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An Introduction to "Mem-Models" for Engineering Mechanics Applications

Jin-Song Pei
Associate Professor, School of Civil Engineering and Environmental Science
Graduate Faculty Member with M3 Status School of Electrical and Computer Engineering
University of Oklahoma, Norman, OK, USA

Abstract:

A significant event happened for electrical engineering in 2008, when researchers at HP Labs announced that they had found "the missing memristor", a fourth basic circuit element that was postulated nearly four decades earlier by Dr. Leon Chua who also developed the theory of memristive systems. One consequence of this announcement has been the revitalized research in all areas of brain-imitating computer technologies, primarily because memristors mimic synapses. Moreover, the theory involving memristor devices and memristive systems was extended to include memcapacitors and meminductors, thereby introducing an entire class of "mem-models". This model class is the foundation of the present study. By applying the well-known mechanical-electrical system analogies, the mathematics of mem-models may be transferred to the setting of engineering mechanics, resulting in mechanical counterparts of memristors, memcapacitors, etc. This transfer is nontrivial, for example, a new concept and state variable called "absement", the time integral of deformation, emerges. We identify some recent examples of "mem-dashpots" and "mem-springs". In addition to a "zero-crossing" condition, we highlight the role played by discontinuities in the model and/or the excitation, the combination of which enables mem-models to produce numerous hysteresis patterns. We also consider some new properties and modeling techniques that call for further improvement so that these new types of mechanical models can become more usable for analyzing real-world data. Both rate-dependent and rate-independent hysteresis can be captured by mem-spring models. A model for a fluid inerter, a partial model for concrete, and qualitative models for shape memory alloy (SMA), rubber, and the Mullins effect are presented as illustrative examples.

Brief Bio:

Dr. Jin-Song Pei received her Ph.D. in Civil Engineering and Engineering Mechanics from Columbia University, while her B.Eng. and M.Eng. degrees in Structural Engineering were obtained from Xi'an Jiaotong University, Xi'an, China and Nanyang Technological University, Singapore, respectively. Dr. Pei has years of practical engineering and development experience in the United States of America, Singapore and China. In particular, she practiced at Weidlinger Associates, Inc., Cambridge, MA. Dr. Pei received the NASA JPL Faculty Research Program award in 2016 and 2017 (twice) to work with Group 352G (Dynamics Environments) on data-driven pyroshock response prediction, and a Center for Academic Partnerships (CAP) award to work with Group 347D (Mobility and Robotic Systems) on improving the modeling fidelity of complex aerospace systems with mem-models from December 2018 to January 2019. Dr. Pei just visited Los Alamos National Laboratory (LANL) to work at Engineering Institute for the second time. From January to June 2018, Dr. Pei was a visiting professor at the Institute of Structural Engineering of ETH Zürich engaging in both teaching and research. Dr. Pei is currently holding a visiting professorship at Eindhoven University of Technology (TU/e), Netherlands, under a Netherlands Organisation for Scientific Research (NWO) travel grant from August to September 2019. Dr. Pei's research centers on theoretical development and numerical analysis for data processing and nonlinear system identification. Modeling nonlinear dynamical systems is inherently challenging; however, it is necessary in that it has broad utility in many engineering disciplines, including engineering mechanics, smart structures, robotics, mechatronics, structural control, structural health monitoring, damage detection, and earthquake engineering.