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Thermodynamic and dynamic modeling of a single cylinder four stroke diesel engine

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ABSTRACT

In this study the conjugate thermodynamic and dynamic modeling of a single cylinder four-stroke diesel engine was conducted. The gas pressure in cylinder was calculated with the first law of the thermodynamic and the general state equation of the perfect gases. The variation of the heat, given to the working fluid during the heating process of the thermodynamic cycle, was modeled with the Gaussian function. The dynamic model of the engine consists of the motion equations of piston, conrod and crankshaft. Conrod motion was modeled by 2 translational and 1 angular motion equations. In the derivation of the motion equations, the Newton method was used. Motion equations involve hydrodynamic and asperity frictions as well as gas forces. By preparing a heat release rate profile consistent with ones given in the literature, thermal efficiency, knocking, vibration, torque and emission characteristics of the engine were investigated. The counterweight mass and its radial distance were optimized. At full load, if the heat release period is initiated soon after the piston passed the top dead center, the pressure rise rate becomes critical from the knocking point of view however, a couple of degree of retarding of the heat release period avoids the knocking without causing significant loss in thermal efficiency. If the throttling is more than 70%, the temperature of the combustion gas is high enough for NOx formation. At full load the vibrational torque exerting on the crankshaft was determined as about 17 times the engine torque.

1. Introduction

For the current situation the principal power sources used in the ground vehicles is piston engines which are classified as gasoline and Diesel engines according to their fuels. In the past the power requirement of the vehicles requiring comfort were provided mostly by gasoline engines while the power requirement of vehicles requiring no comfort were being provided by Diesel engines. For the current situation despite of some disadvantages such as noise and vibration, Diesel engines are used in a large variety of vehicles such as: trucks, buses, automobiles, heavy duty machines, sea and railway vehicles, military security and defense vehicles, tractors and other agricultural machines and so on [1,2].

Compared to the gasoline engines, Diesel engines have some advantages such as: reliability, fuel efficiency, larger power range, longer lifetime and maintenance period, better torque characteristics, higher power density and lower price of Diesel fuel etc. Despite that diesel engines have a history of about 120 years; a great deal of the modern Diesel engine's technology has been developed within the last decades. The principal developments made within the last decades are development of electronically controlled high pressure fuel injection system, reduction of harmful emissions, reduction of vibration and noise partially, increase

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Nomenclature

C	a constant related to the throttling level of the engine (J/rad)
C_{km}	torsional viscous damping coefficient at conrod bearing (N m s/rad)
C_s	dimensionless friction coefficient at piston side surface
C_h	torsional viscous damping coefficient at main bearing (N m s/rad)
C_p	lateral viscous damping coefficient at piston surface (N s/m)
F_w	gas force exerting onto the piston (N)
F_{ch}	crankcase pressure (N)
F_{bx}	x component of the conrod force exerting on piston (N)
F_{by}	y component of the conrod force exerting on piston (N)
F_{dx}	x component of the force generated by counter weight (N)
F_{dy}	y component of the force generated by counter weight (N)
F_{kx}	horizontal force applied by crankpin to conrod (N)
F_{ky}	vertical force applied by crankpin to the conrod (N)
F_{zx}	horizontal trust force exerting on engine block (N)
F_{zy}	vertical trust force exerting on engine block (N)
F_{∞}	ring pack friction (N)
HRR	heat release rate (J/rad)
h	cylinder heat transfer coefficient (W/m^{2}K)
h_p	distance between piston top and gudgeon pin center (m)
I_{cr}	crankshaft mass inertia moment (m^{2}kg)
I_b	conrod mass inertia moment (m^{2}kg)
k	specific heat at constant pressure/specific heat at constant volume
m_b	mass of conrod (kg)
m_d	mass of counter weight (kg)
m_p	mass of piston (kg)
M_s	starter motor moment (N m)
M_q	external moment applied by the foundation to the engine (N m)
n	stroke counter
p	pressure (Pa)
q	heat per kg of air (J/kg)
Q_p	heat released during the cycle (J)
q_p	heat released per kg of air during the cycle (J/kg/cycle)
Q_w	heat transferred to the wall during the cycle (J)
q_w	heat transferred to the wall per kg of air during the cycle (J/kg/cycle)
R	crank radius (m)
R_d	radial distance of counter weight from the crankshaft center (m)
$\Re$	gas constant (J/kg K)
T	temperature (K)
T_w	wall temperature (K)
t	time (s)
u	internal energy per kg of air (J/kg)
v	specific volume of air (m^3/kg)
V	volume of the gas (m^3)
V_p	average velocity of the piston during a stroke (m/s)
x	coordinate element (m)
x_b	conrod gravity center location in x (m)
y	coordinate element (m)
y_p	piston top location in y(m)
y_b	conrod gravity center location in y (m)

Greek symbols

θ	angular position of the crankshaft respect to the initial position, Fig. 1, (rad)
$\dot{\theta}$	angular speed of the crankshaft (rad/s)
$\ddot{\theta}$	angular acceleration of the crankshaft (rad/s^2)
ω	engine speed,$\dot{\theta}$, (rad/s)
ψ	conrod angle with cylinder axis (rad)
φ	a dimensionless constant to indicate the location of maximum heat release