Intentional Nonlinearity at the Nanoscale

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Abstract:
We implement intentional strong nonlinearity at the nanoscale, arising from geometric and/or kinematic effects. Starting from oscillating multi-walled carbon nanotubes with attached discrete particles we show both theoretically and experimentally that geometric nonlinearity leads to extreme resonance bands exceeding in some cases 10MHz, which, in turn, lead to improved senistivity of these systems to sensing of mass and energy fluctuations. This contrasts to current linear nanoresonators whose operation is restricted only to narrow frequency ranges. Then we consider a nonlinear micromechanical cantilever system with intentionally integrated geometric nonlinearity realized through a multi-walled boron nitride nanotube coupling. The geometrically positioned nanotube introduces nonlinearity efficiently into the otherwise linear micromechanical cantilever oscillator. It is shown that a small change in the geometrical parameters of the system produces a complete transition of the nonlinear behaviour from hardening to softening, highlighting the tunability of the nonlinearity of this system with its geometry. Finally, we employ a transfer-printing assembly technique to reliably integrate a silicon nanomembrane as a nonlinear coupling component into a linear system of two microcantilevers. The dynamics of the developed system was modelled analytically and investigated experimentally as the coupling strength was finely tuned via FIB post-processing. The transition from linear to strongly nonlinear dynamic regimes for gradual change in the coupling strength is experimentally studied. At the limit of weak coupling we show that the oscillations of the two microcantilevers become asynchronous in the vicinity of resonance, with the system exhibiting a nonlinear complex mode. We conjecture that the emergence of this nonlinear complex mode is attributed to the nonlinear damping effect due to the attached nanomembrane. These applications highlight the diverse applications of intentional strong nonlinearity in dynamical systems at the small scale.

Short bio:
Alexander F. Vakakis received his PhD in Applied Mechanics from the California Institute of Technology (1990), an MSc from Imperial College, London (1985), and a Diploma in Mechanical Engineering from the University of Patras, Greece (1984). He has been faculty at the University of Illinois since 1990, with an eight year break when he was faculty at the National Technical University of Athens (2000-08). He is a Fellow of ASME, and the recipient of the Thomas Bernard Hall Prize (2012) and the PE Publishing Award (2009), both from the UK Institution of Mechanical Engineers for best journal papers published in two archival journals published by the Institution. In 2014 he received the ASME Applied Mechanics Division Thomas Caughey Award in Nonlinear Dynamics. Among other topics his current research work includes dynamics, vibrations and acoustics; nonlinear system identification, reduced-order modeling and model updating; nonlinear acoustics; nonlinear micro- and nano-resonators; control of fluid-structure interactions and aeroelastic flutter; and nonlinear vibration energy harvesters. A. Vakakis has published over 250 archival journal publications, authored or edited 5 technical monographs, and over 390 conference presentations. Together with L.A. Bergman and D.M. McFarland he co-directs the Linear and Nonlinear Dynamics and Vibrations Laboratory (LNDVL) of the University of Illinois (http://lndvl.mechse.illinois.edu/).