Constant Force Micro Mechanism out of Carbon Nanotube Forest

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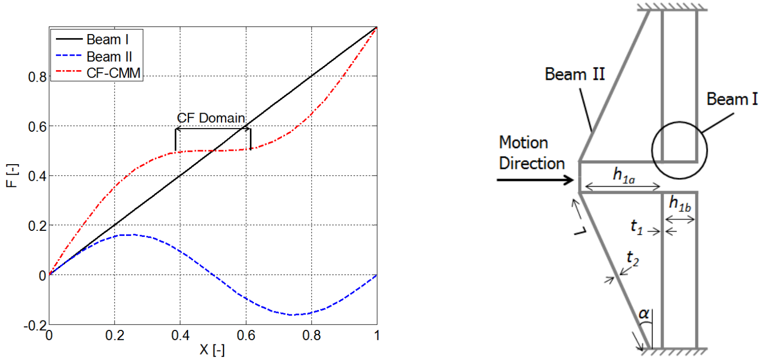
1 Introduction

Many devices benefit from micro-electro-mechanical systems (MEMS), such as customer electronics, automotive, and medical devices. In particular, constant force compliant micro mechanisms (CF-CMM) are needed for several applications such as in medical devices [1-3] and electrical switches [3]. Several studies have been performed in design of large scale constant force mechanisms which can briefly be found in [4], however, constant force mechanisms have never been presented at the micro scale.

This paper presents the first carbon-nanotube-based micro-scale constant force compliant mechanism. In this work we combined a bi-stable mechanism and a crab-leg suspension (i.e. linear stiffness spring) to create a constant force. We fabricate the mechanism out of a forest of carbon nanotubes (CNT) in order to enhance the mechanical properties.

2 Design

Introducing preloading to compliant mechanisms may adjust the stiffness for a nonlinear behaviour [5, 6]. However, in the micro precision range, external pre-loading is not feasible [5]. To solve this, combination of mechanisms with opposite stiffness was used while the structure is stress-free at its initial position [5]. Once motion is implemented, the system will be autonomously pre-loaded, allowing size reduction to the micro scale.



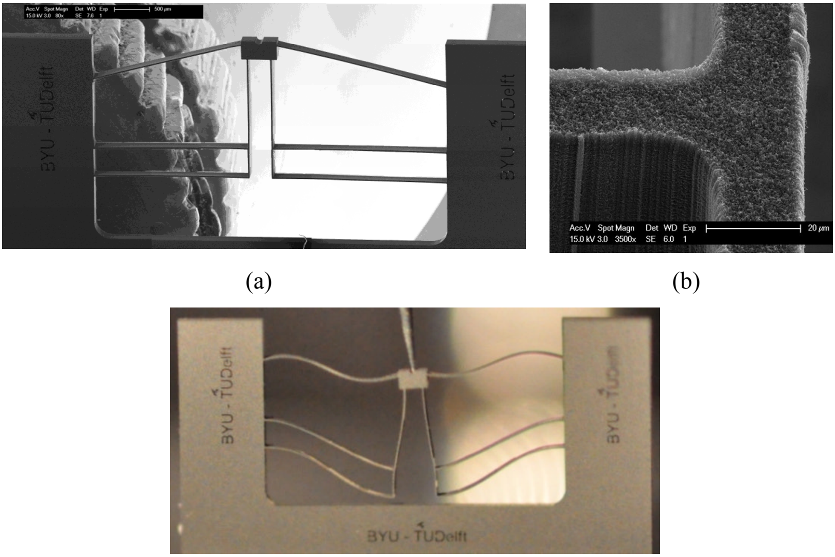
(a) (b)

Figure 1: (a) Predicted force-deflection behaviour and (b) concept of the constant force carbon-nanotube-based compliant micro mechanism (CF-CMM).

The combination of a bi-stable mechanism and a linear spring is used to create a constant force mechanism, as shown in Figure 1(a): the negative stiffness of Beam II compensates for the positive stiffness of Beam I. It has been shown that straight guided beams are efficient in terms of ratio of negative stiffness and stroke to mechanism size [7]. Therefore, arrangement of the straight guided beams as the mechanism with a negative stiffness and crab-leg suspension as a near linear positive stiffness spring has been considered to create the first constant force carbon-nanotube-based compliant micro mechanism, as shown in Figure 1(b). The number of elements in the suspension may vary to reduce the stresses.

3 Fabrication

For the first time, a forest of carbon nanotubes (CNT) has been used to fabricate the constant force structures (i.e. CF-CMM). The Carbon Nanotube Templated Microfabrication (CNT-M) process creates MEMS with large height-to-width ratios, using novel materials that have not commonly been used for microsystems. Figure 2 shows a carbon-nanotube-based CF-CMM grown to a height of 265 um, with feature sizes of L=2500um, α=15, t_1=15um, t_2=17.5um, h_{1a}=1500um, h_{1b}=500um and material properties of E=35Gpa and v=0.3. These dimensions allow minimizing the error for constant force, maximizing its stroke while keeping the stresses below the limit (110Mpa). The CNT-M process works by growing a carbon nanotube forest in the desired pattern, and then infiltrating the forest with the structural material using



(c)

Figure 2: (a) Front view and (b) close-up of CF-CMM fabricated in the CNT-M process and (c) the deflection during the measurement.

chemical vapor deposition (CVD) [8]. To date, CNT-M microsystems have been created using silicon, graphitic carbon, silicon nitride, tungsten, and molybdenum as structural materials. For zero-stiffness structures such as a CF-CMM, the CNT-M provides high aspect ratios, preventing out-of-plane motion, and new materials with high compliance before fracture [9].

4 Results and Disscussion

We have shown the measurement results of the first carbon-nanotube-based micro-scale constant force compliant mechanism in Figure 3. As shown in this figure, the carbon-nanotube-based CF-CMM showed a long constant force stroke (840um) with an error of less than 4%. The results are in good agreement with finite element modelling (FEM) and the hysteresis is negligible. We have shown that the concept of cooperation of bi-stable mechanisms and L shaped linear stiffness compliant mechanisms is successful to create a constant force micro mechanism for a long stroke. Moreover, Carbon Nanotube Templated Microfabrication is suitable for fabrication of zero stiffness structures (i.e. CF-CMM) due to small hysteresis and high aspect ratio fabrication with small fabrication error for in-plane thicknesses.

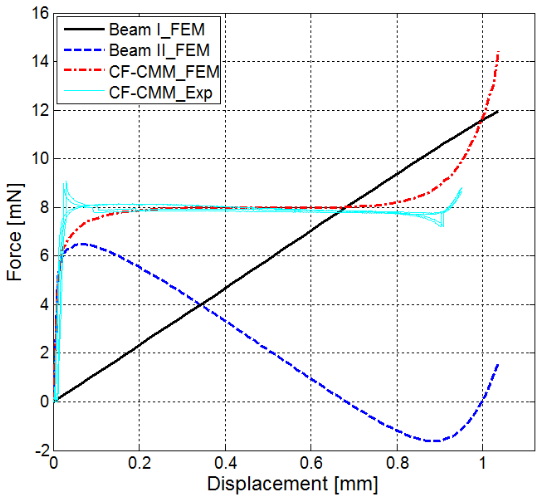


Figure 3: Force-deflection of the carbon-nanotube-based CF-CMM from the measurements and finite element modelling.

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