COST 526 – Project *SI 2*

Final Report

Optimization of Fatigue Resistance of Cold Forging Tools by Considering Damage Mechanisms at Micro Scale

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1. Introduction

An optimization environment is being designed for application in forming technology and in other engineering fields. A number of difficulties that can be encountered when dealing with realistic industrial problems call for a multidisciplinary solution approach. An optimization shell has therefore been developed with an open and extensible architecture that enables harmonized operation of a variety of tools specialised for different tasks, which is necessary for efficient solution of optimization problems. The concept has been demonstrated on selected examples: optimization of tool shape in sheet forming, optimal pre-stressing of cold forging dies in order to extend die life, and optimal design of material with periodic microstructure. Computational complexity of the numerical models and substantial noise in numerical results are common difficulties that aggravate employment of classical optimization techniques An algorithm based on successive local approximations of the response functions with restricted step approach has been constructed in order to overcome these difficulties. Design of an optimization library is considered in order to promote systematic development of similar algorithms.

2. Goal of the project

The main goal was to design methodologies and tools for solution of industrial problems in particular in the area of material forming.

3. Simulator, calibration, quality function and optimization algorithms, including assessment with respect to alternatives

The environment has been designed for connecting different algorithms and simulators, with emphasis on flexibility of definition of objective functions. Commonly applied optimization methods include the Nelder-Mead simplex method and BFGS for unconstrained minimization, Levemberg-Marquardt (predominantly for least square problems), the Feasible Sequential Quadratic Programming of C. T. Lawrence,J. L. Zhou, A. L. Tits, and sequential local approximation methods based on quadratic least squares or moving least squares approximation. Choice of the method depended on the problem (smoothness of the response, time complexity of simulation, etc.). Performance of different algorithms was extensively tested on analytical test problems, comparative tests have also been performed on problems involving large scale numerical models. Interfaced simulators include Rockfield Software’s finite element code Elfen, academic code FEAP, Mathematica driver and custom codes. Different quality functions have been designed with respect to the design objectives tackled in optimization problems.

Two figures below illustrate optimal design of inhomogeneous material with respect to overall properties of the structure (such as stiffness or ability of energy absorption), and comparison of algorithm performance on this problem.

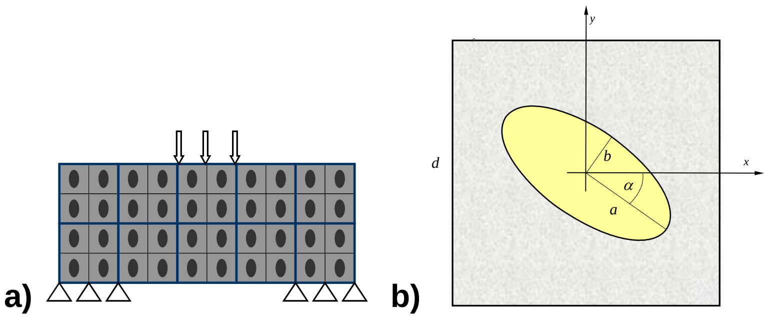

Figure 1: a) Studied structure under loading and b) three parametric description of the shape of inclusions within microscopic periodic cells of inhomogeneous material.

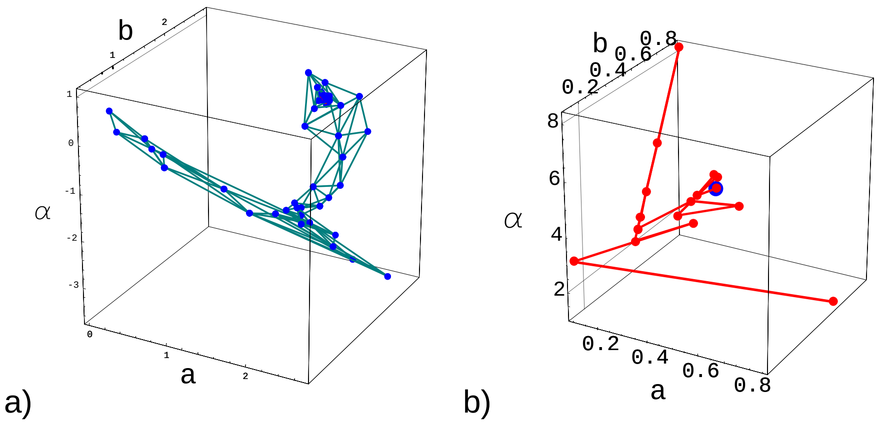

Figure 2: Convergence of a) simplex and b) SQP algorithm in the parameter space of the above optimization problem.

4. Main scientific outcome

A methodology for inter-disciplinary approach to automatic optimization problems as a part of process design has been developed, including serviceable approaches to shape parameterization, solution environment integration and optimization of noisy response.

5. Main technical outcome

Development of solution tools was planned in the scope of an integrated problem solving platform. Rather than building a large, complex homogeneous system that could alone deal with complete problems, the adopted approach was to connect and harmonize smaller specialized units. By having in mind such a modular system, an optimization shell] has been developed whose primary aim is to control the execution of external analysis programs within the optimization loop.

Early experience with practical problems identified the need for high flexibility with respect to problem definition and combination of solution utilities. The shell was therefore built around a powerful interpreter designed for driving numerical applications (Figure 3). A *shell interface library* for accessing the interpreter and other shell functionality enables easy integration of diverse software tools. These are driven in an integrated scheme with centralized data access and synchronized execution flow. Beside for the solution of practical optimization problems, the system is also intended to serve as development and testing environment.

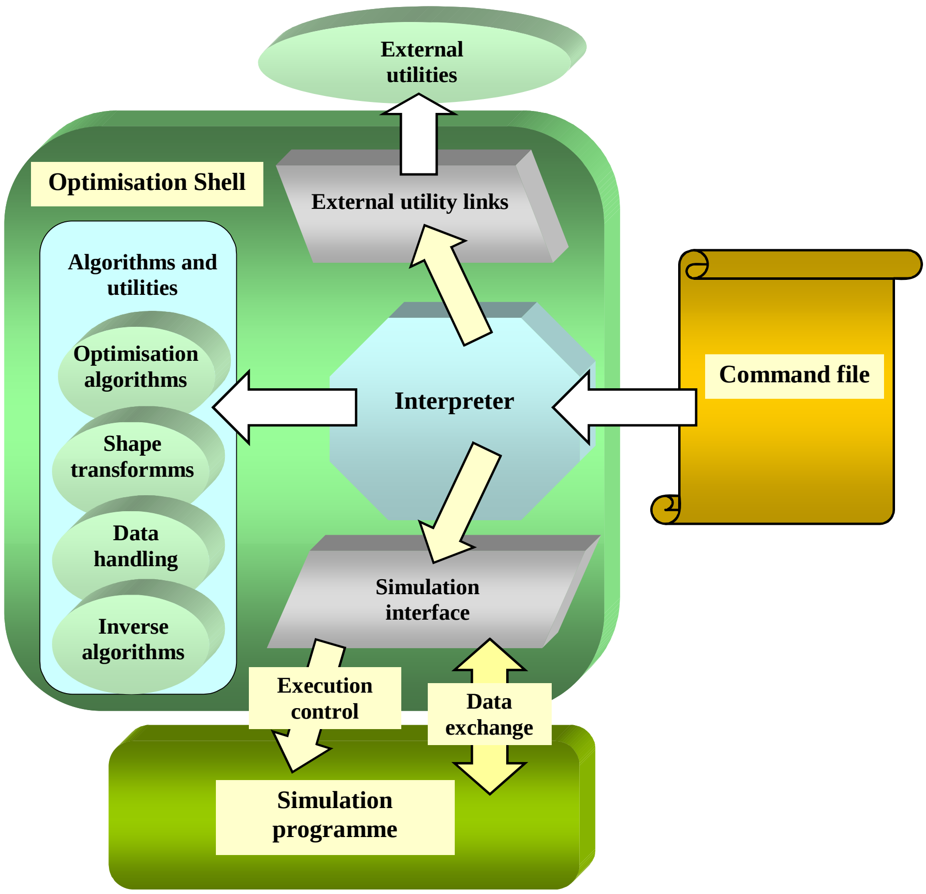

Figure 3: Functional scheme of the optimization system.

The optimization shell connects optimization algorithms with the evaluation of the objective and constraint functions at a given set of design parameters, which typically involves a finite element numerical analysis of the process. Interpretation of a specific *analysis* block of code in the command file is performed each time the evaluation is requested by an algorithm. The user defines the evaluation of the objective and constraint functions within this code block. Execution of the numerical analysis is controlled by interface functions attached to the interpreter, as well as data exchange between the shell and the numerical analysis environment. Exchange of the current values of design parameters and simulation results between the optimization algorithm and the numerical analysis is enabled through pre-defined shell variables. Intermediate functions take care of this, which enables straightforward linking of optimization algorithms from their original libraries.

Development of modules incorporated in the optimization shell is especially focused on general utilities that are closely related to optimization. The simulation and sensitivity analysis tools have been mainly developed separately from the optimization shell and integrated in the pre-application stage. An interfacing methodology has been elaborated for the finite element simulation systems, which enables the shell to have a full control over execution of the finite element analysis and access to its data. Such approach proved suitable for setting up optimization schemes, while possible applications exist beyond that. The scheme can be applied to add flexibility to the simulation environment itself, even when used as stand-alone, e.g. to enable user interference during the analysis or to enable easy switching between available solvers, to facilitate evaluation of user-defined quantities expressed as integral over the time or spatial domains, etc.

6. Collaboration within COST 526

Faculty of Natural Sciences and Technology, University of Ljubljana, Slovenia – collaborative work on definition of material related optimization criteria

Université de Technologie de Compiègne – discussions regarding shape parameterisation

7. Cooperation with industry

Iskra-Avtoelektrika, Slovenia. Analysis of service life of tooling systems.

8. References

[1] Optimisation Shell Inverse, electronic document at http://www.c3m.si/inverse/ , maintained by the Centre for Computational Continuum Mechanics, Ljubljana.
[2] Rodic T and Gresovnik. I. A computer system for solving inverse and optimisation problems. Eng. Comput., 1998, vol. 15, no. 7: 893-907.
[3] Gresovnik I. A General Purpose Computational Shell for Solving Inverse and Optimisation Problems - Applications to Metal Forming Processes. Ph.D. thesis, University of Wales Swansea, 2000. Available on the Internet at http://www.c3m.si/inverse/doc/phd/index.html
[4] I. Gresovnik., T. Sustar, T. Rodic. Parallelization of an optimization shell. In Proc. of The 3rd World congress of structural and multidisciplinary optimization. Buffalo, NY, May 17-21, 1999. pp. 221-223.
[5] Gresovnik I. Quick Introduction to Optimization Shell Inverse. Electronic document at http://www.c3m.si/inverse/doc/other/ .
[6] I. Gresovnik, T. Rodic, D. Jelovsek. Simple two stage transforms designed for optimisation of shape in forming processes. In Proceedings of The 4th ESAFORM Conference on Material Forming, Liege, Belgium, April 23-25, 2001.
[7] I. Gresovnik, T. Rodic, Practical considerations regarding optimisation of shape in forming processes, In Proceedings of The 5th International ESAFORM Conference on Material Forming, Akadeimia Góeniczo-Hutnicza Kraków, 2002.
[8] I. Gresovnik. Spline Interpolation with Sensitivities. Internal report, C3M, 2003.
[9] A. Ibrahimbegovic, I. Gresovnik, D. Markovic, S. Melnyk and T. Rodic Shape optimization of two-phase material with microstructure. Accepted for publication in Engineering Computations.
[10] I. Gresovnik, D. Markovic, T. Rodic, A. Ibrahimbegovic. Optimization of Inclusion Shape in Inhomogeneous Structural Elements. Proceedings of NATO-ARW advanced workshop on Multi-physics and Multi-scale Computer Models in Non-linear Analysis and Optimal Design of Engineering Structures Under Extreme Conditions, Bled, Slovenia, June 13 - 17, 2004.

[11] I. Gresovnik, S. Hartman and T. Rodic. Development of Optimization Methodology for Reduction of Defect Risk at Blow Forming. Proceedings of the 6th World Congress on Structural and Multidisciplinary Optimization, Rio, 2005.
[12] I. Grešovnik, " Ioptlib home", electronic document at http://www.c3m.si/igor/ioptlib/