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Helium Gas Turbine Conceptual Design by Genetic/Gradient Optimization

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ABSTRACT

Helium gas turbine is the key component of the power conversion system for direct cycle High Temperature Gas-cooled Reactors (HTGR), of which an optimal design is essential for high efficiency.

Gas turbine design currently is a multidisciplinary process in which the relationships between constraints, objective functions and variables are very noisy. Due to the ever-increasing complexity of the process, it has becomes very hard for the engineering designer to foresee the consequences of changing certain parts. With classic design procedures which depend on adaptation to baseline design, this problem is usually averted by choosing a large number of design variables based on the engineer's judgment or experience in advance, then reaching a solution through iterative computation and modification**.** This, in fact, leads to a reduction of the degree of freedom of the design problem, and therefore to a suboptimal design.

Furthermore, helium is very different in thermal properties from normal gases; it is uncertain whether the operation experiences of a normal gas turbine could be used in the conceptual design of a helium gas turbine. Therefore, it is difficult to produce an optimal design with the general method of adaptation to baseline.

Since their appearance in the 70's, Genetic algorithms (GAs) have been broadly used in many research fields due to their robustness. GAs have also been used recently in the design and optimization of turbo-machines. Researchers at the General Electronic Company (GE) developed an optimization software called Engineous, and used GAs in the basic design and optimization of turbines. The ITOP study group from Xi'an Transportation University also did some work on optimization of transonic turbine blades.

However, since GAs do not have a rigorous theory base, many problems in utilities have arisen, such as premature convergence and uncertainty; the GA doesn't know how to locate the optimal design, and doesn't even know if the optimal solution exists. At present, combining with other algorithms is a feasible way for GAs to solve such problems.

The gradient method is a traditional optimization algorithm with quick convergence and good exactness. A GA can quickly reduce the design space and then the gradient method can locate the optimal solution.

In this paper, the genetic/gradient method will be employed in the conceptual design of a helium gas turbine, reduce the computation time consumed by iterativeness in the traditional method and work out an optimal design.

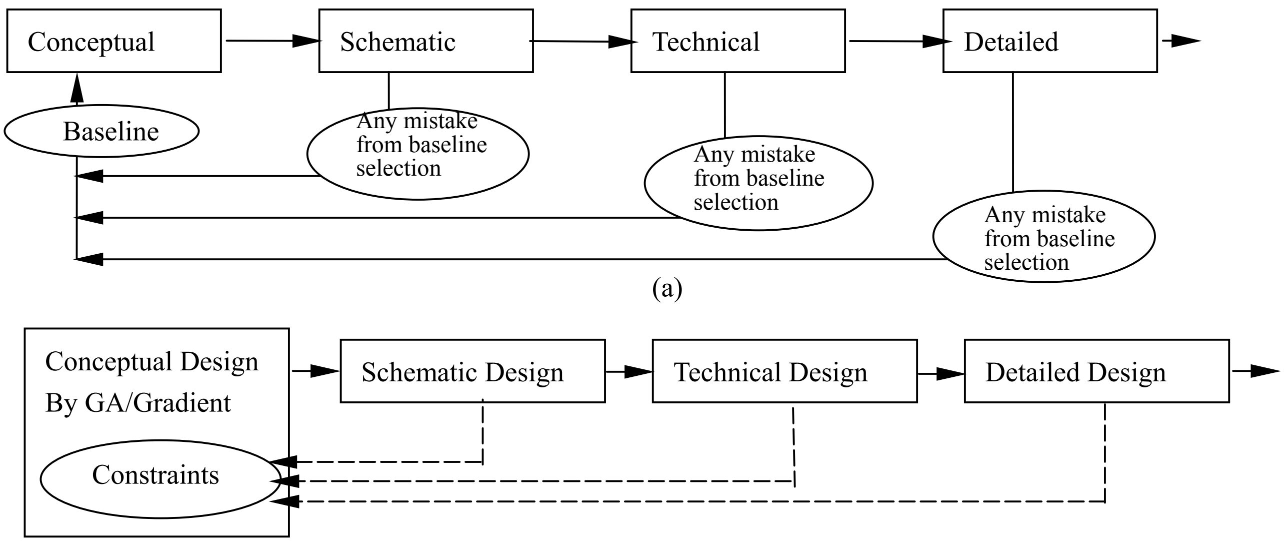
KEY WORDS: Genetic algorithm, helium turbine, conceptual design, optimization

INTRODUCTION

The traditional gas turbine design process can be divided into four parts, conceptual design, schematic design, technical design and detailed design. The aim of conceptual design is to make out a semi-optimal scheme on the basis of design experience, and to define the geometrical properties and parameters such as the stage number. The following three parts emphasize component performance, structures, reliability, material properties. The conceptual design step is definitely important in the whole process because it orients the subsequent steps. If there are any mistakes of conceptual design discovered in the steps that follow it, all the work must be repeated. And because the selection of design parameters in traditional conceptual design is based on experience, the usability of experience becomes essential.

The direct cycle Helium turbine is regarded as the most plausible cycle model for a high temperature reactor. But there is not yet any actual helium turbine in use anywhere in the world. This means no experience of a helium turbine conceptual design can be used. Helium differs greatly from ordinary gas in thermal properties. So using the traditional design method for turbines raised a question: could the design experience of an ordinary gas turbine be correctly used for a helium turbine conceptual design process? In this paper, a genetic /gradient algorithm is employed as a new method of helium turbine conceptual design and an attempt is made to answer this question.

As stated before, conceptual design is just the first step of the turbine design process. In the traditional design process, it is possible for a designer to find that some parameter selected according to the baseline does not meet needs of the resulting design, requiring him to go back to the first step to change the baseline and repeat the process. With the design by genetic /gradient method, such repetition could be avoided because some factors in the latter steps can be involved in the conceptual design as constraints. Figure 1 shows the difference between the two processes.



(b)

Figure 1 Difference between traditional and GA/gradient design process

DESIGN METHOD

The HTR is a typical fourth generation advanced reactor. Most HTRs under construction all over the world use a helium turbine cycle as the probable circulation mode. A helium turbine for the HTR200 was designed using the GA/gradient method. This turbine had a constant inner radius. The parameters needed for the conceptual design of a helium turbine for the 200MW HTR are shown in Table 1.

Table 1 Parameters for theconceptual design of 200MW HTR's helium turbine

Design Parameter	Value
mass flow / G (kg/s)	130.15
temperature at inlet / T_0 (^oC)	850
pressure at inlet / P_o (Mpa)	4.851
pressure at outlet / P_1 (Mpa)	2.22
rotation speed / N (rpm)	3000
blade speed coefficient	0.94
stage number	8-12
Working fluid	helium

As stated before, turbine design is a multidisciplinary process involving thermal dynamics, fluid dynamics, structure analysis and intensity analysis as well as other aspects. In the traditional design process, conceptual design focuses on thermal dynamics, and the others parts are mainly considered in the subsequent design steps. In conceptual design using the GA/gradient method, other parts in addition to thermal dynamics are considered as constraints to the optimization problem. These constraints include elements such as outline size and blade and plate intensity. They also include fluid dynamics items like mach number at the inlet and outlet of every stage and the angle of the flow. Such constraints reduce the design space and keep the optimization process inside a region in which the rules considered as constraints will be followed. Figure 2 shows how constraints reduce the design space.

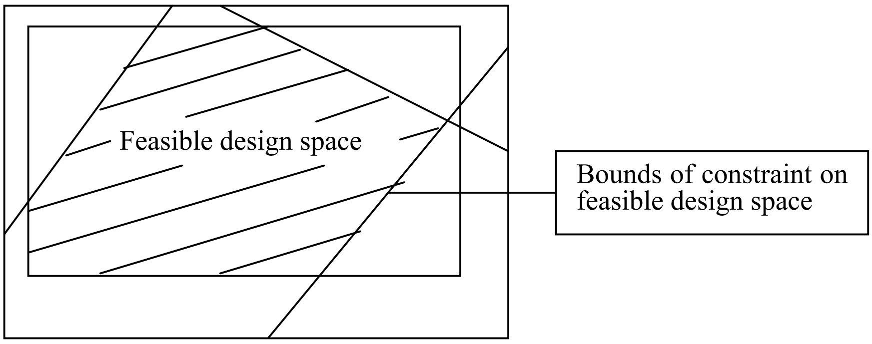


Figure 2 Reduction of design space by constraints

There are many different chromosome coding methods in genetic algorithms. For simple genetic algorithms, binary coding and float coding are usually used. Programming and computation showed that there is no eveident difference between these two modes of coding for this problem, so the more convenient one, float coding, was employed.

Total efficiency for the helium turbine was defined as fitness, and the efficiency was evaluated by the computation step of the traditional conceptual design method. The optimization variable includes the turbine's inner radius, blade length and the reaction of each stage. Considering an eight-stage turbine, there would be 17 problem variables. The population size was 50, which means that in every generation, 50 chromosomes were involved. The proportion of mutated variables was 0.02 and the probability of crossover was 0.1. The maximum number of generations was set as 200.

Figure 3 presents the change of the best chromosome's fitness with generation growth. The fitness grows rapidly from 0.5 to 0.9 within the first 20 generation, and becomes almost stable after that.

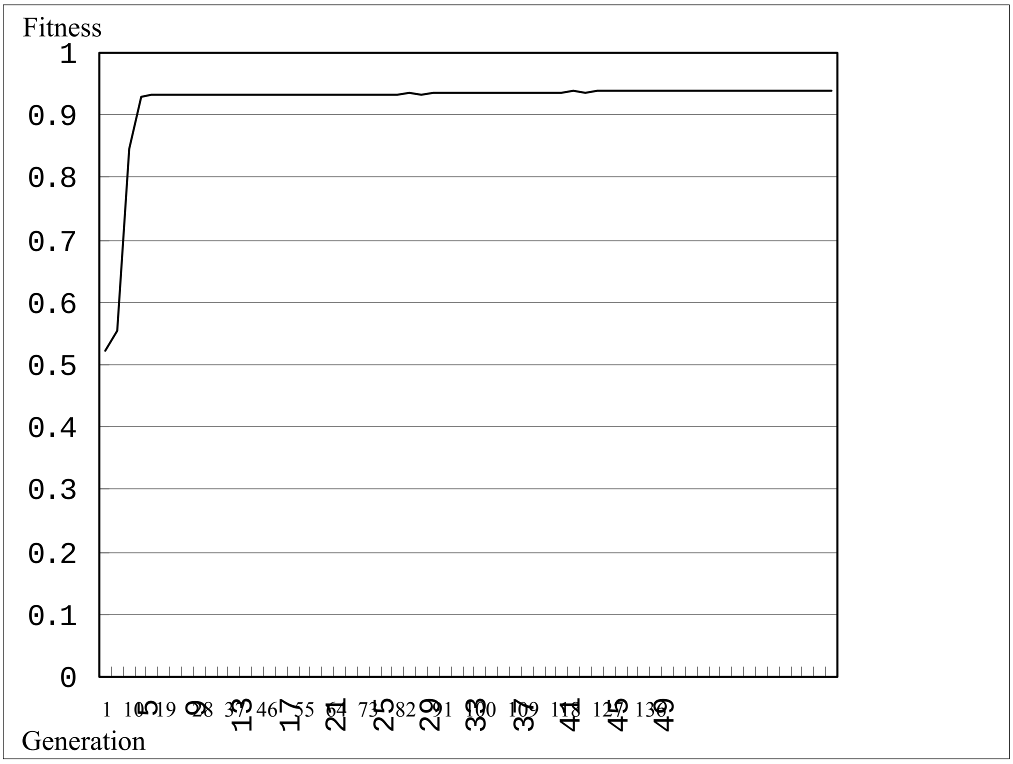


Figure 3 Dependence of fitness on generation

RESULTS AND DISCUSSION

Table 2 shows values of the genes of one chromosome in the 14th generation. Those values are very close to the conceptual design parameter values that the author obtained by the traditional design method. This fact shows that experience of normal gas turbine conceptual design can be at least partly used in helium turbine conceptual design and dose not bring evident error. In addition, the values of some parameters like clearance loss ratio and the blade speed coefficient are still selected according to experience.

Table 2 Comparison of gene values of one chromosome in the 14th generation of the GA/gradient design method and the traditional design method

Traditional design method	Blade length(mm)								Inner radius(mm)	Total efficiency
	1	2	3	4	5	6	7	8		
	60	66	72	78	84	90	96	102	900	0.903
	Reaction									
	0.18									
GA/ gradient design method	Blade length(mm)								Inner radius(mm)	Total efficiency
	1	2	3	4	5	6	7	8		
	60	66	72	78	84	90	96	102	860	0.898
	Reaction									
	0.163	0.175	0.183	0.188	0.19	0.19	0.187	0.181		

CONCLUSION

This optimization method can provide a better value for the design in a relatively short time compared with the design method previously employed. If the design process included enough constraints and no further improvement could be realized after gradient research with different starting points, the final design would be considered acceptable as an optimum. The study proves that some of the experiences from normal gas turbine conceptual design could be used in helium turbine conceptual design without evident error.

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