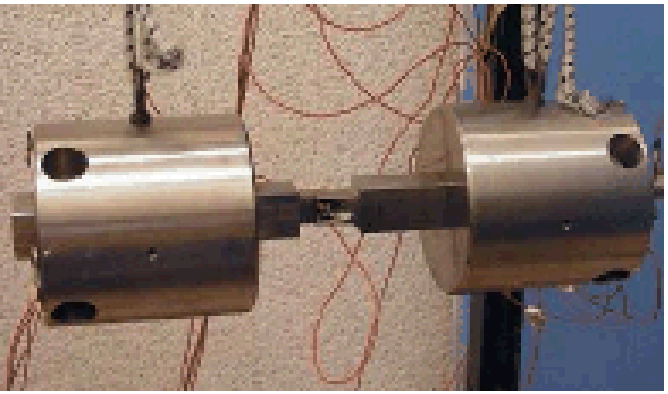
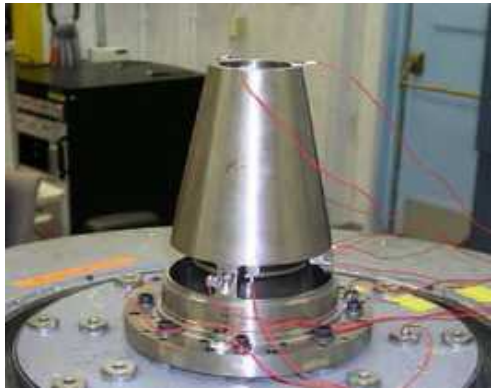
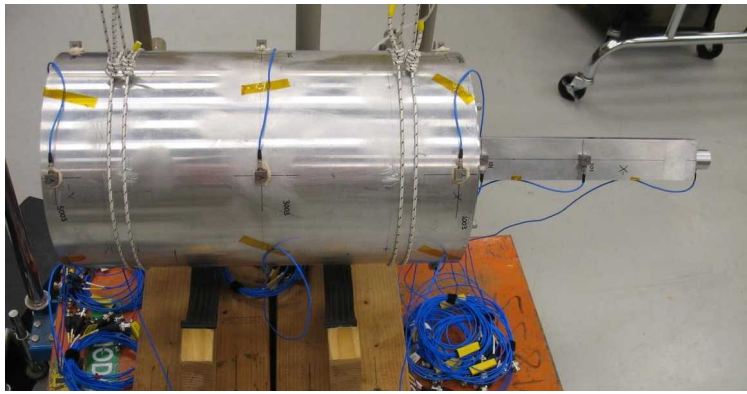
SAND2015-8652PE

Sandia National Laboratories







Applicability – Sandia National Laboratories

Randy Mayes, Matthew Brake, Todd Simmermacher, Adam Brink

Dartington Joints Workshop - October 2015

U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND NO. 2011-XXXXP

Sandia National Laboratories

Technical and Economic Aspects of Mechanical Joints for SNL Requirements - Categories

- Sandia dynamic response requirements and economics
- Social challenges of implementing technology
- Major physics challenges
- Major model implementation challenges
- Major design challenges
- Major experimental challenges

Sandia National Laboratories

SNL Dynamic Response Requirements and Economics

- Define dynamic specifications for component designs
- Design components to successfully meet functional requirements and survive dynamic specifications

Sandia National Laboratories

SNL Social Challenges to Implementing Technology

- To implement technology on a production basis, it moves serially from Research ➡ Development ➡ Application
- SNL struggles to get through the Development phase.
  - The “new” research must get socialized on the way to Application.
  - Has the research approach really addressed all the technical problems?
  - Is it “really” the way to go?
  - Does the relevant community know about the research, understand it and endorse it?
  - Does it require a change in the standard approach to “doing business” .
    - The approach may require new code, and not fit into the old code.
    - The testing community may need to learn new testing techniques and acquire new equipment.
    - The project groups have to be educated to ask for the new approach instead of the status quo approach.
  - The Development phase requires several stakeholders to implement the approach which may be painful (change/investment/boring/frustrating).

Sandia National Laboratories

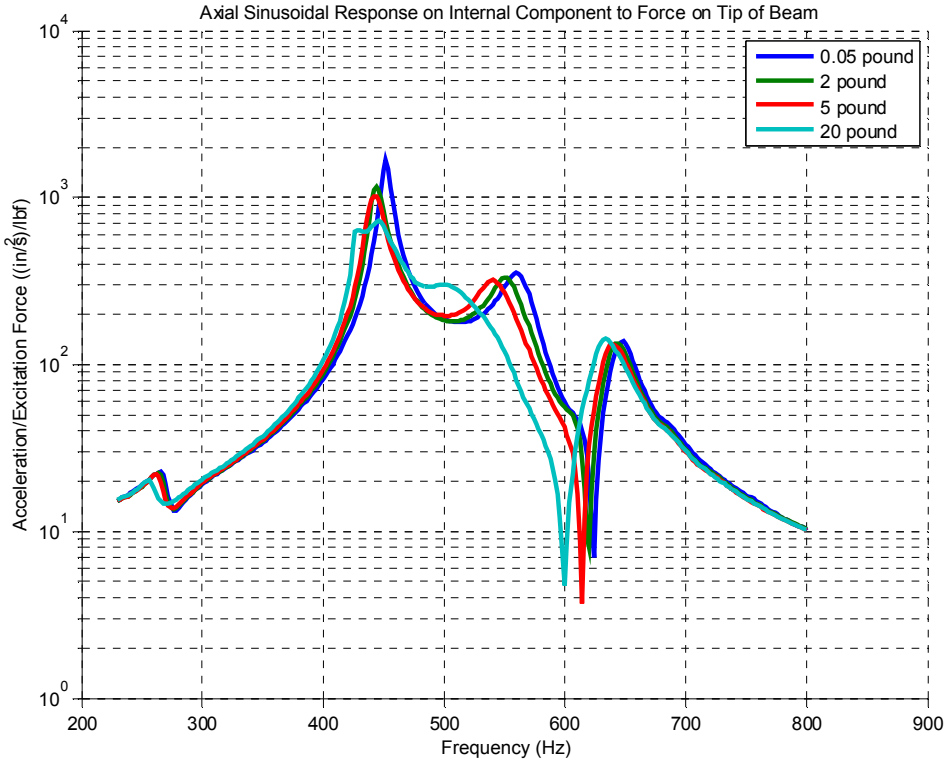
SNL Major Physics Challenges

- The Application state of the art for dynamic modeling at SNL is updating FE model stiffness parameters from modal test data and inserting modal damping derived directly from the low level modal test. Sometimes damping is calibrated from operational shock test data.
- Deriving specifications from linear models for components that actually experience macroslip in an environment typically is unacceptable. Models overpredict >> than a factor of 2.
  - Full system testing that demonstrates this problem comes too late in the program development to impact the design phase.
  - If we had a predictive approach that would get within a factor of 2 it would probably be sufficient.
  - Probably, in some cases, we don't even recognize that macroslip has occurred in full system or subsystem ground tests.
- We need simplified nonlinear models of a component analogous to a "wrist watch" to perform uncertainty quantification (UQ) analyses to see which design parameters are important to keeping the "wrist watch" functional in anticipated environments.
  - Most of these nonlinearities are associated with interfaces between parts. The need is for simplified models so that many computational runs can be performed in a short time to identify the important parameters.

Sandia National Laboratories

SNL Physics Challenges

- A lesser, but significant problem, is predicting (or even calibrating) damping (energy dissipation). Amplitudes of specific modes can be off by a factor of 2 or 3 in operational response if we utilize modal damping derived from a low level modal test.



Sandia National Laboratories

SNL Major Model Implementation Challenges

- The 4 parameter Iwan nonlinear elements we can implement sometimes do not capture the physics to our satisfaction.
  - One analysis required addition of a 5th parameter[2].
  - Iwan not typically used for hardening springs or softening springs where damping remains constant.
  - Implementing Iwan nonlinear elements at many degrees of freedom can be overwhelming.
  - Analytical model researched, but not developed [3].

[1]:

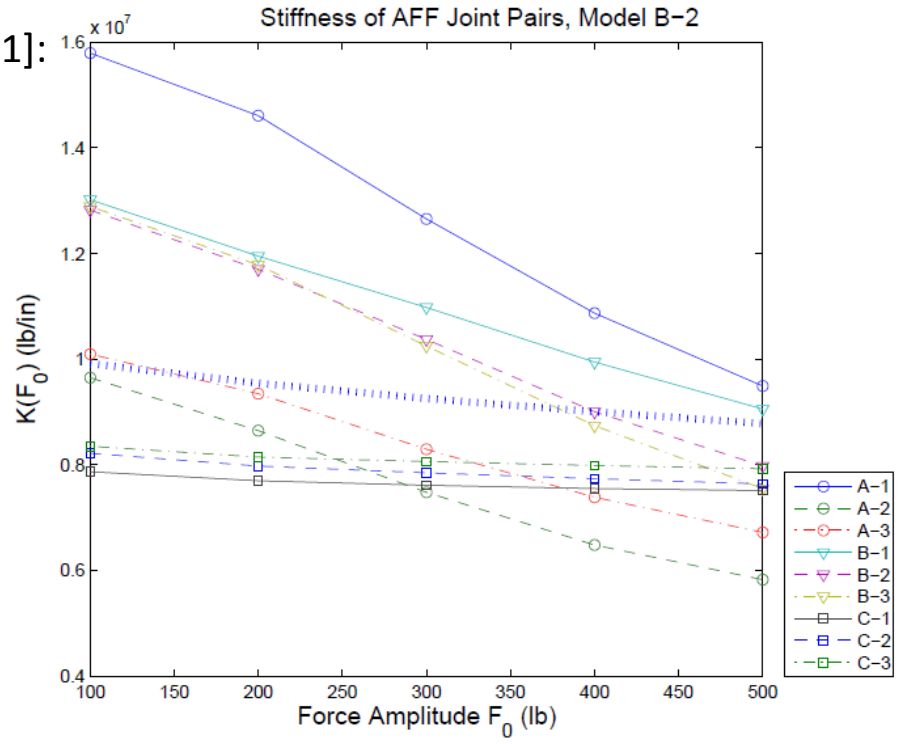


Figure 12.15. Stiffness of AOS Joint Pairs.

The thick dotted line is the stiffness of the four-parameter Iwan model, calibrated to reproduce the dissipation curve with fidelity and to match the stiffness of a load of 400 lb.

Sandia National Laboratories

SNL Major Model Implementation Challenges

- Predictive models are necessary
  - Currently no means to predict dynamic properties *a priori*
  - Onset of macroslip in complicated systems/loading scenarios
  - Prediction of damping to within a factor of two for microslip events
  - Even submodels or 90% solutions could work
- Implementing solvers that can run nonlinear problems efficiently in time domain.
  - Transient solvers necessary for studying environmental specifications
  - Orders of magnitude more computational time required than harmonic balance (HB) methods
- Implementing nonlinear frequency domain solvers.
  - Partly a cultural challenge as HB methods work well, but aren't robust for constitutive modeling
  - Issue still remains in deducing nonlinear damping parameters from HB methods
  - Alternative methods being investigated
- Simplified (but adequate) nonlinear mechanism models are desired, but not easily derived.

Sandia National Laboratories

SNL Major Design Challenges

- Notion that we should design systems to have the damping that we want, rather than to calibrate models after the fact
  - Need for repeatable or predictable standard jointed interfaces
- Repeatability and variability still large issues
  - Manufacturing tolerances unavoidable
  - Ability to specify which tolerances are more important and which are less important could lead to moderate savings in costs
- Benefits of improved design ability:
  - Reduced cost
  - Reduced weight
  - Reduced number of iterations required for design qualification (largest source of savings)

Sandia National Laboratories

SNL Major Experimental Challenges

- In regards to full system and subsystem nonlinear experiments for nonlinear parameter identification:
  - Operational levels are needed to identify nonlinear parameters
    - Standard modal testing equipment may not be sufficient for obtaining operational levels
    - Standard shaker table vibration testing introduces other sources of damping besides test article physics which can overwhelm the desired identification of nonlinear parameters
  - Systems and subsystems have many degrees of freedom which can inhibit isolation of nonlinear parameters for identification
- In regards to first principles experiments:
  - Most techniques are focused on measuring a hysteresis loop response
  - What is really needed is measurement of distributed joint interface forces and displacements to provide validation data for a proposed constitutive model

Sandia National Laboratories

References

1. D.J. Segalman, D.L. Gregory, M.J. Starr, B.R. Resor, M.D. Jew, J.P. Lauffer, and N.M. Ames, “Handbook on Dynamics of Jointed Structures,” Technical Report SAND2009-4164. Sandia National Laboratories, Albuquerque, NM. 2009.
2. X.Q. Wang and M.P. Mignolet, “Stochastic Iwan-Type Model of a Bolted Joint: Formulation and Identification,” 32nd International Modal Analysis Conference, 2014.
3. M.R.W. Brake “A Reduced Iwan Model that Includes Pinning for Bolted Joint Mechanics,” 34th International Modal Analysis Conference, 2016.