# 마이크로 액추에이터의 자동설계를 위한 CAE 평가

# CAE Evaluation for Automated Design of Micro Actuator

최윤종[1], 이은철[1], 김형택[1], *,#이준성[2], 이양창[3]
Y.J. Choi[1], Y.C.Lee[1], H.T. Kim[1], *,#J.S. Lee(jslee1@kgu.ac.kr)[2], Y.C.Lee[3]
[1] 경기대학교 대학원 기계공학과, [2]경기대학교 기계시스템디자인공학부, [3]대림대학 산학관리지원팀

Key words : Computer Aided Engineering, Micromachine, Micro Actuator

## 1. Introduction

Some CAD (Computer-Aided Design) / CAE (Computer-Aided Engineering) systems for micromachines such as SENSIM[1], MEMCAD[2], CAEMEMS[3] have been developed so far. SENSIM allows for the modeling of silicon piezoresistive or capacitive pressure sensors of multiple thin films, and for the calculation of their stress and deflection as a function of both pressure and temperature using both analytical and finite difference solutions under a thermoelastic plane stress conditions. MEMCAD is an integrated CAD system consisting of a structure generation software, FastCap, one of commercial solid modelers Pro/Engineer, one of commercial finite element (FE) codes ABAQUS, and specialized database. This system can perform both mechanical and electrical analyses of structures either described directly, or derived from the design specification (mask data plus process flow). CAEMEMS has a capability of parametric modeling of devices, and employs one of commercial FE codes ANSYS. One module of CAEMEMS is specially developed for diaphragm of pressure sensors. In these systems, FE codes to simulate behaviors of micromachines play very important roles. To more improve efficiency of design processes of actual micro structures with arbitrary geometry shape, it is indispensable to fully automate FE modeling and analyses of them.

One of the present authors has proposed an automatic FE mesh generation method for three-dimensional complex geometry[4]. The authors have integrated this mesh generator, one of commercial FE analysis codes and one of commercial solid modelers into a novel simulation system for micromachines. This simulation system includes the following functions ; (a) definition of geometry model, i.e. solid modeling including boolean operations such as union and intersection and easy formation of free-form surfaces, (b) attachment of boundary conditions and material properties directly to geometry model, (c) fully automated mesh generation, (d) various FE analyses such as electrostatic, stress and modal analyses, and (e) visualization of analysis models and results.

The developed system is applied to evaluate one of electrostatic micro actuators.[5] Through the analyses, fundamental performances of the system are cleary demonstrated.

## 2. Outline of the System

A whole analysis domain is defined using one of commercial geometry modelers, Designbase, which has abundant libraries enabling us to easily operate, modify and refer to a geometry model.

Material properties and boundary conditions are directly attached onto the geometry model by clicking the loops or edges that are parts of the geometry model using a mouse, and then by inputting actual values.

In the present system, nodes are first generated, and then a FE mesh is built. In general, it is difficult to well control element size for a complex geometry. A node density distribution over a whole geometry model is constructed as follows.

The present system stores several local nodal patterns such as the pattern suitable to well capture stress concentration, the pattern to subdivide a finite domain uniformly, and the pattern to subdivide a whole domain uniformly. A user selects some of those local node patterns, depending on their analysis purposes, and designates their relative importance and where to locate them.

The procedure of two dimensional node generation of the base node pattern is illustrated in Fig. 1. The node generation procedure of the special node pattern inside the domain is essentially identical to that of the base node pattern described previously. On the other hand, nodes on the domain boundary are generated one by one by calculating the value of the membership function on the boundary. For example, nodes are generated on straight line as follows:

$$X_{i+1} = X_i + \left(\frac{1}{f^{1/3}}\right) u \quad (1)$$

where function f is the value of membership function, u the unit base vector of the line, $X_{i+1}$ the vector of the new point, and $X_i$ that of the old point, respectively.

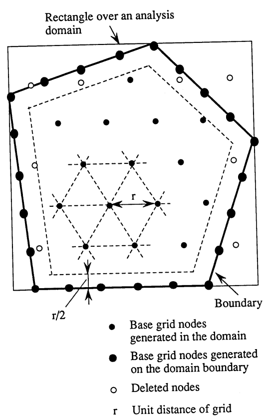


Fig. 1 Generation of base node pattern

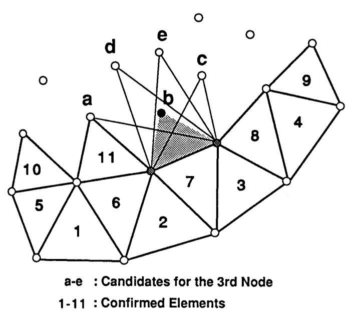


Fig. 2 Schematic view of triangulation mesh

After all the nodes are generated in the analysis domain and on its boundary, the system creates triangular (in the 2D) or tetrahedral (in the 3D) elements. As an example, the algorithm of triangulation used here is described in Fig. 2.

The present system automatically converts a geometry model of concern to various FE analysis models, depending on physical phenomena to be analyzed, i.e. stress analysis, modal analysis, thermal conduction analysis, electrostatic analysis, and so on.

## 3. Micro Actuator

The basic structure of the micro actuator is shown in Fig. 3. Fig. 3(a) shows its schematic plane view, while Fig. 3(b) does its cross-section view. The micro actuator comprises a movable platform, i.e. rotor, three spiral beams, and a plurality of electrodes, i.e. stator. Dimensions of its initial design are as follows. The platform is a ring-like plate of approximately 200 μm in outer diameter and 150 μm in inner diameter. The three beams are disposed at the inner space of the ring, and connect the ring with a substrate. The electrodes are provided in the circumferential region around the platform by about 3 μm to play the same role as ordinary electrostatic micro actuators. Insulator of about 1 μm thick is coated in inner surfaces of electrodes. As each electrode is excited sequentially, the ring rolls inside of the electrodes, accompanied by a little distortion of the three spiral beams. When the ring rolls around the electrodes in one cycle without slipping, it has transversed a distance greater than its own circumference. The driving force produced as an electrostatic attraction force is generated between the two bodies, i.e. the ring and each electrode. Although the rotation of the ring is limited by the spiral beams, the present actuator has several advantages such as high torque and low friction.

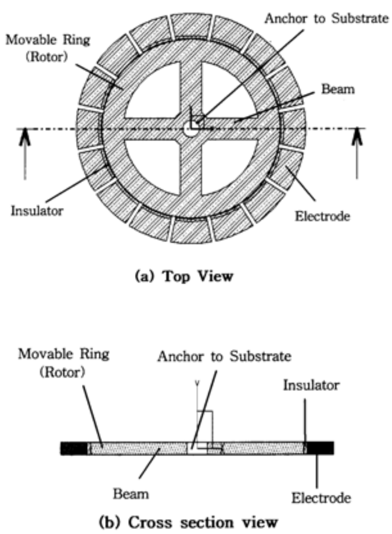


Fig. 3 Structure of micro actuator

## 4. Results and Discussions

Let us examine a fundamental capability of the developed automated simulation system. Since the width of the rotor is very thin compared to its diameter, i.e. 2.5 μm vs. 200 μm, the out-of-plane deformation of the rotor was analyzed using the same FE mesh shown in Fig. 3. The maximum deflection calculated was 2.049 x $10^{-5}$ μm. This value is negligible compared with the in-plane deformation of the rotor. Such a high stiffness of a thin structure is one of typical scaling effects of micro structures.

Fig. 3 Out of plane deformation of rotor

In general, to estimate electrostatic performances of micro actuators, in-plane 2D FE analyses are often conducted because of the complexity of actual micro actuator geometry. Here, an actual 3D geometry of micro actuator is considered in order to take account of electrical leakage phenomena. Fig. 4 shows the electric potential distribution.

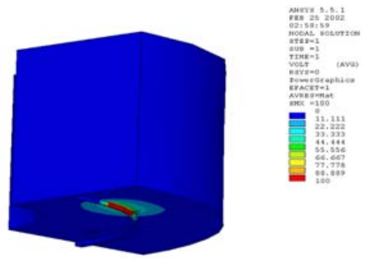

Fig. 4 Distribution of electric potential

In-plane deformation of the rotor portion is analyzed to evaluate the quantitative relationship between a rotation angle and a torque necessary to rotate the rotor within the elastic limit of the beams Since the electrode is much stiffer than the spiral beam, the in-plane deformation of the electrode is negligible. Thus the simplification of the loading condition employed here is quite reasonable. The maximum stress occurs near the internal dent part of one beam and, as anticipated, at a junction part of other beam. The ring itself does not deform much. The detailed shape of the junction may have to be manufactured very carefully in order to avoid dangerous stress concentration.

## 4. Conclusions

Static and dynamic deformation, vibration and electrostatic behaviors of the micro actuator were effectively evaluated in an easy and consistent manner using the developed system. Interactive operations to be done by a user can be performed in a reasonably short time. All the other processes which are time-consuming and labour intensive in conventional systems can be automatically performed.

## References

1. K.W. Lee and K.D. Wise, "SENSIM : A Simulation Program for Solid-State Pressure Sensors", IEEE Transactions on Electron Devices, ED-29, 34-41, 1982.
2. J.R. Gilbert et al., "Implementation of a MEMCAD System for Electrostatic and Mechanical Analysis of Complex Structures from Mask Descriptions", Proceedings of the IEEE Micro Electro Mechanical Systems Workshop, Fort Lauderdale, 207-212, 1993.
3. S. Crary, O. Juma and Y. Zhang, "Software Tools for Designers of Sensor and Actuator CAE Systems", IEEE Solid-State Sensors and Actuators (Transducers '91), San Francisco, CA, U.S.A., 498-501, 1991.
4. J.S. Lee, "Integrated CAE System for Practical Structures", KSME Conference, 11-22, 1999.
5. N. Shibaike, "Design of Micro-mechanisms Focusing on Configuration", Materials and Processes, Materials & Design, To appear.