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Performance improvement of green cars by using variable-geometry engines

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ABSTRACT

The spark ignition engine is the most widely used in land transport sector. Hence, studies to predict and improve its behavior continue to be essential. The behavior of the intake and exhaust systems is important because these systems govern the air flow into the engine's cylinders. Inducting the maximum air flow at full load at any given speed and retaining that mass within the engine's cylinders is a primary design goal. The higher the air flow, the larger the amount of fuel that can be burned and the greater the power produced. The important parameter is the volumetric efficiency along with equal air flows to each engine cylinder. The valves and ports, which together provide the major restriction to intake and exhaust flows, largely decouple the manifolds from the cylinders.

In this work it was intended to find out the effect of variable valve lift and throat diameter on the performance of the SI engine, namely volumetric efficiency, power, brake specific fuel consumption, and pollutants. Hence, it contributes toward having greener cars in the future. A specially designed computer program (Lotus) was used to predict the gas flows, combustion and overall performance.

The results of this investigation show that increasing the valve lift is relatively more effective than throat diameter in boosting volumetric efficiency and power and reducing specific fuel consumption, nitrogen oxide and carbon monoxide emissions. A 10% increase in valve lift resulted in an improvement of 1.8% in η_V, 3.3% in power and a decrease of 1.5% in BSFC and (0.3–0.8)% in engine emissions. However, a 10% increase in valve throat diameter causes 50% less effects than the valve lift.

1. Introduction

Combustion chamber design imposes different constraints on η_V through maximum valve size, valve lift, valve timing, manifold geometry and configuration and the degree of swirl that the chamber and port designs produce to achieve the desired combustion characteristics [1–5]. To obtain its maximum performance and reduce the pumping losses, the size of the valve should be as large as practical [6,7]. The approximate mean piston speed at maximum power is a measure of the maximum mass flow that each engine design can pump [8]. For the purpose of analyzing the engine characteristics, the dimensions were those mentioned in a specially designed program (LOTUS) used to predict the gas flows, combustion and overall performance of spark ignition engines. Engine speed was varied between 500 and 3500 rpm. Ignition was fixed at10° bTDC.

Input data such as inlet pressure, temperature and equivalence ratio have been introduced for all the runs. Also, the required exit data such as the back pressure are given.

The solution of the equations which represent the physical processes helps in predicting the interaction between the elements of the model. The Lotus Program is designed to solve the energy, momentum and continuity equations within each element to obtain the thermodynamic state variables and flow velocity at each crank angle throughout the engine cycle. The solution procedure is "time marching"

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Nomenclature

aBDC	after bottom dead center
a_{oc}	stagnation speed of sound
a_t	the speed of the sound at the valve throat
BMEP	brake mean effective pressure, bar
BSFC	brake specific fuel consumption, g/kW h
bTDC	before top dead center
C_f	flow coefficient
CO	carbon monoxide
CO_2	carbon dioxide
c_p	specific heat at constant pressure, kJ/kg K
F_e	effective area
fn	function
F_{ref}	reference area
F_t	area of valve throat
h	enthalpy
h_{oc}	stagnation enthalpy in the cylinder
h_t	enthalpy in the valve
IVC	inlet valve close, degree
IVO	inlet valve open, degree
m'	mass flow rate, kg/s
L/D	valve lift/throat diameter ratio
N_{max}	maximum speed, rpm
NO_x	nitrogen oxide
overlap	overlap angle, degree
P	brake power, kW
P_c	pressure in cylinder
P_d	downstream static pressure
P_{oc}	stagnation pressure in the cylinder
P_{ou}	upstream stagnation pressure
P_p	pressure drop in the valve
P_t	pressure drop in the pipe
R	gas constant, kJ/kg K
s	entropy, kJ/kg K
T	brake torque, N m
T_{oc}	stagnation temperature in the cylinder
T_{ou}	upstream stagnation temperature
u_t	velocity in the pipe
VL	valve lift, mm
η_{vol}	volumetric efficiency, %
ρ_c	density in the cylinder, kg/m^3
ρ_t	density in the valve throat, kg/m^3

and a number of engine cycles are simulated in order to obtain a converged "cyclic repeatable" solution. To simulate the engine, the processes are broken down in such a way that a number of discrete sub-models including thermodynamic properties are used. The Lotus Program tracks the flow of gas, as a mixture.

At high engine speeds, unless the inlet valve is of sufficient size, the inlet flow during part of the induction process can become chocked (reach sonic velocity at the minimum valve flow area). This reduces η_v hence torque and power [2,9,10]. This relationship can be used to size the inlet valve for the desired η_v at N_{max}. Also, if the inlet valve is closed too early, η_v will not decrease gradually, even if the valve open area is sufficiently large [11,12].

In recent years a lot of attention has been focused on air pollution caused by automobile engines. NO_x is formed at high rates when temperatures are high [8]. Also, when dealing with engine performance, exclusively, improving fuel economy to reduce CO emissions means improving the engine thermal efficiency [9]. Moreover, unless the inlet valve flow area is of sufficient size the induction could be chocked which reduces the volumetric efficiency [2,10].

The objective of this work is to use the Lotus Program to find the effect of valve lift and the throat diameter (variable geometry) on the performance of SI engines (volumetric efficiency, power, torque, BMEP, and BSFC) for optimum engine speed and overlap angle. The engine, valve timing and fuel data are shown in Table 1.

2. Theoretical analysis

Modeling the intake and exhaust ports of engines contains data relating to the valve flow coefficient at various valve lifts. Inlet throat gas velocity is calculated using the continuity equation. This considers the expanding volume of the cylinder as the piston moves down and calculates the corresponding velocity of the gas through the throat, assuming that the gas is an incompressible fluid.

From the Lotus port flow database in which it was found that the inlet port flow coefficients at each valve lift/throat diameter ratio (L/D) is a function of the valve throat to bore area ratio.

2.1. Calculation of the valve effective area, F_e

The specific example of subsonic flow through an exhaust valve will be used to develop an expression for the effective flow area of the valve. The form of the final expression giving the mass flow rate as a function of pressure ratio and effective flow area is identical for subsonic

Table 1
Base engine, gasoline (C_8H_{18}), and valve timing data.

No. of cylinders	Bore	Stroke	Connecting rod length	Compression ratio
1	95 mm	85 mm	129.8 mm	8

Fuel type is iso-octane (C_8H_{18}) of the following properties

Heating value	Density	H/C molar	Molecular mass
43,000 kJ/kg	0.75 kg/l	1.8	114.23 kg/kmol

Single valves are used for inlet and exhaust ports. The original valve timing, inlet throat diameter and valve lift are given below

IVO angle	IVC	EVO	EVC	Inlet throat dia.	Exhaust throat dia.	Maximum valve lifts
20° bTDC	22° aBDC	22° bBDC	30° aTDC	31 mm	26 mm	9.5 mm