A New Analytical Micromotor Design Models For CAD PC-Design Tools

A. Salman*, A. Napieralski*, and G. Jab_o_ski*

*Department of Microelectronics & Computer Science,
Technical University of Lodz, Al.Politechniki 11, Lodz 93-590, Poland.
Salman@dmcs.p.lodz.pl, Napier@dmcs.p.lodz.pl, Gwj@dmcs.p.lodz.pl

ABSTRACT

This paper presents the elaboration of two PC design tools, using new analytic micromotor design models, towards a fully integrated CAD system for finding optimal structure for small size variable capacitance side-drive micromotors. Accuracy, simplicity, and efficiency are the key advantages of these new models compared with the other models implemented in the same tools. These PC design tools, which have been developed and modified at our department, are presented in this paper. The first, called μTORQUE, is devoted to the design of electromechanical structure based on a simulation procedure of static behavior of the electrostatic micromotors. The second is devoted to simulating the dynamic behavior of the micromotor during its operation based on modified analytical dynamic behavior. Both design tools are based on an analytical model, called the modified parallel plate capacitance model, for drive torque, friction torque, and viscous drag torque calculations. These PC design tools (programs) help us to predict and determine the optimum operational performance characteristics of an electrostatic VC micromotor.

***Keywords*:** MPPM micromotor design model, μTORQUE, and MICROTOR PC-design tools.

1 INTORODUCTION

Since the electrostatic micromotor has been studied less than the electromagnetic one, the principles of design, fabrication, and operation of these types of micromotors have been investigated recently in several papers [1-4]. Most of these works on polysilicon surface-micromachined electric micromotors have been concentrated on the design and fabrication of very small size rotary variable capacitance micromotors (VCM), due to their relative simplicity of design and fabrication. Great improvement in understanding the design, modeling, simulation, and operation of micromotor has been achieved [5-9]. However, these studies of modeling or simulation (analytical, numerical, or experimental) are not complete yet and further developments are necessary. Therefore, new simulation tools are needed to accelerate the process of analysis and design. This paper describes our experience towards finding the optimal design of a VC micromotor and is devoted to electromechanical modeling, design, and optimization that can be implemented in CAD procedure. The μTORQUE and MICROTOR are two PC based design tools devoted to the design and simulation of static and dynamic behavior of various constructions of integrated VC micromotors. These tools have been developed and improved at our department. In the beginning, the simple parallel-plate model [3] is provided with these PC-design tools for calculation of electrostatic drive torque for three different micromotor structures. This model is the simplest one and can only be used for preliminary analysis providing almost accurate maximum torque value only when the rotor is in the high torque region. The model does not have enough accuracy for simulation and design of VC micromotors. The solution differs more significantly, if the torque angle characteristics is considered. Although there is a possibility of using one of the numerical FEM simulation models [6-8] in these PC-design tools for accurate micromotor drive torque simulation, the large number of geometric parameter variations makes these models difficult to implement in these PC-design tools. Therefore, an analytical micromotor simulation model, which makes the trade-off between the simplicity and accuracy, becomes a very important issue for these tools. The new modified parallel-plate micromotor simulation model [10], has been developed and successively implemented in these design tools. Also, a modified analytic minimal dynamic behavior model, based on the proposed static model, has been developed and implemented in MICROTOR PC-design tool in order to find optimal micromotor operating conditions.

2 STATIC BEHAVIOR SIMULATION

2.1 MPPM Micromotor Design Model

An analytical model of the rotor-stator capacitance formulation based on parallel plate approximation [10] has been developed. This model takes into account the edge effect of both the rotor and stator poles for actual estimation of total equivalent circuit capacitance in the rotor plane. The micromotor drive torque and electrically based rotor side pull force, including their angular dependence, are modeled here using the modified analytical parallel-plate capacitance model. Since this model makes the trade-off between the simplicity and accuracy as compared to a simple parallel-plate approximation and two-dimensional FEM simulation, it can be used efficiently to extract, and understand, the micromotor behavior (in both static and dynamic mode). Using the MPPM model a large number of micromotor designs can be easily simulated using different types of pole configurations and geometrical variations.

2.2 The µTORQUE PC-Design Tool

The µTORQUE program helps to examine the variation of electrostatic drive torque acting on the rotor of an electrostatic VC micromotor, as a function of rotor position for different values of geometric parameter variations, as well as supply voltage, as shown in Figure 1. There is a possibility of changing 16 parameters. With the aid of this tool, the drive torque is calculated for the specified structure as a function of rotor angular displacement or as a function of different parameter values, as shown in Figure-2. In this work, the µTORQUE PC-design tool has been modified to provide with new analytical micromotor design model implemented under the name MPPM. This model is quite realistic and can be easily implemented in a CAD integrated environment, to provide a very powerful technique for observing tendencies in micromotor optimization. Moreover this model helps us to predict and determine the optimum operational performance characteristics.

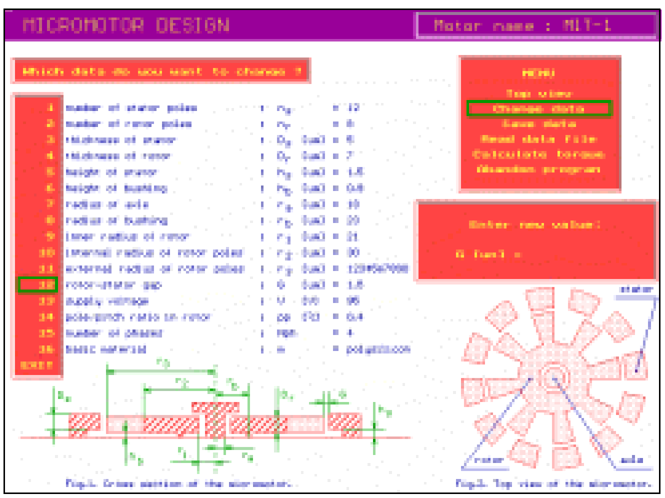

Figure 1: The µTORQUE program allows changing of the micromotor parameters, as well as the supply voltage.

2.3 Model Design Parameter Extraction

The implementation of the new model in µTORQUE PC based design tool requires a modification in the source data files. The basic MPPM micromotor model design parameters and their initial selected values for different pole configurations are introduced to the design tool to be read from specific data files. The procedure for extraction of optimal values of these geometrical parameters is a very important issue when using the proposed model. The strategy used for the determination of these parameters is to determine the geometric design parameters providing maximum average with minimum torque ripple. The optimal geometrical dimensions can be determined by means of successive sampling of the dimensional space describing the main geometrical design parameters in the stator-rotor plane. Figure 2 shows the simulated drive torque for 12/8 pole configuration, as a function of rotor position, for different rotor pole width using MPPM, as displayed by µTORQUE PC-design tool.

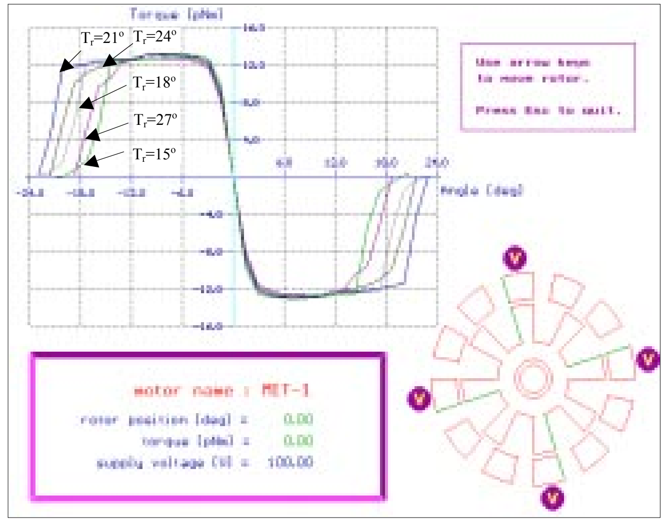

Figure 2: The simulated drive-torque of a 12/8 micromotor as a function of rotor position for different rotor pole width, using MPPM displayed by µTORQUE program.

3 DYNAMIC BEHAVIOR SIMULATION

3.1 Modified dynamic behavior Model

A modified theoretical model to simulate the micromotor dynamic behavior during its operation has been developed. This model has several free parameters, which can be calculated analytically, based on MPPM model, with different geometric parameter variations. The model shows the effect of the most important geometric design parameters (such as bearing clearance, and air-gap spacing), by introducing new coefficients in this model in order to examine the most important frictional term which expresses the side-pull lateral frictional force [4,5]. The value of this friction torque could is assumed to be directly proportional to the bearing clearance G_{br}, and bearing radius R_{br}, and inversely proportional to the cube of air-gap spacing G^3. Also using the exact simulated values of drive torque amplitude and torque shape in this model, we can express the drive torque not only in terms of air-gap spacing but also as a function of pole pitch ratio, in order to create an optimal operational micromotor. Thus, a new dynamic model, which contains these dependencies, can be formulated as follows:

$$J\ddot{\theta} = -B\dot{\theta} - (C_{sp}\frac{R_{br}.G_{br}}{G^3})V^2.\mathrm{sgn}(\dot{\theta}) + V^2 T_d(\theta) \quad (1)$$

where J is the rotor's moment of inertia, B is the coefficient of viscous drag, and are, respectively, the angular velocity and angular acceleration. C_{sp} represents the friction contribution due to lateral forces (side-pull). G, G_{br}, R_{br} represent air gap spacing, bearing clearance, and radius of bearing, respectively. $T_d\ (\theta)$ represents the simulated optimal drive torque per squared voltage, calculated using the MPPM model [10].

$$T_d(\theta) = T_{d\,\max} . T(\theta) \qquad (2)$$

where T_{dmax}, $T\ (\theta)$ represent the maximum amplitude, and the optimal shape of the drive torque as a function of the rotor position, respectively.

3.2 The MICROTOR PC-Design Tool

The MICROTOR (micro-rotor) computer program is a part of a CAD system for simulation of IC-processed micromechanical structures. It is aimed at simulation of dynamic behavior of a VC micromotor during its operation considering dependence on excitation voltage and frequency, and the variation of micromotor geometric design parameters. The displacement and velocity of the rotor is presented in windows on the screen both in numerical and animated picture forms.

This PC-design tool displays several windows on the screen during the simulation process. Figure 3 shows the dialog box window, which allows changing parameters of the micromotor dynamic simulation and initial conditions. We can enter any of the parameters presented in this window plus the name of file, to which the data regarding the position and speed of the micromotor is to be directed. A schematic view of the micromotor showing the current rotor position with respect to time can be also displayed, as shown in Figure 4. Figure 5 shows the data window in which we can observe the parameters and the output variables of the simulation. This data can be also saved in a disk file to allow further processing.

Figure 3: The dialog box allows changing the parameters of the micromotor dynamic simulation and initial conditions, as displayed by MICROTOR program.

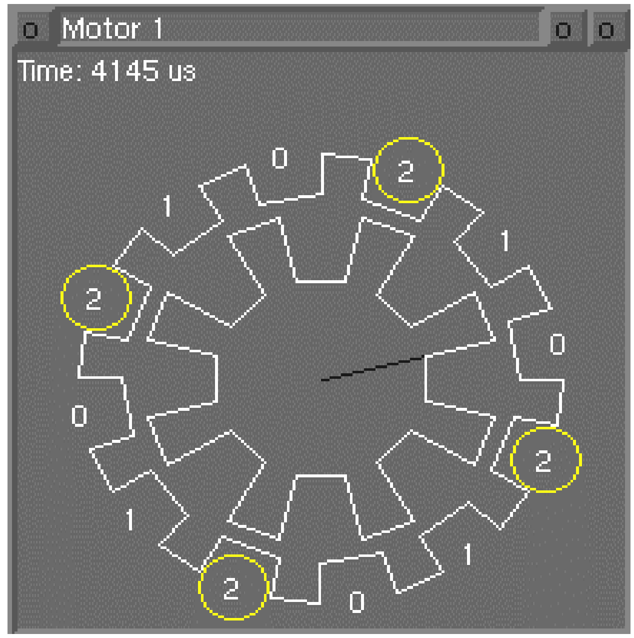

Figure 4: The animation window showing the current rotor position with time.

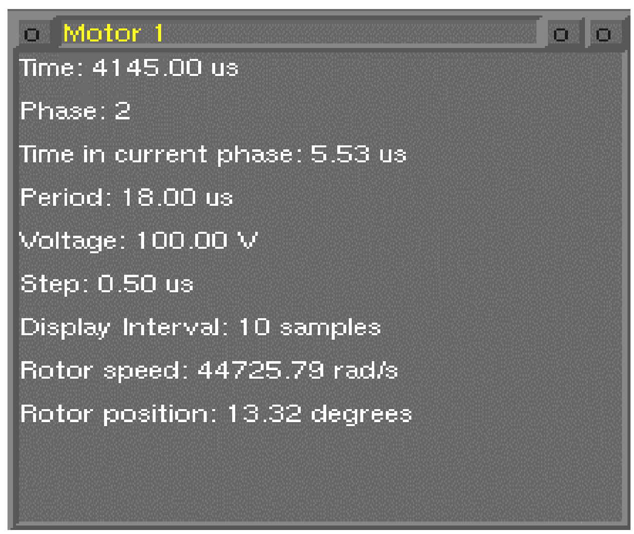

Figure 5: The data window in which the parameters and the output variables of the simulation can be observed.

3.3 Implementation of Dynamic Model in MICROTOR PC-Design Tool

For the simulation of dynamic behavior of a VC side-drive micromotor, the analytical model in equation (1) has been adopted to be implemented in the MICROTOR PC-design tool. The model made possible the development of minimal dynamic behavior that gives insight into the most important mechanisms that underlie the micromotor dynamic behavior, in order to introduce the optimum operational characteristics. The MICROTOR PC-design tool is linked to the MPPM model to perform the calculations for torque angle characteristics.

3.4 Simulation Results

Operational dynamic simulation of a VC side-drive rotary micromotor of 12/8 pole configuration with different geometrical dimension variations as well as excitation voltages are examined using MICROTOR PC-design tool. The torque angle characteristics for all these designs are introduced to the program from outside using the MPPM model. For each configuration of micromotor design parameters, the data regarding speed and rotor position from this simulation tool can be plotted and evaluated, by changing the frequency linearly from zero value up to a certain value. The optimal operational characteristics for this micromotor are presented in Figure 6.

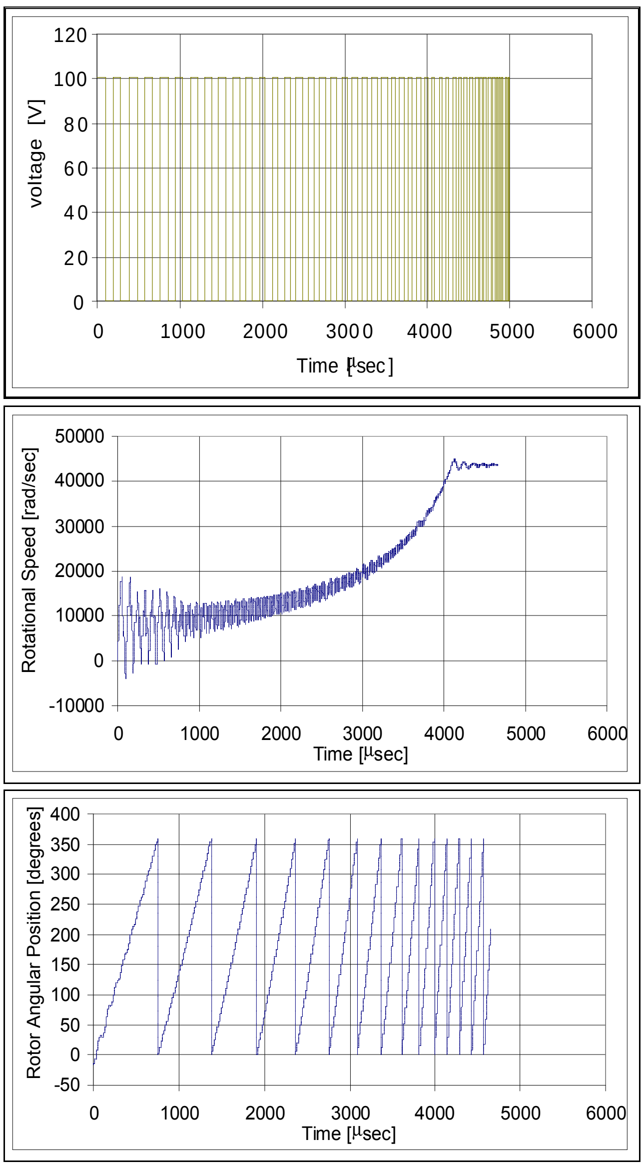

Figure 6: Simulated dynamic behavior during start-up rotation for micromotor of R_o= 50μm, G=1.5μm, and bearing clearance R_{br}=10 μm, G_{br}=0.3μm, using MICROTOR program: (a) The voltage pulse period of 18μsec starts from zero initial condition. (b) The rotor angular position as a function of time. (c) The rotor angular velocity as a function of time.

4 CONCLUSION

Two analytical models, for design and simulation of the static and dynamic behavior, have been successfully implemented in μTORQUE and MICROTOR PC-based design tools, respectively. They can be used for observing tendencies in micromotor optimization, to provide a very powerful technique, in a fully integrated CAD system for finding optimal structure for small size (VC) side-drive micromotors. These design tools have been used to design and determine the optimum electromechanical structure for MIT's micromotor of 12/8 pole configuration. A great improvement to the electromechanical characteristics has been achieved due to the new optimal geometrical dimensions. For pulse voltage of 18μs corresponding to supply frequency of 55.6 kHz, the maximum angular rotor velocity has been calculated to be equal to 44750 rad/sec.

REFERENCES

[1] L. S. Fan, Y. C. Tai, and R. S. Muller, "IC-processed electrostatic micromotors", Sensors and Actuators, vol.20, no. 1/2, pp. 41-47, 1989.

[2] M. Mehregany, S. F. Bart, L. S. Tavrow, J. H. Lang and S. D. Senturia, "A study of three microfabricated variable-capacitance micromotors", Sensor and Actuator, vol., A21, pp. 173-179, 1990.

[3] M. Mehregany, S. F. Bart, L. S. Tavrow, J. H. Lang and S. D. Senturia, "Principles in design and microfabrication of VC side-drive motors", J. Vac. Sci. Technical, Vol. A8, pp.3614-3624, July/Aug. 1990.

[4] L. S. Tavrow, S. F. Bart, and J. H. Lang, "Operational characteristics of microfabricated electrical motors," in Proc. of Int. Conf. On solid-state Sensors and Actuators, pp. 877-881, 1991.

[5] S. F. Bart, M. Mehregany, L. S. Tavrow, J. H. Lang, and S. D. Senturia, "Electric micromotor dynamics, "IEEE Trans. on Electron Devices", vol. 39, no.3, pp.566-574, March 1991.

[6] Di Barba P., Savini A., Wiak S., "2-D Numerical simulation of electrostatic micromotor torque", Second Int. IEE Conf. On Computation in Electromagnetics, Nottingham, pp.227-230, 12-14 April 1994.

[7] Y. Lefevre, M. Lajoie-Mazenc, E. Sarraute, H. Camon, "First step towards design, simulation, modelling and fabrication of electrostatic micromotors", Sensor and Actuator A, vol., 47, pp. 645-648, Issues 1/3, March 1995.

[8] T. B. Johansson, M. Van Dessel, R. Belmans, and W. Geysen, "Technique for finding the optimal geometry of electrostatic micromotors", IEEE Trans. Industry Applications, Vol. 30, No. 4, July/Aug 1994.

[9] I. Dufour, E. Sarraute, and A. Abbas, "Optimization of the geometry of electrostatic micromotors using only analytical equations", J. of Micromech. Microeng., Vol. 6, pp.108-111, July/Aug 1994.

[10] A. Salman, A. Napieralski, G. Jab_o_ski, "Simulation and Optimization of VC micromotors using Modified Parallel-Plate Model", in Proc. 2nd International Conf. "Modeling & Simulation Microsystems", MSM'99, Pureo Rico, USA, pp.609-612, 19-21 April 1999.