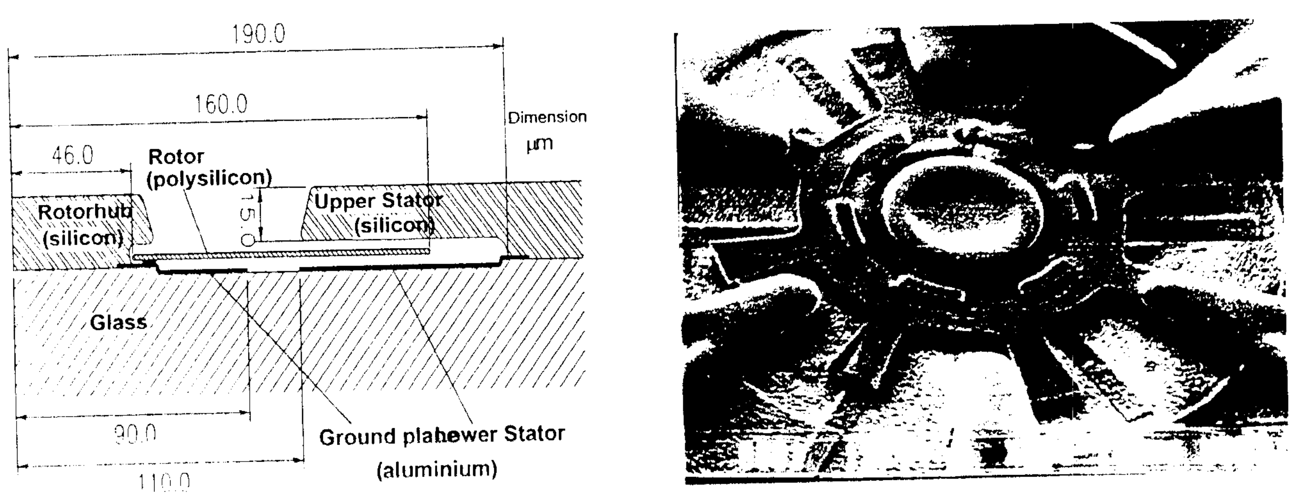

Fig. 2 Detailed construction and of an electrostatic micro-motor.

Due to the geometrical symmetry and periodicity it is possible to model this device by an extrusion based three-dimensional mesh (Fig. 3). The extrusion process is developed around the shaft of the motor. A two-dimensional basis plane is constructed and rotated by angular steps to form the three-dimensional FEM discretisation.

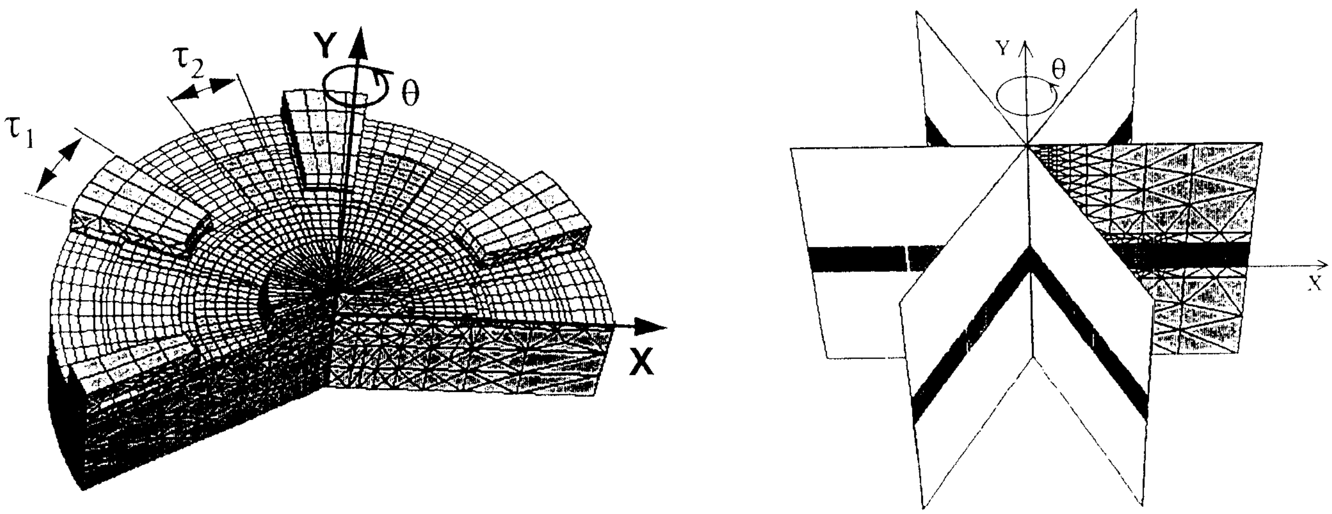

Fig. 3 Finite element discretisation build up by an angular extrusion process.

An other electrostatic micro-motor is of the radial field type variant (Fig.4). When the same height as the axial field machine is considered, the surface that contributes to the interaction between stator and rotor is much smaller. However, the problem is that only very small forces can be generated. Using a radial type of interaction and the LIGA production technique, allowing the fabrication of higher microstructures, results in higher torque values. Both types of micro-motors suffer from the same difficulty during operation, the friction of the rotor on the ground plane of the construction at unsymmetrical forces pulling the rotor into the next position and axial forces at the shaft. To avoid axial forces on the rotor shaft, the motor must be excited symmetrically. Therefore, an analysis of various stator excitation sequences is performed. Both motor types can be analysed in an analogue way.

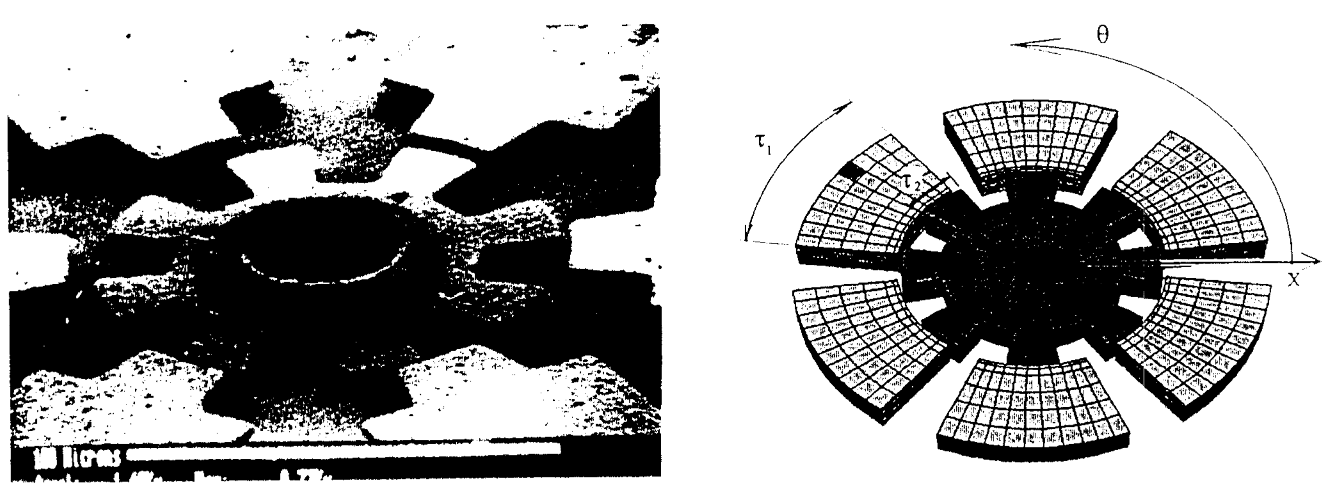

Fig. 4 Radial field type of electrostatic micro-motor.

Numerical Analysis

The energy stored in the electrostatic field is evaluated and serves as global quantity to obtain the parameters of an equivalent circuit.

$$W_{electrostatic} = \frac{CV^2}{2} \tag{1}$$

The use of this equivalent circuit model enables the calculation of the forces of the motor operated with various voltage sequences without new computationally expensive FEM analyses. The desired parameters in the equivalent circuit are the values C of the capacity between the single components of the geometry. The equivalent circuit in Fig. 5 consists of 12 capacitances, twice the number of stator electrodes. The capacitance of each capacitor varies with the rotor position.

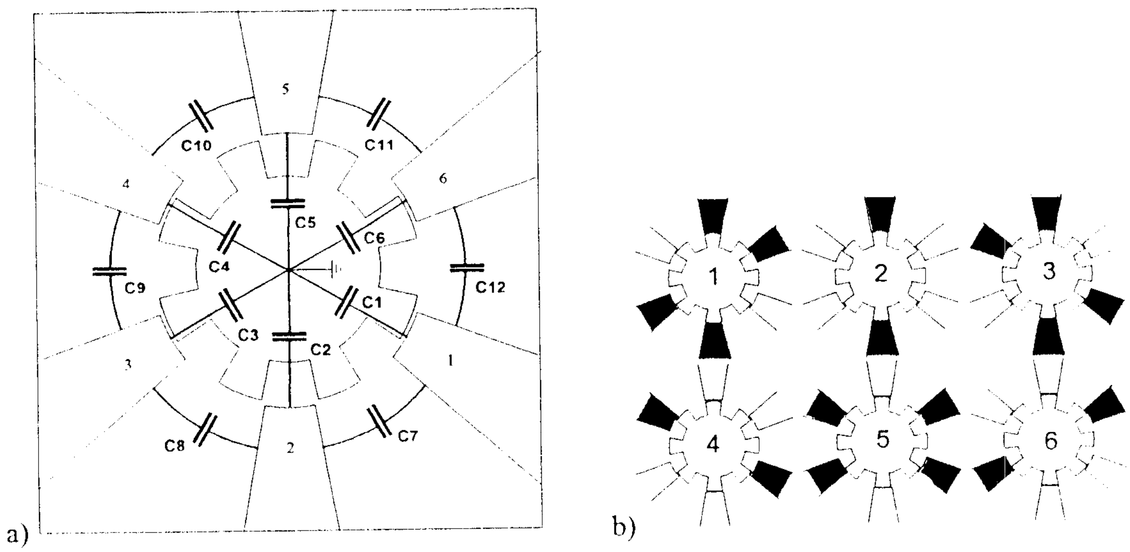

Fig. 5 Definition of the elements of the equivalent circuit for a 6/8 pole radial field electrostatic micro motor and b) possible symmetrical excitation sequence to perform one revolution of the rotor.

Conclusions

The design of micro-motors requires the use of advanced three-dimensional field analysis methods to obtain local field quantities to simulate the static position dependent forces. With the same solution of the FEM it is possible to compute global quantities, such as the field energy to construct equivalent circuit models to determine for example the force distribution at various excitation sequences not again requiring the computationally more expensive finite element method.

References

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