Use of the neBEM Solver to Compute the 3D Electrostatic Properties of Comb Drives

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1. Introduction

Micro-Electro-Mechanical Systems (MEMS) comb drives are used for both as sensors and actuators. As a result, they have been considered to be very important in MEMS and have been under intense study for last few years. Normally, these comb drives have two sets of fingers, one fixed and the other moving. The actuation and the sensitivity are both dependent in a major way on the electrostatic configuration of the comb structure. For example, by applying voltages on these fingers, the fixed finger can be moved through a desired distance or angle. Similarly, by observing the change of capacitance occurred due to the movement of the movable finger with respect to the fixed one, the change in the position of one finger in relation to the other can be sensed. As a result, accurate estimation of the electrostatic configuration of comb drives is crucial in both design and interpretation phases. One of the major problems in solving this electrostatic problem is the simultaneous presence of very small length scales along with those of much larger ones. The boundary element method (BEM) which is efficient and successful in many problems of similar nature, fails badly in its conventional form because of the importance of precise estimation of near-field properties. As a result, several other variations of the method have been used to solve the problem accurately [1]. Many of these methods, unfortunately, involve quite complicated mathematics and are relatively difficult to implement.

The nearly exact boundary element method (neBEM) solver has been developed [2,3] recently and used successfully to solve difficult problems related to electrostatics [4,5]. This solver uses exact analytic expression for computing the influence of singularity distributions instead of adopting the conventional and convenient approximation of nodal concentration of charges. Due to the exact foundation expressions, the solver has been found to be exceptionally accurate in the complete physical domain, including the near field.

In this work, we explore the possibility of using the neBEM solver to solve 3D electrostatic problems related to comb drives. In particular, we investigate the relationship between the accuracy achieved and the computational expenses incurred for realistic comb drive geometry. In the process, we estimate the charge density distribution, potential distribution and the capacitance of the comb structure. The study has led us to the conclusion that the neBEM solver can yield very accurate estimates of all the properties of interest at a reasonable computational expenditure. The solver does not need any special formulation to tackle many of the most difficult problems and can be of great advantage in handling critical problems such as analyzing MEMS structures.

2. Geometry of the problem

The comb drive that we have studied has only one movable finger and is as shown in Fig.1. The dimensions of the drive are as follows: finger width = 5µ, finger length = 100µ, finger overlap = 90µ, movable finger pitch = 15µ, fixed finger pitch = 15µ and comb thickness = 10µ.

![FIG.1: Geometry of the Comb Drive.](image)

The potential applied to the fixed and movable fingers are \(V = 1\,\text{V}\) and \(V = -1\,\text{V}\), respectively.

3. Results

All the surfaces of the comb drive have been discretized keeping the minimum dimension of an element more than a micron. Below this limit, the round-off errors related to computation is likely to deteriorate the accuracy of the results on a 32bit
machine. It may be noted here that by using long double variables on a 64bit machine, it is possible to obtain excellent results even with dimensions of the order of 1nm. In Fig.2, we have presented the potential distribution on the plane of the comb drive. From this distribution it is possible to form a visual impression of distribution of potential and also the accuracy of the solver. The regions with known voltages are found to be quite accurately simulated by the solver.

In order to estimate the accuracy of the computation, we have compared our results with those obtained using analytical approaches and also those from detailed numerical simulations. Under the assumption that the electrode overlap is large compared to the electrode spacing, width and height of the fingers, and the fringe fields at the end of the electrode do not change significantly with change in overlap length, which can be approximated by analytic expressions [6]. We have used this expression to estimate the capacitance of the drive under consideration and it turns out to be \(8.688 \times 10^{-3}\)pF. A very accurate estimate using the industry standard CoventorWare’s MemCap module using a large number of panels (160, 000) turns out to be \(9.69 \times 10^{-3}\)pF. Using the neBEM solver and a very coarse discretization (00 and 1200), the capacitance of the comb drive has been found to be \(9.099 \times 10^{-3}\)pF and \(9.370 \times 10^{-3}\)pF. Thus, it may be said that the neBEM solver produces quite acceptable results at very little computational expenses. The change in capacitance due to the variation of the dimensions of the comb drive has been studied. Moreover, similar variation due to change in the relative positions of the fingers have also been investigated.

4. Conclusions

The nearly exact BEM(neBEM) solver has been used to estimate the 3D electrostatic properties of a simple comb drive having one movable finger. The results and the following comparison clearly shows that results obtained using the neBEM solver are precise and reliable. The effect of variation of the geometrical parameters of a comb drive on its capacitance has been studied.

References