



OPTIMIZATION OF THE GAS TURBINE ENGINE PARTS USING METHODS OF NUMERICAL SIMULATION

ABSTRACT

As the analysis tool the well-known commercial software package (FINE/Design3D) is used. As the optimization software IOSO PM (parallel algorithm of IOSO) is used.

The prospect presents the results of optimizing a three-stage axial compressor. The optimization goal was to improve the compressor efficiency at two flight conditions by optimizing geometry of the 5 compressor rows (**62 design parameters**).

No analogues of solving such kind of complex problem have been published.

INTRODUCTION

The design of modern compressors is a very complex task. There should be taken into account a large number of efficiency parameters and constraints, which are being viewed from different scientific angles. An extensive use of modern numerical design methods combined with highly efficient optimization techniques can substantially reduce the time and cost of the design.

This work is aimed to demonstrate the possibilities of IOSO optimization technique when used in combination with well-known commercial software application for the design of modern compressor.

OPTIMIZATION SOFTWARE FEATURES

The IOSO NM package is designed to solve complex problems of single- and multi-objective constrained and unconstrained optimization with various classes of objective function: smooth, non-differentiable, stochastic, with multiple optima, with the portions of the design space where objective function and constraints can not be evaluated at all, with the objective function and constraints dependent on mixed variables, etc. The optimization procedure is based on the response surface methodology, when response surfaces are constructed for objective functions and constraints and then optimized at each iteration in a current search region. The objective function and constraints are then evaluated at the optimal point using the mathematical model of the system under consideration. Algorithms of IOSO NM have good invariant features, high level of stability of calculation while optimization of complex objects; they also ensure search for extreme with presence of incompatibility areas. These features of the algorithms make it possible to expand substantially the classes of problems being successfully solved, facilitating the use of this software for complex real-life problems.

IOSO NM software has user friendly GUI and is simple to use. The software provides all necessary information to the user interactively. The parameters of IOSO optimization routine are either pre-programmed or adaptively changing during the search for extreme without the user's intervention. Most of the algorithm's tunings are being carried out internally, that is, they are "hidden" from the user. Hence, user is not required to have any knowledge of nonlinear programming or optimization procedures. The only important thing for the user is to understand the physics of the problem and to have a mathematical model of the investigated system. Creating an interface between IOSO and a mathematical model or CAE software and etc. typically takes several minutes.

THREE-STAGE COMPRESSOR OPTIMIZATION

Object under study

We chose the real-life three-stage low-pressure compressor (Fig. 1) to investigate the possible ways of improving the modern gas-turbine engine performance.

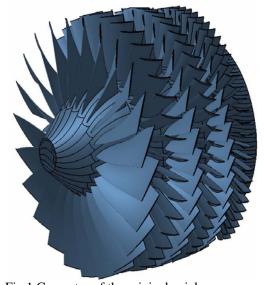


Fig.1 Geometry of the original axial compressor

Specifics of calculating the flow

Parameters of the 3-D flow were calculated using commercial program by NUMECA.

The numerical method used by NUMECA is based on the finite volumes method. It uses the explicit method with central differences discretization and Runge-Kutta time integration method. The calculations employed the Spalart-Allmaras turbulence model with single parameter. This turbulence model results in satisfactory quality of the calculations while requiring relatively small computational resources. In our particular case we used the mesh of the type "HOH" (Fig. 2).

The pressure and temperature values at the inlet to the simulation zone as well as static pressure at the exit were used as the boundary conditions for our calculations. We determined the main compressor parameters at several characteristic points (with corresponding static pressure values at the exit) during optimization.



Fig. 2 Mesh topology

It should be mentioned that only experimentally evaluated and identified, that means reliable models could be applied for the solving of the high-end class of tasks.

Optimization problem statement

The main goal of optimization investigations was to increase the compressor efficiency for the operation mode corresponding to cruse flight (rotation frequency of 87%) while at the same time not to decrease the compressor performance for design mode (rotation frequency of 100%). Because of that the compressor efficiency for the rotation frequency of 87% was chosen as optimization criterion with boundary conditions corresponding to the point of maximum efficiency at the performance map of the original compressor. (Fig. 3)

During optimization problem solving we provided the collection of constraints for two rotation frequencies.

Constraints for 100% of rotational frequency:

- the calculated pressure ratio should be no less than for the initial compressor.
- the efficiency should be no lower than that for the

- initial compressor;
- the stability margin should be no less than for the initial compressor;
- the maximum flow rate through the compressor stage may vary within +/- 1% of the original;
- the axial exit angle with the precision of 1 degree

For the 87% rotation frequency we provided constraint for the margins of stability to be no less than that for the initial compressor.

The chosen set of criteria and constraints results in the situation when one run of mathematical model of flow characteristics calculations during optimization process corresponds to five points at the compressor performance map:

- stagnation point (100% rotation frequency);
- points of the maximum efficiency (87% and 100% rotation frequencies)
- points close to the stability boundaries (87% and 100% rotation frequencies)

The average calculation time (one run of mathematical model) is 15 hours at P-IV PC (2.8 GHz). The optimization was conducted using the cluster of 6 CPUs. The parallel version of the optimization software system IOSO PM was employed, where 6 compressor geometry configurations were calculated at each iteration.

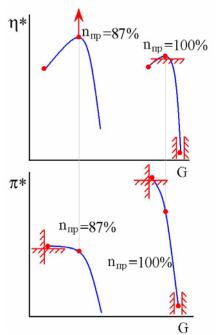


Fig 3 Optimization Problem Statement

The geometry of the compressor blade is described using a set of two-dimensional airfoils located at several radii along the height of the blade (the number of points describing the blade in the Cartesian coordinate system could reach several thousands).

To optimize the geometrical characteristics of such a blade it is necessary to create some 3-D prototype that describes the shape of the blade as accurately as possible using the approximation function for the blade surface. In this particular case the compressor blades parameterization was done at the blade cross-sections, when the original airfoil was substituted

by a symmetric one. The mid-line of the airfoil was described using the spline that goes through the given points (Fig. 4). For the rotor blades we used 4 points and for the stator blades we used 3 points. The distance from a point to some base line was considered a design variable with certain bounds. We considered 5 such cross-sections along the height of the first rotor blade row. We used 3 such cross-sections for the blades of the second and the third rotor blade rows, and for the stator blade rows (Fig. 5). As a result, the optimization problem had 62 variables.

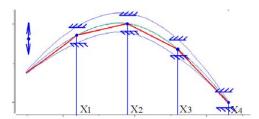


Fig.4 The points on the airfoil midline used as variables.

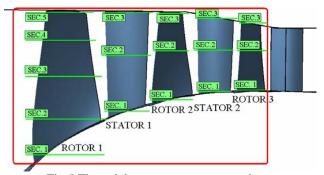


Fig.5 The axial compressor cross-sections.

Main results

The time frame for solving this optimization problem was one month. We performed 925 evaluations of the compressor mathematical model. The dynamics of the efficiency changes is shown in Fig. 6. One can see that initially we had a relatively high rate of increasing efficiency (an increase of 2.5% was achieved after about 400 evaluations). This fact confirms that optimization algorithm in IOSO NM relatively quickly localizes the area of the optimal solution.

As a result of solving this problem we obtained the geometry of the compressor blades that produce a **3% increase** in efficiency at 87% rotation frequency compared to original configuration. As an example, Figures 7 compare some airfoils of the initial and optimal configurations.

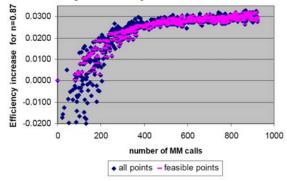


Fig.6 The dynamics of solving the problem

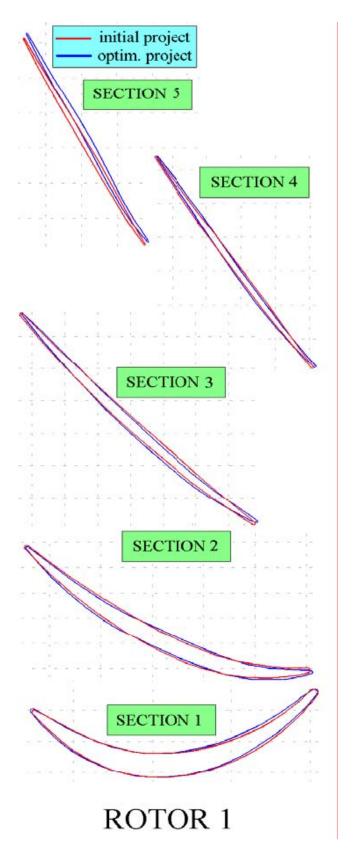


Fig. 7 Comparison of the airfoils for the first rotor blade.

The comparison of the compressor performance maps for the initial and optimal compressor configuration (Fig. 10) shows that the optimal configurations has a better efficiency for both 87% and 100% rotation frequencies. The maximum air flow rate is maintained with the prescribed accuracy at the 100% rotation frequency and is slightly increase at 87% rotation frequency, which does not violate the imposed constraints. The stability margin for 87% rotation frequency is increased by 5% and maintained the same at 100% rotation frequency.

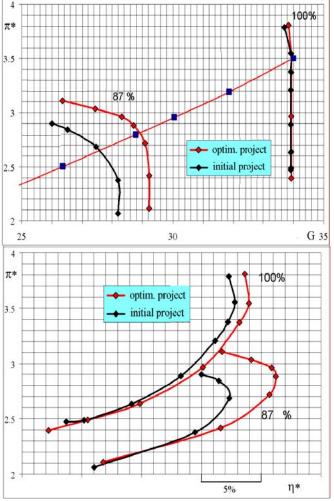


Fig. 10. Comparison of the compressor performance maps for the initial and optimal compressor configurations

CONCLUSION

The conducted investigations showed that it is possible to perform optimization studies using 3-D method of calculating the flow parameters in the axial compressor. The most important elements in organizing the optimization process, that influence the efficiency of such studies are the following: the capability to automatically generate the mesh for a wide range of blade geometry configurations and an efficient optimization algorithm, that allows for a maximum improvement in objective function with minimum number of flow model evaluations. In our particular case as a result of optimizing real-life compressor blade geometry parameters we got a 3% improvement in maximum efficiency while satisfying all the constraints! It is considered as a very essential one taking into account that we operate in high-end technical field and optimize real-life objects.

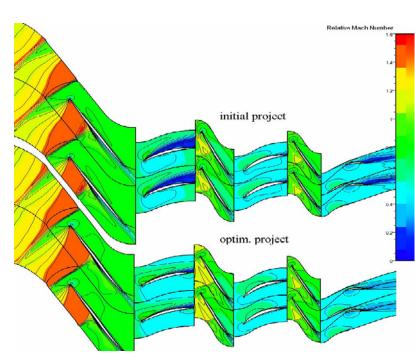


Fig.11. Periphery of h=90% (87% rotation frequency, the point of maximum efficiency).

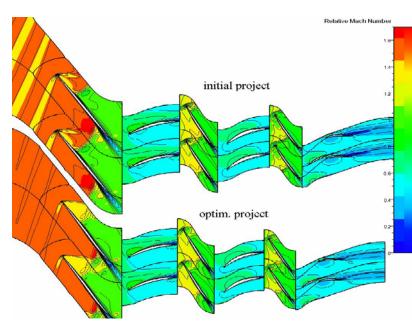


Fig.12. Periphery of h=90% (100% rotation frequency, the point of maximum efficiency).