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Multi-Objective Evolutionary Optimization of Gas Turbine Components

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The world-wide increasing demand for energy is one of the key challenges of our century. However, this demand is in conflict to the Kyoto protocols of 1997 and 2001 that contain an international agreement for reducing green house gases. Energy generation concepts involving alternative energy sources and innovative technologies with high thermodynamical efficiencies are needed in order to address these issues.

Gas turbines are one of the key energy producing devices of our generation. Improved designs of gas turbine components are necessary in order to address the increasing demands of high performance and reduced emissions. The design of gas turbine components is a complex and time-consuming engineering task that involves meeting of several design objectives and constraints. This task is usually addressed in an iterative process. Advances in domain knowledge and in areas such as information technology offer the possibility of accelerating and improving this design cycle through automated optimization procedures.

This thesis addresses the key issue of automated optimization by presenting optimization algorithms that are implemented in realistic design processes of gas turbine components. The results of this work include algorithmic advances and the development of new and efficient designs for turbine components. The proposed optimization algorithms are analyzed and enhanced so that they are applicable to the design of compressor blades and burners. The thesis addresses a number of optimization difficulties such as multiple design objectives and constraints, high sensitivity of the objectives, and noise in the evaluation of the objectives.

Automated optimization requires a blend of efficient algorithms and information technology tools from in order to find optimal solutions in limited time frames.

We find that it is not sufficient to use existing tools but that extensive, problem specific modifications of the algorithms are required. In this thesis, several new algorithms for single and multi-objective Pareto optimization are presented. The focus is on evolutionary algorithms, as they are robust optimization algorithms suitable for engineering applications where pointwise information is only available. In the context of Pareto optimization, several well known evolutionary algorithms are analyzed with regards to their convergence properties and convergence limits. Furthermore, the efficiency of certain algorithms is enhanced by defining adaptive mutation and recombination operators based on self-organizing maps. The robustness to noisy objective functions is improved by defining a dominance dependent re-evaluation interval. In the field of single objective optimization, a new optimization algorithm is proposed that is suitable for engineering problems with relatively few decision variables but expensive cost function evaluations. The algorithm relies on the construction of an empirical model of the objective function. The model is then used to predict function values in order to reduce the number of function evaluations.

For the compressor optimization, an optimization procedure is defined that addresses the relevant design objectives and constraints. The procedure comprises a new blade parameterization and tools for the aerodynamical and mechanical analysis. For the aerodynamical analysis, an inexpensive method for estimating off-design behavior is presented. Four compressor blades of adjacent mid-stages of a gas turbine are optimized and the resulting profile shapes are discussed.

The gas turbine burner is optimized in an experimental test-rig. The objectives are to minimize thermo-acoustic pulsations and NOx emissions. Both objectives are noisy as they result from measurements with limited time averaging. The Pareto optimization results in an approximation of the Pareto set, comprising a number of different trade-off solutions for the two conflicting objectives.