AGTSR

FINAL PROJECT REPORT

Project Title: **STEAM COOLED GAS TURBINE BLADE**

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1. INTRODUCTION

The major aim of all gas turbine manufacturers is to design gas turbines with more power output per unit and higher efficiency. One of the most powerful parameters controlling the gas turbine efficiency is the turbine inlet temperature. Thermodynamically, the higher the inlet temperature the higher the efficiency. The ideal efficiency of a gas turbine is similar to the efficiency of an ideal gas process given by.

$$\eta_{ith} = \frac{T_{max} - T_4 + T_{min} - T_2}{T_{max} - T_2}$$

Figure 1 shows the process of a gas turbine schematically in an h-s diagram. The temperature in the turbine is limited by the properties of the materials used for the turbine. The first stage of the turbine is the critical part because it is subjected directly to the highest pressure and the highest temperature gas coming from the combustion chamber. The temperature profile is non uniform in a radial and circumferential direction. Due to rotation, the rotor blades feel a reduced spanwise temperature distribution, which is a circumferential average. The conditions for the stator blades are high, non uniform temperatures and low stress. For the rotor blades there are very high centrifugal stresses at a relatively lower temperature.

Two factors determine the life of turbine blades mainly: creep and thermal fatigue. Oxidation and corrosion play, additionally, a non negligible role in the onset of failure.

At the beginning of the fifties the only material available was steel which could withstand temperatures up to 1000 K. But the development of high temperature steels and new casting methods made higher temperatures possible. In the present state of the art, the highest temperature allowed for refractory steel does not exceed 1250 to 1300 K. Exceeding the temperature by 40 K shortens the life duration of the blade by half.

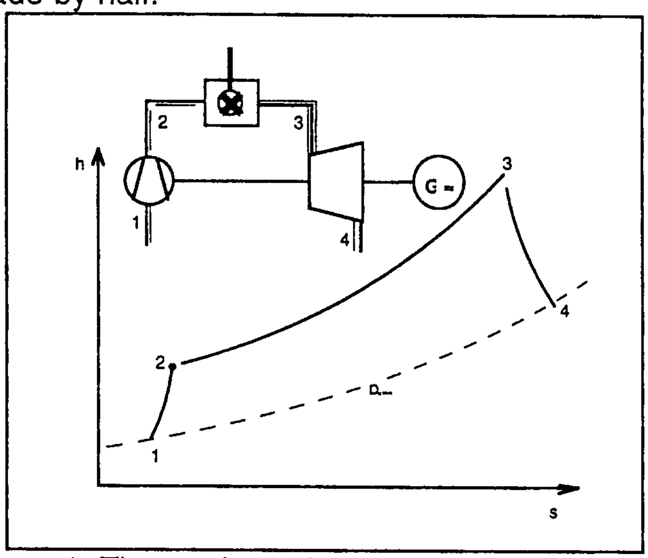

Figure 1. Thermodynamic process of a gas turbine

To achieve higher turbine entry temperatures the blades have to be cooled. There are different methods using different coolants developed over the years for cooling blades.

Generally the following requirements must be fulfilled by the applied cooling system:

- The level and distribution of blade metal temperatures should be such that a satisfactory blade life is achieved.

- The reduction in turbine efficiency and overall cycle efficiency compared to an uncooled turbine with the same turbine inlet temperature should be kept as small as possible.

- The performance level of the cooling system should not deteriorate during operation.

- The system should be mechanically simple and relatively easy to manufacture and to service.

- The application of the cooling system has to be justified on the basis of the overall cost of the installation.

At the present time air is the most often used coolant for gas turbine blade cooling. Air has poor 'coolant' thermal properties. It also has the disadvantage that is taken from the compressor. Although the cooling air is usually blown out into the turbine flow, the pressure losses in cooling channels are so high that the energy of the cooling air cannot be used in the turbine. This means there is a limit to the quantity of the cooling air. More cooling air means higher turbine entry temperature. But the amount of air flowing into the turbine will be reduced and so the efficiency will be reduced. An optimum proportion has to be found. Usually the proportion of the coolant air is up to 15% of the total compressor mass flow.

Liquids have good thermal properties but high viscosity. There are also technical difficulties with liquid cooling because of the possibility of evaporation of the fluid, which causes an abrupt increase of pressure.

Steam has the advantages of both, good thermal properties and low viscosity. Steam can be generated by the heat from the exhaust gas of the gas turbine, which has a high temperature. The necessary pressure can be produced with low energy by pumping the feeding water of the steam generator up to the desired pressure.

In a combined cycle, the heat from the exhaust gas is used to generate steam for the steam turbine; and the combined cycle provides overall efficiency at present up to 58%, which is the highest efficiency of all fossil fired engines.

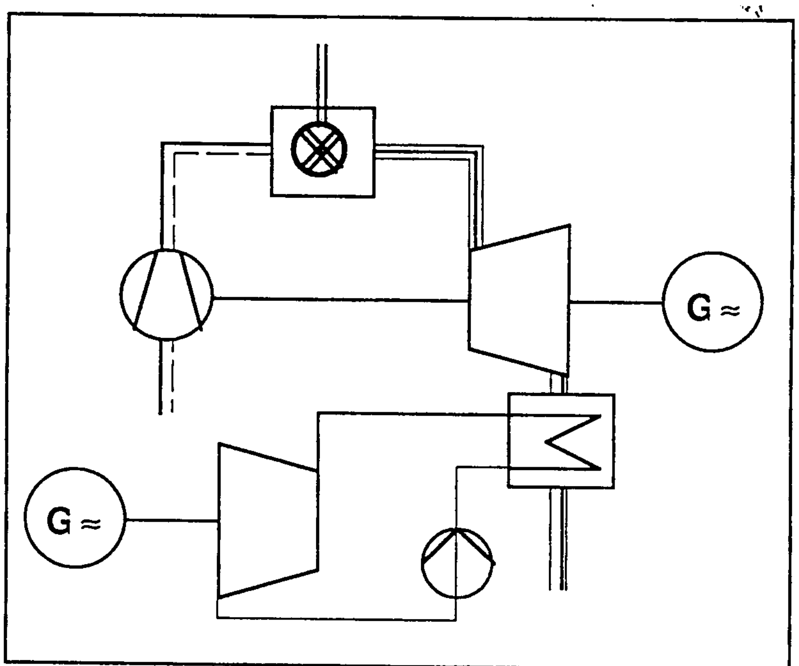

Figure 2 Thermodynamic process of a combined cycle

Steam as a coolant is a possible option to cool blades in high temperature gas turbines. However, to quantify steam as a coolant, there exists practically no experimental data. This work deals with an attempt to generate such data and the design of two experimental setups used for the purpose. Initially, in order to guide the direction of experiments, a preliminary theoretical and empirical prediction of the expected experimental data was performed.

2. CLASSIFICATION OF BLADE COOLING METHODS

A high level of ingenuity has been devoted to the design of cooling techniques, that allows a maximum cooling effectiveness and as low as possible thermodynamic losses. The cooling methods differ by coolant type, shape of the blade, and the way they cool. Figure 3 gives an overview of the existing blade cooling methods.

2.1 Cooling by gaseous fluids

The most common cooling gas is air. The air is generally taken from the compressor outlet and lead directly to the turbine blades after bypassing the combustion chamber. The temperature difference between this air and the hot gas can be as much as 700° C. The cooling air is generally reinjected into the main gas stream in order to utilize its energy and to reduce performance losses of the cycle. From the various gas cooling methods, transpiration cooling