The Effect of Valve Timing
on the Performance and Emission of
Spark Ignition Engines

A Thesis submitted to the university of Ain Shams
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PhD Thesis

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Summary

Both experimental and theoretical work have been carried out to investigate the effect of varying valve timing on the performance of four-stroke Spark Ignition Engines. A variable camshaft was used in the experimental tests by which the inlet valve timing could be changed. During each test, measurements of engine power, speed, air and fuel mass flow rates and the exhaust gas concentrations were taken at different inlet valve timings available from the variable camshaft.

Due to the practical limitation of measuring performance for a large number of values of a large number of variables, a computer program has been developed to simulate the engine performance specially at a wide range of inlet and exhaust valve timings within a reasonable range of engine running conditions.

The first law of thermodynamics coupled with the universal equation of the ideal gases were solved step by step throughout the induction, compression and exhaust strokes. The flow through the carburetter and valves was determined according to the upstream and down stream conditions. The pressure fluctuation in the exhaust pipes was determined by considering the one dimensional unsteady flow system of equations and the solution was achieved by using the characteristic method for homentropic flow. During the combustion stage, the flame was assumed to propagate spherically with a turbulent speed which was a function of the laminar speed and the turbulent intensity. A multi-zone model was adopted through the whole combustion stage such that the cylinder contents at the end of combustion were composed of many burned elements each of these having different temperature and species concentrations.

Both experimental and theoretical results confirmed that the valve overlap period has a great influence on nitric oxide emission. The unburned hydrocarbon concentrations were found to increase and then decrease as valve overlap decreased. Carbon monoxide concentration did not change significantly as valve timings were varied, in the lean range of air-fuel ratios.

To achieve the optimum performance from a four-stroke S.I. Engine, valve timings are recommended, as a result of this study, to be varied as a function of speed rather than load. To get the maximum indicated efficiency, inlet valve opening time must be advanced as a function of speed while inlet valve closing has to be retarded. It is also recommended that exhaust valve opening time must be delayed few degrees after top dead centre position in order to minimize the pumping losses. The best range for exhaust valve opening time was found between 40° to 50° before bottom dead centre position where the blowdown losses were found to be minimum.

The benefit to be expected by implementing these recommendations, as estimated at speed of 3000 rpm and full load, are improvements in the indicated fuel consumption of 2.3%, 1.4%, 1.9% and 1.4% corresponding to the individual optimum timings of inlet valve opening, inlet valve closing, exhaust valve opening and exhaust valve closing respectively. This leads to an overall improvement of about 5-7% in the fuel consumption when all optimum valve timings are implemented. The corresponding reductions in nitric oxide mole fraction are 30.3%, 29.7%, 11.7% and 16.4%. At higher engine speeds the improvement in fuel consumption is expected to be more.

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Nomenclature

a	Speed of sound
A	Area, non-dimensional speed of sound; a / a_r
A/D	Distance from the sprk pulg position to the nearest cylinder edge relative to the cylinder diameter
AFR	Air to fuel ratio; by mass
ATDC	After top dead center position
B.P	Brake power
BTDC	Before top dead center position
CR	Compression ratio
C_d	Coefficient of discharge
C_p	Specific heat at constant pressure
C_u	Coefficient of turbulent intensity in eq. (III 41)
C_v	Specific heat at constant volume
d	Diameter
D	Valve diameter
EGR	Exhaust gas recirculation
EIVC	Early intake valve closing
EIVO	Early intake valve opening
EVC	Exhaust valve closing time
EVO	Exhaust valve opening time
F	Exhaust pipe area
g	Gibbs free energy
GT	Gibbs total free energy
h	Convective heat transfer coefficient, specific inthalpy
h_o	Heat of formation

H	Sensible enthalpy
HC	Unbuned hydrocarbons
HT	Total enthalpy
IMEP	Indicated mean effective pressure
IVC	Inlet valve closing time
IVO	Inlet valve opening time
L	Valve lift, exhaust pipe length
LIVC	Late intake valve closing
LIVO	Late intake valve opening
k	Specific heat ratio
K_b	Backward reaction rate
K_{eq}	Equilibrium constant
K_f	Forward reaction rate
M	Number of hydrogen atoms in the fuel, number of meshes, third body
m_a	Air mass flow rate
m_f	Fuel mass flow rate
N	Engine speed, Number of carbon atoms in the fuel
p	Pressure
ppm	Concentration, part per milion
u_p	Average piston speed
Q	Quantity of heat transfer
Q.V	Lower calorific value
rpm	Revolution per minute
R	Flame radius, specific gas constant
R_{mol}	Universal gas constant
RMR	Residual gases to cylinder content mass ratio
S	Entropy, Spark advance

SCL	Manometer scale
S.F.C	Specific fuel consumption
t	time
T	Temperature
u	Flame speed, velocity
u'	Turbulent intensity
U	Sensible internal energy, non-dimensional velocity; u/a_r
UT	Total internal energy
V	Volume
VCF	Viscosity correction factor
W	Work done
x	position coordinate
X	Non-dimensional position coordinate; x/L_r
Z	Number of oxygen atoms in the fuel, non-dimensional time; $a\,t/L_r$

Subscribts

a	air
act	actual
atm	atmosphere
av	average
b	burned element
c	cylinder
car	carburettor
cr	critical
d	dry, down stream, stem
d.a	dry air
e	exhaust
eq	equilibrium

exp	experimental
f	fuel
i	inlet
ig	ignition
ind	indicated
l	laminar
m	manifold
o	outlet, stagnation
p	piston
P	Product
r	residual, reference
R	Reactants
t	turbulant
th	theoretical, throat
u	unburned mixture, upstream
v	volumetric
w	wet

Greek

λ, β	Riemann variables
η	efficiency
θ	throttle angle of the carburettor
μ	viscosity
ρ	density
Φ	equivalence ratio; based on dry air

Note:

All dimensions are in S.I. units