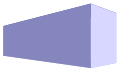

Technische Universität München
Chair of ...

SOME PHD TITLE

Max Muster

Vollständiger Abdruck der von der Ingenieurfakultät Bau Geo Umwelt der Technischen Universität München zur Erlangung des akademischen Grades eines

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Zusammenfassung

Deutsche Version

Abstract

English version

Acknowledgments

This dissertation was written from 2011 to 2014 during ....

Max Muster
Technische Universität München
December 19, 2014

List of Symbols

Calligraphic letters

$\mathcal{E}()$	extrapolation operator for next time step
$\mathcal{I}_i()$	interface constraint operator for interface constraint i
$\mathcal{J}()$	Jacobian extraction operator
${}^{m}\boldsymbol{\mathcal{R}}_i^n$	residual associated with input i at time step n at iteration m (vector)
${}^{m}\mathcal{R}_i^n$	residual associated with input i at time step n at iteration m (scalar)
$\mathcal{S}_i()$	operator of subsystem i

Greek letters

λ	eigenvalue
μ	dynamic viscosity
ν	kinematic viscosity
ω	eigenfrequency
ω_d	damped eigenfrequency
π	$\approx 3.141\,592\,653\,589\,793$
ρ	spectral radius
ε	Hencky strain
ϱ	density

Mathematical symbols

Σ	sum
∂	operator for partial derivative
δ	first variation
$\|\|\ \|\|_2$	euclidean norm
$\|\|\ \|\|_{\max}$	maximum norm
$\mathbb{R}$	set of real numbers

Latin letters

c_D	drag coefficient
c_L	lift coefficient
c_P	pressure coefficient
E	Young's modulus
$\boldsymbol{I}$	identity matrix
${}^m\boldsymbol{U}_i^n$	input of subsystem i at time step n at iteration m (vector)
${}^mU_i^n$	input of subsystem i at time step n at iteration m (scalar)
${}^m\boldsymbol{X}_i^n$	state of subsystem i at time step n at iteration m (vector)
${}^mX_i^n$	state of subsystem i at time step n at iteration m (scalar)
${}^m\boldsymbol{Y}_i^n$	output of subsystem i at time step n at iteration m (vector)
${}^mY_i^n$	output of subsystem i at time step n at iteration m (scalar)

Abbreviations:

ALE	Arbitrary Lagrangian Eulerian
BDF2	Second Order Backward Differentiation Formula
CAD	Computer-Aided Design
CFD	Computational Fluid Dynamics

CSE	Co-Simulation Engine
CSM	Computational Structural Mechanics
DAE	differential algebraic equation
DOF	degree of freedom
DOFs	degrees of freedom
FEM	finite element method
FSI	fluid-structure interaction
GMRES	generalized minimal residual
GS	Gauss-Seidel
GSE	Global Sensitivity Equation
IJCSA	Interface Jacobian-based Co-Simulation Algorithm
JC	Jacobi
JFNK	Jacobian-free Newton-Krylov
NASA	National Aeronautics and Space Administration
NREL	National Renewable Energy Laboratory
ODE	ordinary differential equation
PDAE	partial differential algebraic equations
PID	proportional-integral-derivative
TUM	Technische Universität München (University of Technology, Munich)
URANS	unsteady Reynolds averaged Navier-Stokes
Re	Reynolds number
Sr	Strouhal number

Contents

An investment in knowledge pays the best interest.

Benjamin Franklin

CHAPTER 1

INTRODUCTION

"Storm caused wind turbine fire"[1] this headline news is one which the manufacturers and designers of wind turbines try to avoid. The failure or wrong design of a wind turbine shut down mechanism can have a catastrophic consequence as shown in Figure 1.1.

Vector x x: $\boldsymbol{x}$ $\boldsymbol{\alpha}$
Matrix X X: $\boldsymbol{X}$ $\boldsymbol{\Gamma}$
Tensor x: $\boldsymbol{x}$ $\boldsymbol{\alpha}$
Tensor X: $\boldsymbol{X}$ $\boldsymbol{\Gamma}$

$\vec{\alpha}$

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[1] `http://www.bbc.co.uk/news/uk-16115139` British Broadcasting Corporation [1]

Figure 1.1: Exploded wind turbine in Ardrossan, North Ayrshire, Scotland due to high winds and problems with the emergency shutdown British Broadcasting Corporation [1]

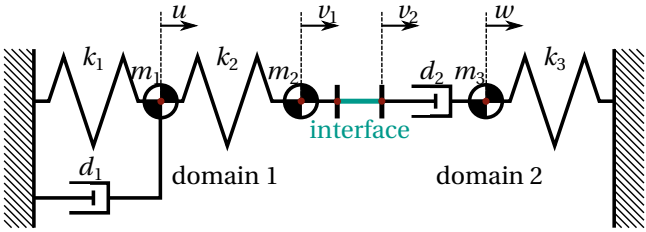

Figure 1.2: Monolithic/co-simulation test problem

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Definition 1.1: (Physical) Field

" A field is a physical quantity that has a value for each point in space and time. "[a]

[a] Gribbin [2]

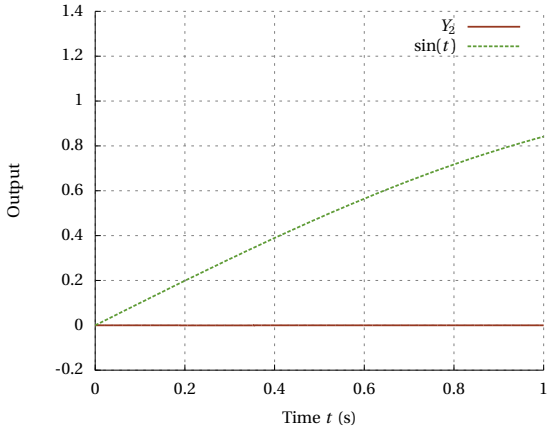

Figure 1.3: Solution over time

Appendices

ALGEBRAIC LOOPS

Figure A.1 which is causing the algebraic loop.

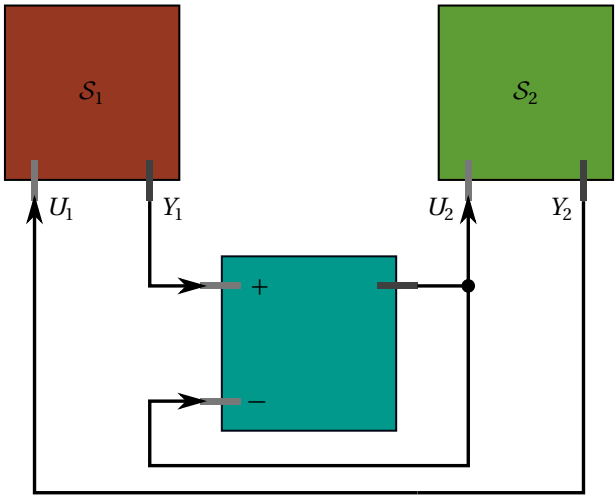

Figure A.1: Block diagram that describes the algebraic loop example

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[1] British Broadcasting Corporation. *Storm caused wind turbine fire*. Dec. 9, 2011. URL: http://www.bbc.co.uk/news/uk-16115139.

[2] J. Gribbin. *Q is for Quantum: Particle Physics from A-Z*. Universities Press (India) Pvt. Limited, 1998. ISBN: 9788173712432.