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A comparative performance analysis of irreversible Carnot heat engines under maximum power density and maximum power conditions

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Abstract

This paper reports the finite time thermodynamic optimization based on the maximum power density criterion for an irreversible Carnot heat engine model which includes three types of irreversibilities: finite rate heat transfer, heat leakage and internal irreversibility. The obtained results are compared with those results obtained by using the maximum power criterion. The design parameters under the optimal conditions have been derived analytically and the effects of the irreversibilities on the general and optimal performances are investigated. The results showed that the design parameters at maximum power density lead to smaller and more efficient heat engines. It is also seen that the irreversibilities have a greater influence on the performances at maximum power density conditions with respect to the ones at maximum power conditions. Also in this study, the optimal conductance allocation parameter is investigated at both maximum power density and maximum power conditions by assuming a constrained total thermal conductance in the case when there is no heat leakage. The relation between the conductance allocation parameter and the thermal efficiencies at maximum power density and maximum power is also investigated. The obtained results generalize the result of previous studies on this subject and provide guidance to optimal design in terms of power, thermal efficiency and engine sizes for real heat engines.

Keywords: Finite time thermodynamics; Maximum power density; Irreversible Carnot heat engines; heat leak; Optimal performance

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Nomenclature

k	specific heat ratio
m	mass of working fluid
$\dot{m}$	mass flow rate
P	pressure
$\dot{Q}$	rate of heat transfer
$\dot{Q}_{HT}$	total heat rate transferred from hot reservoir
$\dot{Q}_{LT}$	total heat rate transferred to cold reservoir
R	ideal gas constant
$R_{\Delta S}$	internal irreversibility parameter
S	entropy
T	temperature
V_4	maximum volume in cycle
$\dot{W}$	power generated from heat engine
x	conductance allocation parameter (α/λ)
α,β,γ	thermal conductance of heat source, heat sink and heat leakage sides, respectively
η	thermal efficiency
λ	overall thermal conductance when no heat leakage $(\alpha+\beta)$
τ	ratio of heat-sink temperature to heat-source temperature

Subscripts

C	Carnot
d	density
H	heat source
L	heat sink
LK	heat leakage
max	maximum
min	minimum
mp	maximum power conditions
opt	optimum
X	warm working fluid
Y	cold working fluid

Superscripts

$*$	maximum power density conditions

1. Introduction

Power optimization studies of heat engines using finite time thermodynamics analysis were started by Chambadal [1] and Novikov [2] in 1957 and 1958 and were continued by Curzon