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Power, efficiency, entropy-generation rate and ecological optimization for a class of generalized irreversible universal heat-engine cycles

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Abstract

The optimal performance for a class of generalized irreversible universal steady-flow heat-engine cycle models, consisting of two heating branches, two cooling branches and two adiabatic branches, and with losses due to heat-resistance, heat leaks and internal irreversibility was analyzed using finite-time thermodynamics. The analytical formulae for power, efficiency, entropy-generation rate and an ecological criterion of the irreversible heat-engine cycle are derived. Moreover, analysis and optimization of the model were carried out in order to investigate the effect of the cycle process on the performance of the cycles. The results obtained include the performance characteristics of Diesel, Otto, Brayton, Atkinson, Dual and Miller cycles with the losses of heat-resistance, heat leak and internal irreversibility.

Keywords: Finite-time thermodynamics; Generalized thermodynamic-optimization; Heat resistance; Heat leak; Internal irreversibility; Power; Efficiency; Entropy-generation rate; Ecological function

1. Introduction

Recently, the analysis and optimization of thermodynamic cycles for different optimization objectives has made tremendous progress by using finite-time thermodynamics [1–14]. Most previous studies have concentrated on power optimization, or the minimiza-

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Nomenclature

A	exergy output of the cycle (kJ)
C_i	heat-leak coefficient(kJ/(kg K))
C_p	constant-pressure specific heat (kJ/(kg K))
C_v	constant-volume specific heat (kJ/(kg K))
E	ecological function of the cycle (kW)/effectiveness of the heat exchanger
F	heat-transfer surface area (m^2)
k	ratio of the principal specific heats
m	mass-flow rate (kg/s)
N	number of heat-transfer units
P	power output of the cycle (kW)
Q	the rate of heat transfer (kW)
q	heat-leak rate (kW)
S	entropy of the cycle (kJ/K)
T	temperature (K)
U	heat conductance (kW/K)

Greek symbols

α	heat-transfer coefficient (kW/(K m^2))
Δ	variation
η	thermal efficiency of the cycle
σ	entropy-generation rate of the cycle (kW/K)
τ	temperature ratio of the heat reservoirs
τ_1	cycle period
ϕ	additional internal miscellaneous irreversibility coefficient

Subscripts

E	ecological
H, $H1$, $H2$	hot side/heat source
in1, in2	input
L, L_1, L_2	cold side/heat sink
max	maximum
0	ambient
out1, out2	outputs
P	power
1, 2, 3, 4, 5, 6	state points of the model cycle

tion of the fixed cost for a heat-engine and the thermal-efficiency optimization. Alternatively, Angulo-Brown [15] proposed the ecological criterion $E' = P - T_L\sigma$ for finite-time Carnot heat-engines, where T_L is the temperature of cold reservoir, P is the power-output and σ is the entropy-generation rate. Yan [16] showed that it might be more reasonable to use $E = P - T_0\sigma$ if the cold-reservoir temperature T_L is not equal to the environment temperature T_0 from the point-of-view of exergy analysis. This criterion function is more