Research Paper

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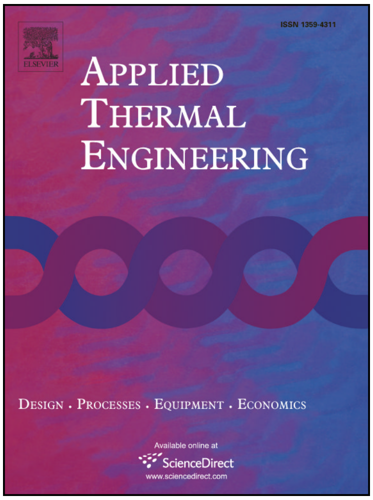

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Thermodynamic analysis of recuperative gas turbines and aero engines

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Abstract

In the current work, the thermodynamic cycle of a conventional recuperative aero engine, in which a heat exchanger is placed after the power turbine, is compared with the thermodynamic cycles of two non-conventional recuperative aero engine configurations. For each configuration, different heat exchanger designs were used, all having the same core arrangement as the heat exchanger in the conventional recuperation aero engine which was designed by MTU aero engines AG and has been initially used in the first concept of the Intercooled Recuperative Aero engine of MTU. The core of the heat exchangers is specially designed to enhance heat transfer and minimize pressure losses when used as a recuperator in aero engines. Regarding the non-conventional cycle configurations, the first one is referred to as 'alternative recuperative' cycle, where a heat exchanger is placed between the high pressure and the power turbine, while the second one is referred to as 'staged heat recovery' where two heat exchangers are employed, one between the high and power turbines and the second one at the exhaust, downstream the power turbine. The comparison is based on the efficiencies and the thrust specific fuel consumption of each thermodynamic cycle. The performance characteristics of the heat exchangers were defined from previous experimental measurements and computational fluid dynamics. For all the examined configurations, the aero engine geometrical constrains were taken into consideration, especially for the alternative recuperative cycle. The results of the study showed that the alternative recuperative and the staged heat recovery cycles were more efficient than the conventional recuperative cycle for a specific range of pressure ratios and heat exchangers characteristics. These cycles combined with appropriate geometrical adaptations and with advanced, temperature resistant ceramics, alloys and other materials have the potential to further optimize the waste heat management exploitation in aero engines.

Keywords: gas turbines, aero engine, heat exchanger effectiveness, recuperation, staged heat recovery

1. Introduction

Fuel consumption and increased pollutants emissions of gas turbines are important factors that an engineer should take into account for both environmental and economic reasons, especially when issues regarding global warming and fuel supply independency arise. For this reasons the design of high efficient gas turbines, with low fuel consumption, is of great interest and practical importance. Currently, a typical gas turbine operates with a ~40% cycle efficiency, depending always on the compressor overall pressure ratio (OPR). As a result, a ~60% of the fuel energy is still left unexploited on the gas turbine exhaust gas and is discarded to the environment as thermal energy. For the exploitation of this discarded thermal energy, the integration of heat exchangers preheating the compressor discharge air in gas turbines, can be of significant value.

The use of heat exchanger based recuperative gas turbine configurations seems to be the most promising solution which is becoming continuously more feasible by the improvement of material properties operating in high temperature environments (e.g. Inconel alloys). For this reason, many researches are now focusing on improving the design of heat exchangers in order to achieve high heat transfer rates and further improve the performance of the cycle, [1]. The installation of heat exchangers can enhance gas turbines performance in order to be competitive to major power production cycle rivals, such as Rankine steam cycles, especially for ground-based applications, where weight and available space constraints present weak limitations. Due to the importance of waste heat recovery for energy efficiency optimization various works have been focused on the assessment of the performance of heat exchangers tubes, Kukulka and Smith [2] or the integration and assessment of the performance of heat exchangers of various types thremodynamic cycles, Kilkovský and Jegla [3] or applications, Klemes and Varbanov [4] .

Regarding gas turbines, the conventional integration of heat exchangers is typically performed with the installation of a heat exchanger system right after the last turbine in order to exploit the hot-gas high thermal energy content. As heat is transferred from the hot-gas to the compressor discharge air, the latter enters the combustion chamber with higher enthalpy content and thus, the cycle fuel demand is reduced leading to increased cycle thermal efficiency and subsequent pollutants emission. The selection of this position for the heat exchanger is mainly based on the available space for heat exchangers integration and the overall relative simplicity for the installation. However, apart from this conventional approach, various researchers, have