Non-linear Mechanics Laboratory

Laboratory Coordinator: Dr. Shakti Singh Gupta and Dr. Pankaj Wahi

Associated Faculty Members: (i) Dr. Manjesh Singh and (ii) Dr. Akhilesh Mimani

List of Major Equipment:

- Shaker platform
- Accelerometers
- Force Transducers
- CCD camera
- Ultra- sound bath
- Balance
- Desiccator
- Hot Plate
- Vacuum pumps
- Freezer
- Spin coater
- Confocal microscope
- Desktop computers
- Fluorescence microscope
- Optical table
- Hot air oven.

Brief description of the laboratory:

The nonlinear mechanics lab used to be jointly shared between Dr. Shakti Singh Gupta, Dr. Sovan Lal Das and Dr. Pankaj Wahi where the primary focus was on understanding nonlinear phenomenon in problems of applied mechanics and biomechanics. However, after Dr. Sovan Lal Das moved to IIT Palakkad, the biomechanics aspect has taken a back seat and the focus has shifted to understanding the mechanics of continuous structures with special relevance to practical systems involving strings, beams, plates etc. One of the main aims of the research activities undertaken in the laboratory is to understand the influence of the nonlinearity on the system response so that this can be utilized to enhance the performance of the system. Also under consideration is the possible exploitation of the nonlinearities into achieving better control strategies. In recent years, the engineering systems of interest being actively pursued include drill-strings for deep borewell drilling used for oil and gas exploration, stability and vibration characteristics of thin-walled shells, energy harvesters including parametric and autoparametric systems with pendulum, vibrations of conveyer belts etc. and the effect of finite-sized pulleys on them. Recently work has also been undertaken to better understand the nonlinearities in traditional independent suspension systems used in automobiles. Optimal synthesis of mechanisms primarily for use in prosthetic devices and finite element-based analysis of various prosthetic devices has been another focus area which is jointly shared with the biomechanics lab under Dr. Niraj Sinha.

Laboratory research keywords:

Nonlinear Vibrations; Stability and Control; Continuous Systems; Drill-string Dynamics, Independent Suspension System, Pendulum based Energy Harvesters, Thin-walled Shells, Unilateral Obstacle and vibrating continua interaction.

Major Research and Development Contribution of the Laboratory

Year	Major research and development activity
2020-2021	▪ During this period, the focus of the lab came back to understanding the implication of the interaction between continuous structures and boundary obstacles. The effect of the boundary obstacle on the vibrations of axially travelling strings beyond the critical velocity was explored for a large pulley at one end with a small pulley at the other end. Parallel studies on the same analysis with pulleys of comparable sizes at both the ends were initiated. The lab members also resurrected their interest in deep drilling system and started exploring the design of drill bits to ensure better resistance to self-excited vibrations during operation.
2019-2020	▪ During this period, the members of the lab largely carried forward the collaborative effort with the Machining Dynamics Lab to better understand the dynamics of the machining process with a view to control them.
2018-2019	▪ During this period, members of the lab diversified into prosthetic devices along with taking forward the work on instability in cylindrical shell structures. In particular, the buckling of cylindrical shells under torsional loading was considered both using reduced shell equations and using computational models in FEM. On the prosthetic devices front, optimal synthesis of polycentric knees was considered and factors effecting the final optimal design was obtained. This analysis was taken further to develop a prosthetic leg with coordinated motion between the knee and the ankle. Members of the lab also started exploring stability and vibration characteristics of machining tools in collaboration with the Machining Dynamic lab of Dr. Mohit Law.
2017-2018	▪ During this period, the major research activity in the lab was geared towards understanding deep drilling systems and pendulum based energy harvesting devices. We extended our understanding of the conditions affecting appearance of self-excited vibrations in a simplified axial-torsional model of the drill-string and also studied the effect of changing boundary conditions at the ground level on the onset of the instability. In the energy harvesting using pendulum based devices, we worked out control laws to ensure continuous rotation of the pendulum from any arbitrary initial conditions which is a must to utilize this whirling motion for generating power. We also studied the influence of the coupling between the harvester and the vibrating source using an autoparametric pendulum system excited by vortex-induced vibrations. ▪ Additionally, in collaboration with Dr. Abhishek from Aerospace engineering, members worked on an initial design and optimization of the main gear-box for a 10-12 tonne class helicopter transmission system. The primary objective was to minimize the weight of the gearbox while ensuring an overall reduction ratio of approximately 25.

2016-2017	▪ During this period, the activities in the lab again continued on analytical and computational approaches to study engineering systems. The computational work focused on understanding the dynamic stresses and the resulting deformations in a shell which is fired from a rifled barrel to provide it directional stability. Another aspect of the computational analysis was to predict the sound pressure levels due to flow in ducted passages with an aim to predict the noise level due to HVAC ducts used in buildings and naval ships. On the analytical front, the use of inerters in suspension system of automobiles to enhance its vibration isolation characteristics was explored. We also worked on a new dynamic friction law to better capture the friction force characteristics in the pre-sliding regime. Parallelly we also worked on obtaining a more comprehensive understanding of the parametric instability in thin-walled shell structures, self-excited vibrations in deep drilling systems and the inherent nonlinear instability in reduced order models of nuclear fission reactors.
2015-2016	▪ During this period, the major research of the lab was focused towards obtaining a better understanding of mechanics of continuous structures and ascertaining the validity of some of the simplified theories for the same. Towards this end, a two pronged approach of analytical studies of simplified theories coupled with computational studies using continuum structures was adopted. Among the simplified theories were the string, beam and shell theories while the computational studies were done on slender and thin-walled structures. The analytical studies using string theories focused mainly on the influence of the presence of a unilateral obstacle at the boundaries on the vibration characteristics. The analytical studies for beams included large amplitude vibrations whose characteristics was compared with a similar response from a computational study using FEM. For shell structures, appropriate equations to study the vibration and stability characteristics were obtained and validated against FEM solutions. Parallelly a computational study on the wrinkling behavior in thin spherical and inflated shell structures was undertaken to ascertain conditions for the appearance of wrinkles on the shell surfaces.

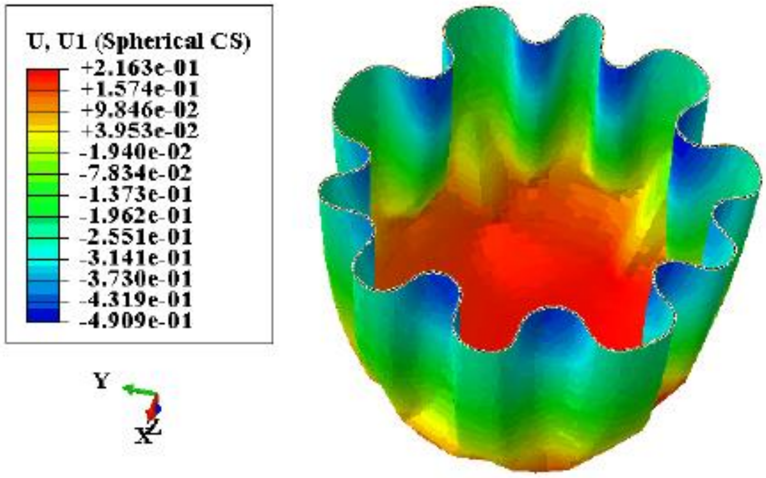
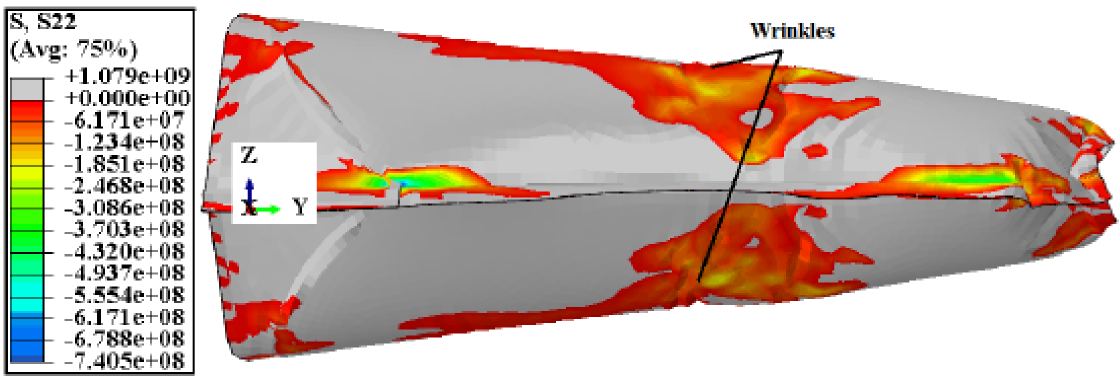
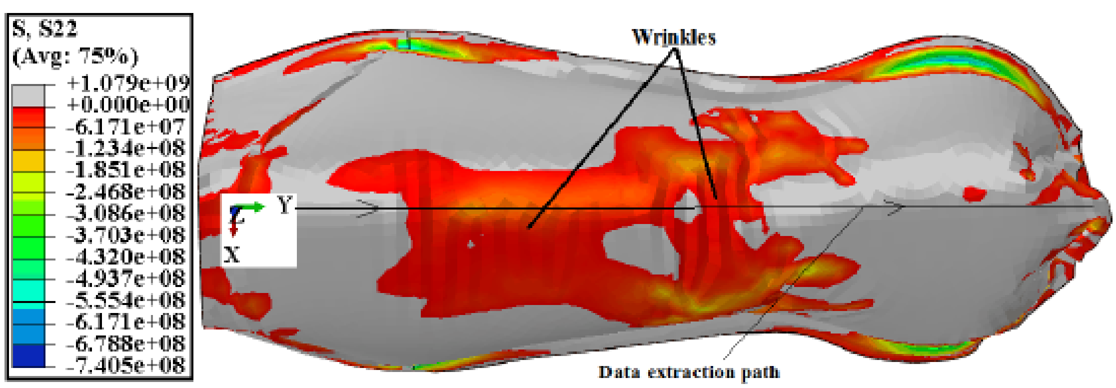


Figure #1: Wrinkling observed in spherical shells under electrostatic forces applied on the outer surface,



(a) Side view



(b) Front view

Figure #2: Principal Stress distribution in an inflated pouch under internal pressure with possible wrinkles appearing on the surface.