engineering
mechanics

Fourth Engineering Mechanics Symposium

18 - 20 November 2001
Rolduc, Kerkrade

Graduate School Engineering Mechanics
c/o Eindhoven University of Technology

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Contents

Preface

The National Research School on Engineering Mechanics, a joint initiative of the Eindhoven and Delft Universities of Technology and the University of Twente, organizes on an annual basis the Engineering Mechanics Symposium. The aim of this symposium is to stimulate the communication and the exchange of information with respect to ongoing research in the field of Engineering Mechanics. To achieve this the program contains a keynote lecture by a leading expert in the field, topic sessions in relation to the selected research program of the Graduate School, poster presentations of actual research projects by PhD- and Twaio-students and a meeting of the senior academic staff.

The Fourth Engineering Mechanics Symposium takes place November 18th-20th, 2001, at Rolduc-Kerkrade. In the opening session Prof.Dr.-Ing. Edwin Kreuzer, from the Technische Universität Hamburg-Harburg, Germany will present a keynote lecture entitled: Nonlinear Dynamics in Marine Technology.

Furthermore, there are the following topic sessions:

- Fluid-Structure Interaction and Multiphase Problems,
  organized by Jacques Huyghe (TU/e), Steve Hulshoff (TUD) and Kees Venner (UT),
- Dynamics and Control,
  organized by Henk Nijmeijer (TU/e), Paul van Woerkom (TUD) and Ronald Aarts (UT)
- Mechanics of Materials,
  organized by Harm Askes (TUD), Timo Meinders (UT) and Bert van Rietbergen (TU/e).

Each topic session contains a general introduction by the session organizers, focussing on activities, trends, outlooks and perspectives of the field. In subsequent contributions PhD- and Twaio-students report on their specific research projects in more detail. For the best AIO-presentation a prize will be awarded. The winner will be announced directly before the closing of the symposium on Tuesday, November 20th.

Additionally, there are two poster sessions in which about 50 PhD- and Twaio-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 years members of the jury are Dr.Ir. J.M.R.J. Huyghe (TU/e, Eindhoven), Ir.Drs. P.D. van der Koogh (TNO-Automotive Delft and Stan Ackermans Institute, TU/e, Eindhoven) and Dr.Ir. F.J. Klever (Shell International Production, Rijswijk). Winners will be announced directly before the closing of the symposium on Tuesday, November 20th.

On Tuesday November 20th a meeting of the senior academic staff participating in Engineering Mechanics takes place. Important point on the agenda will be the application for renewal of the ECOS/KNAW-accreditation of the Graduate School as well as the Self-Assessment Report that has been formulated for this purpose. Furthermore, the coordination and combination of research activities of participating groups will be discussed.

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

- **Section 1:** Detailed program of the symposium.
- **Section 2:** Abstracts of the keynote lecture and the introductions to the topic sessions.
- **Section 3:** Abstracts of presentations at the topic sessions.
- **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 Fourth 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

Sunday, 18 November, 2001	
17.00-18.00	Registration
18.00-19.30	Dinner
19.45-21.30	**Poster Session** **Presentation of current research projects, carried out by PhD- and Twaio-students participating in Engineering Mechanics**
21.30-01.00	Bar “De Verloren Zoon”
Monday, 19 November, 2001	
08.00-09.00	Breakfast
09.00-10.10	**Session 1: Opening Session**
09.00-09.10	Opening of the Symposium: Prof.Dr.Ir. R. de Borst
09.10-10.10	Opening lecture: Prof.Dr.-Ing. E. Kreuzer, Technische Universität Hamburg-Harburg, Germany Nonlinear Dynamics in Marine Technology
10.10-10.40	Break
10.40-14.30	**Session 2: Fluid-Structure Interaction and Multiphase Problems** **Session organizers: Huyghe (TU/e), Hulshoff (TUD), Venner (UT)**
10.40-11.20	Introduction by the Session Organizers
11.20-11.40	Marco Stijnen (TU/e) Influence of prosthetic mitral valve orientation on left ventricular flow
11.40-12.10	Gheorghe Popovici (UT) Effects of load system dynamics in elasto hydrodynamic lubrication
12.10-12.30	Yodi Gunawan (TU/e) In-phase and out-of-phase break-up of liquid threads
12.30-13.40	Lunch
13.50-14.10	Mathieu Molenaar (TU/e – Shell Research) Application of compressibility in mixture models for porous media
14.10-14.30	Sandra Smolders (TU/e) Residual stresses in an injected moulded product
14.30-17.10	**Session 3: Dynamics and Control** **Session organizers: Nijmeijer (TU/e), v. Woerkom (TUD), Aarts (UT)**
14.30-15.00	Introduction by the Session organizers
15.00-15.20	René van Rooij (TU/e) Reliability optimization of dynamical systems
15.20-15.50	Break

Monday, 19 November 2001 (cont.)	
15.50-16.10	Alexei Pavlov (TU/e) The output regulation problem for nonlinear systems
16.10-16.30	Arend Schwab (TUD) Basin of attraction of the simplest walking model
16.30-16.50	Rob Waiboer (UT) Robot identification for dynamic simulation
16.50-17.10	Rogier Hesseling (TU/e) Control design in restraint systems
17.10-17.55	Informal reception
18.00-19.30	Dinner
19.45-21.30	**Poster Session:** **Presentation of current research projects, carried out by PhD- and Twaio-students participating in Engineering Mechanics**
21.30-01.00	Bar "De Verloren Zoon"
Tuesday, 20 November 2001	
08.00-09.00	Breakfast
09.00-12.10	**Session 4: Mechanics of Materials** **Session organizers: Askes (TUD), Meinders (UT), v. Rietbergen (TU/e)**
09.00-09.40	Introduction by the Session Organizers
09.40-10.00	Edwin Lamers (UT) Finite element modelling of fabric draping
10.00-10.20	Chuanjun Liu (TUD) Progressive failure modelling of matrix cracking in notched cross-ply laminates
10.20-10.50	Break
10.50-11.10	Joris Remmers (TUD) Analysis of delamination growth with discontinuous finite elements
11.10-11.30	Hermen Pijlman (UT) Material modelling of sheet metal by bi-axial experiments
11.30-11.50	Rens Evers (TU/e) Crystal plasticity model for FCC metals with enhanced hardening based on dislocation densities
11.50-12.10	Eelco Verhulp (TU/e) Simulation of the failure behavior of trabecular bone-like structures
12.15-12.25	**Announcement of the winning contributions in the AIO Presentation contest and in the Poster contest**
12.25-12.30	Closure
12.30-13.30	Lunch
13.30-14.30	**Assembly of Project Leaders EM**

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KEYNOTE LECTURE

and

INTRODUCTIONS TO THE SESSIONS

This section contains abstracts of the keynote lecture by Prof.Dr.-Ing. E. Kreuzer, Technische Universität Hamburg-Harburg, Germany, and of the introductions to the sessions by the session organizers. Abstracts are ordered according to the program of the symposium, as presented in section 1.

Keynote lecture:

Nonlinear Dynamics in Marine Technology

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Marine Technology is a rapidly evolving field with increasing demands for economy, speed and safety. The ability to predict the behavior of marine systems before large financial commitments are made to their manufacture is an essential ingredient of contemporary engineering. Linear analysis often will not provide sufficient accuracy and reliability to analyze and predict the dynamics in a satisfying manner. Nonlinear effects have to be taken into account when setting up tools, which support the design process. For example ship motions in rough sea and crane vessels under wave excitation show essentially nonlinear behavior. Unfortunately, the systems operate under certain conditions at the stability limit and this sometimes leads to heavy accidents with loss of human lives and causing huge environmental pollutions. A future goal should be the optimization of ship design and ship as well as crane vessel operations such as the nonlinear dynamics is taken into account.

The lecture is intended to describe the dynamics of floating marine structures under wave excitation. We start with the discussion of the ship stability assessment based on conventional and modern approaches. In order to determine whether or not a marine vehicle will be capable of maintaining a stable stationary and upright position (usually an essential requirement), it is necessary to examine all forces, which act on the vehicle. Therefore, the modelling of freely floating bodies will be presented in some detail. In order to explain the analysis procedure, two important examples from marine technology are considered, the dynamics of ships and crane vessels. The nonlinear dynamic responses to regular waves are investigated theoretically and experimentally. The main subject of interest is the appearance of nonlinear phenomena like bifurcations and the existence of multiple attractors.

Session 2:

Fluid-Structure Interactions and Multiphase Problems

J.M.R.J. Huyghe (TU/e), S.J. Hulshoff (TUD), C.H. Venner (UT)

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The classical approach to engineering analysis involves the breaking of a system into components which can be analysed independently. By definition, fluid-structure interaction and multiphase problems are those for which this is no longer possible; one is forced instead to deal simultaneously with two or more components with very different physical characteristics.

The analysis technique used depends very much on the nature of the interaction. At larger scales, one may need to consider the interaction of an air or water flow with a fixed but flexible solid. In this case the interaction is primarily dynamical, but the relative motion of the components poses an additional analysis challenge. At much smaller scales, micro-mechanical and thermodynamic behaviour may dominate the interaction. For these cases the number of interfaces can be very large, and their geometry is often unknown.

In our introduction, we will discuss a series of problems which span this range of scales. First we will consider fluid-structure interaction where relatively flexible structures interact with a high-speed flow. Some aerospace applications will be described, along with the issues being considered within the EM school related to their numerical analysis. These include techniques for dealing with relative motion of the domains and the time integration of the fluid and solid systems. The talk of Stijnen will describe the analysis of a biomechanical application where such techniques are employed.

Then we will turn to fluid-structure interaction problems in hydrodynamic and elasto-hydrodynamic lubrication. These problems arise in force-transmitting systems such as gears, journal bearings, roller bearings and aqua-planing tires. They are characterized by the presence of a lubricating layer of fluid which may be only one tenth of a micrometer thick, while transmitting contact pressures of up to 1-3 GPa. Such pressures result in deformation of the solid components of the force-transmitting system, along with variations in the viscosity and rheological behaviour of the fluid. In some cases, the problem can become multiphase due to cavitation occurring within the fluid layer. The talk of Popovici will give an overview of the state of the art in the analysis of these systems.

Finally, we will give an introduction to problems encountered in multiphase mechanics. This will provide a background for the talks by Gunawan, Molenaar, and Smolders, which consider such disparate multiphase problems such as interface break-up, swirling shales, and liquid-to-solid phase transitions.

Session 3:

Dynamics and Control

H. Nijmeijer (TU/e), P.Th.L.M. van Woerkom (TUD), R.G.K.M. Aarts (UT)

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“Dynamics” and “Control” are combined in several research projects of the Graduate School Engineering Mechanics (EM) as well as in the “Dutch Institute of Systems and Control” (DISC). In this presentation we will highlight some of the EM-activities on “Dynamics and Control”.

In Eindhoven research activities in the Dynamics and Control section [1] include:

- Nonlinear dynamics: modeling and analysis of mechanical systems with mixed continuous and discrete behavior such as systems with friction, impacts or contact.
- Nonlinear control: control of nonlinear mechanical systems, systems with nonholonomic constraints, hybrid systems. Experimental validation.
- Structural acoustics and structural optimization: optimal design of mechanical structure with low noise/vibrations.
- Synchronization/coordination and oscillations: how to achieve identical machine motions through coupling and/or feedback.

The above activities are, where possible, experimentally validated in the Dynamics and Control laboratory.

In Delft [2] research is directed both to the development of numerical tools and to the improvement of understanding of the dynamics of complex mechanical systems. In the first category the multibody software system SPACAR is being enhanced with the incorporation of modules representing realistic physical properties (stiff components, friction, contact and impact, and clearances); in another project the occurrence of bifurcations and chaos in non-smooth systems (that experience sudden changes in properties) is predicted. In the second category the dynamics of nonlinear systems is to be identified using specific nonlinear identification methods; the challenge to identify mechanical sources for the occurrence of lower back pain (originating in the sacro-iliac joint area) is taken up and model reduction of nonlinear dynamic systems will be explored.

In Twente projects in the Group “Mechanical Automation” [3] are on “robots and machine dynamics” and “sound and vibration control”. In the first theme experimental robot identification and realistic dynamic simulations play an important role in an NIMR project on off-line programming for laser welding. The simulations rely heavily on the ongoing development of the non-linear finite element package SPACAR. Research on controller design is part of DISC. In the second theme projects are carried out in cooperation with the “Applied Mechanics and Polymer Engineering” group and TNO-TPD. Research is focused on obtaining an optimal reduction of noise levels in compartments of vehicles by using a combination of active and passive isolation techniques.

References:

[1] http://www.wfw.wtb.tue.nl/dyna/ of: Eindhoven University of Technology, Department of Mechanical Engineering, Dynamics & Control Group, P.O. Box 513, 5600 MB Eindhoven, The Netherlands.
[2] http://www.ocp.tudelft.nl/tm/ of: Delft University of Technology, Department of Design, Engineering and Production, Subfaculty of Mechanical Engineering and Marine Technology, Department of Engineering Mechanics, Mekelweg 2, 2628 CD Delft, The Netherlands.
[3] http://www.wa.wb.utwente.nl/ of: University of Twente, Department of Engineering, Laboratory of Mechanical Automation, P.O. Box 217, 7500 AE Enschede, The Netherlands.

Session 4:

Mechanics of Materials

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- Modelling of composites -

Introduction

Composites are increasingly used in various fields of engineering such as aeronautics and mechanical engineering. Due to improved production processes, composites such as fibre-reinforced plastics and laminates can become competitive to more traditional engineering materials.

The modelling of composites is important to further improve production and extend usage. Two important aspects that will be highlighted in this session are the forming process of a composite and the failure of composites.

Forming process of rubber

One of the studied processes is the forming of rubber. A fibre-reinforced thermoplastic is heated and formed in a mould. A finite element model is developed to study the drapability of the rubber and the fibre orientation. The results are compared to experimental results.

Failure of laminates

Another process under investigation is the failure of laminates. The multi-layered nature of a laminate leads to different failure modes, such as matrix cracking and delamination.

Numerical modelling concentrates on formulating proper material models and failure criteria on the one hand, and developing advanced discretisation techniques on the other hand. It is important to take into account the various failure modes and their mutual influence. The effect of these failure modes on notch-induced splits is studied.

Finally, new discretisation methodologies are used to describe the discontinuities that arise upon delamination. An enhancement of the finite element shape functions allows for discontinuities inside the element, so that delamination of a multi-layered laminate can be modelled with only one element in the thickness direction.

- Metals -

Numerical tools become more and more important in the design of products manufactured by metal forming processes. One of the demands of a numerical tool is that it gives an accurate prediction of what in reality occurs. This accuracy strongly depends on the accuracy of material modeling.

Research in this field ranges from micro-scale to macro-scale level. For example, on micro-scale level research is done on atomic level and discrete dislocation theory, on meso-scale level research is done on crystal plasticity and dislocation densities, and on macro-scale level research is done on yield functions, hardening models and damage. All these fields of research interact with each other.

The results gained from research on micro-level can give insight of the behavior of materials at meso-scopic level. The results of the meso-scopic research can give insight (or even directly coupled) of the material behavior at macro-scopic level, which will lead to a better material model and a more accurate prediction of the deformation of a metal product.

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ABSTRACTS OF PRESENTATIONS

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

Crystal plasticity model for FCC metals with enhanced hardening based on dislocation densities

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In the classical local-global interaction approaches like the Taylor and Sachs models, the entire crystal is used as a participating component, and the interactions between individual crystals are disregarded. On the other hand, in the case of intermediate models, such as for example the self-consistent models, both the consistency conditions of compatibility and stress equilibrium between the grains and their surroundings are accounted for. This makes intermediate models more rational, however, they require severe assumptions in order to simplify the formulations and to reduce the computational effort. In this contribution, an intermediate model is proposed as a basis for developing a local plastic strain gradient dependent crystal plasticity model.

The processes of inelastic deformations at grain boundaries during large plastic deformation and texture evolution of polycrystalline FCC metals, such as *e.g.* the movement, accumulation, pile-up and migration into the crystal core of dislocations and the onset of shear bands, cause the constitutive response of a polycrystal to be grain-size dependent. In this work, attention is focused on these crystal boundaries. They are modeled by regarding them as fictitious bi-crystals, having the crystallographic orientations of their two adjacent crystals. Furthermore, the crystal cores are modeled as single crystals, and the interaction between the representative partitions is taken into account by an adapted Taylor approach.

The present model originates from the work of Ahzi et al. [1], where a two-phase composite inclusion is used as a representative volume element of a crystalline lamella and its associated amorphous layer in two-phase semi-crystalline polymers. The extension of this approach to use the composite inclusion as a bi-crystal for the modeling of grain boundaries in FCC metals was first performed by Lee et al. [2]. However, in their work, only the crystal interfaces, *i.e.* the bi-crystals, are taken into account, disregarding the presence of the crystal interiors. They found that the prediction of the crystallographic texture evolution using the bi-crystals results in more diffuse patterns than the, with respect to experimental findings, too stiff predictions of the conventional Taylor approach.

Entering in more detail on the actual model, in a material point, a set of single crystals is considered having volume fractions assigned to their cores, whereas the boundaries (bi-crystals) constitute the remaining volume. On one hand, the Taylor interaction law imposes the crystal interior deformations to be uniform and equal to the macroscopic deformation. On the other hand, the deformation within the bi-crystals is not necessarily identical, yet uniform in each part, compatible at the interface and in average sense equal to the macroscopic deformation. Moreover, stress equilibrium is enforced at the bi-crystal interfaces. In both the single crystal cores and the bi-crystals, the constitutive description of the metal is supposed to be given by an elastic-viscoplastic model, with crystallographic slip as the sole mechanism of plastic deformation.

The presented intermediate model is extended to include grain-size dependency. Based on the discontinuity of the plastic deformation gradient between the single crystal core and its bi-crystal counterparts, the geometrically necessary dislocation (GND) densities can be determined which preserve the crystallographic lattice to be compatible. The accompanying obstacle densities on the slip systems can be determined by taking into account the various types of interactions between the dislocations. The obstacle densities obstruct the motion of gliding dislocations associated with the ongoing plastic deformation, i.e. introduce extra hardening. This enhanced hardening is attributed to the bi-crystal contributions. As the GND densities depend on the plastic deformation differences as well as the distance between the core and the boundaries, the introduced extra hardening varies with the grain size and leads to a numerical confirmation of e.g. the (empirical) Hall-Petch relation.

References:

[1] S. Ahzi, D.M. Parks and A.S. Argon. Modeling of plastic deformation evolution of anisotropy in semi-crystalline polymers. In B. Singh, editor, Computer Modeling and Simulation of Manufacturing Processes (ASME), MD-20, 287–292, (1990).

[2] B.J. Lee, S. Ahzi and D.M. Parks. Intermediate modeling of polycrystal plasticity. In Proceedings of Plasticity ’99, 377–380, (1999).

In-phase and out-of-phase break-up of liquid threads

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The dynamical behaviour of two infinitely long adjacent parallel liquid threads immersed in a liquid is considered under influence of small initial perturbations. Assuming all fluids to behave Newtonian, we used the creeping flow approximation, which resulted in Stokes equations. Applying cylindrical coordinates and separation of variables, and writing the dependence on the azimuthal direction in the form of a Fourier expansion, we obtained general representations of the equations for both the threads and the surrounding fluid. Substitution of these expressions into the boundary conditions leads to an infinite set of linear equations for the unknown coefficients. Its solutions for the lowest two orders of the Fourier expansion, the so-called zero and first order solutions are presented. Much attention is paid to the (in)stability of the configuration, in terms of the so-called growth rate of the disturbance amplitudes. The growth rate of these amplitudes determines the behaviour of the break-up process of the threads. It turns out that this breaking up occurs either in-phase or out-of-phase. This depends on the viscosity ratio of the fluids and on the distance between the threads.

These findings agree with experimental observations. The results of the present work also show that the zero order solution yields the qualitatively correct insight in the break-up process. The extension to a one order higher expansion only leads to relatively small quantitative corrections.

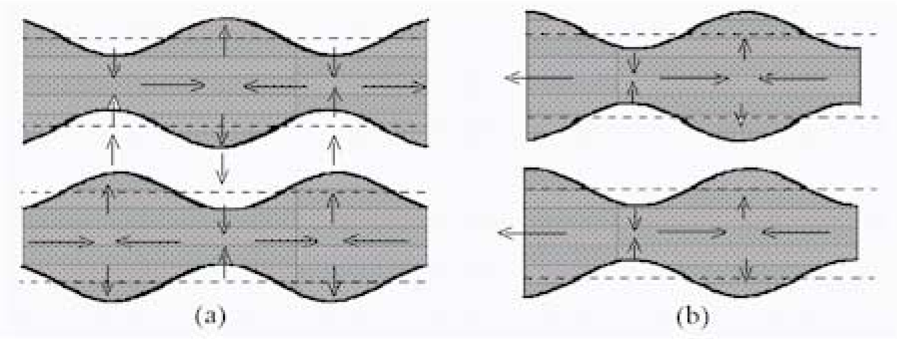

Figure 1: A sketch of two typical examples of break-up behaviour observed in the experiment: (a) out-of-phase, (b) in-phase break-up.

References:

[1] Gunawan A.Y., et al., In-phase and out-of-phase break-up of two immersed liquid threads under influence of surface tension, submitted to Eur. J. Mech. B/Fluids, 2001.
[2] Knops Y.M.M., et al., Simultaneous breakup of multiple viscous threads surrounded by viscous liquid, accepted for publication in AIChE Journal, 2001.

Control design in restraint systems

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Introduction

In the past ten years, vehicle safety becomes more and more important. Passive safety refers to the components of a vehicle reducing the occupant injuries when an accident occurs. These components can be divided in two groups; components which do have contact with the occupant during a crash and components which do not have contact with the occupant during the crash. The latter group is referred to as restraint system, e.g. the airbag.

Currently, restraint systems are adaptive only in the sense that the most appropriate setting for the actuators of the restraint system is chosen once, directly after a crash has been detected. Obviously, occupant injuries will be less severe if it is possible to manipulate the restraint system during the crash. The goal of this project is to set up a method to control the occupant injuries by manipulating the restraint system online. The method is set up using models in the finite element and multibody package MADYMO, see Figure 1.

Problem statement

The problem to start with is to develop a design method to control and minimize the chest acceleration by online manipulation of the beltforce in one standardized crash test. The control algorithm will be based on feedback. The adopted injury measure is the maximal value of the chest acceleration, i.e. $J = max\left|\ddot{x}(t)\right|$. An appropriate reference trajectory is set up, based on a simple representation of a crash.

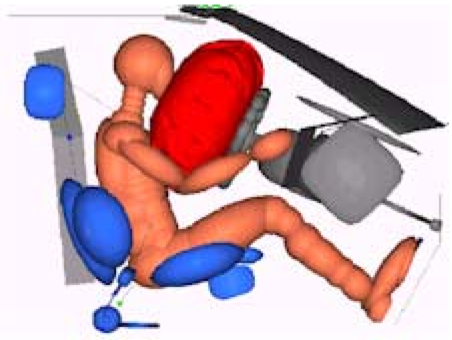

Figure 1: Numerical model of a BMW

Approach

The numerical model in Figure 1 is complex and non-linear. The problem is how to get insight into the behaviour of this model, such that it is possible to design a controller. Two problems arise. The first has to do with the complexity of the restraint system. This problem is partly solved by excluding the airbag. The second has to do with MADYMO. MADYMO has no facilities for model reduction or linearization.

Therefore, it is chosen to identify the transfer function from beltforce to chest acceleration by analyzing the disturbed chest acceleration to a stepwise perturbation in the beltforce. The transfer function of a LTI SISO system is identified on the difference between the original chest acceleration and the disturbed chest acceleration.

The identified SISO system has the beltforce as input and the chest acceleration as output. Based on this SISO system, a controller can be set up and then be validated in the complex and non-linear MADYMO model.

Results

Application of the controller in the non-linear MADYMO model results in a reduction of the injury measure of approximately 60% with respect to the non-controlled situation.

Finite Elements Modelling of fabric draping

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Introduction

Over the last years, the demand for high strength and low weight materials, such as fabric-reinforced thermoplastic composites, is growing in the aeronautical industry. Due to better production processes, production costs could be reduced. Therefore, fabric-reinforced thermoplastics are getting increasingly better economical competitors to other construction materials such as for example Aluminium.

However, when producing doubly curved parts, the process of draping causes the angle between the warp and weft yarns to vary over the product with this double curvature. As a result the thermomechanical properties of the fabric-reinforced thermoplastic show a corresponding distribution. Obviously, the resulting fibre orientations must be predicted accurately to predict the overall thermomechanical properties of the product.

Rubber Forming Process

The forming of fabric-reinforced thermoplastics takes place in, for example, the rubber forming process. In the rubber forming process, a fibre-reinforced thermoplastic pre-form is heated above the glass-transition or melting temperature and then pressed between the steel lower mould and the upper rubber mould. In the mould, the product is rapidly cooled until it is form stable. Typically the cycle time for a product is in the order of a few minutes and the processing forces are low (unlike the high processing forces with metal forming).

Modelling

In this work a simulation model to predict the drapability of a product and the resulting fibre orientation is presented. This model is based on a Finite Element (FE) approach and is implemented in the FE package *Dieka*, an in-house developed special-purpose program for modelling for instance the process of deep drawing in metals.

For the rubber forming process of composite materials, extensions have to be made with respect to the process-specific boundary conditions and the specific material behaviour. As a first approximation, the process can be considered isothermal and the laminate behaviour can be described with a fabric-reinforced viscous-like response [1]. In a further step more sophisticated material models will be developed and the thermal problem will be solved in order to predict process-induced distortions of the final product.

Results

The results of the finite element model are compared with the experimental results on rubber formed double dome composite products.

Reference

[1] A.J.M. Spencer, Theory of fabric-reinforced viscous fluids, Composites: Part A, 31, p.1311-1321, (2000).

Progressive failure modelling of matrix cracking in notched cross-ply laminates

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A number of different forms of matrix-dominated failure occur before the final catastrophic failure in a fibre reinforced polymer composite laminate with or without notches. These matrix cracks (displacement discontinuity in a single layer or between laminae) cause local material decomposition and local stress redistribution on a laminar scale or between laminae (three-dimensionally), and speed up the global structural failure in different failure mechanisms. Geometrical notches may radically change these forms of matrix failure through notch provoked stresses. Therefore, various forms of matrix failure in polymer composites have been a subject of extensive investigation in the field of composite materials.

In order to study the matrix dominated failure, a progressive failure finite element (FEM) model was created. In combination with a group of stress/strain based strength criteria, this approach was used to study the notch-induced splits in cross-ply laminates with double-edge semicircular notches. Constitutively, it is assumed that the laminate is made up of homogeneous orthotropic layers even after local matrix failure has occurred. A group of strength criteria is, in a very local scale, applied to a single layer to introduce the local micro-scale matrix failure. Once one or more of the failure criteria is satisfied, the local material stiffness will degenerate to a given level, and stress redistribution occurs locally at the site. Subsequently, the notch-induced split (NIS), with the effects of transverse cracks and local delamination, was studied. The numerical simulation predicts that the split length propagates linearly with the far-field applied strain. It also indicates that other forms of matrix failure will accelerate the growth of NIS, e.g. transverse cracks and local delamination. In other words, a strong interaction exists between these different forms of matrix failure. For a correct prediction of the evolution of the failure, those failure events occurred earlier have to be taken into account.

Keywords: notch, cross-ply laminate, matrix cracking, finite element analysis

Application of compressibility in mixture models for porous media

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In the past decades, mixture theory has been successful in modeling finite deformations of porous solids, including physico-chemical effects. In the field of cartilaginous materials, Huyghe and Janssen recently developed a model for saturated incompressible porous materials, including Donnan osmotic swelling.

Osmotic swelling is associated with electrical charges fixed to the porous solid matrix, counteracted by corresponding charges in the pore-fluid, which in turn attracts water. As a consequence of the fixed charges a variety of physical phenomena are observed, such as streaming potentials, diffusion potentials, electro-osmosis, and electro-phoresis. These phenomena play a significant role in many bio-mechanical and geo-mechanical applications, such as ion transport through skin, deterioration with age of cartilage, nuclear waste disposal in clay barriers and stability of soils.

In some of these application however, compressibility is an essential feature, which cannot be ignored. For example, the bulk modulus of the mineralized bone is about six times stiffer than that of the fluid, therefore in the application of poro-elasticity models to bone, it is essential to take compressibility of the porous bone matrix and the fluid in the pores into account. Another special application area where the compressibility between solid and fluid constituent is important is in oil and gas well drilling, where incorrect estimation of the rock strength results in collapse of the drilled borehole.

Using the mixture theory, a constitutive model has been developed, for compressible constituents (solid and fluid). It integrates the know-how of compressible poro-elasticity and electro-chemo-mechanical theory. In the limiting case without ionic effects, the model is consistent with solid-fluid interaction models from literature, and in the limiting case without the solid reduces to the theory of electrolyte solutions. This constitutive model has been implemented in finite-element code and validated against analytical solutions.

The output regulation problem for nonlinear systems

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The presentation is devoted to the problem of asymptotic regulation of the output of a dynamic system, which is subject to disturbances generated by an external system. Many problems in control theory can be considered as a particular case of the output regulation problem: tracking of a class of reference signals, rejecting a class of disturbances, stabilization, partial stabilization. For linear systems the problem is completely solved resulting in the well-known ”internal model principle”. Recently necessary and sufficient conditions for the solvability of the *local* output regulation problem were obtained, starting new increase in interest in this problem. In this presentation the main results on the nonlinear output regulation problem are reviewed, the ways of extending the results to more general cases as well as applications to some current control problems such as controlled synchronization are discussed.

Material modelling of sheet metal by bi-axial experiments

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In Finite Element calculations the plastic material behaviour can be described with a yield criterion and a hardening rule. Commonly used yield criterions in sheet metal forming are based on uni-axial tensile tests. These criterions do not always describe the yield behaviour sufficiently accurate. Therefore Vegter [1] proposed a new yield criterion.

The Vegter yield criterion is based on measurements of multi-axial yield stress states: the pure shear state, the uni-axial state, the plane strain state and the equi-bi-axial state.

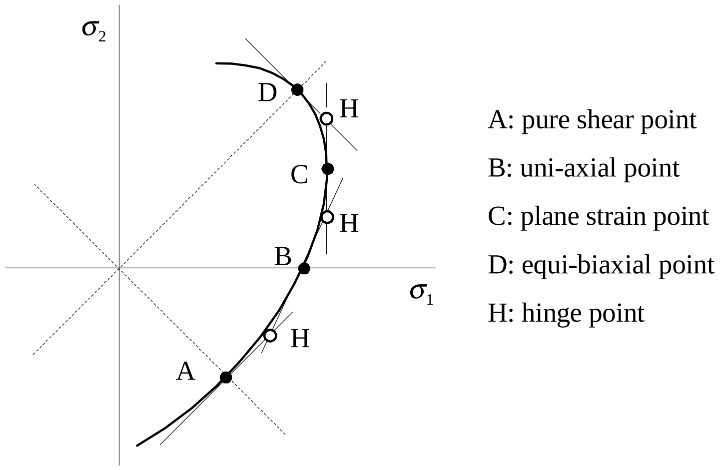

Figure 1: *The four reference points to construct the Vegter yield function*

To measure the multi-axial stress states a multi-axial test equipment has been designed. The test equipment is capable of imposing a shear deformation and a plane strain deformation, including combinations of both deformations. With the test equipment the part of the yield surface between the pure shear reference point and the plane strain point can be measured, see figure 1.

The Vegter yield function is validated on basic deep draw products and a complicated product, in which it provides realistic results.

Reference:

[1] H. Vegter, P. Drent, J. Huétink, ‘A planar isotropic yield criterion based on mechanical testing at multi-axial stress states’, Numiform’95, S. Shen et. al. (eds.), 1995

Effects of load system dynamics in elasto hydrodynamic lubrication

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The prediction of the formation and the behaviour of the lubricant film in the contacts between machine elements in relative motion under high contact loads can be seen as a Fluid Structure Interaction problem. The field is generally referred to as Elasto-Hydrodynamic Lubrication. The key elements in the prediction of the flow and surface separation are the elastic deformation of the surfaces, the rheological behaviour of the fluid, and the motion of the surfaces. Fast algorithms have been developed for the numerical simulation of such EHL contacts and the operation under steady state conditions can be accurately predicted nowadays.

However, trends in design are towards smaller parts, implying higher loads and thinner films. Under these circumstances surface roughness effects become increasingly important. Also government regulations regarding sound levels imply that the vibration levels of machines, and thus of bearings should be very low.

To understand the vibrational behaviour of bearings requires detailed understanding of the vibrational behaviour of EHL contacts. In the present lecture one aspect of the dynamic behaviour of EHL contacts is illustrated, i.e. the relation between the response of the contact to speed changes and the dynamics of the load support system.

Analysis of delamination growth with discontinuous finite elements

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An important failure mechanism in layered composite materials is delamination. This phenomenon can be investigated with the finite element method on a mesoscopic level. The individual layers are modelled with continuum elements, and the interlaminar bond can be represented by interface elements, which are equipped with a damage model to simulate debonding of the layers.

In an alternative approach, which will be pursued here, the interlaminar crack can be incorporated directly in continuum elements using the partition of unity method [1]. Here, the crack is represented as a discontinuity in the displacement field of the continuum elements [2]. The magnitude of this jump is governed by an additional set of degrees of freedom that is added to existing nodes of the continuum element. Debonding can be simulated with the same damage model as used with interface elements. This method has been implemented in a two-dimensional model and its flexibility and superior behaviour has been demonstrated with some classical benchmark problems [3]. Recently, the method has been applied to a three-dimensional model.

The new approach has a number of advantages. The most important relates to the significant reduction in the number of degrees of freedom: the additional degrees of freedom are only activated when a crack propagates. More importantly, the complete laminate can be modelled with just one element through the thickness, instead of one element per individual layer.

The use of the partition of unity method for the simulation of delamination growth in general, and the performance of the three-dimensional model in particular will be discussed in the presentation.

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[1] I. Babuška, J.M. Melenk. The partition of unity method., Int. J. Num. Meth. Engng., 40 (4), (1997), pp. 727–758.

[2] G.N. Wells, L.J. Sluys, A new method for modelling cohesive cracks using finite elements. Int. J. Num. Meth. Engng., 50 (12), (2001), pp. 2667–2682.

[3] J.J.C. Remmers, G.N. Wells, R. de Borst, Analysis of delamination growth with discontinuous finite elements, Proc. 2nd European Conference on Computational Mechanics, ECCM-2001, Cracow, (2001).

Reliability optimization of dynamical systems

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"Learn from each others mistakes" or, to put it in a more positive way "Using each others expertise", that is the main idea behind the ADOPT project. Three different groups within EM, each with its own background have joint forces in this project. The objective: to develop a software tool that can be applied to a wide range of optimization problems.

The 'wide range' does not only refer to the various fields of application but also to the type of optimization problems. Apart from the classic deterministic optimization problems, involving continuous design variables and functions, more complex optimization problems should be handled as well. With more complex problems we mean problems which involve uncertainties, discrete design variables and discontinuous functions. As can be expected an increase of the complexity of a problem also means an increase of the effort that's required in order to solve the problem. The new methodologies that are being developed by the ADOPT team aim at increasing the efficiency with which large scale and complex optimization problems can be solved.

This presentation will show what impact uncertainties in the design variables (due to production tolerances) have upon the optimization problem formulation and what techniques can be used to solve such problems. This will be illustrated with two examples; the vehicle fleet compatibility problem and the problem of an autobalancing unit.

Basin of attraction of the simplest walking model

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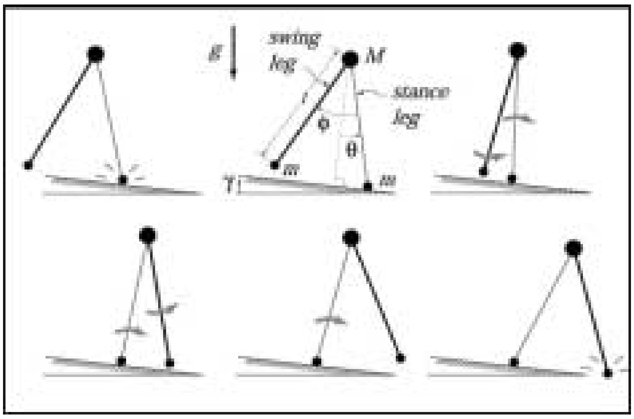
Passive dynamic walking is an important development for walking robots, supplying natural, energy-efficient motions. However, in practice the cyclic gait of passive dynamic prototypes appears to be stable only for small disturbances. Therefore we research the basin of attraction, which represents the set of all allowable disturbances, of the cyclic walking motion. To stress the fundamental importance of the size of the basin of attraction on successful walking we used the simplest walking model: 2D motion and straight legs with point masses at the feet and the hip.



The simplest walking model, a typical passive dynamic walking step. Reprinted with permission from Garcia et al [1].

Although applied to this simple walking model, the presented method for deriving the equations of motion and the impact equations is also very efficient for analysis of complex multibody systems as in more refined walking models. To suppress repetitive calculations in the determination of the basin of attraction, fruitful use was made of the cell mapping method.

Our results show that the basin of attraction of the simplest walking model is a small region in the Poincaré section. It is conjectured that the stability of the cyclic motion is related to its position within the basin of attraction rather than to the size of the basin of attraction.

Reference:

[1] Garcia, M., Chatterjee, A., Ruina, A., and Coleman, M. J., 1998, “The simplest walking model: Stability, complexity, and scaling," ASME Journal of Biomechanical Engineering, **120**(2), pp. 281-288.

Residual stresses in an injected moulded product

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Introduction

Injection moulding is a commonly used technique to produce plastic products in large numbers, where the cycle time (production time) is short, the accuracy is relatively high, and the costs are low. At the beginning of a production cycle, hot molten polymer is injected under high pressure into a cooled closed mould. After the polymer has cooled down and solidified to attain its final shape, the mould opens, and the plastic product is ejected from the mould.

During the injection moulding process stresses develop in the plastic product. The residual stresses have a great impact on the final shape of the injected moulded product. There are two kinds of residual stresses, namely frozen-in flow induced stresses, and thermally induced stresses.

Flow induced stresses are caused by the orientation of the polymer molecules and develop in the fluid state, i.e. the state where the temperature is above the glass transition temperature. Due to the fast solidification by high cooling rates these stresses will not completely relax. These stresses are relatively small compared to the thermally induced stresses, but influence the mechanical and optical (birefringence) behaviour. Thermally induced stresses develop in the solid state, due to differential shrinkage caused by inhomogeneous cooling. These stresses will, e.g., cause warpage of the product.

Research project

The goal of the research project is to predict the residual stresses in an injected moulded product in case the mould is a straight cavity, consisting of the narrow space between two adjacent parallel circular plates. The cavity is thin, meaning that the distance between the plates is much less than their radius. The flow is rotationally symmetric. Both temperature and pressure effects influence the flow, due to e.g. compressibility and viscous dissipation, and because the material coefficients of the polymer melt are strongly temperature and pressure dependent. In order to calculate the flow induced stresses a viscoelastic model for the stresses is chosen, namely the compressible version of the Leonov model. This model is solved together with the balance laws from continuum mechanics. For a thin plate, this model can be simplified by using the thin film approximation. Also the influence of the flow front is taken into account. The model is implemented in a Matlab program; the results will be shown at the presentation.

After ejection, the partially solidified thin polymer disc consists of thin solidified layers at the upper and lower surface and a still molten kernel. The interface between the layers and the kernel is a free (unknown and time dependent) surface. The thermally induced stresses will be calculated using a linearization of the compressible version of the Leonov model. This linearization is based on the assumption that in the solidified state the deformations are small. The stage of the research is in this modeling part; results cannot be shown yet.

Influence of prosthetic mitral valve orientation on left ventricular flow

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Introduction

The orientation and geometry of prosthetic heart valves have a major influence on the flow pattern in the ventricle [1,2]. In the development of prosthetic heart valves, knowledge of the flow properties is of great importance to optimization of the designs and to the determination of the optimal orientation for implantation of the valve prosthesis.

The objective of this study is to analyze the flow in a left ventricle model by means of an experimentally validated 3D computational method. The computational method, using an arbitrary Euler-Lagrange finite element method to solve the instationary Navier-Stokes equations for newtonian fluids, was applied to two orientations of a model mitral valve prosthesis and resulted in two significantly different flow fields. An additional model of the aortic root with a sinus cavity is studied in which a fluid-structure interaction model is incorporated.

Methods

A 3D computational model of the left ventricle was developed using an arbitrary Euler-Lagrange finite element method to solve the instationary Navier-Stokes equations for newtonian fluids on a moving grid. In this model a very simple valve model is used: the viscosity of the fluid is locally prescribed to be high enough to prevent fluid motion at the location of the valve structure. The shape of the valve was a thick plate, which was placed in two different orientations in the mitral orifice. Furthermore the valve was modeled to be opened or closed, without transition.

In a later stage a more complex valve model will be used incorporating motion of the valve by means of fluid-structure interaction and a realistic valve geometry using a fictitious domain method [3,4]. For the development of this model a 2D model of the aortic valve with a sinus cavity is being studied.

Results

The results of the 3D computations show significant differences in the flow fields in the model ventricle if the orientation of the valve is rotated over 90 degrees. Furthermore computations of the fluid-structure interaction model of the aortic valve have been performed. The results show a large vortex developing in the sinus cavity during deceleration of the pulsatile fluid flow.

References

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[2] Garitey et al, Ventricular flow dynamic past bileaflet prosthetic heart valves. Int J Art Organs 1995; 18: 380-391
[3] Glowinski et al, A fictitious domain method for dirichlet problems and applications. Computer Methods in Applied Mechanics and Engineering 1994; 111: 283-303
[4] Bertrand et al, A three dimensional fictitious domain method for incompressible fluid flow problems. Int J of Num Methods for Fluids 1997; 25: 719-736

Simulation of the failure behavior of trabecular bone-like structures

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Introduction

The failure behavior of complex porous structures such as trabecular bone is not well understood. Recent developments enabled the calculation of trabecular-level stresses and strains with micro-finite element (FE) models that represent the trabecular structure in detail [1]. It was shown that such models could create accurate results on the yield behavior of bovine specimens at the bone apparent level [2]. So far, however, it has not been possible to validate the predicted failure behavior at the level of the trabeculae. This is of particular importance for the development of accurate tissue-level failure criteria, since stresses, strains and tissue properties at the level of individual trabeculae determine the occurrence of failure.

In this study we aim to predict the failure behavior of porous trabecular-like structures in detail and to compare these with measurements of the same structures after failure.

Methods

Three-dimensional reconstructions of open-cell aluminum foam specimens, with a structure similar to trabecular bone, were obtained using a micro-CT scanner. Stepwise compression was performed to complete failure on the specimens, placed within the CT scanner; reconstructions were made after each step. Finite element models, built with linear hexahedral elements, were generated based on the initial geometry. The failure process was simulated in a geometrically and materially non-linear FE-analysis. The deforming geometry and the stress-strain curves were measured in the experiment and compared to the results predicted by the simulation.

Results and discussion

The results demonstrate that the failure behavior of complex structures such as trabecular bone can be well reproduced by FE analyses. Good agreement was obtained between the predicted and experimentally measured geometry after failure, and between the stress-strain curves (Fig. 1).

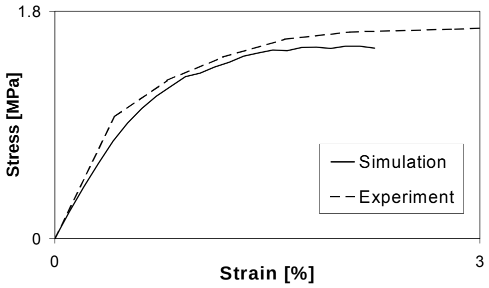

Figure 1: Stress-strain curves for both the experiment and the FE simulation.

The use of aluminum foams rather than real bone enabled the exclusion of the (largely unknown) effects of tissue material properties and inhomogeneities that could affect measurements on real bone.

References:

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Robot identification for dynamic simulation

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Robotized laser welding is an application, which requires high speed combined with high precision. Realistic Dynamic Simulations combined with Off-line Programming, significantly enhances the *a priory* prediction of the weldability of a specific product. Obviously, realistic dynamic simulations require realistic models of the robot and controller.

A 3DOF robot model has been formulated which includes lumped inertia parameters, stiffness parameters of the gravity compensation spring and a -three parameter- friction model to describe joint friction. The equations of motion are expressed in the vector of generalized coordinates $\underline{q}$ and the vector of model parameters $\underline{p}$:

$$\underline{\tau} = M(\underline{q},\underline{p})\ddot{\underline{q}} + C(\underline{q},\dot{\underline{q}},\underline{p})\dot{\underline{q}} + \underline{g}(\underline{q},\underline{p})$$

where $M(\underline{q},\underline{p})$ is the reduced mass matrix, $C(\underline{q},\dot{\underline{q}},\underline{p})$ represents the Coriolis and the centrifugal forces as well as the friction model, $\underline{g}(\underline{q},\underline{p})$ is the vector which includes stiffness properties and external nodal forces, including gravity, and the driving torques are expressed by $\underline{\tau}$. The model parameters $\underline{p}$ are estimated using experimental parameter identification. The set of model parameters is found using a linear least squares method. This linear least squares method requires that the robot dynamic model is rewritten in a parameter linear form:

$$\underline{\tau} = \Phi(\underline{q},\dot{\underline{q}},\ddot{\underline{q}})\underline{p}$$

where $\Phi(\underline{q},\dot{\underline{q}},\ddot{\underline{q}})$ is known as the regression matrix. The quality of the least squares fit depends strongly on the condition of the regression matrix. Using excitation trajectories $(\underline{q},\dot{\underline{q}},\ddot{\underline{q}})$ consisting of a Fourier series with 5 frequencies, this condition can be manipulated by choosing the phase and amplitude. Non-linear optimization techniques are used to find the best phase and amplitude combination while obeying motion constraints. The simulations are performed using SPACAR [1] and MATLAB.

Parameter estimation for a 3DOF model has been performed. The torques are obtained by measuring the servo currents and transforming them to joint torques. The trajectories are programmed in the robot control software. All experiments are done without modifications to the original industrial robot.

Simulation of the 3DOF robot model shows good agreement with the experimental results. Friction plays an important role in the dynamics of an industrial robot. The goal is a realistic 6DOF robot model, which enables the accurate and realistic simulations needed with off-line programming for laser welding.

Reference

[1] J.B. Jonker and J.P. Meijaard. SPACAR-computer program for dynamic analysis of flexible spatial mechanisms and manipulators. In W.Schiehlen, editor, Multibody Systems Hand-book, pages 123–143, Berlin, Germany, 1990. Springer-Verlag.

4

SURVEY

of

POSTER PRESENTATIONS

This section contains a survey of poster presentations of actual PhD- and Twaio-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	Univ.	Title
Ir. N.P.I. Aneke	TU/e	Control of an underactuated PPR manipulator
Ir. C.A.J. Beijers	UT	Hybrid isolation of structure borne sound: modelling and analysis
Ir. F.X. Debiesme	TU/e	Fast optimization in structural acoustics
Ir. W.J. Dijkhof	TU/e	Robust optimization in structural acoustics
Drs. W.D. Drenth	TU/e	On domain decomposition solvers for domains with substructures
Ir. R.A.B. Engelen	TU/e	On damage initiation and evolution
Ir. L.P. Evers	TU/e	Dislocation density based crystal plasticity model
Ir. I.C. Faraon	UT	Stribeck curves for starved line contacts
Ir. L. Geerts	TU/e	Coordinate free analysis of myofiber orientation in the normal and infarcted heart
Ir. H.J.J. Gramberg	TU/e	Flow front instabilities of an injection moulding process
M.Sc. I. Gueorguiev	TUD	Dynamic crack propagation in a thin beam
Drs. A.Y. Gunawan	TU/e	In-phase and out-of-phase break-up of liquid threads
Ir. M. Hagenbeek	TUD	Thermal and off-arts behaviour of dare
Ir. E. van der Heide	UT	Failure of sheet metal forming tools due to adhesion
Ir. F.M. Hendriks	TU/e	Characterization of mechanical properties of dermis and fat in vivo
Ir. R.J. Hesseling	TU/e	Control design for restraint systems
Ir. L.H. van den Heuvel	TU/e	Culturing coronary arteries under physiological conditions
Ir. C. Van 't Hof	TUD	Mechanical characterization of curing thermosets
Ir. B. Jacod	UT	Friction in EHL contacts
Ir. R.C.P. Kerckhoffs	TU/e	Cardiac electro-mechanics in numerico
Ir. G. Kloosterman	UT	Contact and friction in forming simulations
Mr. A.V. Kononov	TUD	Application of radiation emitted by moving photothermal sources to non-destructive inspection
Ir. V. Kouznetsova	TU/e	Multi-scale constitutive modelling
Ir. E.A.D. Lamers	UT	Finite elements modelling of fabric draping
Ir. Q Liu	UT	Friction calculations and experiments in the mixed lubrication regime
Ir. R. Loendersloot	UT	Resin transfer moulding of high performance composites
Ir. M.A. Masen	UT	Failure of sheet metal forming tools due to abrasive wear
Ir. J. Mediavilla	TU/e	From ductile damage to ductile fracture in forming processes
Mr. C. Michler	TUD	A space-time finite element flow solver for fluid-structure interaction
Ir. P. Mohanty	TUD	Measuring sweet spots of tennis rackets
Ir. E.A. Munts	TUD	Large eddy simulations
Ir. M.H.H. Oude Nijhuis	UT	Actuator optimization for active structural acoustic control
Ir. H.R. Pasaribu	UT	Combined mechanical and thermal severity index
Ir. E.A.G. Peeters	TU/e	Measuring dynamic mechanical properties of individual skeletal muscle cells
Ir. S. Postma	UT	Penetration control in laser welding of sheet metal using optical sensors
Ir. J. Remmers	TUD	Analysis of delamination growth with discontinuous finite elements
Ir. R.A. van Rooij	TU/e	Methodology: Dealing with design uncertainties
Ir. M.J. de Ruiter	TUD	Combining the topology description function with optimization tools
Dr. G. Santoboni	TU/e	Symmetry and partial synchronization of coupled oscillators
Dr.Ir. D.J. Schipper	UT	Sheet metal forming of tailor made blanks
Ir. A.L. Schwab	TUD	Why walking robots fall down
Ir. H. Super	UT	Hybrid isolation of structure borne sound
Mr. Y.C. Taşan	UT	Measuring of wear on roughness level
M.Sc. B Tasić	TU/e	The flow methods
Ir. H.G. Tillema	SKF	Validation of an airborne noise toolbox
Ir. R.L.J.M. Ubachs	TU/e	Microstructural evolution of solder joints

Name	Univ.	Title
Ir. K. Vervenne	TUD	Gradient based response surfaces
Ir. E.M. Viatkina	TU/e	Forming limit diagrams for sheet deformation processes
Ir. R.R. Waiboer	UT	Robot identification for dynamic simulation
Ir. A.P.D. Weustink	TUD	Filament winding using in situ impregnated fibre bundles with thermoplastic polymer
Ir. S. Wijskamp	UT	Warping of rubber pressed composite panels
Mr. D. Yang	TUD	Investigation on flip chip solder joint fatigue with cure-dependent underfill properties
Ir. Y. Yu	UT	A displacement based formulation for stead state problems

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