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Electromechanical microdevice pull-in voltage maximization using topology optimization

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ABSTRACT

Because it provides a short response time and is relatively easy to implement, electrostatic actuation is often used in MEMS. However, these actuators possess a limit voltage called pull-in voltage beyond which they are unstable. Above a given displacement and the corresponding voltage, elastic forces of suspension system can not equilibrate electrostatic forces and electrodes stick together. The pull-in effect, can eventually damage the device since it can be impossible to separate the electrodes afterwards. Consequently, pull-in phenomenon should be taken into account during the design process of electromechanical microdevices to insure that it is avoided within utilization range. That's why, the authors are developing a topology optimization procedure which allows controlling pull-in phenomenon during the design process. In the present work, the maximization problem of the pull-in voltage of an electromechanical microdevice is under consideration.

The application of topology optimization to control microstructure stability via the pull-in voltage maximization has already been studied by the authors [1,2]. Our approach consists in formulating the topology problem as material distribution problem using continuous pseudo-density variables on each element of the optimization domain finite element mesh (see Ref. [3] for further details). Moreover, the pull-in optimization procedure is based on the association of the multiphysic simulation software Oofelie [4] and the mathematical programming optimizer Conlin developed by Fleury [5]. The objective function sensitivities are given by a semi-analytic expression requiring the computation of the pull-in conditions. The pull-in point is obtained using a monolithic electromechanical finite element analysis [6] and a continuation method as the Normal Flow algorithm [7].

Previous works of the authors [1,2] are based on a simplified optimization problem where the optimization domain is separated from the electrical domain by a perfectly conducting material layer making the optimization domain purely mechanical. Therefore, difficulties related to the modification of the electrostatic pressure distribution by the optimization process are avoided. Nevertheless, this method provides interesting and promising results.

However, works by M. Raulli [8] and by G.H. Yoon [9] studying optimization of electrostatic actuators in order to maximize the output force show the interest of considering a coupled optimization domain. Similarly, the present work considers the possibility to generalize the pull-in optimization problem by removing the separation between optimization and electrical domains. Unlike the original method, the dielectric permittivity has now to be a function of the element density as well as the Young Modulus to represent the different electrostatic behaviour of void and solid. Therefore, the permittivity is interpolated between void permittivity (ε_0=8.85 10^{-12} F/m) and a high value (about 10^{-3} F/m) to model a perfect conductor. Thanks to this improvement, the freedom of the optimization process is enlarged since the optimizer is now able to modify the electrostatic force distribution applied on the structure which results in a higher efficiency of the optimal device.

Nevertheless, we could observe that under these new conditions, pull-in optimization is not straightforward. Indeed, recent works show that void areas of the optimization domain can suffer from local pull-in modes. In fact, during the optimization process, some elements from low density areas collapse for an applied voltage lower than the global structure pull-in voltage. Obviously these local pull-in modes are pure numerical artefacts since they only involve void zones of the optimization domain. In addition, it stems out that local pull-in results from the appearance of electrostatic forces on nodes surrounded by void elements. Since the surrounding elements are void, these electrostatic forces have no physical relevance and in fact are related to a lack of accuracy of the electrostatic forces computation. That's why, as void elements possess a very low stiffness, important deformation of the mesh occurs and leads to a local pull-in mode. Therefore, in order to avoid local pull-in, improvement of the coupled finite element accuracy is under study.

REFERENCES

[1] E. Lemaire, P. Duysinx, V. Rochus, J.-C. Golinval, *Improvement of pull-in voltage of electromechanical microbeams using topology optimization*, ECCOMAS conference Lisbon, June 2006

[2] E. Lemaire, V. Rochus, C. Fleury, J.-C. Golinval, P. Duysinx, *Topology optimization of microbeams including layer deposition manufacturing constraints*, 7^{th} WCSMO, Seoul 2007.

[3] M. Bendsøe, O. Sigmund, *Topology oprimization : theory, methods and applications*, 2003, Springer Verlag.

[4] I. Klapka, A. Cardona, M. Géradin, *An object-oriented implementation of the finite element method for coupled problems*, Revue Européenne des Elements Finis, 1998, 7(5), 469-504.

[5] C. Fleury, CONLIN: *An efficient dual optimizer based on convex approximation concepts*, Struct. Opt., 1989, 1(2), 81-89.

[6] V. Rochus, D. J. Rixen, J.-C. Golinval, *Monolithic modelling of electro-mechanical coupling in micro-structures*, Int J. Num. Meth. Engng., 2006, 65(4), 461-493.

[7] S. Ragon, Z. Gurdal, L. Watson, *A comparison of three algorithms for tracing nonlinear equilibrium paths of structural systems*, Int. J. Solids & Struct., 2002, 39, 689-698.

[8] M. Raulli, K. Maute, *Topology optimization of electrostatically actuated Microsystems*, Struct. & Mult. Opt., 2005, 30(5), 342-359.

[9] G. H. Yoon, O. Sigmund, *Topology optimization for electrostatic system*, 7^{th} World Congress on Structural and Multidisciplinary Optimization, Seoul 2007.