Design of Very Small Electromagnetic and Electrostatic Micro Motors

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Abstract - The paper describes a general design tool that can be used for small and extra small electric and magnetic devices, aiming at producing micromotions. Due to the dimensions and specially due to the small dimensions, and specially as one of the dimensions is large with respect to the other one, a three dimensional analysis of the field is required.

I. INTRODUCTION

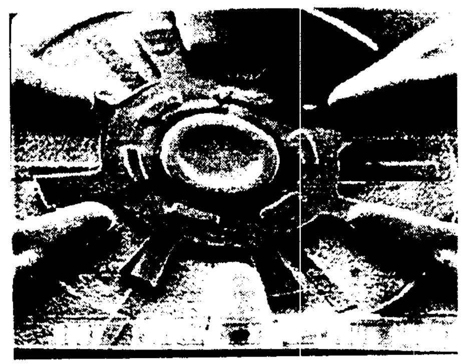
The paper describes a general design tool that can be used for small and extra small electric and magnetic devices, aiming at producing micromotions. Micro machines can be defined as very small devices in the millimeter and sub-millimeter range. Due to the dimensions and specially as one of the dimensions is large with respect to the other one, a three dimensional analysis of the field is required.

When the dimensions of the electromagnetic devices become smaller, it can be shown that the electrostatic forces scale advantageously when compared to the magnetic forces [1]. Therefore, when dealing with motion systems in the extra small area, one will encounter both electric and magnetic devices to analyze. A design system aiming at assisting the engineer, has to be capable to handle both types of problems.

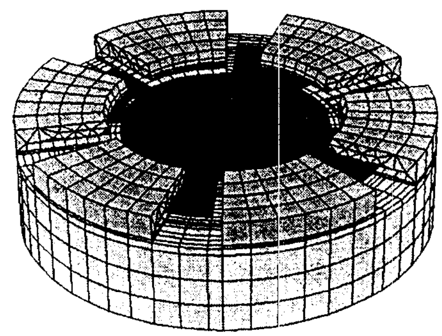
The design tool developed is based on the three dimensional finite element analysis of the field [2]. Rather than using the field solution as such, the designer wants to obtain the macroscopic parameters from the field solution. For the electrostatic motors, a capacitance based equivalent circuit is derived. For the magnetic motors, the normal inductance based circuit is used.

The torque is evaluated as a function of the position. Specific simulation and design tools to automate the design process are discussed. The designer is not confronted with the finite element method as such, but has to enter only the main dimensions and characteristics of the device. In the post-processing portion of the work, the data are extracted and are introduced in an optimization procedure, leading to a new set of geometric parameters and the process is restarted until an optimum is reached.

Using different types of electrostatic and magnetostatic micro devices, it will be shown how the designer can use the field calculation methods to obtain the macroscopic parameters that are the basis of dynamic simulation yielding the required behavior of the motor or actuator.



a)



b)

Fig. 1. a) Electrostatic micro motor (ESIEE, Paris) and b) the finite element model of an axial field micro motor.

II. DESIGN OF ELECTROSTATIC MICRO MOTORS

Scaling analysis shows that as size is reduced electrostatic designs become advantageous over the electromagnetic versions that dominate at dimensions starting in the millimeter range. In contrast to for example the wobble design, the electrostatic micro motors that were investigated here, are based on the principal of variable capacitance. This type of motors is more promising as the wobble motor is difficult to connect with his load. The operation principal is very simple. A voltage on the stator electrodes induces a charge on a conducting rotor that then moves to minimize the field energy.

The cheapest fabrication technology of electrostatic micro machines being a thin film process, infers planar structures [3]. Therefore, such rotating actuators are extremely flat and the generated forces are very low. Figure 1 shows an axial field electrostatic micro motor and the three dimensional cribing the technical physical properties of the machine. e to the presence of the iron, the calculations have to count for the non-linearities. The inductance is found from stored magnetic energy after replacing the permanent ignets by air:

$$W_{magnetic} = \frac{LI^2}{2} \tag{3}$$

The torque is found from the virtual work.

$$T = \frac{\partial W_{magnetic}}{\partial \vartheta} \tag{4}$$

Clearly, the permanent magnets have to set back to their al behavior, when compared with the inductance alculations. The evaluation of the torque as a function of the otor position is performed by an automated process.

In this type of application, the supply source is an essential art of the system. Due to the non-linear behavior, in omparison with the electrostatic motors that are strictly inear, the link with the time pattern of the supply voltage can not be simulated using pure superposition. Once the device dependent parameters are known an equivalent circuit is modeled and in combination with the characteristic values of the supplying energy source, the whole system is modeled, simulated and analyzed [8].

The results of this calculation again are fed into an optimization process. The process leads to changes in the back iron and the magnets. Again it will be shown how the optimization process can be controlled in order to find the best motor with a minimum of effort. Different strategies are combined (simulated annealing and evolution strategy). The implementation of these essentially parallel search techniques can lead to much faster solutions when compared to deterministic methods, that require consecutive solutions. Furthermore, these techniques do not require differentiation, and are therefore more accurate.

IV. CONCLUSIONS

The design of micro motors requires the use of advanced three dimensional field analysis methods to obtain the field distribution and subsequently the elements of the equivalent circuit (capacitance or inductance) and the torque. Using appropriate preprocessing tools, the meshing of the model is automated, requiring no interference of the designer. The evaluation of the parameters serves as the input of an optimization process, that search in a multivariable space to find the best design. The search process is designed in an appropriate way in order to find the best solution with a minimum of calculation time. By using a combined statistical optimization method, parallel processing may be used to minimize the calculation time.

Three practical designs (axial field electrostatic motor, radial field electrostatic motor and axial field permanent magnet motor) are used to show the versatility and the flexibility of the method. The total process is described and the actual prototypes are discussed.

ACKNOWLEDGMENTS

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