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Comparative performance analysis of irreversible Dual and Diesel cycles under maximum power conditions

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Abstract

In this study, a comparative performance analysis and optimisation based on maximum power and maximum thermal efficiency criteria have been performed for irreversible Dual and Diesel cycles. Optimal performance and design parameters, such as pressure ratio, cut-off ratio and extreme temperature ratio, of the cycles has been derived analytically and compared with each other based on maximum power (MP) and the corresponding thermal efficiency criteria. The effects of the internal irreversibilities of the cycles on overall performance in terms of isentropic efficiencies for the compression and expansion processes are also investigated. The obtained results may provide a general theoretical tool for the optimal design and operation of real engines.

Keywords: Irreversibility; Analysis; Performance; Dual cycles; Diesel cycle

1. Introduction

During the last decade, several authors have conducted optimisation studies for heat engines based on endoreversible and irreversible models by considering fine time and finite size constraints and friction losses under various heat transfer modes, mainly linear and non-linear ones [1–6]. Much interest has been recently focussed on optimisation of the air standard Otto, Diesel and Dual cycles [4–9]. In these optimisation studies, optimal design and operation parameters under maximum power (MP) conditions were investigated. Usually in these studies, power and thermal

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efficiency were chosen for the optimisation criteria, and the design parameters at MP and/or at maximum thermal efficiency were investigated [10].

Bhattacharyya [4] proposed a simplified irreversible model for an air-standard Diesel cycle by using the finite time thermodynamic approach. In his study, global thermal and friction losses are lumped into an equivalent friction term, which is linear in the piston velocity. Chen and coworkers [7] extended the same technique to an irreversible air standard Dual cycle model by considering a friction like term loss during finite time.

Anggulo-Brown et al. [8,11] optimised an irreversible Otto cycle model to obtain higher power output and efficiency. Other studies [12,13] analysed endoreversible internal combustion engine cycles using finite time thermodynamic techniques. However, these studies excluded internal irreversibilities, making them less suitable for practical applications.

No comparative performance analyses of irreversible internal combustion engine Dual and Diesel cycles under a MP criterion in terms of isentropic efficiency and extreme temperature ratio appear to have been published in the open literature yet. The isentropic efficiency terms for the compression and expansion processes of the cycle were considered in a similar manner to the definitions of compressor isentropic efficiency for the compression process and turbine isentropic efficiency for the expansion process occurring in a gas turbine system [10]. The extreme temperature ratio was used to account for the effect of combustion on engine performance. It is important how the performance changes with increase of the extreme temperature ratios because of its importance for ceramic engines. The isentropic efficiencies for the compression and expansion processes can be used to account for the trends for all the irreversibilities, such as the friction effect on performance. A comparative performance analysis has been performed with the aim of understanding this effects under the MP criterion. Further study could be of benefit to the analysis of an irreversible Dual cycle considering finite time thermodynamics with the aim of accounting for trends of the heat transfer effects on overall performance of the engine.

2. Theoretical analysis

A ***T–S*** diagram of the considered irreversible Dual cycle is shown in Fig. 1. In the diagram, the process 1–2′ is an isentropic (reversible adiabatic) compression, while process 1–2 is an irreversible adiabatic process that takes into account the internal irreversibilities in the real compression process. The heat addition occurs in two steps: Processes 2–3 and 3–4 are heat additions at constant volume and constant pressure, respectively. Process 3–4 also includes the first part of the power stroke. The process 4–5′ is an isentropic (reversible adiabatic) expansion process, while process 4–5 takes into account the irreversible adiabatic process that occurs in the real expansion process. A constant volume heat rejection process, 5–1, completes the cycle.

The derivations are made only for the irreversible Dual cycle because the Diesel cycle is a special case of the irreversible Dual cycle ($\beta = 1$).

The working fluid system in the cycle flows continuously so that the Dual cycle operates in a steady state. Assuming the working fluid is an ideal gas with constant specific heats, the net cyclic power of the working fluid can be written approximately in the form:

$$\dot{W} = \dot{Q}_{23} + \dot{Q}_{34} - \dot{Q}_{51} \tag{1}$$