DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF WALES SWANSEA

A GENERAL PURPOSE COMPUTATIONAL SHELL FOR SOLVING INVERSE AND OPTIMISATION PROBLEMS

APPLICATIONS TO METAL FORMING PROCESSES

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THESIS SUBMITTED TO THE UNIVERSITY OF WALES
IN CANDIDATURE FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

C/Ph/239/00 APRIL 2000

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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This thesis is the result of my own investigations, except where otherwise stated.

Other sources are acknowledged by giving explicit references. A bibliography is appended.

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To my parents

Acknowledgments

I would like to thank:

- my supervisor, Prof. D.R.J. Owen, for his guidance and advice;
- my mentor, Dr. Tomaž Rodič, for his guidance and support;
- the Slovenian Ministry of Science and Technology for financial support;
- my parents for encouragement and support;
- my colleagues in C3M for productive collaboration;
- Suzana for her patience and understanding.

Summary

A general-purpose optimisation shell has been developed which utilises an arbitrary simulation system for solution of inverse and optimisation problems. Focus is directed at an open and flexible structure of the shell which allows application to a wide variety of problems and independent development of different solution tools, which can be easily integrated into the optimisation system. In this respect, an approach based on isolated treatment of different subproblems, which can be identified in the overall problem, is followed.

The developed concepts were applied to the solution of problems related to metal forming. The approach includes finite element analyses and related design sensitivity evaluations, which are applied in gradient based optimisation algorithms. The combined algorithms are examined by considering implementation of the overall optimisation system.

Examples include inverse estimation of constitutive parameters as well as optimisation of shape and thermo-mechanical processing parameters for thermo-mechanical systems which show highly nonlinear, transient, coupled and path dependent behaviour.

Contents

1 INTRODUCTION 1

1.1 MOTIVATION AND SCOPE 1
1.2 LAYOUT OF THE THESIS 3

2 SENSITIVITY ANALYSIS IN FINITE ELEMENT SIMULATIONS 8

2.1 FINITE ELEMENT SIMULATIONS 8
2.2 SENSITIVITY ANALYSIS 10

3 NUMERICAL OPTIMISATION 19

3.1 INTRODUCTION 19
  3.1.1 Preliminaries 19
  3.1.2 Heuristic Minimisation Methods and Related Practical Problems 21
3.2 SIMPLEX METHOD 25
3.3 BASIC MATHEMATICAL BACKGROUND 30
  3.3.1 Basic Notions 32
  3.3.2 Conditions for Unconstrained Local Minima 36
  3.3.3 Desirable Properties of Algorithms 37
3.4 LINE SEARCH SUBPROBLEM 42
  3.4.1 Features Relevant for Minimisation Algorithms 42
  3.4.2 Derivative Based Line Search Algorithms 46
  3.4.3 Non-derivative Line Search Algorithms 49
3.5 NEWTON-LIKE METHODS 53
  3.5.1 Quasi-Newton Methods 55
  3.5.2 Invariance Properties 59
3.6 CONJUGATE DIRECTION METHODS 63
  3.6.1 Conjugate Gradient Methods 63
  3.6.2 Direction Set Methods 67
3.7 RESTRICTED STEP METHODS 70
3.8 BASICS OF CONSTRAINED OPTIMISATION 73
  3.8.1 Langrange Multipliers and First Order Conditions for Unconstrained Local Minima 74
  3.8.2 Second Order Conditions 82
  3.8.3 Convex Programming Results 85
  3.8.4 Duality in Nonlinear Programming 87
3.9 QUADRATIC PROGRAMMING 88
  3.9.1 Equality Constraints Problem 89
  3.9.2 Active Set Methods 93
3.10 PENALTY METHODS 96
  3.10.1 Multiplier Penalty Functions 100
3.11 SEQUENTIAL QUADRATIC PROGRAMMING 105
3.12 FURTHER REMARKS 110

4 OPTIMISATION SHELL “INVERSE” 116

4.1 AIMS AND BASIC STRUCTURE OF THE SHELL 116
  4.1.1 Basic Ideas 116
  4.1.2 Requirements Taken into Consideration 120
  4.1.3 Operation Synopsis 122
4.2 FUNCTION OF THE SHELL 125

4.2.1 Basic File Interpreter Syntax 125
4.2.2 Expression Evaluator 128
4.2.3 User Defined Variables 130
4.2.4 Argument Passing Conventions 135
4.2.5 Summary of Modules and Utilities 137
4.2.6 A Simple Example 140
4.3 SELECTED IMPLEMENTATION ISSUES 143
4.3.1 Programming Language and Style 143
4.3.2 File Interpreter and Open Library 151
4.3.3 Incorporation of Optimisation Algorithms 158
4.3.4 Parallelisation 165

5 ILLUSTRATIVE EXAMPLES 174

5.1 INVERSE ESTIMATION OF THE HARDENING CURVE FROM THE TENSION TEST 174
5.1.1 The Tension Test 174
5.1.2 Estimation of an Exponential Approximation 175
5.1.3 Estimation of a Piece-wise Linear Approximation 177
5.1.4 Numerical Tests 181
5.1.5 Concluding Remarks 184
5.2 SHAPE OPTIMISATION OF COLD FORGING PROCESSES 185
5.2.1 Optimisation of Preform Shape 185
5.2.2 Shape Optimisation of a Tool in a Two Stage Forging 190
5.2.3 Optimisation of Heating Parameters for Hot Forming Operation 194
5.3 OPTIMAL PRESTRESSING OF COLD FORGING DIES 200
5.3.1 Optimisation of the Geometry of the Outer Surface of an Axisymmetric Die 200
5.3.2 Evaluation of Optimal Fitting Pressure on the Outer Die Surface 203
5.4 FURTHER EXAMPLES 207

6 CONCLUSIONS AND FURTHER WORK 214

6.1 FURTHER WORK RELATED TO THE OPTIMISATION SHELL 215

1 INTRODUCTION

1.1 Motivation and Scope

Optimisation is a logical step forward from direct analyses of products and processes. For linear problems this is already a well established field while active research in areas related to nonlinear, transient, coupled and path dependent problems has become feasible relatively recently[4]-[14] due to advances in computer science, numerical analysis[1]-[4] and sensitivity analysis[15],[16].

This work represents an attempt to develop a general purpose optimisation system which can be effectively adapted to problems emerging in engineering and science. A computational shell *Inverse* has been developed, which can be used in conjunction with existing simulation systems in order to perform optimisation tasks. A tempting challenge of designing an optimisation system that is flexible enough for general application has been taken up. A contemporary finite element based simulation environment *Elfen*[21] was utilised in the system, which enabled exploitation of state of the art achievements[22]-[25] in the field of numerical simulations in continuum mechanics.

A prime aim of the shell development was to provide a solution environment capable of solving a large variety of problems. Such an environment has been built around a traditionally structured simulation code, which was not primarily designed to solve optimisation problems and can not be easily restructured. This imposed a particular emphasis on an open and flexible approach to shell development and a tendency of division of problems to sets of separately treated sub-problems.

Under these circumstances the shell has evolved into a general optimisation programme whose scope is not limited in advance to solution of any specific kind of optimisation problems or to usilisation of a specific simulation software. It provides a framework for independent development of optimisation algorithms and other solution tools in the form of separate modules, which are readily integrated in a common optimisation environment. Its flexible user interface implemented through a file interpreter enables interaction of built-in optimisation algorithms and utilities with additional functionality provided in separate modules. The available utilities can be arbitrarily combined in order to define solution strategies for complex problems. These utilities include interfaces with simulation programmes, which provide access to simulation capabilities.

The shell is developed in the scope of a broader project, the aim of which is to build a complete general optimisation system based on advanced development concepts (Figure 1.1)[17]. This system will include a finite element solution environment developed from the very beginning with the intention of being applicable to solution of optimisation problems. This imposes an open and modular structure convenient for building interfaces with other programmes and acceptable to introducing changes in programme structure.

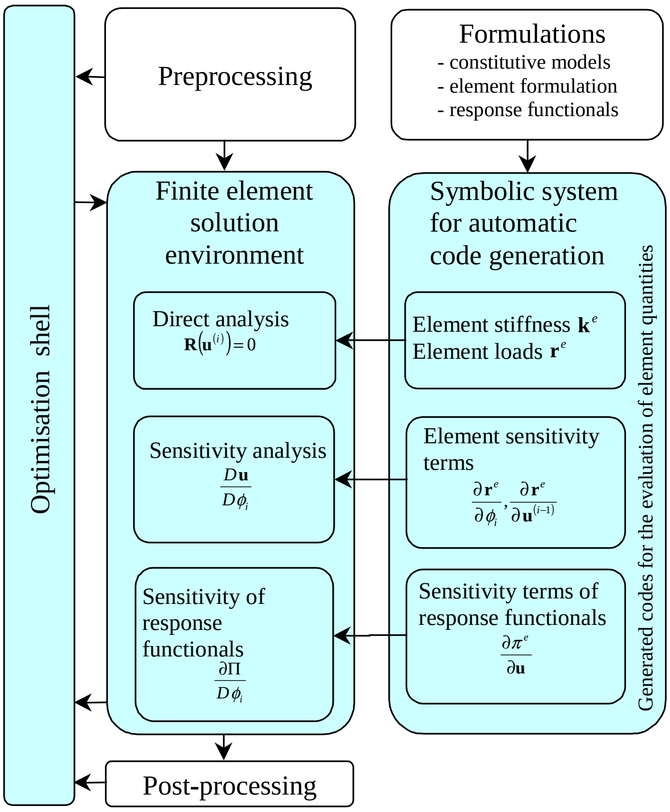

Figure 1.1: Outline of the idea of a complete optimisation system[17].

A particularly appealing feature is the use of a symbolic system for automatic generation of element quantities such as element stiffness, loads and sensitivity terms[18]. Element formulations, constitutive models and response functionals are defined on an abstract mathematical level. The system then derives the necessary relations and generates the appropriate functions which are directly incorporated in the simulation code through a standard interface. Such an approach enables quick incorporation of new models and is convenient for handling complexity of sensitivity analysis.

The adequacy of the developed concepts was tested on examples related to metal forming processes. Some typical optimisation problems which arise in this field were tackled, such as optimisation of pre-forms in two stage forming processes and optimal prestressing of cold forging tools.

It is acknowledged that numerical tools must be applied to such complex processes with certain care. Numerical simulations often fail to adequately replicate experimental results obtained in real metal forming processes or even in simple tests. The reason for this often lies in inaccuracy in parameters of physical models or processing conditions which are used as input data for simulations.

Obtaining accurate input data is not always a simple task. Direct evaluation of the required constitutive and processing parameters requires measurements which can not always be performed. This can be overcome by inverse analyses [19],[20], [11]-[14] where the parameters are estimated through minimisation of discrepancies between indirect measurements and simulation results by applying an optimisation algorithm. This approach has been illustrated on some inverse identification problems, for which the developed optimisation shell is also applicable.

1.2 Layout of the Thesis

Chapter 2 introduces the basic aspects of numerical simulations with a main emphasis on sensitivity analysis for non-linear problems, which is performed by using the direct differentiation and adjoint method. A general formal basis is indicated and further references are quoted.

In chapter 3 the mathematical background of numerical methods for the solution of optimisation problems is given. Implementation of some commonly used algorithms is outlined. Discussion is limited to nonlinear programming algorithms which were used within the scope of this work. The aim of this chapter is to give a clear overview with some insight to the numerical complexity behind optimisation algorithms. In the final part of the chapter some practical algorithmic issues are highlighted.

Chapter 4 describes the optimisation shell, which was developed in the scope of the present work. The first part of this chapter is devoted to description of the shell basic concepts and function. This is supported by a brief description of the shell file interpreter and a short example in order to make the presented material less abstract.

The second part touches on the internal structure of the shell through a few representative implementation issues. The selection of the considered issues was made on the basis of significance for the shell concepts and connection with the material in the first part.

Chapter 5 provides some examples which were solved by applying the optimisation shell in conjunction with the finite element simulation programme *Elfen*. In the first example experimental results from a standard tension test are used for the inverse estimation of material hardening parameters. The second example is a simple test for studying the applicability of optimisation techniques in optimal pre-form design. In the third example optimal heating conditions of a two-stage forming process are evaluated. The fourth example is an industrial application where prestressing conditions for cold forging dies are optimised in order to prevent initiation of cracks in the tool and therefore improve the tool life. The chapter is concluded with some other problems, which have been solved using the shell by different authors.

The final part summarises the significance and the scope of the performed work. Some current deficiencies of the optimisation shell are pointed out and guidelines for further development are indicated.

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