engineering mechanics

Third Engineering Mechanics Symposium

20 - 21 November 2000
Rolduc, Kerkrade

Graduate School Engineering Mechanics
c/o Eindhoven University of Technology

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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 a two-day 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, a broad range of activities is on the program, such as 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 Third Engineering Mechanics Symposium takes place on November 20th and 21st, 2000, at Rolduc - Kerkrade. In the opening session Prof.Dr.-Ing. E. Ramm, from the University of Stuttgart, Germany will present a keynote lecture entitled: Structural Optimization – The Interaction between Form and Mechanics.

Furthermore, there are the following topic sessions:

- Biomechanics,
  organized by Peter Bovendeerd (TU/e) and Fred van Keulen (TUD),
- Mechanics of Materials,
  organized by Miguel Gutiérrez (TUD), Ron Peerlings (TU/e) and Bert Geijselaers (UT)
- Vibrations and Noise,
  organized by Daniel Rixen (TUD), Bert Verbeek (TU/e) and Peter van der Hoogt (UT).

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 21st.

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. P. van den Berg (Delft Geotechnics), Ir.Drs. P.D. van der Koogh (TNO-Automotive Delft and Stan Ackermans Institute, TU/e, Eindhoven) Drs. N.J.W. Thijssen (Corus R&D, IJmuiden). Winners will be announced at the evening session of the symposium on Monday, November 20th.

On Tuesday November 21st a meeting of the senior academic staff participating in Engineering Mechanics takes place. Topics regarding 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 Third 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 Third 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, November 20th, 2000		
10.30-11.00	Registration and informal get-together	
11.00-12.10	**Session 1: Opening Session**	
11.00-11.10	Opening of the Symposium: Prof.Dr.Ir. R. de Borst (TUD)	
11.10-12.10	Opening Lecture: Prof.Dr.-Ing. E. Ramm, University of Stuttgart, Germany Structural Optimization – The Interaction of Form and Mechanics	Page 8
12.15-13.25	Lunch	
13.30-15.20	**Session 2: Biomechanics** **Session organizers: Bovendeerd (TU/e), v. Keulen (TUD)**	
13.30-14.00	Introduction by Dr.Ir. P.H.M. Bovendeerd (TU/e): Biomechanics within Engineering Mechanics	Page 9
14.00-14.20	Ir. Martijn Wisse (TUD): A Bi-Pedal Walking Robot: Simulations and Design	Page 26
14.20-14.40	Ir. Liesbeth Geerts-Ossevoort (TU/e): Form Follows Function: Cardiac Fiber Orientation in Response to Changed Mechanics.	Page 13
14.40-15.00	Ir. Chris van Oijen (TU/e): Numerical Modeling of NonlinearAnisotropic Incompressible Materials	Page 19
15.00-15.20	Ir. Jurgen de Hart (TU/e): Fluid-Structure Interaction in the Aortic Heart Valve	Page 14
15.20-15.50	Break	
15.50-17.35	**Poster Session:** **Presentation of current research projects, carried out by PhD- and Twaio-students participating in Engineering Mechanics**	Page 27
17.35-18.05	Informal reception	
18.05-19.35	Dinner	
19.45-21.30	**Poster Session:** **Presentation of current research projects, carried out by PhD- and Twaio-students participating in Engineering Mechanics.** **Announcement of winning contributions in the poster contest**	Page 27
21.30-01.00	Bar “De Verloren Zoon”	

Tuesday, November 21st, 2000		
08.00-09.00	Breakfast	
09.00-12.10	**Session 3: Mechanics of Materials** **Session organizers: Gutiérrez (TUD), Peerlings (TU/e), Geijselaers (UT)**	
09.00-09.20	Introduction by Dr. M.A. Gutiérez (TUD): Composites	Page 10
09.20-09.40	Ir. Ingrid Schipperen (TUD): Delamination in Fibre Reinforced Plastics	Page 21
09.40-10.00	Ir. Sebastiaan Wijskamp (UT): Modeling of Residual Stresses in Rubber Pressed Composite Products	Page 25
10.00-10.30	Break	
10.30-10.40	Introduction by Ir. H.J.M. Geijselaers (UT): Micromechanics	Page 10
10.40-11.00	Ir. Bernard Schrauwen (TU/e): Toughness Enhancement of Semi-Crystalline Polymers	Page 22
11.00-11.20	Ir. Varvara Kouznetsova (TU/e): Micro-Macro Modeling of Heterogeneous Materials	Page 18
11.20-11.30	Introduction by Dr.Ir. R.H.J. Peerlings (TU/e): Modeling and Applications	Page 10
11.30-11.50	Ir. Garth Wells (TUD): Modeling Discontinuities in Solid Mechanics	Page 24
11.50-12.10	Ir. Benoit Jacod (UT): A Generalized Traction Curve for EHL Contacts	Page 15
12.10-13.20	Lunch	
13.30-15.20	**Session 4: Vibrations and Noise** **Session organisers: Rixen (TUD), Verbeek (TU/e),** **V.d. Hoogt (UT)**	
13.30-14.00	Introduction by Prof.Dr.Ir. D.J. Rixen (TUD): Vibro-Acoustics in Engineering Practice and Research	Page 11
14.00-14.20	Ir. Peter Kessels (TU/e): Noise Reduction for MRI Scanners	Page 17
14.20-14.40	Ir. Marco Oude Nijhuis (UT): Active Noise and Vibration Control using Piezoelectric Sensors and Actuators	Page 20
14.40-15.00	Ir. Eelco Jansen (TUD): Nonlinear Vibration of Composite Cylindrical Shells	Page 16
15.00-15.20	Ir. René Visser (UT): Acoustic Imaging	Page 23
15.20-15.40	Break	
15.40-15.50	**Announcement of the winning contribution in the AIO Presentation contest**	
15.50-16.00	Closure	
16.00-17.00	**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. Ramm, University of Stuttgart, 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:

Structural Optimization - The Interaction of Form and Mechanics

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Usually mechanical laws are applied for a prescribed design of a structure in order to determine its response. The external loads, boundary conditions, and also the geometry, which is defined by the topology and the shape of the structure, are given. However, the mechanical principles can also be used to determine the conceptual layout (topology) and shape of structures for a prescribed structural response. This inverse method is called 'Structural Optimization'. Since structural optimization problems deal in general with nonlinear and implicit functionals with respect to the variables, only numerical methods are suitable to solve application-oriented problems in engineering design. Structural optimization can be distinguished into topology, shape, sizing, and material optimization depending on what is varied during the optimization process.

But the value of optimization results in the design of structures strongly depends on the relevance of the underlying mechanical and numerical model. For example a key question is how good the level of the chosen kinematic relation or the underlying material model are able to represent the real behavior of the structure. The quality of the selected models can be increased applying adaptive techniques. The more the mechanical model is simplified by assumptions, for example neglecting nonlinear effects or by approximating the in general 3-dimensional structural layouts and/or stress state by 1- or 2-dimensional models, the less meaningful and the more sensitive the optimization results may be.

For gradient based optimization procedures sensitivity information has to be provided. Depending on the kind of the mechanical problem different methods for the sensitivity analysis are applied. For path--dependent problems, like elastoplasticity, a variational approach turns out to be suitable while for problems with pure geometrically nonlinear behavior a discrete approach is favorable.

In the present contribution several topology and shape optimization problems are discussed based on different mechanical models which show on the one hand the principles of the methods and on the other hand the relevance of an appropriate mechanical model in the optimization process in order to generate reliable designs. The objective is to stress the basic features of the underlying concepts, the mechanical and numerical model rather than to demonstrate big applications.

References:

[1] M. P. Bendsøe, Optimization of structural topology, shape and material, Springer, Berlin, 1995.
[2] R. Kemmler, S. Schwarz and E. Ramm, “Topology optimization including geometrically nonlinear response", Proc. of the 3rd WCSMO, Buffalo, USA, 1999.
[3] M. Kleiber, H. Ant’unez, T. D. Hien and P. Kowalczyk, Parameter sensitivity in nonlinear mechanics: Theory and finite element computations, Wiley & Sons, Chichester, 1997.
[4] K. Maute, S. Schwarz and E. Ramm, “Adaptive topology optimization of elastoplastic structures", Structural Optimization, Vol. 15, pp. 81--91, 1998.
[5] K. Maute, S. Schwarz and E. Ramm, “Structural optimization -- The interaction between form and mechanics", ZAMM, Vol. 79, pp. 651--673, 1999.
[6] R. Reitinger and E. Ramm, “Buckling and imperfection sensitivity in the optimization of shell structures", Thin--walled Structures, Vol. 23, pp. 159--177, 1995.
[7] S. Schwarz, R. Kemmler and E. Ramm, “Shape and topology optimization with nonlinear structural response", Proc. of the ECCM, Munich, Germany, 1999.
[8] S. Schwarz, K. Maute and E. Ramm, “Topology and shape optimization for elastoplastic structural response", accepted for publication in Comput. Meth. Appl. Mech. Eng., 2000.

Session 2:

Biomechanics

P.H.M. Bovendeerd (TU/e), F. van Keulen (TUD)

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By definition, biomechanics is an interdisciplinary research area between mechanical engineering and biology/physiology. But for a long time its practical implementation has been either mechanics or biology, with a cosmetic sauce of the other discipline. With the advancement of theoretical concepts and experimental and computational facilities, a true interdisciplinary field of research has come within reach.

The universities, participating within Engineering Mechanics, each have their own biomechanics research themes. Roughly speaking, Twente and Delft concentrate on biomechanics at organism level, and the associated models are of a multibody type. In Twente, walking motion of the healthy human and the human with a leg prosthesis are studied. In Delft the mechanics of the shoulder girdle, the control of hand movement, and walking motion are important research topics. Lately, the DIPEX project was started, aimed at development of improved endoprostheses for the upper extremities, involving 8 PhDs and 4 postdocs.

Biomechanics research in Eindhoven, traditionally is focussed more at the tissue level, and associated continuum models are solved using finite element techniques. Research topics involve cardiovascular mechanics, muscle mechanics, injury biomechanics, bone mechanics and cell biomechanics.

In the introduction of the biomechanics session, an overview of the biomechanics research within Engineering Mechanics will be given, illustrated with interesting examples from the various PhD-projects. The PhD presentations, which form the main body of this session, have been selected to illustrate the advanced computational and experimental techniques that are used in the current biomechanics research.

Session 3:

Mechanics of Materials

H.J.M. Geijselaers (UT), M. Gutiérrez (TUD), R.H.J. Peerlings (TU/e)

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A broad selection of activities may be posted under the heading “Mechanics of Materials”. The presentations in this session reflect the wide scope of the subject.
On the EM homepage a definition of Mechanics of Materials is given as prediction and description of behavior of structural materials.

Fibre reinforced composites are a classical example of heterogeneous materials. Continuum properties are derived from the properties of the constituents. However some phenomena on the scale of the interaction between fibers and matrix or between individual layers greatly influence the overall performance. Residual stresses and edge effects are covered in the presentations by Wijskamp and Schipperen.

The prediction of macroscopic behavior from microscopic features is another interesting area. The talk by Kouznetsova deals with algorithmic aspects, whereas Schrauwen presents an application. At first sight exotic in this context, but actually fitting rather well, is the account by Jacod on endeavours to predict friction between lubricated surfaces with a realistic surface topology.

When the macroscopic behavior of materials exhibits softening, due to damage or localized plasticity, difficulties are encountered when a mathematical description suitable for computational modeling is desired. In the lecture by Wells some of these difficulties and remedies to them will be presented.

Other activities within the Engineering Mechanics school in the field of Mechanics of Materials, which are not presented in an oral presentation, will be dealt with in short presentations by the session organizers.

Session 4:

Vibrations and Noise

D.J. Rixen (TUD), G.Verbeek (TU/e), P.J.M.v.d. Hoogt (UT)

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Introduction

The field of vibro-acoustics tackles the coupled problem where small oscillations in a fluid generate excitations on a structure and where, in turn the vibration of a structure creates oscillations in the fluid. As for all multi-physical topics, the interest in vibro-acoustics has been boosted by the surging demand for detail modelization and by the advent of efficient numerical techniques and powerful computers allowing accurate analyses. Vibro-acoustics plays an important role in many mechanical fields such as design and control, bio-mechanics, fatigue analysis, structural optimization, damage monitoring and inverse radiation problems. Hence, since many mechanical engineers will be confronted to coupled acoustics and vibrations, we will give a general introduction to the field.

Formulation of the vibro-acoustical problem

The equation for small oscillations in a fluid is derived from the basic equations of fluid mechanics (conservation of mass and momentum, and thermodynamics of the fluid): the variation of the pressure field *p* is governed by the Helmholtz equation

$$\Delta p = \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2}$$

where *c* is the propagation speed and Δ is the Laplace operator. This equation is very similar to the linear equations for structural vibrations except that oscillations in the acoustic domain are described by the single pressure variable whereas in a structure, displacement fields in every direction must be considered in general. The coupling between the fluid and the structure is expressed by equating the velocities on the interface and by stating that the fluid pressure is acting as a force on the structure. The discretization by finite or boundary elements then leads to the non-symmetric matrix form

$$\begin{bmatrix} M_{fluid} & M_{fluid-struct} \\ 0 & M_{structure} \end{bmatrix}\begin{bmatrix} \ddot{p} \\ \ddot{u} \end{bmatrix} + \begin{bmatrix} C_{fluid} & 0 \\ 0 & C_{structure} \end{bmatrix}\begin{bmatrix} \dot{p} \\ \dot{u} \end{bmatrix} + \begin{bmatrix} K_{fluid} & 0 \\ K_{fluid-struct} & K_{structure} \end{bmatrix}\begin{bmatrix} p \\ u \end{bmatrix} = F$$

where *u* are the structural degrees of freedom. While in most vibration problems the structural behavior can be represented by a few modes, the modal density of vibro-acoustical models is so high that classical modal analysis may not be applicable. Also, the acoustic domain must often be discretized either by a very fine finite element mesh or by boundary elements, thus resulting in very large or dense systems that must be solved by specific procedures.

In our presentation, we will briefly outline common numerical and experimental techniques and show applications. In particular, we will indicate the research in vibro-acoustics currently undertaken within the Graduate School of Engineering Mechanics.

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ABSTRACTS OF PRESENTATIONS

This section contains abstracts of presentations at the Third 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.

Form Follows Function

Cardiac Fiber Orientation in Response to Changed Mechanics.

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Numerical studies have shown that the distribution of fiber stress and strain is very sensitive to fiber orientation [1]. Considering that in a normal left ventricle, geometry and fiber orientation are such that mechanical workload is uniform, we hypothesize that long-term disturbance of local mechanics leads to structural changes in fiber orientation. This hypothesis is tested by induction of an infarction in the goat heart, where fibers in the region adjacent to the stiff infarction are impeded.

An infarct was induced in 2 goats, the local mechanics were assessed using MR Tagging. The fiber orientation was determined in 5 healthy goats and in the 2 infarcted goats using Diffusion Tensor Imaging (DTI). Results of the MR tagging measurements 6 weeks post infarction indicate impaired contraction in the region adjacent to the infarction as compared with normal. The DTI measurements of fiber direction show deviations in the fiber course 10 weeks post infarction in the same region.

Therefore we conclude that long-term disturbance of local mechanical load leads to structural changes of the fiber field. Main question that now remains is whether these changes in fiber course are adaptive in nature.

Reference:

[1] P.H.M. Bovendeerd *et al*. (1992) Dependence of local left ventricular wall mechanics on myocardial fiber orientation: A model study. Journal of Biomechanics , 25(10), pp. 1129-1140

Fluid-Structure Interaction in the Aortic Heart Valve

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Introduction

The opening and closing behavior of the valve is a delicate interaction between blood flow and geometrical and stiffness properties of the heart valve leaflets and aortic root. Numerical analysis of the opening and closing behavior is complicated by the three-dimensional finite motion of the very flexible leaflets in a compliant system of fluid and structure. Fluid-structure interaction models of the heart valve have been developed before, e.g. see Peskin & McQueen [1] and Horsten [2]. However, none of these models was able to analyse the physiological condition in which the valve functions because of numerical artefacts. The Fictitious Domain/Arbitrary Lagrange-Euler method is introduced, which allows numerical modeling of valves under physiological conditions.

Methods

In modeling fluid-structure interaction, the fluid domain is most conveniently described with respect to an Eulerian reference frame while a Lagrangian formulation is more appropriate for the structure domain. However, these formulations are incompatible. A solution to this problem is the use of an Arbitrary Lagrange-Euler (ALE) formulation. It involves a continuous adaptation of the fluid mesh without modifying its topology. This method is used to describe the expansion of the aortic wall caused by internal fluid pressures. However, with respect to the large leaflet motion within the computational fluid domain it is generally difficult, if not impossible, to adapt the fluid mesh in such a way that a proper mesh quality is maintained without changing the topology. Alternatively, remeshing can be performed, either continuously, using a Lagrangian formulation, or in conjunction with an ALE formulation, where remeshing is performed if the mesh quality has degenerated too much. Remeshing, however, not only introduces artificial diffusivity, it also may be difficult to perform with sufficient robustness and accuracy for three-dimensional problems. To solve this problem a Fictitious Domain method is used where the fluid is described in an Eulerian setting, and the structure in a Lagrangian setting, allowing the use of commercial available software. The method is based on the imposition of velocity constraints associated with moving internal boundaries by means of Lagrange multipliers.

Results

The method of Fictitious Domain (FD) has been tested on a two-dimensional model of the aortic valve [3]. The model has been validated experimentally using Laser Doppler Anemometry and digitized High-Speed video recordings to visualize the fluid flow and leaflet motion in corresponding geometries. Results show that both the fluid and leaflet behavior are well predicted for a different range of leaflet thickness. The implementation towards three-dimensional valve models of flexible leaflets within a compliant aortic root, using this new combined FD/ALE technique, is currently under investigation.

References

[1] Peskin & McQueen, 1994. Mechanical equilibrium determines the fractal fiber architecture of the aortic heart valve leaflets. American Journal of Physiology 35, 319-328.
[2] Horsten, 1990. On the analysis of moving heart valves: a numerical fluid-structure interaction model. PhD. Thesis, Eindhoven University of Technology.
[3] De Hart, 2000. A two-dimensional fluid-structure interaction model of the aortic valve. Journal of Biomechanics 33, 1079-1088.

A Generalized Traction Curve for EHL Contacts

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In this presentation the subject of friction prediction is revisited with the aim to obtain a general formula predicting the coefficient of friction over a wide range of operating conditions. By means of full numerical simulations of the smooth isothermal elliptic contact and assuming Eyring non-Newtonian behavior, the coefficient of friction has been computed for a wide range of operating conditions.

It is shown that with respect to sliding friction, all results can be presented on a single generalized friction curve relating a reduced coefficient of friction to a characteristic non-dimensional shear stress. Finally, it is shown that some measured data presented in the literature when presented in terms of the derived parameters closely follow the derived behavior, which provides validation to the theoretical results.

Nonlinear Vibrations of Composite Cylindrical Shells

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A theoretical investigation of the nonlinear flexural vibration behavior of thin-walled composite cylindrical shells is presented. Theoretical models with different levels of complexity have been developed, which capture several characteristic aspects of this behavior (the coupling between asymmetric and axisymmetric modes and the possibility of circumferentially travelling waves). They can be used to study the influence of important parameters (geometric imperfections, static loading and boundary conditions). Nonlinear Donnell-type governing equations have been adopted in combination with classical laminate theory. The shell is statically loaded by axial compression, radial pressure, and torsion.

First, the stationary nonlinear flexural vibrations of imperfect anisotropic cylindrical shells under harmonic lateral excitation have been studied via a Level-1 Analysis or `Simplified Analysis'. In this analysis, a small number of assumed modes, which approximately satisfy simply supported boundary conditions, is used in a Galerkin procedure. Galerkin's method and the method of averaging are applied in sequence to obtain frequency-amplitude curves for free and forced nonlinear vibrations. Results of the nonlinear vibrations of isotropic and orthotropic cylinders are presented. The effect of imperfections on the vibrations of an anisotropic cylinder is discussed.

The effect of the boundary conditions at the shell edges on the flexural vibration behavior of composite cylindrical shells is assessed via a Level-2 Analysis or `Extended Analysis'. In this analysis, the specified boundary conditions are accurately satisfied by means of numerical solution of corresponding two-point boundary value problems. The effect of finite amplitudes is investigated via a perturbation expansion for both the frequency parameter and the dependent variables. Imperfections and a nonlinear static deformation are included in the formulation. The specified boundary conditions are satisfied rigorously by solving the resulting two-point boundary value problems numerically via the parallel shooting method. Numerical results show the effects of different sets of boundary conditions on the nonlinear vibration behavior of (composite) cylindrical shells.

Noise Reduction for MRI Scanners

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Introduction

MRI (Magnetic Resonance Imaging) is a non-invasive technique used to display internal structures. In medicine, MRI-scanners are applied as a diagnostic tool, able to make images of bones, tissue and blood flow. While image quality and operational speed have been advanced to their limits, sound radiation has remained a problem. As it will grow to excessive levels in future devices, the noise problem has become a main issue in MRI research and development.

Research project

While the noise problem has been a concern for a long time, solutions have been less obvious. Computational tools and knowledge needed to analyze sound problems for a device as complex as MRI scanners and for other noise producing structures have not been available. In order to close this gap, a research project has been conducted at the Eindhoven University of Technology in cooperation with Philips Medical Systems. The main goal of this project is to supply computer-aided tools and modeling directives to support engineers in including structural-acoustics in the design stages.

Future research

The single most important way of improving the usefulness of numerical tools in structural acoustics, is the development of stochastic analysis tools. Two ways in which an engineer could benefit from such an enhancement can be distinguished. Firstly, it would help the engineer in taking variations in material behavior and fabrication inaccuracies into account during the design process. Secondly, structural details could be smeared out in the models by assigning averages and variances to parameters of a coarser model. In the computations, more uncertainty in the model's response are acceptable, provided that the CPU-times can be reduced sufficiently. For applications in which products exhibit structural complexity, this would make numerical tools become viable earlier. Current developments in which the variances of the stochastic parameters are linearized will not suffice, since only small variances can be handled when such methods are used. For a general framework, numerical operations, such as multiplication and integration, on stochastic variables will have to be developed and implemented.

Micro-Macro Modelling of Heterogeneous Materials

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Most of the materials utilized in industry are heterogeneous. Examples are metal alloy systems with a second phase in the form of precipitates, polycrystalline materials and composites. The mechanical and thermal behavior of these materials strongly depends on the size, shape, properties and spatial distribution of the second phase. Therefore it is very important to introduce the microstructural information into the modeling of the macroscopic behavior of heterogeneous materials. For the solution a variety of homogenization techniques is available, but usually they take into account only a few of the microstructural features mentioned above and most of them are not suitable for large deformations (and large rotations), history dependent material behavior and non-uniform loading. A feasible and generally applicable modeling strategy is achieved by the multi-level micro-macro approach. A particular procedure has been proposed by Smit *et al.* [1], which is developed in the present work.

In this method the physical and geometrical properties of the microstructure are identified by a Representative Volume Element (RVE) and for each integration point of the macromesh a separate finite element computation on the RVE, assigned to this integration point, is performed. From the macroscopic deformation tensor the appropriate boundary conditions are derived and imposed on the RVE. The macroscopic stress tensor is obtained by averaging the resulting RVE stress field over the volume of the RVE. The consistent tangential macroscopic stiffness matrix at a macroscopic integration point is derived from the total RVE stiffness matrix by reducing the latter to the relation between the forces acting on the vertices of the RVE and displacements of these vertices. When using this approach there is no need to specify any macroscopic constitutive behavior, which, in the case of large deformations and complex microstructures, would be a hardly feasible task generally. Instead, the averaged constitutive behavior in the macroscopic integration point is determined by the behavior of the microstructure, assigned to the macropoint.

As an example the method is applied to numerically simulate pure bending of a microscopically heterogeneous metal sheet. The local material behavior at the RVE level is described by the elasto-visco-plastic Bodner-Partom model in the context of finite kinematics. The method (i) provides the possibility to introduce the microstructural information in the macrostructural analysis, (ii) enables the incorporation of large deformations and large rotations and (iii) is suitable to incorporate arbitrary material behavior, including characterizations with physical nonlinearities and time dependence. However, in the presented above formulation the method (as well as the other similar approaches, introduced by the other authors) is completely insensitive to the microstructural size. Some prospects of the incorporation of the size effects into the micro-macro modeling are discussed.

Reference

[1] R.J.M. Smit, W.A.M. Brekelmans and H.E.H. Meijer. Prediction of the mechanical behaviour of nonlinear heterogeneous systems by multi-level finite element modelling. *Comput. Methods Appl. Mech. Engrg.*, 155:181-192, (1998)

Numerical Modeling of Nonlinear Anisotropic Incompressible Materials

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Introduction

In vascular computational mechanics one often has to deal with highly nonlinear incompressible materials which show large amounts of anisotropy. Physically such materials consist of a matrix material and several oriented layers of fibers.
When the Finite Element Method is used to model such complex materials several problems are encountered. The use of a mixed formulation gives better results for incompressible materials, but the combination of anisotropy and nonlinear incompressible properties causes difficulties. A way of modeling these composite materials has been developed to make implementation in FEM code easy and allow for extension to more complex material properties such as viscoelastic materials and fiber contraction.

Method

Concept

The concept of the composite model is similar to the classical composite lamina theory: anisotropy is introduced by adding a layer with other material properties with possible different principle material directions. This concept is expanded by allowing multiple layers, which in each point can have different material properties and/or principle directions.
Each layer is modeled as a one-dimensional material. Because all properties related to the fiber material only work in the local fiber direction, some precaution must be taken.

Implementation

In a mixed Updated Lagrange formulation the Cauchy stress is splitted into a hydrostatic part and an extra stress tensor. To incorporate the anisotropic behavior the extra stress tensor is written as a rotation of the stress difference between the fiber and the matrix in the local direction to the global direction. As the material is modeled with a one-dimensional constitutive law only the (1,1)-component of the volume fraction tensor the tensor will be filled. The tangential stiffness is derived from the derivative of the stress with respect to the deformation gradient.

Results

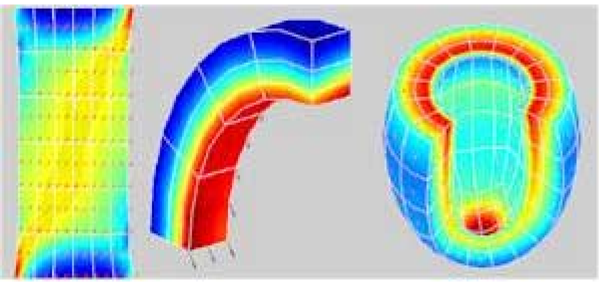

Figure 1: Results of simulations with different geometries
(left: flat plate, center: tube, right: heart)

Active Noise and Vibration Control using Piezoelectric Sensors and Actuators

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Active noise and vibration control can adapt the response of mechanical systems to external disturbances. For instance sound radiation into free space or sound levels in acoustic enclosures can be reduced with active noise control systems. Typical problems, which can be tackled with active vibration control, are enhancement of the comfort in cars or trains and the reduction of vibration levels of flexible robot arms. An active noise or vibration control system typically consists of *sensors* to measure the response, *actuators* to modify the response, and a *controller* to calculate the appropriate actuator signal from the sensor signal.

Materials showing *piezoelectric* behavior produce an electrical charge on the material surface when subjected to a mechanical stress. Furthermore the opposite effect also occurs: when an electric field is applied the material changes its shape and size. For these reasons, piezoelectric materials can be used in active noise and vibration control systems both as sensors and actuators.

In many noise and vibration problems the structural vibration patterns that have to be reduced are determined by bending or transverse modes. In those cases piezoelectric patches, which are bonded to the structure can serve as distributed sensors and actuators (see Figure 1). When a voltage is applied across the electrodes the patch will induce a strain and deform the structure. In the opposite case when the patch is used as a sensor, a strain in the structure will result in an electric field.

In order to successfully implement a control system, the interaction between the applied or measured electric field and the deformation of the structure has to be known. Therefore dynamical models, which describe the piezoelectric coupling, have been developed. A simple test case was studied consisting of a clamped beam with two piezoelectric patches. An analytical model and a finite element model of the system were compared and a good agreement was found. Furthermore the numerical results were validated with experimental results. For the test case a feedback controller was designed to reduce the vibration level of the beam.

Figure 1: Piezoelectric patch bonded to a beam

Reference

[1] Fuller, C.R., Elliott, S.J., Nelson, P.A., (1996) Active Control of Vibration, Academic Press.

Delamination in Fibre Reinforced Plastics

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Nearly in every structure free edges or cut-outs occur. When fibre reinforced plastic laminates are used for such a structure the risk of delamination in the areas near these free edges or cut-outs arises due to stress concentrations. This phenomenon is one of the main failure mechanisms of laminated composites and has therefore been the subject of much research since the early 1970s. Besides experimental research also much effort is put into the development of numerical tools for the description of delamination. In this presentation several material models which can be utilized in a finite element analysis are discussed. Normally the delamination is divided into pure mode-I delamination, which occurs in the midplane of a symmetric laminate and mixed-mode delamination. For both types material models have been developed and analyses of laminated strips using these models have been compared to experiments. For a numerical model to be efficient, not only the actual results have to match the experiments, but the model should also be robust, numerically stable, easy to implement and of course take as little computational time as possible. To achieve this several analyses have been performed in which both the geometrical modeling of a specimen and the formalistic base of the physical model are varied.

Toughness Enhancement of Semi-Crystalline Polymers

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Most semi-crystalline polymers are ductile, but start to behave brittle under severe conditions: high deformation rate and low temperature. It is known that impact toughness of both amorphous and semi-crystalline polymers can be increased by rubber modification. The disadvantage of these heterogeneous systems is that due to the lower elastic modulus of the rubber, the stiffness of the total system decreases.
For semi-crystalline polymers modification with certain hard filler particles also results in an increase in toughness. In this case the elastic modulus of the total system increases as well, so both toughness and stiffness are improved.

Recently the toughening mechanism for heterogeneous semi-crystalline polymer systems was postulated by A.S. Argon (MIT) [1]. This toughening mechanism is based on the idee that an interface is formed around the filled inclusions (rubber or hard filler), which consists of preferentially oriented crystalline lamellae, having a reduced plastic shear resistance in the crystal planes parallel to the filler surface. Because of this, upon cavitation or debonding of the particles, the regions around these formed cavities can undergo large shear deformation. If the ligament thickness between the inclusions is small enough for these oriented lamellae to bridge between the particles this low shear resistance behavior percolates throughout the structure and toughness is enhanced.

The existence of a crystal oriented layer in HDPE on a substrate surface has been investigated by using multi layer systems of alternating layers of HDPE and a substrate material. With Wide Angle X-ray Diffraction an increase in crystal orientation was found for a reducing thickness of the HDPE layers, indicating the presence of a preferentially oriented crystalline lamellae layer.
From experiments with hard filler modified systems of HDPE it can be concluded that an increase in toughness depends on processing related conditions like flow history and cooling rate. For verification of the postulated toughening mechanism the influence of these processing conditions on the crystallization behavior needs to be investigated.

Reference

[1] Z. Bartczak, A.S. Argon, R.E. Cohen, M. Weinberg. Toughness mechanism in semi-crystalline polymer blends: II. High-density polyethylene toughened with calcium carbonate filer particles. *Polymer*, vol. 40, 2347-2365, (1999)

Acoustic Imaging

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Introduction

Increasingly stricter government regulations and customer demands require silent products. As a consequence, manufacturers need to be able to predict and validate the sound field generated by their products to comply with legislation and customer requirements.

The current research focuses on the development of efficient measurement techniques and numerical algorithms to predict sound fields and corresponding surface velocity patterns of acoustic sources. The acoustic measurements will be performed with a novel acoustic velocity sensor, the microflown (Figure 1), invented by de Bree [1] at the University of Twente. Numerical algorithms will use these measurements to reconstruct the total sound field surrounding the product. With this information, modifications to the original product can be made to manipulate the acoustic field (e.g. minimize the radiated power).

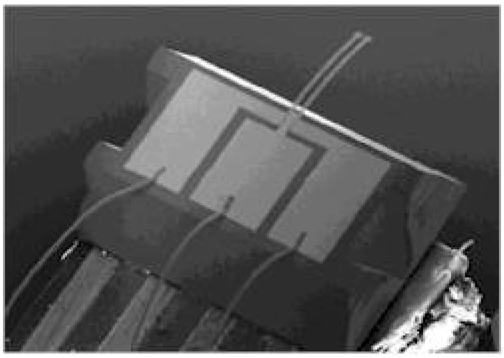

Figure 1: Microflown (≈ 2x2 mm).

Methods

When the surface vibrations of the acoustic source are known, it is possible to determine the sound field by direct evaluation of an integral equation. However in many cases the surface velocity pattern is unknown and inverse source identification based on acoustic measurements is needed. These inverse methods require recording of the sound field (acoustic pressure or velocity) on a measurement grid close to the surface of the acoustic source.

From these measurements the total sound field and normal velocity distribution at the source surface can be reconstructed. The current research is focused on the application of two methods: **nearfield acoustic holography** (NAH) and the **inverse frequency response function method** (IFRF).

NAH, see Williams [2], is a process which solves the inverse acoustic problem in an elegant way using fast Fourier transforms. IFRF is a more computationally intensive technique capable of solving the inverse problem even in case of an arbitrary shaped source and measurement grid. To decrease computational effort, application of fully efficient **multilevel algorithms** is investigated. Both calculation procedures tend to be highly ill conditioned and regularization methods are necessary to obtain a physically meaningful solution.

Acknowledgements

I would like to thank the Dutch Technology Foundation (STW) for funding the project.

References

[1] de Bree, H-E. (1997) The Micro own, PhD-thesis, University ofTwente.
[2] Williams, E.G. (1999) Fourier Acoustics, Washington D.C., Academic Press.

Modelling Discontinuities in Solid Mechanics

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Discontinuities arise in many different problems in mechanics. In some cases, a discontinuity is part of the exact solution, while in other cases a discontinuity is used to approximate a continuous field which has a very high gradient across a small length. This presentation will focus on computational methods for modelling discontinuities when the location of discontinuities is not known *a priori*.

The failure of solids is usually characterised by the appearance of discontinuities. A crack in an elastic solid is the most obvious example. Another examples is a shear band. At one scale of observation, a shear band can be represented as a jump in the strain field across a finite width, while at another scale it can be considered as a displacement discontinuity across a surface. This is a case where a continuous field with high gradients across a small zone can be approximated as a discontinuity. Computationally, discontinuities can be captured by including discontinuous functions in the span of the basis used for interpolating a field. With the finite element method, including functions is the underlying basis allows discontinuities to propagate arbitrarily in a body, independent of the mesh structure. The key to including discontinuous functions in the underlying basis is treating finite element shape functions as *partitions of unity*. This special property, which requires that a collection of continuous functions sum to unity everywhere in a body, allows the underlying basis to be locally enriched during a calculation by adding extra degrees of freedom to existing nodes. It will be shown that this method can be used to simulate discontinuities, completely independent of the finite element mesh structure and element size. The method is illustrated for mode-I (tension) and mode-II (shear) type failure problems under both quasi-static and dynamic loading.

Modelling of Residual Stresses in Rubber Pressed Composite Products

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Continuous-fibre-reinforced thermoplastic composites are increasingly used in demanding applications in, for example, the aerospace industry. The use of specialty thermoplastics such as polyetherimide (PEI), polyphenylenesulfide (PPS) and polyether-etherketone (PEEK) reinforced with glass, carbon or aramid fibres results in solvent and corrosion resistant products with high specific stiffness and high melting temperature. These composites can be moulded into complicated shapes with the rubber pressing process where a relatively hot laminate is shortly pressed between a cold rubber mould and a cold steel tool. The process is fast compared to the forming of thermosetting polymer matrix composites where extensive curing times are involved.

During the moulding, residual stresses build up that cause unwanted distortions of the final product. These stresses are caused by anisotropic shrinkage and non-symmetric process conditions. The anisotropic shrinkage can be thermally induced or it can be a result of crystallization. The upper and lower mould induce non-symmetrical process conditions: the former is a highly deformable elastomeric with a very low thermal conductivity, whereas the latter is made from high stiffness steel with a high thermal conductivity. As a result, the laminate exhibits a non-uniform temperature profile through the thickness during moulding, and has different mechanical boundary conditions on the top and bottom side.

The objective is to model the build-up of residual stresses in carbon fabric reinforced PPS (a semi-crystalline polymer) during moulding and the shape distortions they cause in the final product. The geometry of the moulding tool can then be compensated for the distortions, resulting in a “first time right”-design of the tool.

Previous studies [1] showed that the largest part (75%) of the residual stresses is induced by anisotropic shrinkage. Now, the attention is focused on the stresses due to the temperature profile during pressing and the resulting morphology. This profile is computed by solving the one-dimensional heat transfer problem with the crystallization kinetics using an explicit finite difference method. Subsequently, the evolution in time of the internal stress profile is solved, resulting in the final residual stress profile when the product is released from the mould.

The results from both the heat transfer simulation and the stress computations need to be verified by an experimental program, involving the measurement of the temperature profile and residual stress measurements on simple geometries. In the future, FE will be applied to include thermal contact and the non-symmetric mechanical boundary conditions.

Reference

[1] S. Wijskamp, E.A.D. Lamers & R. Akkerman, Effects of out-of-plane properties on distortions of composite panels, in: A.G. Gibson (editor), *International Conference on Fibre Reinforced Composites FRC2000*, Woodhead Publishing Ltd., 2000

A Bi-Pedal Walking Robot: Simulations and Design

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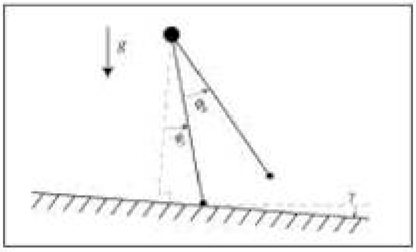
Human-like walking robots have been a hot research topic for over 50 years. Two important potential benefactors of this field of research are rehabilitation research (prosthetics/orthotics) and the entertainment industry. Both applications have specific demands to walking machines. They need to be lightweight, energy-efficient, and simple in construction and control. Thus far, emphasis has been on creating highly controlled machines trying to mimic the human walking motion. Instead, we propose to look at walking from an EM perspective. Our walking robot designs are based on our understanding of the underlying dynamics of the human walking motion; basically a set of free swinging pendulums.

Bipedal (=two-legged) walking can be reduced to its essential form; two rigid legs, interconnected by a passive hinge. Carefully designed, a machine like this is able to walk down a shallow slope, with no controls or motors at all. Small energy losses due to the fully inelastic heelstrike collision are compensated for by gravitational energy, thus allowing the model to sustain cyclic gait.



In its most simple form, we get a non-dimensionalized model with only one free design parameter; the angle of the slope of the walking surface. Garcia *et al.* described this ‘simplest walking model’ and performed an elaborate stability analysis. For this a limit cycle analysis is used, focussing on a cyclic (self-repeating) walking motion and small disturbances there upon. We extended their analysis, identifying the behavior resulting from large disturbances. For some initial conditions (leg angles/angular velocities) the robot will fall over, for others it will settle into a stable cyclic gait. The set of initial conditions resulting in stable gait is called the ‘basin of attraction’. The research presented here shows the boundaries of the basin of attraction, and classifies the failing mechanisms occurring outside the basin of attraction (falling forwards, backwards, tripping in mid-stance, etc.).

Using the results from this research, we can identify the most troublesome failure modes, and introduce appropriate stabilizing reflexes. Once successful in simulation, these reflexive controls will be applied to our new passive dynamic walker, which is currently under construction. The new robot will be a combination of the successful features of previous robots developed at our laboratory.

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.	Short description
Ir. T.G.H. Basten	UT	Damping Structural Vibrations by Vortex Shedding
Ir. C.A.J. Beijers	UT	Hybrid Isolation of Structure Borne Sound
Ir. E.M.H. Bosboom	TU/e	Passive Transverse Properties of Skeletal Muscle
Ir. H.L.A. van den Bosch	TU/e	Modelling and Specifications for an Improved Helmet Design
Ir. D.W.A. Brands	TU/e	Silicon Gel, a Mechanical Brain Tissue Model?
Ir. R.G.M. Breuls	TU/e	On Day 8, There Were Muscles …
Drs. W.D. Drenth	TU/e	On Preconditioning Techniques for Problems with Inhomogeneities
Ir. F.J.M. van der Eerden	UT	Sound Absorption for a Predefined Frequency Range
Ir. R.A.B. Engelen	TU/e	Gradient-Enhanced Ductile Damage Formulation
Ir. L.P. Evers	TU/e	Meso-Scale Crystel Plasticity Model with Plastic Strain Gradient Induced Grain Size Dependency
Dr. J. Fatemi & Ing. J.R. van Deursen	TUD	Fixation of the Edoprosthesis
Ir. L. Geerts-Ossevoort	TU/e	Form Follows Function: Cardiac Fiber Orientation in Response to Changed Mechanics
Ir. J. de Hart	TU/e	Fluid-Structure Interaction in the Aortic Heart Valve
Ir. O.M. Heeres	TUD	Modern Strategies for Finite Element Analysis of Soils under Cyclic and Transient Loading
Ir. F.M. Hendriks	TU/e	Mechanical Properties of Different Layers of Human Skin
Ir. L.H. van den Heuvel	TU/e	Mechanical Aspects of Cardiac Interventions
Ir. C. van 't Hof	TUD	Mechanical Characterization of Curing Thermosets
Ir. M.J. van der Horst	TU/e	Head-Neck Response During Acceleration Impacts: Phase 3
Ir. S.H.M.J. Houben	TU/e	The Periodic Steady State of a Free-running Oscillator
Ir. J.H. Jacobs	TU/e	ADOPT: Sequential Approximate Design Optimization: Application to Discrete-Event Simulation of Manufacturing Systems
M.Sc. B. Jacod	UT	Friction in EHL Contacts
Ir. E.L. Jansen	TUD	Nonlinear Vibrations of Composite Cylindrical Shells
Ir. R.C.P. Kerckhoffs	TU/e	Beat it!
Ir. G. Kloosterman	UT	Simulating Contact in Forming Processes
Mr. A.V. Kononov	TUD	Application of Radiation Emitted by Moving Sources of Excitations to Non-Destructive Inspection
Dr.-Ing. E. Kuhl	TUD	Energy Conserving Time Integration Schemes in Nonlinear Structural Dynamics
Ir. E.A.D. Lamers	UT	Modelling the Distortions of Skewed Woven Fabric Reinforced Composite
Ir. M. Maenhout	TU/e	Quantification of Superficial Deformation During Contraction of the Rats Tibialis Anterior
M.Sc. V. Nefedov	TU/e	Local Defect Correction for Glass Tank Model
Ir. C.H.G.A. van Oijen	TU/e	Composite Synthetic Vascular Prosthesis Design
Ir. M.H.H. Oude Nijhuis	UT	Modelling of Piezoelectric Sensors and Actuators for Noise and Vibration Control
Ir. E.A.G. Peeters	TU/e	Pressure Sore Research on a Cellular Level
Ir. J.J.C. Remmers	TUD	Delamination Buckling in Fibre-Metal Laminates
Ir. R.A. van Rooij	TU/e	ADOPT; Sequential Approximate Design Optimizations. First Preliminary Draft of the Optimization Tool
Ir. M.J. de Ruiter	TUD	Topology Optimization using a Topology Description Function
Dr. G. Santoboni	TU/e	Coexistence and Selection due to Chaotic Advection
Ir. J.H.A. Schipperen	TUD	Failure in Laminated Graphite-Epoxies
M.Sc. A. Simone	TUD	Enhanced Modelling of Fibre-Reinforced Concrete
Ir. J.M.A. Stijnen	TU/e	Computational and Experimental Investigation of the Flow in the Left Ventricle
Ir. H.G. Tillema	UT	Noise Reduction of an Electric Motor
Ir. J.C.J. Verhoeven	TU/e	Modelling of Laser Percussion Drilling
Ir. K. Vervenne	TUD	Accuracy Improvement of Semi-Analytical Design Sensitivities by Laplacian Smoothing
Ir. E. Viatkina	TU/e	Non-Uniform Straining and Forming Limits
Ir. R. Visser	UT	Acoustic Imaging

Ir. R.R. Waiboer	UT	Efficient Dynamic Simulation of Flexible Link Manipulators for Robotized Laser Welding
Mr. K. Wang	TU/e	The Axisymmetric Dual Reciprocity Method
Ir. S. Wijskamp	UT	Modelling of Residual Stresses in Rubber Pressed Composite Products
Mr. D.G. Yang	TUD	Influence of Cure-induced Micro-damage on Reliability of Microelectronic Packages
Ir. Y. Yu	UT	A Displacement Based Formulation for Steady State Problems

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