Fifth
Engineering Mechanics
Symposium

18 - 19 November 2002
Rolduc, Kerkrade

Graduate School Engineering Mechanics
c/o Eindhoven University of Technology

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Preface

In 2002 the Graduate School Engineering Mechanics, a joint initiative of the Eindhoven and Delft Universities of Technology and the University of Twente, received the ECOS/KNAW-accreditation for its second period of operation, 2002-2007. This accreditation was awarded, based on the successful activities employed in its first period of operation, 1997-2002. The now upcoming Fifth Engineering Mechanics Symposium spans a bridge between both periods. On the one hand it keeps the good traditions of the former Engineering Mechanics Symposia, with a keynote lecture by a leading expert in the field, poster presentations of actual research projects by PhD-students, a meeting of the senior academic staff and the stimulating and informal ambiance of the former Rolduc Monastry. On the other hand a new start is made by introducing the format of parallel workshops to stimulate interaction and discussion on ongoing research in the field of Engineering Mechanics.

The Fifth Engineering Mechanics Symposium takes place November 18-19, 2002 at Rolduc - Kerkrade. In the opening session Prof. Norman A. Fleck from the University of Cambridge, Department of Engineering, will present a keynote lecture entitled: Microarchitectured Porous Metals. Furthermore, two workshops are organized that partly run plenary and partly run in parallel. Topics of this years' workshops are:

- **Mechanics of Materials and Structures**
  Part A: Adaptive Discretization Methods
  Part B: Material Modelling and Length Scale Problems,
  organized by Akke Suiker (TUD), Patrick Anderson (TU/e) and Dik Schipper (UT).
- **Dynamics, Control and Optimization**
  Part A: Computational Methods
  Part B: Contact Problems,
  organized by Nathan van de Wouw (TU/e), Sergio Turteltaub (TUD) and Johannes van Dijk (UT).

Firstly, plenary introductions to the Workshops are provided by the Workshop Organizers. Next, the Workshops run in parallel. Each Workshop consists of two parts, each containing 5 presentations by AIO's and Postdocs, followed by a discussion in which overall trends and conclusions are to be noticed. The duration of each of the AIO/Postdoc presentations is 20 min. Finally, there will be a plenary presentation of the trends and conclusions of the Workshops by the Workshop Organizers. For the best AIO-presentation within each workshop a prize will be awarded. Winners will be announced directly before the closing of the symposium on Tuesday, November 19th.

Additionally, there is a poster sessions in which a good 50 PhD-students participating in the Graduate School Engineering Mechanics present their current research project. In relation to these presentations a contest is organized in which an external jury selects the best three contributions. This year's members of the jury are Prof.Dr.Ir. F. van Keulen (TUD, Delft), Prof.Dr. H. Nijmeijer (TU/e, Eindhoven) and Ir. D.Ph. Schmidt (TNO-TPD). Winners will be announced directly before the closing of the symposium on Tuesday, November 19th.

On Tuesday November 19th a meeting of the senior academic staff participating in Engineering Mechanics takes place. Topics regarding plans for the second period of operation, 2002-2007, a consolidation of the position of the Graduate School Engineering Mechanics and the coordination and combination of research activities of participating groups will be discussed.

This report contains more detailed information on the Fifth Engineering Mechanics Symposium. Included are the following sections:

- **Section 1:** Detailed program of the symposium.
- **Section 2:** Abstracts of the keynote lecture and introduction to the workshops.
- **Section 3:** Abstracts of presentations in the workshops.
- **Section 4:** Survey of poster presentations.

Individual poster presentations are collected in a separate report, which will be supplied at the start of the symposium. It also can be obtained from the Secretariat of the Graduate School. Furthermore, poster presentations are available through:

http://www.em.tue.nl

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PROGRAM

This section contains the detailed program of the Fifth Engineering Mechanics Symposium. Information on the keynote lecture and introductions to the sessions are presented in section 2. Abstracts of the presentations can be found in section 3.

PROGRAM

Monday, 18 November 2002 morning		
10.30-11.00	Registration and Informal get-together	
11.00-12.10	**Opening Session**	
11.00-11.10	Opening of the Symposium: Prof.Dr.Ir. R. de Borst	
11.10-12.10	Opening lecture: Microarchitectured Porous Metals Prof. N.A. Fleck, Cambridge, UK	
12.10-13.30	Lunch	
Monday, 18 November 2002 afternoon		
13.30-17.30	**Workshops**	
13.30-14.15	**Introduction to Workshop 1: Mechanics of Materials and Structures** Akke Suiker (TUD), Patrick Anderson (TU/e) and Dik Schipper (UT).	
14.15-15.00	**Introduction to Workshop 2: Dynamics, Control and Optimization** Nathan van de Wouw (TU/e), Sergio Turteltaub (TUD) and Johannes van Dijk (UT).	
15.00-15.30	Break	
15.30-17.30	**Workshop 1, Part A: Adaptive Discretization Methods**	**Workshop 2, Part A: Computational Methods**
	Christian Michler (TUD) A Comparison of Partitioned and Monolithic Methods for Fluid-Structure Interaction	Gerard Nijsse (UT) Real Time Control of a Six-Degree-of-Freedom Vibration Isolation Setup
	René Ubachs (TU/e) Microstructure Evolution of Tin-Lead Solder	Clemens Beijers (UT) Hybrid Isolation of Structure-Borne Sound: Numerical Models
	Bert Keestra (TU/e) Phase Separation in Shear-Flow	Dragan Kostić (TU/e) Dynamic Identification for Model-Based Control
	Irinel Faraon (UT) Stribeck Curve – Towards Elasto-Plastic Modelling	Marco Oude Nijhuis (UT) Optimization Strategy for Actuator and Sensor Placement in Active Structural Acoustic Control
	Ion Barosan (TU/e) Adaptive Mesh Refinement Techniques for Spectral Elements	Devi Putra (TU/e) Limit Cycling in Observer-Based Controlled Mechanical Systems with Friction
17.30-18.00	Informal reception	
18.00-19.30	Dinner	
19.45-21.45	**Poster Discussion Session: Presentation of current research projects, carried out by PhD-students participating in Engineering Mechanics**	
21.45-01.00	Bar “De Verloren Zoon”	

PROGRAM

Tuesday 19 November 2002 morning

9.00-12.15	**Workshops**	
9.00-11.00	**Workshop 1, Part B:** **Material Modeling/Length Scale Problems**	**Workshop 2, Part B:** **Contact Problems**
	Angelo Simone (TUD) Continuous/Discontinuous Modelling of Damage and Fracture in Quasi-Bittle Materials	Prasenjit Mohanty (TUD) Extending Operational Analysis Procedures to Include Harmonic Excitations
	Edwin Munts (TUD) The Partition-of-Unity Method: A Performance Study for Fluid-Dynamic Model Problems	Pieter Nuij (TU/e) Measurement Technique to Determine Modal Parameters of Friction Induced Resonance
	Thierry Massart (TU/e) Anisotropic Damage Effects in Masonry Walls	Alexei Vostroukhov (TUD) Three-Dimensional Dynamic Models of a Railway Track for High-speed Trains
	Viktor Gonda (TUD) Non-Hertzian Spherical Indentation	Bratislav Tasic (TU/e) Numerical Methods for Solving Flow of ODE
	Marc Masen (UT) Abrasive Wear between Rough Surfaces in Deep Drawing	Stas Veritchev (TUD) Instability of a Vehicle Moving on an Elastic Structure
11.00-11.15	Break	
11.15-11.45	**Presentation of results of Workshop 1: Mechanics of Materials and Structures**: Akke Suiker (TUD), Patrick Anderson (TU/e) and Dik Schipper (UT).	
11.45-12.15	**Presentation of results of Workshop 2: Dynamics, Control and Optimization** Nathan van de Wouw (TU/e), Sergio Turteltaub (TUD) and Johannes van Dijk (UT).	
12.15-12.25	**Announcement of the winning contributions in the AIO Presentation contest and in the Poster contest**	
12.25-12.30	Closure	
12.30-13.40	Lunch	

Tuesday 19 November 2002 afternoon

13.40-14.40	**Assembly of Project Leaders EM**
15.00-17.30	**Meeting of EM Advisory Board**

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KEYNOTE LECTURE

and

INTRODUCTION TO THE WORKSHOPS

This section contains abstracts of the keynote lecture by Prof. Norman A. Fleck, Cambridge University, UK, and introductions to the workshops “Mechanics of Materials and Structures” and “ Dynamics, Control and Optimization” by the session organizers.

Keynote lecture:

Microarchitectured Porous Metals

Prof. Norman A. Fleck

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Recent advances in manufacturing methods have allowed for the fabrication of a wide range of lattice materials. These materials have a periodic micro-architecture, and resemble multi-layered versions of the space frames produced by Civil Engineers. They include the Buckminster Fuller octet-truss, the Kagome microstructure, and various triangulated prismatic materials. Construction methods include injection moulding, investment casting, rapid prototyping, laser cutting followed by CNC folding, and weaving. The mechanical properties of lattice materials are compared to other competing concepts such as metallic foams, corrugated materials and egg-box microstructures. Emphasis is placed on stiffness, strength and energy absorption, and the practical application of lattice materials in sandwich panels is explored.

The microstructures may be classified into 2 types by treating them as rigid pin-jointed trusses:

1. Macroscopic strain-producing mechanisms. The welded joint version of these structures (eg metallic foams) relies upon the bending resistance of the members and joints for their macroscopic stiffness and strength. Such materials show size effects associated with boundary layers, as a consequence of the fact that the boundary conditions can involve bar rotation as well as bar translation.
2. Statically indeterminate (redundant) structures, which have a larger number of bars per node than is required to endow macroscopic stiffness. These structures have high stiffness and strength, scaling with the relative density. Lattice materials such as the octet-truss are of this class.

The Kagome structure appears to be a hybrid – its collapse mechanisms do not produce macroscopic strain, and so the structure has a high stiffness (characteristic of redundant structures). However, any bar of the Kagome structure can be actuated to produce macroscopic strain, without an energy penalty associated with stretching of the other members. Thus, this microstructure shows promise for application as an actuating but stiff material. Planar, double layer grid and 3D versions have been developed, and their actuating characteristics explored.

Workshop 1:

Mechanics of Materials and Structures

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Analysis of the mechanical behaviour of materials and structures requires the development of accurate and robust models that represent the temporal and spatial discretisation of the corresponding initial/boundary value problem. The complexity of these models is steadily growing due to a continuous need to develop and analyse new mechanical structures that closely meet ongoing demands on structural safety, integrity, durability, weight and manufacturing costs. For the analysis of these structures it is essential that (i) the coupling between various mechanical processes, and (ii) the coupling between the various length scale effects are properly accounted for. In the workshop "Mechanics of Materials and Structures" these two categories are covered in an individual fashion and an interrelated fashion, where the presentations focus on various (adaptive) discretisation models and material models.

The so-called multi-phase problems fall within the first category. Fluid-structure interaction problems emerging in aerospace engineering or bridge design are typically multi-phase problems, where the key factor is to adequately simulate and effectively solve for the complex mechanical coupling between the unsteady fluid flow and structure motion. The presentation by Michler will address the stability, accuracy and computational effort of several numerical solution techniques that can be used for modelling fluid-structure interaction problems. Furthermore, the presentations of Ubach and Keestra focus on multi-phase problems in metals and polymers, respectively. They use the Cahn-Hilliard theory, which essentially couples hydrodynamics with thermodynamics, taking into account non-local effects. Ubachs's study concerns the microstructure evolution of tin-leader, and the research of Keestra deals with the analysis of phase separation of polymer blends. The presentation of Faraon treats a mixed lubrication model that can be used for describing the contact behaviour of lubricated components in machines. In general, multi-phase problems require large computational effort in order to solve them. In this respect, the talk of Barosan focuses on an effective numerical implementation procedure to solve partial differential equations. He uses an adaptive mesh-refinement technique in combination with an object-oriented design approach.

The second category mentioned above corresponds to processes for which the response depends on mechanical effects occurring at various scales of observation. Depending on the length scale, these are often distinguished as nano-, micro-, meso- and macro-scales. Examples of mechanical processes characterised by specific length scales are micro-cracks that evolve into localised macroscopic damage, or the emergence of thin viscous regions associated with wall bounded flows. The overall response of these processes is typically inhomogeneous and often localised. To compute an accurate and physically sound solution, one approach is to modify the standard finite element shape functions that capture the displacement field. This can be achieved by adding a displacement discontinuity to the basis of the displacement field interpolation. This method is known as the 'partition-of-unity method'. The efficiency and applicability of this approach with respect to damage mechanics and fluid mechanics problems are shown in the presentations of Simone and Munts, respectively. On the other hand, in the presentation of Massart, a homogenisation procedure is proposed to connect the mesoscopic and macroscopic collapse behaviour of masonry. It is demonstrated that the use of a mesoscale, scalar damage model can lead to a desired anisotropic evolution of the macroscopic failure characteristics. The presentation of Gonda considers the nano-indentation behaviour of a thin film on a substrate of finite thickness. The indentation characteristics of the film are computed for various substrate thicknesses and stiffnesses, using a visco-elastic model. Finally, the talk of Masen will focus on the development of an elasto-plastic contact model that can be used to simulate local, abrasive wear occurring during sheet metal forming.

Workshop 2:

Dynamics, Control and Optimization

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Many research projects currently running within the Graduate School Engineering Mechanics (EM) encompass one or more of the subjects of dynamics, control and optimization. In this presentation, the most important research topics, within these three subjects, currently under investigation will be illuminated.

The research being conducted at TUDelft on dynamics, control and optimization spans several groups in Aerospace, Mechanical and Civil Engineering. Research areas are fairly broad and a brief overview will be given in this presentation. Furthermore, topics presented in the current workshop are concerned with the development and improvement of techniques to solve direct and inverse problems of dynamics of rigid and deformable systems. In particular, one problem addressed is the accurate identification of system parameters in cases where harmonic inputs are superimposed to random excitations, which is a situation of great practical interest. Further, other topics deal with different aspects of the dynamics of high-speed vehicles interacting with elastic structures. An important example is the new generation of high-speed trains. The excitations in this setting are such that they might approach and exceed those of the relevant surface wave speeds and an accurate three-dimensional modeling and stability analysis is essential.

Research at the University of Twentes mechanical engineering department on Active Control of Noise and Vibration: adaptronics. This project concerns the reduction of structural vibrations and acoustic radiation by means of a combination of active and passive techniques. The term "adaptronics" refers to the fact that sensors and actuators are integrated in the structure. The research project combines the efforts of the CTW-Mechanical Automation group (control, sensors and actuators), the Composites group (material concepts) and the Structural Dynamics and Acoustics group. A four-year co-operative program with TNO-TPD on "hybrid isolation of structure born noise" was started. A number of PhD-projects have been defined at both the Structural Dynamics and Acoustics group and the Mechanical Automation group. These PhD-projects consider modeling of combined dynamic- and acoustic-systems, design of hybrid mounts and design and verification of control algorithms. The groups have already gained experience in an international project under the auspices of Garteur, a co-operation between the European aerospace industry, universities and technological institutes. The project dealt with the isolation of sensitive electronic equipment from external structural and acoustic loads by means of passive or active techniques. In this project the UT-groups worked closely together with NLR and Dutch Space.

At the Eindhoven University of Technology, in the group 'Dynamics and Control' [1] research projects are concentrated on the following topics:

- Nonlinear Dynamics: modeling and analysis of mechanical systems. Within this subject specific attention is given to mechanical systems with impact and friction. Examples of application areas under investigation are drill-strings, CDROM players, robotics, human body modeling, the milling process and toys.
- Nonlinear Control: with a focus on synchronization (in this perspective think of cooperating robots in a production line), underactuated systems, and controller and observer design for mechanical systems with impact and friction. Applications currently studied are robotics, mobile carts, DVD players etc.
- Structural acoustics: with a focus on the development of computational tools and the analysis of systems with uncertainties.
- Structural optimization: robust and reliability optimization, meta-modeling. An application area currently investigated is the auto-balancing of rotor-systems.
- Vehicle Dynamics: modeling, analysis and control. More specific application areas are automatic guided vehicles and tire modeling.

Reference:

[1] http://www.dct.tue.nl/ of: Eindhoven University of Technology, Department of Mechanical Engineering, Dynamics and Control Group, P.O.Box 513, 5600 MB, Eindhoven, The Netherlands.

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ABSTRACTS OF PRESENTATIONS

This section contains abstracts of presentations at the Fifth Engineering Mechanics Symposium. Abstracts are in alphabetic order on the (first) author. Abstracts of the keynote lecture and an introduction to the workshops are presented in section 2.

Adaptive Mesh Refinement Techniques for Spectral Elements

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A common bottleneck for numericists is the complexity of implementing programs. The usual procedural programming approach demands time and effort to program, develop and test new formulations. This presentation will introduce an infrastructure for the implementation of the parallel adaptive mortar elements method that uses adaptive mesh-refinement techniques for the solution of partial differential equations, using the object-oriented (OO)design approach. It will be shown how the user can implement a program using a set of OO classes and an OO environment for adaptive mesh refinement.

Adaptive hp spectral/finite element methods, in which both grid size h and local polynomial order p are dynamically altered, are very effective discretization schemes for numerical solution of a large class of partial differential equations.

Parallel versions of these methods offer potential for accurate solutions of physically realistic models of important physical systems. The influence of these parallel versions are an order of magnitude more complex that the sequential implementations. In such cases it is commonly the case that 70% of the code of a parallel adaptive code written in conventional programming system is concerned with procedurally realizing dynamic distributed data structures on top of static data structures such as Fortran arrays.

A very important observation is that this code has little connection with the physics or engineering being solved. We describe here the development of a suit of data structures and load balancing techniques that will address the following difficulties specific to parallel processing:

1. need to dynamically allocate and deallocate memory in a distributed memory environment as the computation proceeds
2. need to maintain refinement/enrichment constrains during the adaptive process
3. need to balance the computational load dynamically among the multiple processes

A few contributions of Berger and Saltzman (CHAOS++ system), Baden (Kely system) and Parashar and Browne (DAGH system) have tried to solve problem of adaptive mesh refinement with h-version finite elements. In this presentation we introduce a set of distributed dynamic data structure and load balancing scheme, that address the three needs/difficulties listed above.

Hybrid Isolation of Structure-Borne Sound: Numerical Models

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Interior noise problems become more important due to the tendency to construct lighter vehicles. An important source for interior noise in a vehicle is the engine. The structural vibrations induced by the engine will transmit through the vehicle and will finally result in interior noise, so-called structure-borne sound. A method to reduce the interior noise is to isolate the engine with respect to the vehicle. This isolation can be passive, active or a combination of both called hybrid. A research project has been started in cooperation with TNO called hybrid isolation of structure borne sound. The project is splitted in two parts: One part of the project has the goal to investigate this type of isolation by means of numerical simulations, the other part deals with the design of demonstrators and practical implementations of hybrid isolation units. This presentation focuses on the numerical modeling approach for this type of problems.

Hybrid isolation consists of two types of isolation: passive isolation and active isolation. Passive isolation techniques are suitable for isolation of high frequency vibrations, while active techniques are used for the low frequency vibrations. To investigate the active isolation, a numerical model will be presented. This model consists of a structural and a bounded acoustic part that are representative for a vehicle. The responses of both parts are determined efficiently with modal superposition. The controller design is performed with the optimal control theory that is based on minimization of a cost function. Different cost functions will be compared with each other with emphasis on the performance of the structural related cost functions (e.g. minimization of structural velocities) in comparison with the acoustical cost functions (e.g. minimization of sound pressures).

The passive isolation is in practise realised by placing the engine on rubber mounts. The relatively non-stiff mounts cause a good isolation of the engine, especially at high frequencies. However, already at low frequencies the dynamic behaviour of rubber mounts may result in relatively stiff behaviour of the mount. This phenomenon will be illustrated by determination of the dynamic transfer stiffness of a rubber mount with the finite element method. The calculation is splitted in two parts: first a nonlinear static calculation is made to determine the relatively large pre-deformation due to the weight of the engine. After that a linear harmonic analysis is performed and superimposed on the pre-deformed mount. It is hereby assumed that the vibration amplitudes of the engine are sufficiently small to consider the kinematic and material response as linear perturbations about the pre-deformed state. It will be shown that the dynamic stiffness is strongly dependent on the frequency and pre-deformation. In some frequency ranges the mount will be considerable stiffer, resulting in decreasing isolation.

References:

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Stribeck Curve
Towards Elasto-Plastic Modelling

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The contact between lubricated components in machines can operate under (elasto-) hydrodynamic lubrication (EHL), mixed lubrication (ML) or boundary lubrication (BL) conditions. Therefore, the Stribeck curve is an important tool to determine in which lubrication regime lubricated contacts operate.
A mixed lubrication model is developed by combining the Greenwood & Williamson contact model and the full film theory. In this model the load applied to the contact is divided in, the load carried by the interaction asperities and load carried by hydrodynamic action. Based on this mixed lubrication model the Stribeck curve for concentrated contacts can be predicted.

This mixed lubrication model is extended by using an analytical solution for starved lubrication and as a result Stribeck curves for starved contacts can be calculated. A comparison between line and point contacts is made and in terms of the used dimensionless parameters the results are the same.
Greenwood & Williamson’s contact model assumes that, the surface asperities are elastically deformed. The probability that, at the contact of interactions asperities the pressure exceeds the elastic limit is more realistic. This phenomenon is the mechanism for the running-in process and any other situation where the contact between two surfaces operates above the elastic limit. Due to elasto-plastic deformation the surface topography changes, therefore the Stribeck curve changes as well. Changing the surface topography during the action of the different operating conditions is one of the most important features, which influence the friction, and thus the life of the machine components.

Many attempts have been made to give an elasto-plastic model but only for specific situations like indentation or the contact between a rigid flat and different deterministic geometrical shapes. Also a lot of FEM calculations are performed in this specific area for different material combinations and shapes. No general analytical model exists to describe the transition phenomenon between the elastic and the plastic regime for two rough surfaces in contact.

To predict changes in Stribeck curve due to the aforementioned phenomenon an analytical elasto-plastic model is required. Future research will focus on developing an elasto-plastic contact model to predict the Stribeck curve.

Non-Hertzian Spherical Indentation

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Nano-indentation is a widely used testing method for determination of material properties of thin films. It is derived from a conventional hardness test, however it is extensively used for evaluation of the elastic modulus besides the hardness. In this highly precise testing, an indenter with a certain shape (flat, cone, hemi-sphere, pyramid) is pushed into the material surface, and the penetration depth as a function of the indentation force is measured during testing. The force is measured in a range of milinewtons, and the penetration depth is scaled in nanometers, as we are entering to the sub-micron sizes, therefore the method is so-called ‘nano-indentation’.

An important assumption in the analysis of the indentation that the indented medium is a semi-infinite plane or half-space, say it has an ‘infinite thickness’. In nano-indentation the analysed material is a thin film, that is deposited on a substrate. It is obvious that the assumption does not hold, and it is straightforward to analyse the effect of the finite thickness and the effect of substrate on indentation. There is an analytical solution for the problem by Chudoba and Schwarzer for the elastic case. Modelling beyond linear elastic materials requires numerical tools, e.g. FEA, which is extensively used for the elastic case too.

Our measurements (indentation-creep test) are carried out on a polymer film deposited on a substrate. Polymeric materials show time-dependent material behaviour. The objective of the investigation is to characterise the thin polymer film with an estimated linear visco-elastic material model, considering the substrate influence.

A quasi-elastic approach is used to involve substrate influence and time dependency acting at the same time. Elastic indentation curves were simulated with varying the modulus of the film in an expected interval. The modulus in a function of penetration depth is determined for the creep load levels providing an easy measurement data processing.

A benefit of the low modulus ratio (film to substrate) can be used to simplify calculations by neglecting the substrate. We refer to it as a ‘finite thickness’ case.

The coefficients for Maxwell relaxation model are calculated, and verified through FEM simulations. As a conclusion we can say that the linear visco-elastic characterisation of and elimination of the substrate influence of a nano-indentation creep test is successful with the quasi-elastic method.

Further research will be carried on extending the model with temperature dependency and influence of the degree of cure and non-linear material behaviour.

Phase Separation in Shear-Flow

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To study the structure development and kinetics of phase separation in shear-flow a diffuse interface model is used in combination with light scattering experiments (SALS). The diffuse interface model gives results of the change of morphology on a microscopic level. To quantify these changes various analysis methods, such as Fourier transforms and correlation functions will be discussed.

Furthermore, a well-known problem in diffuse interface models is the fact that the length scale of the interface, represented by the Cahn number, is much smaller than the global length scale. It is difficult for computational methods to resolve both length scales at the same time. Proper scaling of the Cahn number and the Peclet number that characterizes the composition equation can solve this problem.

As a model system for the SALS experiments, poly(methyl methacrylate) (PMMA) and the poly(styrene-co-acrylonitrile) (SAN) are used.

Dynamic Identification for Model-Based Control

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Introduction

There is always a tendency to increase the speed of systems while preserving a prescribed set-point accuracy or accuracy of trajectory tracking, as well as a level of robustness against uncertainties. To achieve faster and more accurate tracking in robotics, we need relevant models of both kinematic and dynamic aspects. The models enable analysis and simulation. They are used in motion planning and for control design. This presentation shows a procedure that comes up with a dynamic model applicable in model-based robot control. This model contributes to both performance and robustness in robotic operation.

Methodology

The procedure consists of the following steps: (i) derivation of the rigid-body dynamics, preferably in closed-form [1-3]; (ii) validation of the model in simulation [3,4]; (iii) design of excitation trajectories needed for experimental estimation of model parameters, enabling a reliably representation of the robot within a bandwidth of interest [5]; (iv) efficient experimental estimation of the model parameters using an adaptive technique [5,6]; (v) validation of the resulting model in experiments.

Results

As a case-study, a spatial robotic arm with tree revolute joints and direct-drive actuation is considered (RRR robot [3,7]). When a dynamic model for the given kinematic structure is available, a time-efficient estimation of the model parameters using the adaptive technique is performed online. For the robotic arm this means estimation of the parameters for any robot load within one minute. The estimated parameters reliably match the model with the real robot dynamics along any robot motions within the bandwidth of the excitation trajectories (up to 10 Hz). This is experimentally verified in the demanding writing task [3,8].

References:

[1] M.Vukobratović,V.Potkonjak,*Dynamics of Manipulation Robots: Theory and Application*, Springer-Verlag, Berlin, 1982.
[2] K.S. Fu, R.C. Gonzales, C.S.G. Lee, *Robotics: Control, Sensing, Vision, and Intelligence*, McGraw-Hill, London, 1987.
[3] D. Kostić, R.H.A.Hensen,A.G.de Jager,M.Steinbuch,"Closed -from Kinematic and Dynamic Models of an Industrial-like RRR Robot," *IEEE Int. Conf. Rob. Autom.*, pp. 1309-1314, Washington D.C., USA, 2002.
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Abrasive Wear between Rough Surfaces in Deep Drawing

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A recent development in sheet metal forming industry is the application of tailored blanks: blanks prepared from separate pieces of sheet material, welded together prior to the forming process. The pieces of sheet material can have different properties, enabling weight reduction of components, corrosion resistance using cathodic protection or the possibility to create local weak spots, resulting in well defined deformation zones in the event of an accident (e.g. crash zones in automotive applications). However, a major draw back in the utilisation of these pre-welded or tailored blanks is that the weld between the pieces of sheet exhibits increased hardness and roughness, leading to possible abrasive wear of the sheet metal forming tool [1]. In this work a model is developed describing the abrasive wear of deep drawing dies caused by the application of tailored blanks.

Many surface contact models are based on the assumption that surfaces are composed of a collection of small asperities of which the tips are equally sized and spherically shaped and have some kind of statistical height distribution. This approach was used in 1966 by Greenwood and Williamson [2] and was successfully followed by many researchers during the following decades. The statistical representation of surface topography enables calculation of contact forces and asperity deformations with reasonable accuracy using well-established equations. Although this approach has proven to be suitable for static contact situations, alternative representations of the surface topography are required when modelling abrasive wear. In the current work an elastoplastic contact model is developed in which a representation of the surface topography is obtained by best-fit approximations of the microcontacts, obtained from real, measured surface height data. In this deterministic surface representation the tips of the contacting asperities are assumed to have an ellipsoidal shape. Given the material parameters and contact conditions, the load and deformation of a single asperity can be computed. Subsequently, the wear induced by each individual asperity is obtained by inserting its size and shape and the conditions into a ''single asperity micro-abrasion model''. By summing the contributions of all individual asperities, the total abrasive wear volume is obtained. The results of the developed abrasive wear model are compared with results obtained using a statistical approach.

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Anisotropic Damage Effects in Masonry Walls

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This contribution refers to the characterization of plane masonry behaviour under the assumption of plane stress. Masonry may be seen as a two-phase (bricks and mortar) periodic anisotropic material with complex macroscopic behaviour due to the possible occurrence of cracking in each of the phases. Non-linear constitutive equations have thus to be used in order to realistically represent masonry structures. Most existing macroscopic models defined for such materials are by essence phenomenological. This leads to weakly motivated frameworks and rather complex models, especially if one wants to account for material symmetry evolution due to in plane cracking. The aim of this contribution is to identify a simple set of damage mechanics variables for the constituents that could be used in homogenization procedures to infer the overall behaviour of the material from its mesostructural features (geometrical arrangement and mechanical properties of the constituents). Based on unit cell computations, it is shown that scalar damage meso-models allow to obtain realistic in plane damage patterns encountered in experiments. Results suggest that at the meso-scale, it is possible to use a scalar damage model for the individual phases, which naturally leads to the desired anisotropy evolution into the macroscopic descriptions. This macroscopic anisotropy evolution is illustrated using a numerical homogenization procedure to identify the degraded stiffness associated to damage patterns. The influence of variations in the constituent characteristics is also correctly captured as illustrated for some of the loading schemes.

A Comparison of Partitioned and Monolithic Methods for Fluid-Structure Interaction

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Many engineering problems require the solution of a fluid interacting with a structure, e.g., aero-elastic instabilities of aircraft and brigdes, flow-induced pipe vibrations and the interaction between blood flow and heart valves. There is an increasing demand for the accurate numerical simulation of these phenomena. The numerical simulation of fluid-structure interaction is in general computationally expensive. Therefore one is interested in efficient numerical solution techniques to obtain the desired accuracy with the least amount of work.
Typically, partitioned numerical methods are employed, in which the fluid and structure equations are alternatingly integrated in time and the interface conditions are enforced asynchronously [1]. This allows for software modularity. However, partitioned methods are commonly energy increasing and, hence, numerically unstable [2].

The deficiencies of partitioned methods have motivated the investigation of monolithic numerical methods, which treat the interaction of the fluid and the structure at the interface synchronously. The discretized equations are then usually solved by subiteration [3]. Monolithic schemes can be made to maintain the conservation properties at the interface [4], in which case they are unconditionally stable. Consequently, they allow for larger time steps than partitioned schemes, but the computational work associated with each time step is larger than for partitioned methods.

We investigate the stability, accuracy and computational effort of monolithic and partitioned methods, and compare their efficiency. We demonstrate that the admissible time-step size of partitioned methods is restricted by stability considerations. Moreover, we illustrate the superior accuracy of monolithic methods. Finally, we consider different possibilities to improve the efficiency of monolithic solution methods. Numerical results are presented for a prototypical fluid-structure interaction problem, viz., the piston problem from [2].

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Extending Operational Analysis Procedures to Include Harmonic Excitations

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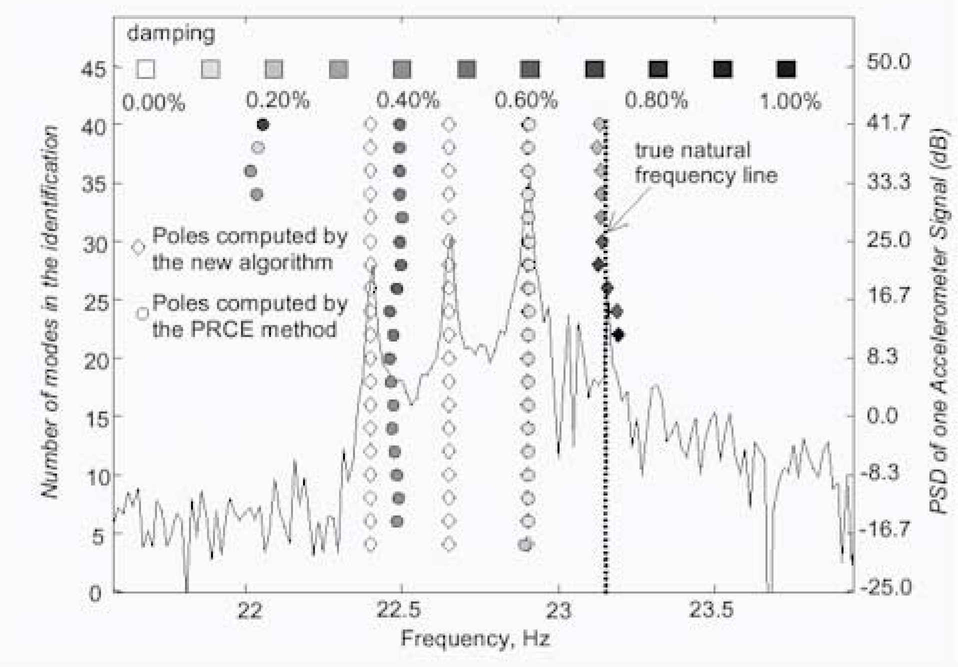
Operational Modal Analysis (OMA) techniques allow extracting modal properties of a structure when the excitation is not known. Natural Excitation Technique (NExT) assumes that the unknown input excitations are random. Response correlations are processed by time-domain techniques (e.g. Polyreference Complex Exponential techniques). In practice however, many structures are vibrating due to harmonic excitation in addition to stationary white noise. Harmonic excitation can occur due to components like unbalanced rotors or fluctuating forces in electric actuators. If the frequency of the harmonic component of the input is close to an eigenfrequency of the system, operational modal analysis procedures fail to identify the modal parameters and lead to inaccurate identified modal parameters.

Therefore we propose a modification of the Least Square Complex Exponential identification procedure to include the effect of purely harmonic vibrations in the time-domain algorithm, assuming the harmonic frequencies are known. In that way, the modal parameters can be identified properly. We illustrate the efficiency of the proposed approach on the experimental example of a beam structure excited by multi-harmonic loads superposed on random excitation.

In the graph below results obtained on a beam are shown. It depicts the stability diagram for the identification of modal parameters by OMA in the presence of harmonic excitations at 22.4Hz, 22.65Hz and 22.9Hz. The natural mode of the structure is 23.15Hz. Whereas the standard complex exponential procedures fail to identify properly the modal parameters, the new method finds the parameters accurately.



The Partition-of-Unity Method:
A Performance Study for Fluid-Dynamic Model Problems

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The partition-of-unity method [1] has emerged as a powerful technique for incorporating special functions into the finite-element method. These special functions, also called ‘enrichment functions’, can be chosen based on approximate analytic solutions in order to provide a better approximation than can be obtained from standard polynomial shape functions. This feature was clearly demonstrated by Strouboulis et al [2], who considered the Laplacian in domains with several elliptical voids. In this case, superior accuracy was obtained by incorporating harmonic basis functions corresponding to the problem of the elliptical void in an infinite medium. The partition-of-unity method has become particularly popular in the computational modeling of propagating discontinuities such as cracks in solid materials [3]. Here, the incorporation of discontinuous enrichment functions has the advantage of eliminating the need for pre-defined crack paths and re-meshing. It was shown by Taylor et al [4], that a form of p-adaptivity can also be realized by incorporating higher-order polynomials into the finite-element approximation. This concept was successfully applied by Wells [5] to overcome volumetric locking during plastic flow.

In contrast to crack-propagation problems, in many fluid-dynamic applications we would like to represent strong continuous variations in the solution using relatively coarse meshes; for example, in the viscous regions associated with wall bounded flows. We investigate the performance of the partition-of-unity method on a model problem for such phenomena, the solution of the linear diffusion equation for Stokes’ 2nd problem. We consider two types of enrichment functions, one containing characteristics of the analytic solution, and one corresponding to the higher-order approximation as described by Taylor [4].

We show that the choice of an enrichment function appropriate for diffusion dominated regions can have implications for the computation of convective phenomena. In general, Galerkin finite-element discretizations require additional stabilization operators in order to compute convection-dominated problems. Recently, such stabilization operators have been re-interpreted in a multiscale framework [6]. We show that the partition-of-unity method can also be interpreted as a multiscale method, and that the choice of enrichment effects the convective stabilization properties of the method. We illustrate this effect using results from a dispersion analysis for the linear convection equation.

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Real Time Control of a Six-Degree-of-Freedom Vibration Isolation Setup

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Vibration isolation aims at reducing the transmission of vibration from one body or structure to another, to prevent undesirable phenomena such as sound radiation [2].A well-known method for vibration isolation is passive isolation, such as the use of supports which consist of springs and dampers. By designing the stiffness properties of the material, it is possible to provide a certain level of vibration isolation. However, vibrations in the lower frequencies are difficult to isolate [2].A more promising method for vibration isolation is hybrid isolation. In addition to passive isolation, an active vibration isolation control system is used with sensors and actuators, which compensates for vibrations in the lower frequencies.

For research and development, a six-degree-of-freedom vibration isolation prototype has been built at our laboratory (see Figure 1 on the left for a photo of the prototype). The setup consists of three mounts carrying a plate, which is being vibrated by a shaker, attached to it. The plate is connected to the mounts by six piezo-electric actuators (two actuators per mount). The three mounts itself are attached to a ground plate and every mount has two acceleration sensors on top of it. The goal of the setup is to suppress tonal disturbances at the ground plate, by minimizing the signals from the six acceleration sensors and by steering the six piezo-electric actuators, accordingly. The adaptive controller W we adopt is a finite impulse response model, which is updated on the basis of the least mean squares algorithm [1]. It is demonstrated that by using an accurate linear model of the secondary path S nearly perfect isolation control is achieved.

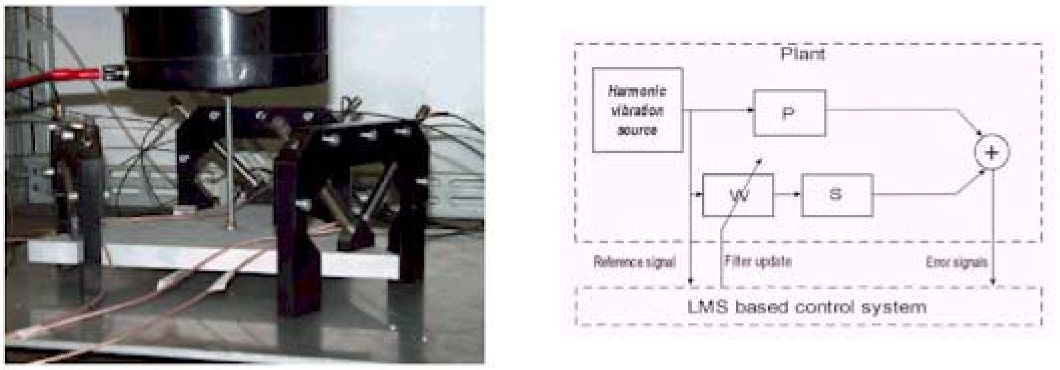

Figure 1:
Left: A photo of the six-degree-of-freedom vibration isolation setup.
Right: A block scheme of the experimental setup as depicted on the left. P represents the one input / six output primary path from the disturbance to the error sensors, S represents the six input/six output secondary path from the actuators to the error sensors and W represents the one input/six output adaptive controller.

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Measurement Technique to Determine Modal Parameters of Friction Induced Resonance

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A frequency domain based measurement method is presented to determine modal parameters of friction-induced resonance in a mechanical system. This resonance occurs in the stick-phase and is due to the tangential stiffness in the friction contact in combination with the inertia of the system. The resonance frequency and damping are functions of the RMS level of the motion of the system and of the type of the applied excitation signal. Several experiments are carried out using random excitation and sine on random signals.

Optimization Strategy for Actuator and Sensor Placement in Active Structural Acoustic Control

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There are several methods available for the attenuation of noise produced by machines, domestic appliances, etc. Passive sound absorption or reflection, e.g. by means of absorbing materials (glasswool) or noise shields, are usually effective at high frequencies. Active control methods seem to be an interesting solution for low frequency noise problems.

In many cases, the noise is produced by large shell like parts of a structure, which are excited by a certain disturbance (e.g. incident sound field). The out-of-plane vibration of such structures couples to the acoustic medium, resulting in sound radiation. The goal of a control system is to cancel the response generated by the disturbance by introducing one or several secondary controlled source(s). In *active structural acoustic control* (Asac), actuators are directly attached to the structure, and a reduction of the radiated sound is obtained by changing the vibration of the structure. Furthermore, control systems are used with sensors that measure vibrations instead of acoustic pressure. Piezoelectric materials are often used in Asac as actuator or sensor, mainly because they can be bonded directly to the structure.

For linear systems the sound radiated by structure is superposition of the sound field due to the disturbance (primary field) and the sound field due to the control input(s) applied to the actuators (secondary field). So in principle structure does not radiate sound if the secondary sound field matches the primary field in time and space. The control algorithm and hardware determine the quality of the temporal match, whereas the spatial match is strongly determined by the location and characteristics of the actuators and sensors.

In this work, an approach for optimization of actuator and sensor locations in Asac is presented. The objective is to find the actuator and sensor locations corresponding with minimal closed loop sound radiation, i.e. with the control system turned on. Such an objective is evaluated using a finite element model, which includes piezoelectric patches, combined with a model to predict the radiated sound. A genetic algorithm is applied as the optimization tool. An important advantage of this algorithm is that it is effective in finding the global minimum of an objective function with several local minima.

The optimization approach is tested for a setup consisting of a clamped rectangular plate with one or more piezoelectric patch actuators, and, one or more structural or acoustical sensors (accelerometers or microphones). The results show that control system with optimal actuator and sensor configuration outperforms an arbitrary chosen configuration in terms of reduction in radiated sound power.

Limit Cycling in Observer-Based Controlled Mechanical Systems with Friction

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A negative manifest of friction in positioning controlled mechanical systems is limit cycling. Limit cycling is undesired phenomenon due to its oscillatory and persistent behaviours. Friction induced limit cycling has gained increasing interest in the last decade. However, limit cycling that is induced by the interaction between friction and the dynamics of observer in observer-based controlled systems with friction is not understood yet. Experimental results on a rotating arm setup show that observer-based controlled systems with friction can exhibit limit cycling. In this presentation, the experimentally observed limit cycling phenomenon is analysed by using the shooting method. The numerical results match well with the experimental results. These results indicate that for bounded error of initial estimated state the limit cycling can be suppressed and apparently can be eliminated by enlarging the controller gain and the observer gain. The goal of this study is to find design procedure for choosing the controller gain and the observer gain that eliminate the limit cycling.

Continuous/Discontinuous Modelling of Damage and Fracture in Quasi-Bittle Materials

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The failure process of many engineering materials is characterised, in the early stage of loading, by diffuse micro-cracking and, at a later stage, by macro-cracking. A proper numerical characterisation of this failure process must deal with the description of the continuum as well of the discrete failure phenomena in a unified and coherent fashion.

Traditional phenomenological approaches are mostly based on the simplistic assumption that the failure phenomena can be described either in a continuum or in a discrete way. In both approaches, the limitation of the underling numerical model prevents to accomplish a realistic simulation. Continuum based approaches fail in the final stage of failure due to the kinematical inability of developing a real discontinuity; discrete based approached are usually restricted in their applications by the prescribed path which a discontinuity must follow unless costly remeshing techniques are used. Moreover, the discrete approach performs unrealistically in situations with diffuse micro-cracking.

In this lecture, a numerical model is presented in which diffuse micro-cracking in a regularised continuum develops in a discrete crack. The continuum is regularised by the introduction of non-local interactions in the continuum damage constitutive relationship. Discontinuities in the problem fields are introduced using the partition of unity concept, which allows discontinuities in the problem fields to cross arbitrarily through solid elements. It is shown that this model is able to trace the entire failure process, from the initial diffuse micro-cracking to the final discrete macro-crack. Further, some issues related to the choice of an appropriate regularised model will be discussed.

Keywords:
gradient damage; discontinuities; partition of unity; enriched finite elements; fracture; damage

Numerical Methods for Solving Flow of ODE

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For an autonomous problem:

$$\dot{\boldsymbol{x}} = \boldsymbol{f(x)}$$

where $\boldsymbol{x}(0)$ is any point in an interval **I**(0) say, the solution **x** is called *a flow*.

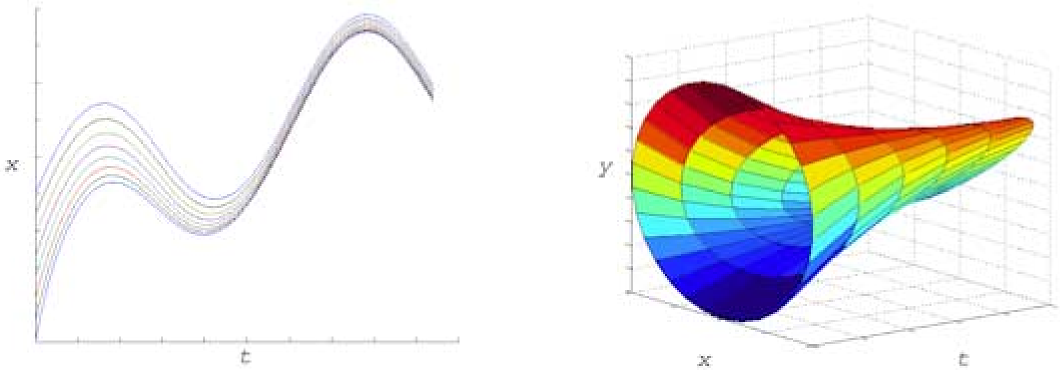

Figure 1: Flow examples in 1D and 2D

Using any numerical method for solving ODEs (Ordinary Differential Equations) can solve flow problems. The method of choice can be either explicit or implicit. Explicit methods are easier to apply due to their straightforward algorithms. However, they all have similar problems concerning numerical stability, e.g. in stiff problems. On the other hand, implicit methods have much better stability properties, but they have more involved algorithms in sense that there is a nonlinear equation (or system in general) to be solved in every time step for every point in the flow. This is usually done by applying some iterative method, which can significantly increase computational costs. One way to avoid using any iterative method is the interpolation technique. The, so-called, flow methods are obtained by modifying existing implicit methods and applying this interpolation technique.

This presentation will show the outline of the flow methods principle, methods accuracy and numerical stability and several numerical examples.

Microstructure Evolution of Tin-Lead Solder

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During its lifetime a solder joint is subjected to cyclic temperature loads caused by the on and off switching of the electronic device. Because of the difference between the coefficients of thermal expansion of the electronic component and the board onto which it is connected internal stresses arise within the joint which can cause damage eventually leading to failure of the joint. Under the influence of temperature and shear stresses a coarsening process takes place which continually changes the microstructure. The damage initiation and propagation is strongly influenced by the microstructure of the solder, necessitating modelling the microstructure evolution of a solder joint in order to make accurate life-time predictions.

To describe the coarsening process a diffuse interface theory is used. The theory is based on the concept that the free energy density depends not only on a local order parameter but also on a nonlocal order parameter. The free energy density is taken to be a function of the local and a strongly nonlocal mass fraction, which can be calculated by solving a Helmholtz equation. The difference between the nonlocal and the local mass fraction is associated with the surface energy, which acts as a driving force for the coarsening process. Incorporation of additional driving forces into the free energy is straightforward. In this way the effect of stresses on diffusion can also be accounted for through the elastically stored energy.

The current model can be seen as an extension of the Cahn-Hilliard model [1] which is a weakly nonlocal model, since it depends on higher order gradients which are by definition confined to the infinitesimal neighbourhood of the considered material point. Next to introducing a truly nonlocal measure in the free energy, this nonlocal formulation has the advantage that higher level derivatives are absent in the formulation, facilitating a finite element procedure.

This model results in a computational efficient algorithm, which is capable of simulating the phase separation and coarsening of a solder material caused by combined thermal and mechanical loading. Two-dimensional calculations show a qualitatively good agreement with experimental results.

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Instability of a Vehicle Moving on an Elastic Structure

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Introduction:
Vibrations of a vehicle that moves on an elastic structure can become unstable if the vehicle moves with a high speed. A typical example of such a vehicle is a high-speed train, whose vibrations can grow unstable because of its interaction with the railway track. The instability shows itself in the exponential increase of the amplitude of the vehicle vibrations in time. The necessary condition of instability is that the vehicle speed exceeds the minimum phase velocity of waves in the elastic structure.

Model:
The model under consideration is shown in Figure 1. It consists of a moving bogie and an elastically supported beam. Various types of the beam support are investigated: one-dimensional homogeneous foundation, one-dimensional periodically-inhomogeneous foundation and a visco-elastic half-space.

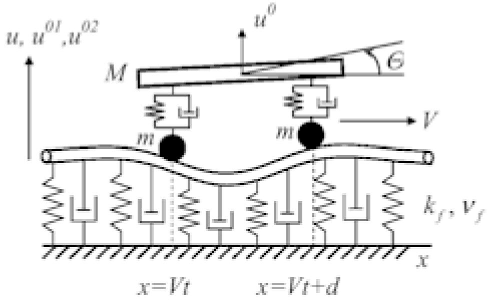

Figure 1. A bogie moving on a supported beam

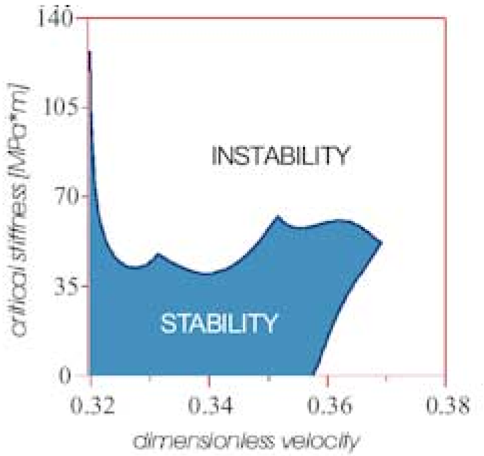

Figure 2. Instability domain

Objectives:
The project is aimed at:

a) finding conditions under which the instability may arise;
b) studying possibilities of passive avoiding of the instability by a proper choice of the vehicle parameters.

Methods and Results:
Stability of the vehicle is studied by subsequent application of the integral Fourier and Laplace transforms, D-decomposition method and the principle of the argument. These methods allow for obtaining the instability zones, one of which is shown in Figure 2.

Three-Dimensional Dynamic Models of a Railway Track for High-speed Trains

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Introduction:
Modelling the dynamic response of a high-speed railway track one has to account for elastic waves that can be generated in the track subsoil. This is necessary, since a modern high-speed train can travel with a velocity that is comparable to the velocity of surface waves in the ground. By moving with such a velocity the train causes a pronounced amplification of the track response and generates powerful ground vibrations that can be perceptible at large distances from the track. Besides this, generation of ground vibrations may lead to a noticeable increase of the train energy consumption. In this project, the aforementioned phenomena are studied analytically by employing three-dimensional linear models for a railway track.

Model:
As shown in Figure 1, the model under consideration consists of two Euler-Bernoulli beams that are mounted to a visco-elastic layer (or layered half-space) by periodically spaced sleepers.

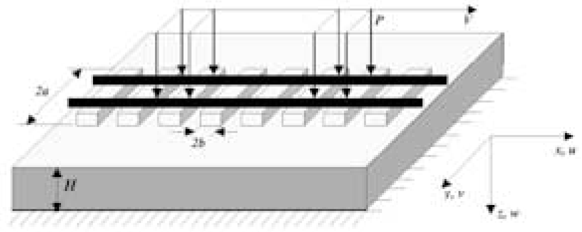

Figure 1. 3D model for the conventional railway track.

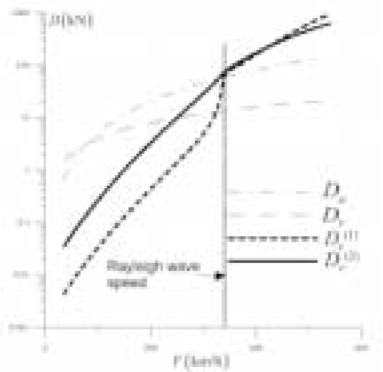

Figure 2. Elastic drag (D_e), rolling drag (D_r) and aerodynamic drag (D_a) versus train velocity.

Objectives:
The main objectives of the project are to study:
a) dynamic response of the railway track;
b) waves in the ground, perturbed by the train;
c) energy loss of the train engine due to excitation of the ground vibrations.

Results:
A method has been developed that allows for an exact reduction of original three-dimensional model to an equivalent one-dimensional model. This method is based on introduction of the equivalent dynamic stiffness of the subsoil. Employing the developed method, critical velocities of the train motion have been determined and the effect of damping in the pads has been examined. It has been shown that there exists one critical velocity, which is related to the Rayleigh wave speed in the ground. The response has turned out to be quite sensitive to variation of damping. “Elastic drag”, as a measure of energy loss due to excitation of waves in the ground has been introduced and studied. It has been shown that this drag, being compared to the aerodynamic and rolling drag measured for a French TGV, can be dominant, starting from the velocities close to the shear wave velocity in the layer, see Fig. 2.

4

SURVEY

of

POSTER PRESENTATIONS

This section contains a survey of poster presentations of actual PhD-projects within the Graduate School Engineering Mechanics. Individual poster presentations are collected in a separate report, which will be supplied at the start of the symposium and can be obtained from the Secretariat of the Graduate School. Furthermore, poster presentations are available through:

http://www.em.tue.nl

Survey of Poster Presentations:

Name	University	Poster title
Ir. A. Andreykiv	TUD	Modeling of bone ingrowth into the porous backing of a glenoid prosthesis
Ir. M. Avetisyan	UT	Springback: Improvement of its predictability to meet industrial requirements
Mr. C.A.J. Beijers	UT	Dynamic behaviour of rubber engine mounts
Ir. D.B. Chung	TUD	Stochastic finite elements: application to layered materials
M.Sc. F.X. Debiesme	TU/e	Fast optimization in structural acoustics
Mrs. E.L. Deladi	UT	Static friction in metal forming processes
Ir. W.J. Dijkhof	TU/e	Robust optimization in structural acoustics
M. van Drogen	UT	Tribological properties of the pushbelt Continuously Variable Transmission
Ir. R.A.B. Engelen	TU/e	Incorporation of failure modes into pasticity
Ir. L.P. Evers	TU/e	Dislocation density based crystal plasticity model
Mr. I. Faraon	UT	Starved line contacts
Dr.Ir. J. Fatemi	TUD	On Cosserat modeling of cancellous bone
M.Sc. I.M. Gitman	TUD	Representatieve volumes for quasi-brittle heterogeneous materials
M.Sc. V. Gonda	TUD	Non-Hertzian spherical indentation
M.Sc. I. Gueorguiev	TUD	Crack growth analysis using PUM method
Mr. S.P. Gurav	TUD	Bounded-but-unknown uncertainties in design optimization by combining multipoint approximations and design sensitivities
Ir. M. Hagenbeek	TUD	Thermomechanical modelling of glare
Ir. R.J. Hesseling	TU/e	Control design for smart restraint systems
Ir. R.A. Huls	UT	Vibrations in industrial gas turbines
Ir. C. Iacono	TUD	Development of an inverse procedure for parameters estimate of numerical models
M.Sc. Y. Kasyanyuk	TU/e	Mesoscopic modelling of fatigue damage and crack initiation in aluminium alloys
Ir. G. Kloosterman	UT	Contact algorithms in forming
Dr. A.V. Kononov	TUD	Application of radiation emitted by moving photothermal sources to non-destructive inspection
Ir. M.P. Kruijer	UT	Modelling of a reinforced thermoplastic pipe
Ir. E.A.D. Lamers	UT	Multi layer drape modelling
Ir. M. Langelaar	TUD	Optimization-based design of shape memory alloy micro-actuators for active catheters
Ir. R. Loendersloot	UT	Through-thickness permeability measurements of fibre reinforcements
Dr.Ir. I. Lopez	TU/e	Friction damper for squeal noise reduction of railway wheels
Ir. M.A. Masen	UT	Modelling abrasive wear in sheet metal forming
Ir. T.J. Massart	TU/e	Damage induced anisotropy in masonry walls
Ir. J. Mediavilla	TU/e	From ductile damage to ductile fracture
Mr. C. Michler	TUD	Efficiency considerations of numerical methods for fluid-structure interaction
M.Sc. N. Mihajlovic	TU/e	Torsional vibrations in drill-string systems
Mr. P. Mohanty	TUD	Extending operational modal analysis procedures to include harmonic excitations
Ir. E.A. Munts	TUD	The partition-of-unity method: a performance study
Ir. M.H.H. Oude Nijhuis	UT	Active structural acoustic feedback control
Mr. T. Pannachet	TUD	Goal-oriented mesh adaptivity in crack modelling
H.R. Pasaribu	UT	Mild to severe wear transition of ceramics
M.Sc. A. Pavlov	TU/e	The local output regulation problem: convergence region estimates
Ir. G. Poort	TUD	FE-mesh generation of the scapula
M.Sc. D. Putra	TU/e	Limit cycling in observer-based controlled mechanical systems with friction
Ir. M.J. de Ruiter	TUD	Topological derivatives in topology optimization
Ir. I.E.M. Severens	TU/e	DEM simulations of the DI toner assembly
Mr. A. Simone	TUD	Continuous/discontinuos analysis of failure

Name	University	Poster title
Ir. H. Super	UT	Hybrid isolation of structure borne sound
M.Sc. B. Tasic	TU/e	Numerical methods for solving flow of ODE
Ir. R.H.W. ten Thije	UT	Springback analysis of coubly curved GLARE panels
Ir. H.G. Tillema	SKF	Silent running electric motor by viscoelastic bearing supports
M.Sc. S.N. Veritchev	TUD	Instability of a vibration of a vehicle moving on an elastic structure
Ir. E.M. Viatkina	TU/e	Strain path dependency in metal plasticity
Ir. B.H. Villa Rodriguez	UT	Braiding of RTM preforms
Mr. R. Visser	UT	Acoustic field prediction
M.Sc. Vostroukhov	TUD	Three-dimensional dynamic models of a railway track for high-speed trains
Ir. Waiboer	UT	Realistic robot simulation
Ir. Weustink	TUD	Fiber path calculation for impregnation
Mr. Wijskamp	UT	High precision moulding of thermosetting composites

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