Research Interests

Tribology, the science and technology of interacting surfaces in relative motion; and one of the most far reaching subjects of science and engineering, having importance and effects on scales ranging from microelectronics to earthquakes. Economically, tribology studies are of immense importance as US industries alone are estimated to lose 2% of the GDP annually due to wear. While applications and areas of research abound they are generally separated into two categories: 1) the "technical" scale (e.g., rotating shafts, bearing contacts) primarily studied in the engineering fields, and 2) nanotribology, an area in which scientists study the physics of interfaces from the standpoint of atomic forces. A mesoscopic scale, ranging from microns to millimeters, lies between the two extremes, ripe for the development of new experimental techniques to explore the mechanics of interfaces. Of particular interest to me are the mechanics due to dynamic excitation and the differences in the response and observed phenomena due to the individual vector components of motion, on this mesoscopic scale.

1 Research Background

I was first exposed to the study of material properties as a Materials Science & Engineering major at the University of Nevada, Reno, where I developed a skill set in various metallurgical techniques which then took me to work briefly in the aircraft industry. Upon entering graduate school for Physics, I maintained an interest in studying material properties of solids and began to study elastic properties of materials using a newly developed technique known as Resonant Ultrasound Spectroscopy (RUS). While studying elasticity using RUS, I was introduced to the concept of nonlinear elasticity and its manifestations in a variety of materials (geomaterials, ceramics, sintered metals, and materials containing fractures). As a post-doc at Los Alamos National Laboratory (LANL) I developed experimental systems using a technique known as Time Reversal (TR) in conjunction with techniques broadly referred to as Nonlinear Elastic Wave Spectroscopy (NEWS) for the purpose of locating and imaging nonlinear elastic features in solid materials.

In my years as a researcher I have observed many interesting phenomena (e.g., hysteresis, elastic wave mixing, modulus softening, and slow dynamics) associated with what we refer to as nonlinear elasticity. The presence, or lack of, these phenomena has been utilized to characterize materials and in some cases develop nondestructive evaluation (NDE) techniques. While these phenomena have been used and observed as early as 1906, surprisingly little is known of the mechanisms responsible. Many theories and models exist, both constitutive and phenomenological, yet few experiments have proven capable of examining the behavior in such a way as to definitively support or contradict the models available. By bringing together my experience and knowledge of TR and NEWS with tribological studies, I intend to explore the mechanisms of nonlinear elastic behavior and develop new experimental tools to examine the mechanics of interfaces, linear and nonlinear.

2 Proposed Projects

Time Reversal, a technique to temporally and spatially focus wave energy, provides a unique ability to locally excite regions of interest with select displacement components, i.e., the three individual vector components of motion. It is this fact that allows for experiments to now be designed to explore mechanical motion, elasticity, nonlinear mechanisms, etc., in a manner not previously possible. In the field of nonlinear elasticity, separation of vector components may finally provide a means to determine and/or discriminate the mechanical motion responsible for the observed phenomena of dynamic stress-strain hysteresis, elastic modulus softening, slow dynamics (i.e., logarithmic modulus recovery), elastic wave mixing (harmonic generation, intermodulation distortion). In other tribological studies, the use of TR may provide the means to explore the transition from nanotribology to macro-tribology.

2.1 Principal Direction: development and application of the surface displacement probe

Initial efforts will be to develop a fully elastic surface displacement probe (SDP) using TR. This SDP will be the first simultaneous 3-component excitation system of its kind, and have the highest spatial resolution currently possible in elastic systems, resulting in the ability to focus elastic wave energy in sub-millimeter (50 - 100 μm) focal regions. This is a straight forward extension of systems which I have currently designed and constructed at LANL. Two systems will be developed: a direct contact system and a non-contact system. These systems will be the foundation for dynamically exciting the interfaces and exploring both the linear and nonlinear behavior.

Theories and models describing the nonlinear elastic behavior involve contact mechanics (e.g., Hertzian contacts, asperity distributions) and fluid/surface interactions (e.g., adsorption, lubrication). The importance of those issues dictate the necessity to quantify surface roughness characteristics (nm to mm scales) and precisely control temperature and humidity. With measures and controls of these parameters in hand, application of the surface displacement probe will yield dynamic property measurements exploring the linear and nonlinear elastic phenomena in such a manner as to separate the response due to friction versus adhesion, for example.

It is known that unbonded (and possibly weakly bonded) interfaces are sources of nonlinearity in a dynamically excited elastic system. The models for mechanisms alluded to above can account for this nonlinear response through the use of sliding interfaces (what I will refer to as in-plane motion) and interface separation (out of plane motion), with the plane of reference being that of the interface. Interfacial sliding would be dominated by frictional forces where stick-slip motion or ratcheting might be used to describe, for example, a hysteretic elastic response. In interfacial separation the hysteretic phenomenon, if observed, may be due to adhesion of the surfaces, i.e., sticky contacts. These mechanisms are quite different, though current experimental systems cannot separate or identify one from the other. By separately focusing in-plane motion or out of plane motion using the SDP, these and other issues may finally be addressed.

Another advantage to the SDP is the ability to change the excitation area without changing the central location. With this ability, theories of contacting asperity distributions (i.e., surface roughness) interacting dynamically can be interrogated. By quantifying the surface roughness and systematically exciting larger and larger ensembles of asperities (always including the previous ensembles), can some parameter be established to, say quantify surface roughness or contact area if one is known and the other is incapable of being inspected by other means?

2.2 Secondary Studies

TR is a technique that has become widely studied in a variety of fields, e.g., elasticity, acoustics, seismology, communications, etc. One of the main emphasis of TR research is location determination and imaging, an area in which I have extensive experience and contacts. I have an interest to maintain involvement in this area and community, primarily through collaborations and student projects. Interesting techniques in signal processing and wave scattering that remain unexplored in using TR with elastic waves provide a good source of student projects that will develop skills directly applicable in my lab, and have the potential to enhance the knowledge in other fields using wave propagation and/or TR.

The equipment required to pursue the primary studies introduced above, also allows for other materials characterization techniques to be conducted, specifically RUS. RUS is an extremely sensitive method of determining the elastic tensor of a material. Monitoring changes in the elastic properties with RUS is a powerful technique for studying phase changes, or other mechanical changes due to changes in the environment, or due to changes in the material itself. RUS also provides the linear elastic behavior upon which the nonlinear behavior must reside. Therefore, conducting linear elasticity experiments using RUS is a necessary component to developing an elasticity laboratory.

Nonlinear wave mixing is a phenomena that will be exploited using elastic waves as a primary research direction of my laboratory. This phenomenon is also seen in other systems, e.g., nonlinear optics and in magnetic levitation using superconductors. Utilizing this nonlinearity for a variety of purposes should be possible, just as it is in elasticity. I have ideas in which this can be done in both of those examples and would be supportive of a student (or students) who would like to pursue these directions.

3 Summary

For more than a decade ideas of combining linear and nonlinear elastic measurements in order to develop tools for nondestructive testing and materials characterization have arisen. While there has been some modest amount of success in this area, there has been a major hold up in applying nonlinear response - the lack of clearly identified (and proven) mechanisms and quantification of these mechanisms. By bringing together tribological studies with linear and nonlinear elastic phenomena, I intend to pursue this determination and quantification. With these questions answered, potential applications abound. My personal experience has brought me to use TR and NEWS to examine diffusion bonds for stockpile stewardship, measure fatique damage in human cortical bone and examine osteo-integration for implants in bone (e.g., dental and hip). Monitoring rock bolts for mine stability and fractures in solar cells are other projects which have recently shown interest in this research area. While often the presence of nonlinearity in materials is a drawback (e.g., indicating damage), others seek to increase the nonlinear response (e.g., wave mixing) in materials to exploit the phenomena for a specific purpose. A major oil company is showing such interest for oil exploration (the details of which are proprietary). In short, the application areas are vast with a diverse possible funding base and there exist ample opportunities for students to contribute at all levels.