Third International Workshop on Jointed Structures – Minutes

August 16, 2012, Morning Session

Attendees (full contact information given at the end of the meeting notes):
David Ewins
Larry Bergman
Michael Starr
Dan Segalman
Laura Jacobs
Randy Mayes
Matt Brake
Dan Brown
Jenny Stroud
Hugh Goyder
David Hills
David Nowell
Christoph Schwingshackl
Evgeny Petrov
Muzio Gola
Liu Tong
Ed Berger
Dane Quinn
Marc Mignolet
Arif Masud
Alex Vakakis
Melih Eriten
Matt Allen
Brandon Deaner
Robert Flicek
Wes Harris
Lothar Gaul
Pascal Reuss
Bernhard Stingl
Weidong Zhu
Simon Medina
Pablo Tarazaga

Review of Workshop 2 Outcomes – Actions and Challenges

Recall historical development of the meetings:
Sandia, 2000
New Orleans, AFOSR 2001
West Palm Beach, Turbo Expo

From the last workshop, the following Actions and Challenges were identified:

During the last session of the Dartington, UK, Workshop, there was a discussion seeking to distill the essential issues and topics which would emerge as the main items defining the new Road Map for the subject. The resulting list divides into 2 sets – Actions and Challenges. The Actions are tasks that are essentially short-term goals deemed to be necessary in order to consolidate the foundations of the subject to provide a sound basis for further research. The Challenges are much more substantial tasks, each requiring several man-years of research effort, whose objectives are to move the whole subject on to a new level of technical competence, heading to the ultimate goals of the ability to model, and to predict the dynamics of mechanical joints and thereby to design structures with optimum dynamic properties – including those whose dynamics are actively controlled by the joints themselves. In many cases, offers of leadership of the tasks were recorded as were expressions of interest in participation. The outcomes of each of the challenges given under each element

Actions

1. Terminology & Vocabulary (***Segalman****; Bergman*)

   Modest listing of vocabulary was compiled, publish somewhere and gather comments from the members.

2. Develop Hills Chart (***Dini****; Berger*)

   It is difficult to assess spatial location of understanding/length scale relationship outside of one's field of expertise. Still some value in notional idea. Perhaps construct diagram actively within the community through website.

3. Classification of Standard Joint Types (*Hills; Vakakis;* ***Starr***)

   Short descriptions of classical contact definitions and standard joint interfaces have been compiled.

   Perhaps look to machine elements standards; draw knowledge from the design community for the role of joints in dynamics. Ask the question, 'Why are we necessary?' Distinguish ourselves from the knowledge of the design community.

   How do mechanisms couple in with the ultimate dynamics?
   Have to answer questions of people in industry. Should we restrict ourselves to a certain class of contact? We're not necessarily interested in the "glue" but rather the influence of the interface on the response of the structure. **The joint is the interface**; the properties of the materials may or may not be required to proceed with modeling.

   Active or passive joints? (or both)
   Ask for contributions from the community about classifications.

4. Classification/Cataloging of
   (a) Non Linearity ID Methods (***Vakakis***)

   Paper in Mech. Syst. Signal Processing. Make report available, add Matt Allen to action list.

   (b) Modelling approaches (***Polycarpou****; Quinn*)

   Start with the Joints Handbook. Ongoing action, make Dane Quinn the lead for this element.

   (c) Measurement methods (***Nowell****; Bergman; Akay*)

   This is bigger than just making a list of measurement methods.

5. Benchmark current computation multi-scale methods against analytic solutions (***Masud****; Laursen; Quinn*)

   Work is in progress. Quasi-continuum approaches needed. System-based approaches have not been developed.

   Consult Kai Willmer – Nurnberg

   Elevate to a Challenge.

6. Create a formal Joints Modelling Network (or Community) with more frequent and regular contacts (this was expressed emphatically); meetings at relevant conferences; workshop series;... Wiki..Joints Chat room (***Ewins****; **Segalman****; Nowell; **Bergman****; Gaul; Green; Surampudi; Dini; Quinn*)

   YES!

Challenges

1. Round Robin/Benchmark Exercise for Hysteresis Measurements (***Ewin****s; Nowell; Gola; Polycarpou; + possibly Epsion(Technion)*)

   Still an activity that must be pursued: Imperial, Torino, add Eriten, Schwingshackl.

2. Round Robin/Benchmark for Measurement/Prediction of Dissipation in Standard Joints (***Leming****; Goyder; Gaul; Ind; Vakakis*) *task moved to ***Jacobs***

   Yes, let’s keep this element. Put a timescale on this activity. Additional interested parties: Jacobs, Segalman, Allen, Eriten.

3. Repeatability (measurement-to-measurement) and Variability (unit-to- unit) Issue: need to be able to distinguish between, and to greatly improve performance in both aspects (i.e. design of better, more repeatable joints) (*Leming; **Goyder**; Gaul; Ind; Polycarpou; Farris; Mignolet*)

   Problem is funding! No collaboration at all, yet. Should we make a regular meeting location associated with a conference?

4. Framework for multi-scale modelling (*Masud; Dini; **Nowell***)

   Elevated from Action 5.

The ASME Research Committee on the Mechanics of Jointed Structures

With respect to Action 6 above, the ASME Research Committee on the Mechanics of Jointed Structures has been created. We should seek to develop means of giving standing to the group.

Replace Andreas Polycarpou with Matt Brake on the Events Subcommittee

On the Publications Subcommittee, Lothar Gaul, Matt Allen, Weidong Zhu, and Wes Harris will replace Ed Berger and Arif Masud.

It was suggested (Gaul) that we make IDETC a regular meeting place for the members of the research committee. Other suggestions are Turbo Expo (Petrov), Recent Advances in Dynamics, or organize or own conference. Attendees were polled on likely conference attendance and the following conference attendance counts were:

IDETC – 12
IMECE – 3
Turbo Expo – 5
Tribology – 5
IMAC – 12
SEM – 0
AIAA – 0

Establish a depository for works on mechanical joints (Mechanical Joints Depository)

- open source
- administered by the committee
- links to PhD theses

Dartington Workshop Report: SAND2010-5458
Sandia Joints Handbook: SAND2009-4164
Research Committee Site: http://committees.asme.org/K&C/TCOB/BRTD/MJS
www3.imperial.ac.uk/medynamics/research/future/joints2009

Starr will pursue membership in the committee for all workshop attendees.

August 16, 2012, Afternoon Session

The afternoon session of the workshop was focused on identifying strategic themes and challenges for the community.

Objectives: to identify the major research themes for the next 5-10 years
Brief introductory remarks (10-15 minutes) on your research focus area. We would like to initiate discussion related to your focus area while addressing the overarching question: How does this area fit into the larger research community? It is desired that your prepared remarks be more than simply addressing your current research, but should be strategic in content. For instance: enumeration of what we cannot now do well with respect to joints. Some basic questions that you might consider discussing are:

1. What are the important problems in your area?
2. How do you decide which problems you take on?
3. Who will be the end user of the results of your work?
4. How do you get funding?

The following topics and speakers were invited to present:

1. Institutional Structure and Vision (Alex Vakakis)
2. Fatigue and Contact Mechanics (David Hills and David Nowell)
3. Physics-based/data driven modeling (Melih Eriten)
4. View from Germany (Lothar Gaul and Bernhard Stingl)
5. Flight systems/satellites/weapons (AWE/Sandia)
6. Vibrations/Turbine engines (Muzio Gola and Christoph Schwingshackl)
7. Uncertainty Approaches to Joints and Interfaces (Marc Mignolet)

1. Institutional Structure and Vision

Educate undergrad and graduate students alike.

Promote joints research as an important topic – Make case
We need sustained funding! Or else this will not be a first priority. Any proposed institutional structure should facilitate this.

Develop a research plan that can initiate a dialog, such as the benchmarking of computational and experimental problems.

- Choose benchmarks through dialog with industry
- Define a set of "real" problems (interesting and difficult)
- Form teams to address these problems from different perspectives (competition is alright, we need to be challenged!)
- Show what we can do

Define a Grand Challenge – What is the challenge?

What is the cost to industry of not understanding joint dynamics?

- Promote (with industry) ideas to government
- Topics such as weight savings in engines and flight structures
- Can industry tell us, 'if there was a redesign of an interface, life would change dramatically.'
- Consortium:
    - Data storage INSIC
    - Fatigue and fracture
    - Industry funds short term; government long-term
    - MURI – Multi-disciplinary University Research Institution
        - Topics released every four years
        - Can we (with industry) influence the topic

2. Fatigue and Contact Mechanics

Need to measure stiffness (normal and tangential)

Measurements of stiffness including time dependence, reconciling:

- Measuring techniques
- Tribology
- Models for wear

We don't know how to measure some important things yet.

Understand non-orthogonal nature of contact

Why is damping repeatable in some interfaces and not in others?
This is a fundamental question.

3. Physics-based/data driven modelling

Need for reduced-order models

- Multiple length scales

- Multiple time scales
- Coupled DOFs
- Joint fretting apparatus
- Interface constitutive models

Non-linear system identification – this is a top-down approach
We may be able to handle more complex phenomena with such a global approach.
However, not physics-based.

4. View from Germany

Identified needs are:

Local joint models
Nonlinear finite element joint models
Parameter identification from isolated joints

Fundamental research

- Greenwood-Williamson, stochastic, fractal (surface roughness)
- Non-linear normal and tangential contact equations
- Modelling epistemic and aleotoric uncertainty

Damping in the design phase

- Motors
- Bolted joints in cylinder, gearbox, etc.
- Seal systems

Uncertainty description of assembled structures
Bolted joint damping layers

Control Problems

Brake dynamics

Funding

- FVV
- DFG (German Research Society)
- Research groups
- Industrial transfer (NSF 50/50)

Participation

Brake squeal/ nonlinearities in brake systems
Implementation in commercial software
Model order reduction
Non-linear stability analysis/limit cycle calculation

Is Coulomb friction sufficient?
Failure of joints – Derivation of design rules, monitoring
Multiscale systems – structure of interface dynamics, scales may interact

6. Vibrations/Turbine engines

Imperial
Analytical research problems
- Friction contact elements
- Bifurcation and instability
- GUI
- Application to aircraft engine: methodology, response behaviour
- Validation

Nonlinear structural damping
- Engine components
- Rotating and stationary systems

Measurement techniques
- Large amplitude excitation
- Data processing
- Novel test methods

Overall dynamic response, effect of joint on stiffness and damping

Robust prediction methods
- Macro-level
- Variability of joints
- Contact conditions unknown

Design intolerant joints
- Manufacturing tolerances
- Wear
- Damping
- Fast and reliable
- Criteria for effective joint design

Non-linear friction joint validation

Torino
Develop Models and Software
- Contact mechanics and tribology
- Turbine and gear dynamics
- Damping and wear assessment
- Damper mechanics
- Contact modelling on rotating components

Improve predictive power, reduce testing
Validation of contact models

Funding
Discussions within institutions
Government/industry partnerships

- Fiat
- GE
- Avio
- Turbogas & Steam
- ANSALDO

European projects

7. Uncertainty Approaches to Joints and Interfaces

We need to start thinking about building models while simultaneously including uncertainty. It does not make sense to subsequently add uncertainty.

August 17, 2012, Morning Session

From yesterday afternoon's activities, each focus area presenter was asked to produce a list of the three most important elements (short and long term) to make progress in your focus area. Those elements are recorded here.

2. Fatigue and Contact Mechanics

2-1. Measurement of contact stiffness
- How measured?
- Understanding techniques

2-2. Variability in joints
- Frictional shakedown
- Dependence on initial conditions

GRAND CHALLENGE

2-3. Mechanisms of friction
- **What causes energy loss?**
- **What are the relevant length scales?**

2-4. Extending modeling scope
- non-metallics, e.g. rubber, gaskets
- thermomechanical contact problem

3. Physics-based/data driven modelling

3-1. Interface mechanics modeling
- bridging multiscale, temporal and spatial

3-2. Variability and uncertainty
- stochastic modeling

3-3. Proceed in both directions of modeling
- top-down
- bottom-up

4. View from Germany

4-1. Derive constitutive equations based on physical parameters
- Hardness
- Asperity distributions
- Surface chemistry

Parameters are independently measureable

4-2. Compare models (simulations) on same hardware using different measurement techniques:

- Optoelectronic, etc.
- Transient, steady-state

Are lap joints the best specimen to perform benchmarking studies?

- ball-on-flat
- dovetail

4-3. Compare non-local with local friction descriptions, local, e.g Coulomb, non-local, e.g. bristle model

4-4. Compare the performance of passive, semi-active, and active joints.

5. Flight systems/satellites/weapons

5-1. Bottom-up approach to modelling structures

- Better ways to parameterize models
- Better ways to implement in FE models
- Better joint models (higher dimension)
- Enlarge catalog of existing models

5-2. Need to engage analysts, research tool vs. production tool

5-3. How do we model joints in the absence of experimental data?

5-4. Engage the broader community

- Industry
- Funding agencies
- Code developers (begin integration at earlier stage)
- Panel discussion at symposium comprised of code developers

6. Vibrations/Turbine engines

6-1. Toolkit for modeling

- Experimental and analytical
- Hierarchical

GRAND CHALLENGE

6-2. Develop prediction tools to design joints to perform "optimally"

7. Uncertainty Approaches to Joints and Interfaces

7-1. Get data!

Simple benchmark structure. Data are structure dependent:

- Load
- Displacement

- Time histories
- “Slip”
- Part-to-part
- Assembly/disassembly

Yield predictions of uncertainty

7-2. Reassess deterministic modelling
Put uncertainty into such models and identify where uncertainty analysis is necessary

7-3 How do you discover model form error?
- Hierarchical constitutive models, enforce thermodynamic consistency

7-4 Can we use uncertainty principles to guide modelling techniques?
- Sensitivity analysis (no data required)
- Uncertainty (requires data)

Reducing order of model through such analysis

(see Michael Hanss “Applied Fuzzy Arithmetic”)

How do we define a Grand Challenge?

1. Discuss with stakeholders
2. Define deliverable date, e.g. deliver report at next IDETC on progress/actions

Proposed Grand Challenge:

Cost benefit of reducing the weight of a joint
- Cost of joint failures
- Time to design
- Opportunity cost

Produce a statement of mission goals of the research group

Pablo has “volunteered” to work on developing/maintaining a research group website.

Challenges, Joints Workshop 2012

Out of the discussions of requirements to make progress in our focus areas, a new set of challenges has been developed. This is the principle outcome of the Joints Workshop. Each of these challenges is associated with a set of deliverables. The challenges are listed here.

1. Round Robin/Benchmark Exercise for Hysteresis Measurements (**Ewins**, Nowell, Gola, Eriten, Schwingshackl)

December 2012 – Define scope, hardware, measurement technique
April 2013 – Mid-year progress report
September 2013 – Report results

2. Round Robin/Benchmark for Measurement/Prediction of Dissipation in Standard Joints (**Jacobs,** Goyder, Gaul, Ind, Vakakis, Allen, Eriten, Harris, Segalman)

December 2012 – Define scope, hardware, measurement technique
April 2013 – Mid-year progress report
September 2013 – Report results

3. Methodology to quantify cost benefits of improved joint design (Brake, Goyder, Ewins, Reuss, Schwingshackl, Allen)

Definition of calculation criteria
How to pose the question to stakeholders
December 2012 – Draft delivery

4. GRAND CHALLENGE – Define Mechanisms of Friction (Interface Mechanics) (Nowell, Brake, Eriten)

January/February 2013 – "Green" paper

5. Modelling non-metallics (Gaul, Goyder, Petrov)

February 2013 – "Green" paper

6. Multiscale modeling framework (Eriten, Masud, Petrov)

February 2013 – "Green" paper

7. Definition of variability and uncertainity (linked to Round Robin Challenges 1 and 2, also address how to model in the absence of experimental data) (Mignolet, Starr)

January 2013 – Framework for data/criteria

8. Epistemic and Aleatoric Modeling (Segalman, Bergman, Brake, Vakakis, Willner)

January 2013 – Problem definition

9. Time varying model parameters, modeling and experiment "surface chemistry" (Dini, Medina, Eriten, Schwingshackl)

April 2013 – Problem definition, including scales, wear, meeting at ISFF7

10. The derivation of constitutive equations based on physical parameters (including measurement of spatial dependence of key physical parameters) (Gaul, Hoffmann, Starr, Mayes)

January 2013 – "Green" paper

11. Eventual implementation of prediction methods in commercial numerical codes (Brown, Goyder, Petrov, Brake)

January 2013 – "Green" paper

12. Develop Statement of Mission and Workshop Report (Ewins, Bergman, Starr)

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