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Comment on 'Design of MEMS Cantilever - Hand Calculation' [Sensors & Transducers Journal, Vol. 91, Issue 4, April 2008, pp. 55-69]

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Abstract: Hand calculations and approximations for design of MEMS cantilevers by Kshirsagar, *et al.* [1] are very useful for the design of MEMS sensors but the approximations used by the authors are valid for beam loading of 5 % or less and are inadequate for moderate and full loading of the beam. The errors can be more than 50 % in extreme cases.

Keywords: Spring constants Cantilever, MEMS sensors.

1. Introduction

Micro-Electro Mechanical Systems (MEMS) based sensors are matured and used in many systems due to their high sensitivity, low noise, low temperature sensitivity and low power dissipation characteristics. Kshirsagar, *et al.* [1] reported basic hand calculations for design of MEMS cantilever for beginners. Their results are indeed very useful and handy for the design of variety MEMS sensors. Majority of MEMS sensors use cantilevers, fingers, suspended beams, comb type beams, circular structures etc. All of these MEMS structures are associated with a spring which has a particular spring constant K depending upon material, shape and loading on the beam. Theses authors proposed a simple formula for a fixed-free beam with one free movable edge (see Fig. 1B of Ref. [1]) given by

$$K(\lambda_r) = \frac{2Ebh^3}{3l^2}\left[\frac{3}{8-6\lambda_r+\lambda_r^3}\right], \qquad (1)$$

where E is Young's modulus, b is width of cantilever beam, h is thickness of cantilever beam. Further,

$$\lambda_r = l_c / l, \qquad (2)$$

where lc is the length over which equal distributed transverse load is applied and l is the total length of cantilever. They used λ_r^2 in denominator of second bracketed term instead of λ_r^3. The generalized equation of $K(\lambda_r)$ was originally proposed by Pamidighantam, *et al.* [2] which is very long and cumbersome (see Eq. 2 o Ref. [2]) who the simplified it for case where axially induced forces are absent and partial loading was taken into account in the analysis.

Spring constant K being one of the fundamental parameters for the design of MEMS sensors, its basic and handy knowledge is certainly useful and essential to start any design. Kshirsagar, *et al.* [1] presented such results and they can be really useful for the workers in the field.

However, the point we want to make is that while estimating the effect of parameters lambda (λr) and l on the spring constant K in Eq. (1) they cannot be treated independent. It may be seen from Eq. (2) that the percentage of loading on the beam given by l_c will change the value of λr. Kshirsagar, *et al*. [1] while estimating K from Eq. (1) kept λr constant while varying l. It is evident from eqn. (2) that variation of l automatically leads to variation in λr. This approximation leads to errors in estimation of K. This is valid only for very small and negligible loading on the beam say less than <10 % or so.

In the present comment, we have re-calculated K without this approximation and compared the results with those of Kshirsagar, *et al*. [1]. Kshirsagar, *et al*. [1] presented the results for λr=0.1, 0.2, 0.4, 0.6, 0.8 and 1.0. However, we reshowing the results for lower, middle and upper cases only i.e. λr=0.1, 0.6 and 1.0 to reduce the clutter in the figure while comparing and yet covering the whole range and capturing the trends of the results.

Fig. 1 presents the results of beam length l versus spring constant K for the fixed value of beam width w of 150 microns as was used by these authors. It may be seen that the approximation of Kshirsagar, *et al*. [1] holds true only for loading of 10% i.e. λ_r=0.1 as expected. As the value of λ_r is increased to 0.6, the value decreases from 4.0 to 3.3 N/m at l=1.5e-4 meters the disagreement increases to 17.5 %. Similarly this disagreement is 31 % at l=1.5e-4 meters. So, for the case of full loading, the error in estimating K is as high as 31 %.

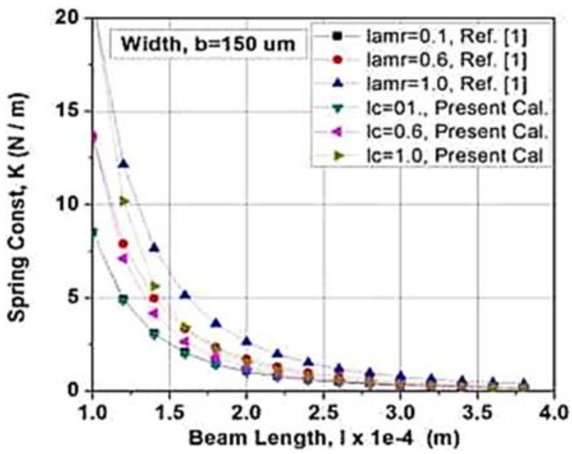

Fig. 1. Variation of spring constant as a function of cantilever length.

Fig. 2 presents the results of beam width b versus spring constant K for the fixed value of beam length l of 300 microns as was used by these authors. Again, it may be seen that the approximation of Kshirsagar, *et al.* [1] in this case does not even hold for loading of 10 % i.e. λ_r=0.1. The maximum disagreement is still 5.7 % at the highest beam width w of 200 microns. Similarly this disagreement is as high as 50 % at w=200 microns for the case of full i.e. loading λ_r=1.

Fig. 3 presents the results of beam thickness t b versus spring constant K for the fixed value of beam length l of 300 microns as was used by these authors. Again, it may be seen that the approximation of Kshirsagar, *et al.* [1] in this case does not even hold for loading of 10 % i.e. λ_r=0.1. The maximum disagreement is still somewhat lower i.e. 6.3 % at the highest beam width w of 200 microns. However, this disagreement is as high as 50 % at w=200 microns for the case of full i.e. loading λ_r=1.

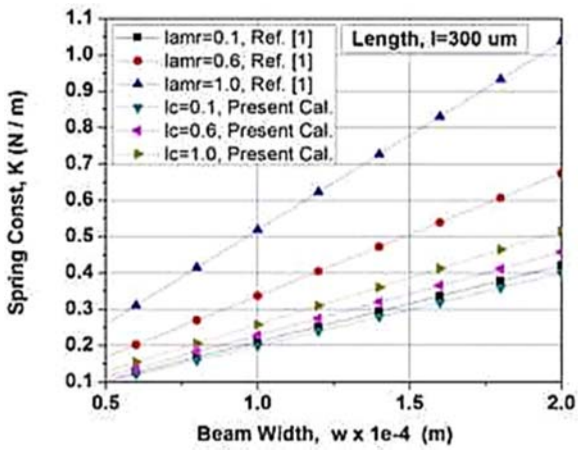

Fig. 2. Variation of spring constant as a function of cantilever width.

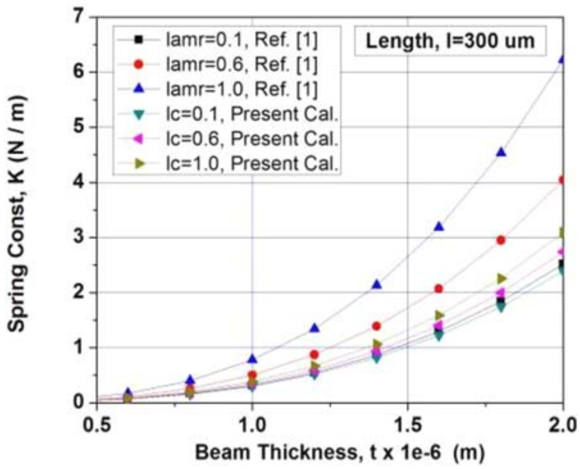

Fig. 3. Variation of spring constant as a function of cantilever thickness.

The above results clearly show approximation used by Kshirsagar, *et al.* [1] for calculation of K is valid for beam loading of 5 % or less and it is inadequate for moderate and full loading of the beam. The errors can be more than 50 % in extreme cases.

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