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A new design method for maximizing the work output of cycles in reciprocating internal combustion engines

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ABSTRACT

A unified description to maximize the work output of reciprocating internal combustion engine is given in this paper. A dual-Miller cycle as a universal cycle for reciprocating internal combustion engine has been selected and established by a new design method. The results show that the work output has linear relationship with the intake temperature, friction coefficient, working fluid, chemical energy release by combustion and heat-transfer coefficient, while there are optimal values of the cut-off ratio, pressure ratio, geometric-compression ratio, specific heat ratio and expansion-compression ratio at which the work output attain their maxima. Thus, the work output can be differentiated with respect to the optimal values and set the resultant derivative equal to zero. In this paper, the results obtained show that the maximum work output of the dual-Miller cycle is greater than that of the classical-Otto, classical-Diesel, classical-dual, Otto-Miller, Diesel-Miller, Otto-Atkinson, Diesel-Atkinson and dual-Atkinson cycles at their optimal values of the cut-off ratio, pressure ratio, geometric-compression ratio, specific heat ratio and expansion-compression ratio, as well as at the same values of the intake temperature, friction coefficient, working fluid, chemical energy release by combustion and heat-transfer coefficient.

1. Introduction

The comparison and optimization of different thermodynamic cycles for improving the design and operation of reciprocating internal combustion engines was considered by several researchers [1]. Lin et al. [2] established a classical-Miller cycle model for four-stroke free-piston engine based on the finite-time thermodynamic modeling. In this study, comparison of the classical-Miller and classical-Otto cycles showed that the classical-Miller cycle had a higher thermal efficiency through extra expansion work. The results demonstrated that the thermal efficiency enhances with decreasing specific heat of working substance. Atmaca and Gumus [3] analyzed and compared the thermodynamic process of the classical-Diesel cycle under three alternative performance criteria, namely, maximum power, maximum power density and maximum efficient power. They concluded that design parameters such as volume ratio and extreme temperature ratio of the cycle under maximum efficient power conditions were better that those under maximum power and maximum power density conditions. The efficient power criterion is more suitable for design of practical Diesel engines. Ebrahimi [4] conducted a theoretical study to investigate the effect of variable specific heat ratio on the classical-Otto cycle process. It was observed from the results that the maximum power output, the optimal power output corresponding to maximum thermal efficiency, the optimal geometric-compression ratio corresponding to maximum power output, and the optimal thermal efficiency corresponding to maximum power output diminish with increasing specific heat ratio. Acikkalp and Yamik [5] showed that the first and second law efficiencies in classical-Diesel and classical-Otto cycles continuously increase as the geometric-compression ratio increases, while exergy destruction decreases. They also showed that the first efficiency in Atkinson-Otto cycle continuously increases as the pressure ratio increases, while exergy destruction parameter decreases. Ust et al. [6] optimized and compared the Otto–Miller, Diesel–Miller and dual–Miller cycle based on exergetic performance criterion and exergy efficiency. It was demonstrated that engine design parameters considerably affect the engine performance. Zhu et al. [7] presented a comparative analysis between the classical-dual cycle and classical-Miller cycle under different operating conditions. The classical-Miller cycle provides lower combustion temperatures compared the classical-dual cycle at the same specific fuel consumptions. Gonca et al. [8] conducted a theoretical study to compare the performance of the Otto-Miller cycle, Diesel-Miller cycle and dual-Miller cycle based on the maximum dimensionless power output. Also, Gonca [9] carried out a theoretical study on the performance of the dual-Atkinson cycle with considerations of heat-transfer and friction losses. The effective power and power density rise up to a specified value and then start to decrease with rising geometric-compression

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Nomenclature

A	chemical energy release by combustion (kJ mol^{-1})
B	heat-transfer coefficient of the chamber wall (kJ mol^{-1} K^{-1})
b	global friction coefficient (J mol^{-1})
$\widetilde{c}_p$	molar constant-pressure specific heat capacity (kJ mol^{-1} K^{-1})
$\widetilde{c}_v$	molar constant-volume specific heat capacity (kJ mol^{-1} K^{-1})
r_c	geometric-compression ratio
Q	heat (kJ mol^{-1})
$\widetilde{R}$	molar gas constant (8.3143 kJ mol^{-1} K^{-1})
T	temperature (K)
W	work output (kJ mol^{-1})

Greek letters

α	pressure ratio
β	cut-off ratio
γ	specific heat ratio
∂	derivative
δ	blowdown ratio
ψ	expansion-compression ratio

Subscripts

f	friction
ht	heat-transfer
in	input
max	maximum
mw	maximum work
out	output
1, 2, 3, 4, 5 and 6	state points of the cycle

ratio. Mousapour et al. [10] conducted a performance analysis of a classical-Miller cycle based on the power output with the consideration of the friction and the heat-transfer losses. Also, they compared the results of finite-time thermodynamics analysis and artificial neural network prediction. Dobrucali [11] showed that the engine design and running parameters had significant effects on the cycle performance for an Otto-Miller cycle; and the cycle temperature ratio, cycle pressure ratio, engine speed, mean piston speed, inlet pressure, equivalence ratio, compression ratio and bore-stroke length ratio affect positively the engine performance in terms of the effective power, effective power density and effective efficiency. Ahmadi et al. [12] suggested a classical-Diesel cycle model based on entransy method and optimization conducted by considering four different scenarios. Zhao et al. [13] showed that there are the optimal values of geometric-compression ratio making the classical-Atkinson cycle performance the best. It is found that increasing the cylinder bore has negative effects on the cycle performance. When the equivalence ratio is constant, the power increases as increasing the mean piston speed. Wu et al. [14] and Ge et al. [15] optimized the ecological function performance of a dual-Miller cycle and a classical-Otto cycle. Ge et al. [16] performed a theoretical study on an irreversible classical-Otto cycle. It was observed that optimization of the exergy-based ecological function not only gives a compromise between the power output and the rate of entropy generation but also gives a compromise between the power output and the thermal efficiency. Zhao et al. [17] applied the finite-time thermodynamics model to analyze the performance of the classical-Otto, classical-Miller and classical-Atkinson cycles by considering irreversible energy losses.

As can be seen in the relevant literature, the critical parameters and non-critical parameters involved in the work output affect each other. However, the simultaneous investigation of all parameters involved to optimize the work output of the dual-Miller cycle as a universal cycle for reciprocating internal combustion engines does not appear to have been published. Motived by this, firstly the critical parameters that maximize the work output of dual-miller cycle are found. Then, all parameters involved in the work output of the dual-Miller are investigated.

2. Thermodynamic modeling

The pressure-volume ($P-V$) and temperature-entropy ($T-S$) diagrams for the dual-Miller heat engine are depicted in Fig. 1, where T_1, T_2, T_3, T_4, T_5 and T_6 are, respectively, the temperatures of the working substance in state points 1, 2, 3, 4, 5 and 6. Processes that occurred in this cycle are as follows: 1 → 2: Reversible isentropic compression; 2 → 3: Isochoric heat addition; 3 → 4: Isobaric heat addition; 4 → 5: Reversible isentropic expansion; 5 → 6: Isochoric heat rejection; 6 → 1: Isobaric heat rejection. Thermodynamic design parameters are the expansion-compression ratio, ψ, pressure ratio, α, cut-off ratio, β, blowdown ratio, δ, as follows:

$$\psi = V_6/V_1 = T_6/T_1 \quad (1)$$

$$\alpha = P_3/P_2 = T_3/T_2 \quad (2)$$

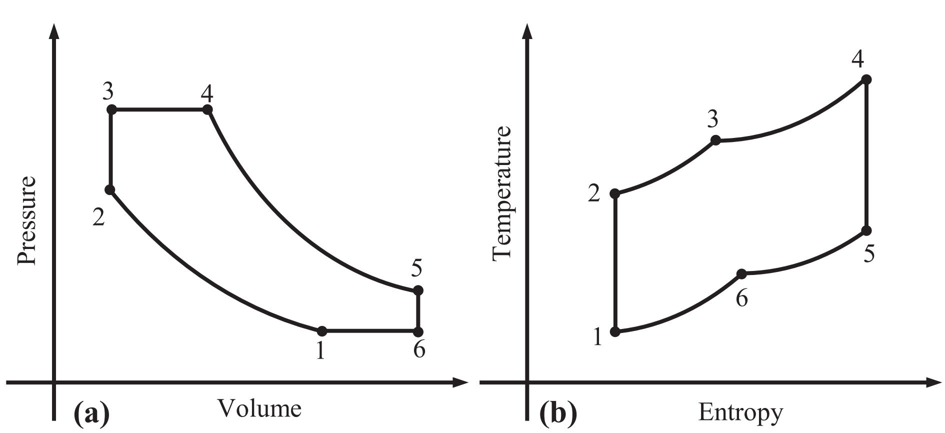

Fig. 1. (a) Pressure-volume diagram; (b) temperature-entropy diagram for the dual-Miller cycle.