Int. Symp. on Heat Transfer in Gas Turbine Systems
9*14 August 2009, Antalya, Turkey

OPTIMIZATION OF A GAS TURBINE STATOR NOZZLE COOLING USING GENETIC ALGHORITMS

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INTRODUCTION

The maximum temperature attainable in a Joule cycle is an important design variable affecting both the efficiency and energy output of the power system. The increase of maximum gas temperature is one of the main issues for turbogas systems. As a consequence, the components immediately downstream the combustion chamber are exposed to higher thermal stress and, in order to assure their mechanical strength, an appropriate cooling system has to be employed.

Oxidation, corrosion and thermal fatigue are phenomena that affect components, such first stage stator nozzles and rotor blades. In order to extend the mean time between maintenance and the life of such components, cooling systems draw air from compressor.

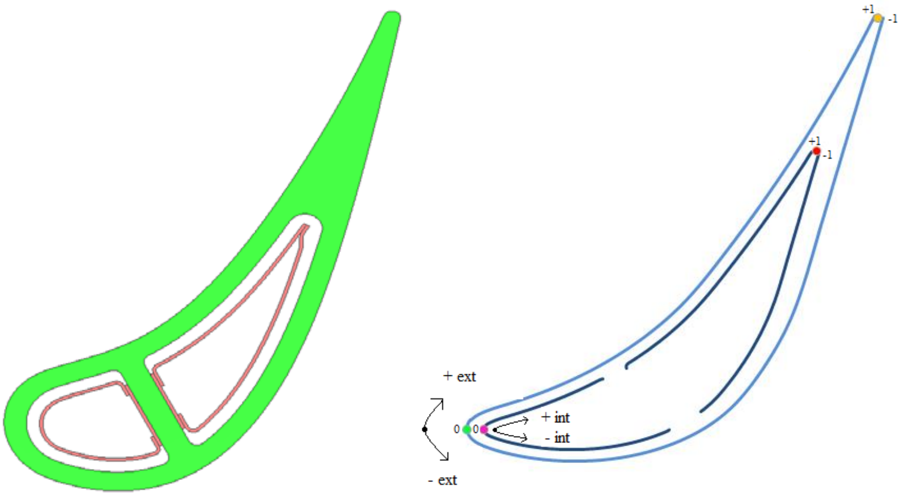
The drawing of air from the compressor reduces the available power output of the turbogas systems. Thus an important goal of the cooling system optimization is to minimize the cooling air flow rate assuring a safe operating temperature of the cooled parts in order to preserve their mechanical strength. The cooling systems to be more efficient employ the combined effect of film cooling and impingement jets to this purpose.

AIM OF THE PAPER

The aim of the present work is to optimize the geometry of the cooling system for the first stage stator nozzles by means of a genetic algorithm developed to this purpose. Such algorithm has been interfaced with a thermo-fluid dynamic code, which computes the Nusselt number in the meatus of the nozzle, attributing a fitness value to each possible solution considering both thermo fluid dynamic and structural analysis.

The maximization of heat transfer is constrained by several limits; in particular, air flow rate drawn from compressor has to be minimized while impingement and film cooling hole dimensions and placement must guarantee both heat transfer and mechanical strength of the nozzles.

Such constraints are included in the fitness function of the genetic algorithm in order to take into account their effects on the optimization. Despite the algorithm performs an accurate investigation of the search space, the solution of the optimization could be a local optimum because of the complexity of the problem and the high number of design variables.



(a) (b)

Figure 1. Geometry of the (a) midplane stator nozzle, and (b) normalized curvilinear abscissas, Pressure and Suction side starting from the leading edge

The paper aims at seeking different optimal impingement and film cooling holes positioning for the first stage nozzle cooling system. The main goal is the finding of the holes positioning along the curvilinear abscissa of the boxes inside the nozzle, which maximizes the Nusselt value, taking into account the required constraints.

The analysis has been accomplished for a two dimensional geometry obtained by sectioning the nozzle with a plane orthogonal to the stacking axis at 50% of the span. A sketch of the blade together with the employed normalized curvilinear abscissa is reported in Figure 1.

METHODS OF SOLUTION AND OPTIMIZATION

Steady-state has been assumed for the thermal and fluid dynamics fields, and their solution has been obtained by means of a numerical program using finite element method. When the fluid dynamics field is determined, the optimization procedure evaluates the objective function by means of the thermal code.

The Nusselt numbers have been evaluated by means of Florschuetz correlation equation, Florschuetz et al. [1981]:

$$\mathrm{Nu} = \mathrm{A} \cdot \mathrm{Re}_j^m \cdot \left\{1 - \mathrm{B} \cdot \left[(z/d) \cdot (G_c/G_j)\right]^n\right\} \cdot \mathrm{Pr}^{1/3} \tag{1}$$

where the parameters A, B, m and n depend on geometric factors, z is the pitch of the holes and G is the mass flux.

The design variables involved in the Nusselt number evaluation are:

- Impingement: hole diameter, position and pitch.
- Film cooling: hole position, diameter, compound angle.

The Genetic Algorithms, GAs in the following, have been chosen for optimizing the cooling system of the first stage stator of a power gas turbine. Such optimization algorithms are search algorithms based on natural selection and genetics, Goldberg [1989]. When the optimization procedure is started, a

population of possible solutions, codified in string structures, is randomly initialized. A fitness value is assigned to each string based on the value assumed by the objective function. The fitness represents the probability that the solution has to survive and pass its gene pool to subsequent generations. After selection, genetic operators are applied to perform exploration of the search space. In this way a new population is obtained and, if the convergence criterion is not verified, a new iteration starts.
GAs are different from traditional optimization and search procedures in four ways:

1. GAs work with a coding of the parameter set, not the parameter themselves.
2. GAs search from a population of points, not a single point.
3. GAs use objective function information, not derivatives or other auxiliary knowledge.
4. GAs use a probabilistic transition rules, not deterministic rules.

DISCUSSION OF THE MAIN RESULTS

The result of an optimization process is reported in Figure 2, showing the distribution of the film cooling and impingement holes. Since the hot gas impacts the nozzle at the leading edge, the presence of impingement holes in this area is necessary to limit the temperature values. The pressure conditions at the leading edge make difficult to open film cooling holes in this area because of hot gas ingestion in the meatus. Moving towards the trailing edge, the pressure conditions become positive for positioning film cooling holes both on the pressure and suction side, as is reported in Figure 2.

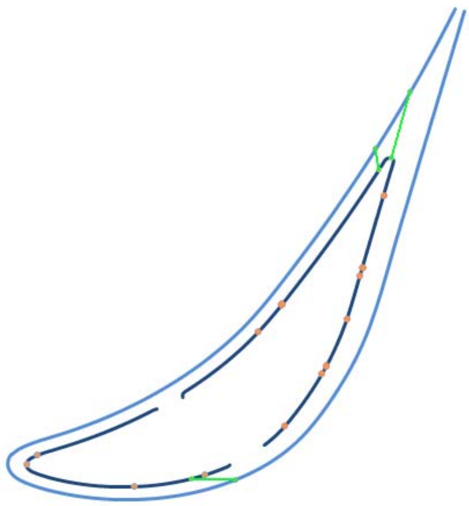
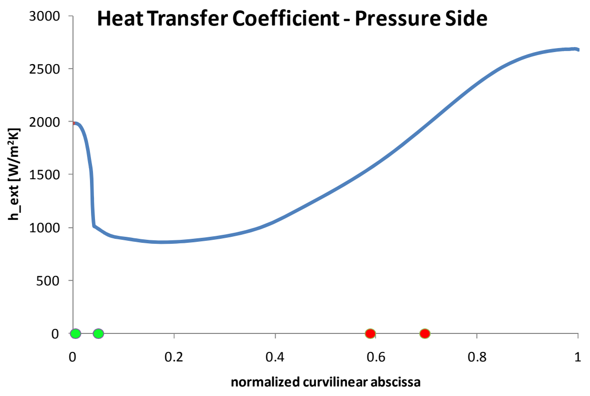
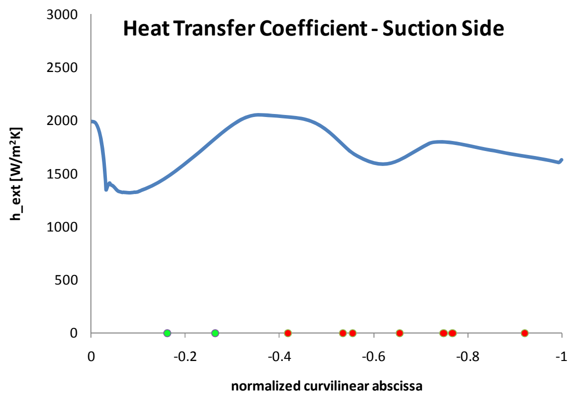


Figure 2. An example of an optimized configuration with impingement and film cooling holes.
Orange: impingement holes placement, Green: film cooling holes position.

The heat transfer coefficients between hot gases and turbine nozzle are reported in Figure 3 (a) for the pressure side and in Figure 3 (b) for the suction side, as a function of the normalized curvilinear abscissa. In the same figure the position of the impingement holes have been reported. It can be observed, Figure 3 (a), that the optimization procedure places two impingement holes very close to the leading edge since it is the most critical part of the blade. The values of the heat transfer coefficient attain values of about 1500 $Wm^{-2}K^{-1}$. On the same side two other holes are placed far downstream where the gas flow reattaches to the blade. Instead on the suction side the heat transfer coefficient shows a more uniform profile along the abscissa since the gas stream flows along the profile which corresponds to a uniform placement of the impingement holes.



(a)



(b)

Figure 3. Convective heat transfer coefficients vs. normalized curvilinear abscissa:
(a) Pressure side; (b) Suction side.

In Table 1 four different optimization solutions are compared, showing the number, the average diameter and the standard deviation of the impingement holes. All the proposed solutions present similar cooling configurations, in terms of hole number and diameter.

Table 1
Number of holes, average diameter and the standard deviation for four different optimized solutions

Configuration	Number of Holes	Average Diameter [mm]	Standard Deviation [mm]
1	13	1.35	±0.40
2	16	1.34	±0.42
3	14	1.29	±0.40
4	13	1.31	±0.52

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