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Effect of Intake Valve Closing Time on Engine Performance and Exhaust Emissions in a Spark Ignition Engine

Can ÇINAR *, Fazıl AKGÜN **
* Department of Mechanical Education, Faculty of Technical Education,
Gazi University, 06500 Teknikokullar, ANKARA
** Department of Mechanical Education, Institute of Science and Technology,
Gazi University, 06570, Maltepe, ANKARA

ABSTRACT

In this study, a special variable valve control mechanism that can vary intake valve closing (IVC) time was designed and manufactured. IVC time was varied in a range of 38º crankshaft angle (CA) after bottom dead center (aBDC) to 78º CA aBDC. Exhaust valve opening and closing time, intake valve opening time and lift were not varied. A single cylinder, four stroke, SI engine was used for the experiments. Depending on the engine speed, brake torque, volumetric efficiency, specific fuel consumption (SFC) and exhaust emission variations were investigated for different IVC time values. The brake torque was increased by 5.1% at low engine speeds and it was increased by 4.6% at high engine speeds with variable intake valve time. SFC was decreased by 5.3% and 2.9% at low and high engine speeds, respectively. Also, HC and CO emissions were decreased at high engine speeds.

Key Words: Intake valve closing time, Spark ignition engine, Engine performance, Exhaust emissions

Buji ile Ateşlemeli Bir Motorda Emme Supabı Kapanma Zamanı Değişiminin Motor Performansı ve Egzoz Emisyonlarına Etkisi

ÖZET

Bu çalışmada, emme supabı kapanma zamanını kontrol edebilen özel bir değişken supap mekanizmasının tasarımı ve imalatı yapılmıştır. Emme supabı kapanma zamanı AÖN'dan sonra 38º -78º krank mili açısı aralığında değiştirilmiştir. Egzoz supabı açılma ve kapanma zamanı ile emme supabı açılma zamanı ve kalkma miktarı sabittir. Deneylerde, tek silindirli, dört zamanlı, buji ile ateşlemeli bir motor kullanılmıştır. Farklı emme supabı kapanma zamanlarında, motor devrine bağlı olarak moment, volumetrik verim, özgül yakıt tüketimi ve egzoz emisyonlarının değişimi incelenmiştir. Değişken supap mekanizması ile moment düşük devirlerde %5,1, yüksek devirlerde %4,6 iyileşmiştir. Özgül yakıt tüketimi, düşük ve yüksek motor devirlerinde %5,3 ve %2,9 azalmış, ayrıca yüksek motor devirlerinde HC ve CO emisyonlarında azalma görülmüştür.

Anahtar Kelimeler: Emme supabı kapanma zamanı, Buji ile ateşlemli motor, Motor performansı, Egzoz emisyonları

1. INTRODUCTION

Traditionally, valve timing has been designed to optimize operation at high engine speed and wide-open throttle (WOT) operating conditions (1-3). Controlling valve events and timings provides the best possible filling of the cylinder at all engine speeds. This supercharging and the developed engine torque and power make it possible to downsize engine size and thus reduce fuel consumption and exhaust emissions at all operating conditions. Variable valve timing (VVT) technology make it possible to control the valve timing, lift and phase. A VVT system can vary intake or exhaust valve timings or lift to improve the brake torque, power and fuel economy and reduce exhaust emissions in SI engines (1,4-7). Numerous VVT mechanisms have been proposed and some of these have been demonstrated in engines, however most of the mechanisms in automotive engines are for two-mode change between low and high speeds (8-17). The investigations showed that the intake valve timing, especially of IVC time, is a very important factor for a VVT system. Because the IVC time affects the amount of the cylinder charge, it thus affects the maximum temperature and pressure in the cycle and therefore the progress of the combustion process (2). Variable IVC systems are the simplest in mechanism and the cheapest in cost (9,13,18-20).

The main objectives of this study are to optimize IVC time in order to increase engine performance and reduce exhaust emissions. For this purpose, a special variable valve control mechanism that can vary IVC

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time was designed and manufactured. Depending on the engine speed, brake torque, volumetric efficiency, SFC and exhaust emission variations were investigated.

2. EXPERIMENTAL APPARATUS AND PROCEDURE

The experimental study was conducted on a single cylinder, four-stroke, SI engine. The specifications of the engine are given in Table 1.

A special variable valve control mechanism that can vary IVC time was manufactured and installed in the test engine. Fig. 1 shows a photo of our camshaft. The intake cam profile varies along the camshaft axis to vary IVC time from 38º CA aBDC to 78º CA aBDC with 10º CA intervals. The variation in closing time was achieved by the motion of the camshaft axially while leaving the tappets stationary. The lift and opening time of the intake valve were fixed when the camshaft moves in the axial direction (Fig. 2).

Table 1. Specifications of the test engine

Item		Specification
Engine type		SI engine, SOHC
Number of cylinder		1
Cycle		Four stroke
Cylinder bore (mm)		88
Stroke (mm)		80
Swept volume (cc)		487
Maximum power		7.82 kW (at 3000 rpm)
Compression ratio		9:1
Intake / exhaust valve lift (mm)		6.75
Valve timing (CA)	Intake valve opening (bTDC)	19º
	Intake valve closing (aBDC)	38º, 48º, 58º, 68º, 78º
	Exhaust valve opening (bBDC)	59º
	Exhaust valve closing (aTDC)	8º

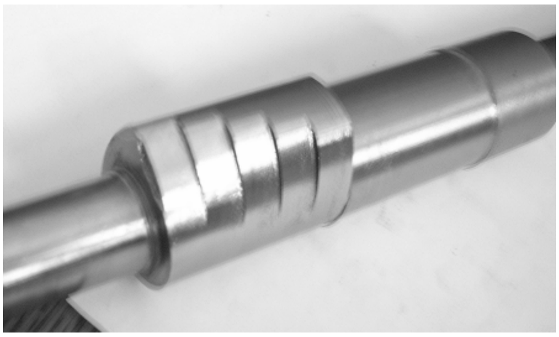

Fig. 1. Variable intake cam profile

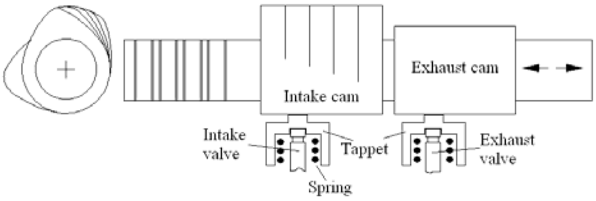

Fig. 2. Variable IVC time mechanism

Fig. 3 shows the intake and exhaust valve timing diagram. The exhaust valve opening and closing time and lift were not varied. The exhaust valve is opened and closed at 59º CA bBDC and 8º CA aTDC respectively. The overlap period is 27º CA in the engine.

A Cussons-P8160 type standard engine test bed consists of an electrical dynamometer, measurement instruments were used in the experiments. The schematic view of the test equipments is shown in Fig. 4.

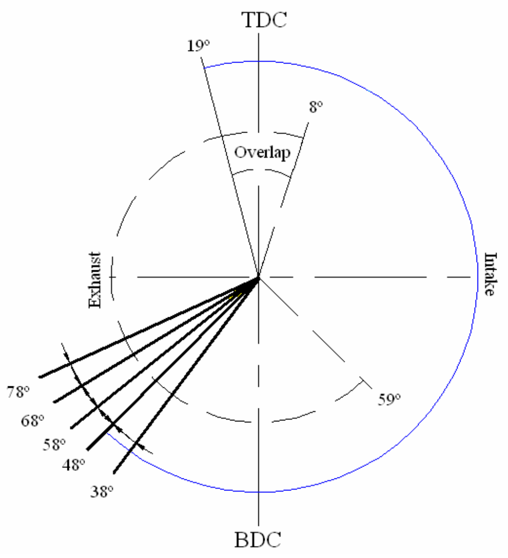

Fig. 3. Valve timing diagram

The engine speed and load were controlled by the dynamometer. Air flow rate was measured by an air flow meter placed on the dynamometer with an accuracy of 1 mm-H_2O. The experiments were performed under variable IVC time conditions (standard, 10º CA advance, 10º CA, 20º CA and 30º CA retard) at WOT and 6 different engine speeds. Matron 808 type conventional ignition system was used as the ignition source. For each test, the spark timing was optimized for maximum brake torque (MBT).

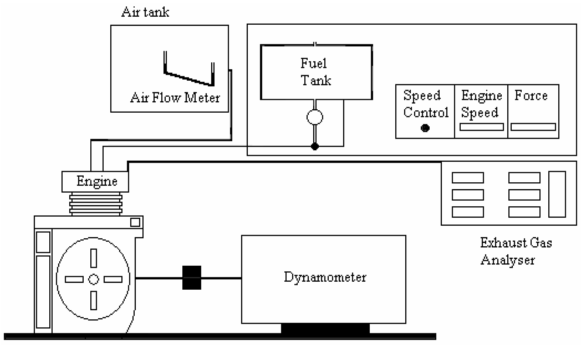

Fig. 4. Schematic view of the test equipment

The concentrations of the exhaust emissions were measured by Sun MGA-1200 type emission analyzer. Before the experiments the analyzer was calibrated. Specifications of the analyzer are shown in Table 2.

Table 2. Specifications of Sun MGA-1200 type emission analyzer device

	Measurements Range	Accuracy
Lambda (λ)	0.80–2.00	0.001
CO (% vol.)	0-10 %	0.01 %
CO_2 (% vol.)	0-20 %	0.01 %
HC (ppm)	0-20000	1
O_2 (% vol.)	0-21 %	0.1 %

3. RESULTS AND DISCUSSION

The variation of brake torque with engine speed for 5 different IVC time is shown in Fig. 5. Fig. 6 also shows the variation of brake torque with engine speed for standard and variable IVC time. Maximum brake torque (MBT) was obtained at the engine speed of 2400 rpm as 28.3 Nm for standard IVC time (48º CA aBDC). At low engine speeds, to increase brake torque it is required to advance IVC time because the fresh charge is prevented from being pushed back through the intake port by the moving piston towards the TDC. As shown in Fig. 5, brake torque was increased by 5.1% at the engine speed of 2000 rpm when the IVC time was advanced 10º CA according to the standard timing. However it was decreased by 8% at 3000 rpm when the IVC time was advanced 10º CA.

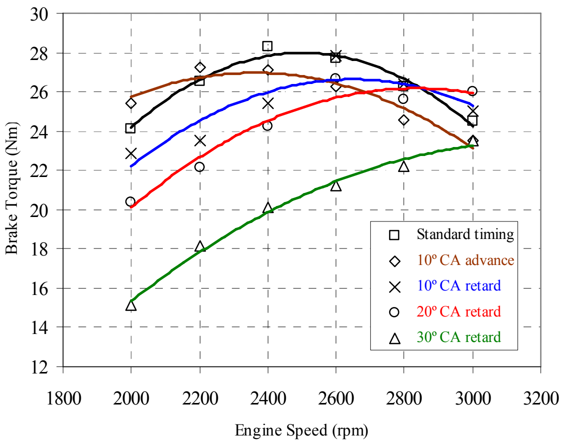

Fig. 5. Variation of brake torque with engine speed

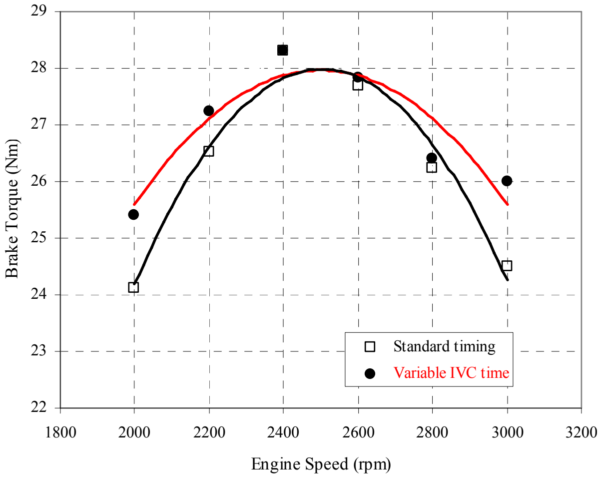

Fig. 6. Variation of brake torque with engine speed for the standard and variable IVC time

At higher engine speeds, as the piston speed is increased, the air in the manifold flowing through the intake port will attain higher velocities. An early IVC time will not permit enough fresh charge to enter the cylinder. A late intake closing allows the charge to fill-up the cylinder volume, but short time afterwards allows the charge to flow back through the intake port before intake valve closes due to the piston moving upwards. A late intake closing after BDC will shorten the compression stroke, so result in reducing the maximum pressure and temperature in the cycle and therefore the maximum engine torque. The existence of an optimal timing for closing the intake valve at full engine load is thus clear (4,17). The brake torque was increased by 4.6% at 3000 rpm engine speed when the IVC time was retarded 20º CA compared to the standard timing. MBT was obtained at 2400 rpm engine speed with the standard timing, however it was obtained at 3000 rpm engine speed when the IVC time was retarded 20º CA.

Fig. 7 shows the variation of volumetric efficiency increase with engine speed. Under low engine speeds, advancing the intake valve increases the volumetric efficiency because the fresh charge is prevented from being pushed back through the intake port by the moving piston towards TDC. As seen in Fig. 7, volumetric efficiency was increased by 3.2% at a low engine speed of 2000 rpm when the IVC time was advanced 10 ºCA compared to the standard timing. At higher engine speeds, retarding the IVC time increases the volumetric efficiency. Volumetric efficiency was increased by 4.8% at 3000 rpm when the IVC time was retarded 20 ºCA. However at a low engine speed of 2000 rpm the volumetric efficiency was decreased by 4.7%. Volumetric efficiency was rapidly decreased when the retardation of IVC time exceeds 30 ºCA according to the standard timing at all engine speeds because the piston pushes back a portion of fresh charge.

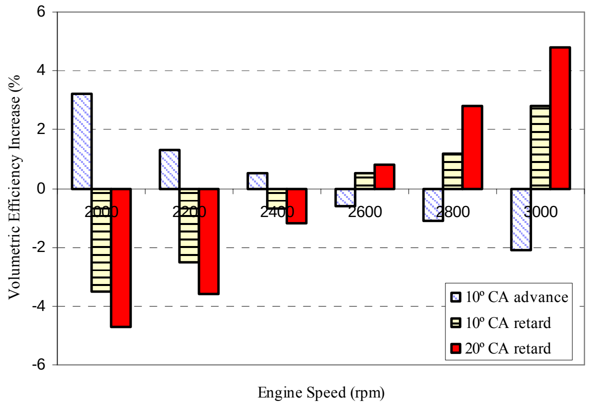

Fig. 7. Variation of volumetric efficiency increase with engine speed

The variation of SFC with engine speed for the standard and variable IVC time is shown in Fig. 8. Fig. 9 also shows the variation of SFC reduction with engine speed for 10º CA advance, 10º CA retard and 20º CA retard compared to the standard timing. Experimental results in Fig. 8 and Fig. 9 show that SFC was decreased by 5.3% at 2000 rpm engine speed when the IVC time was advanced to 10º CA compared to the standard timing, however it was increased by 4% at 3000 rpm. SFC was decreased by 2.9% at 3000 rpm engine speed when the IVC time was retarded 20º CA (68º CA aBDC).

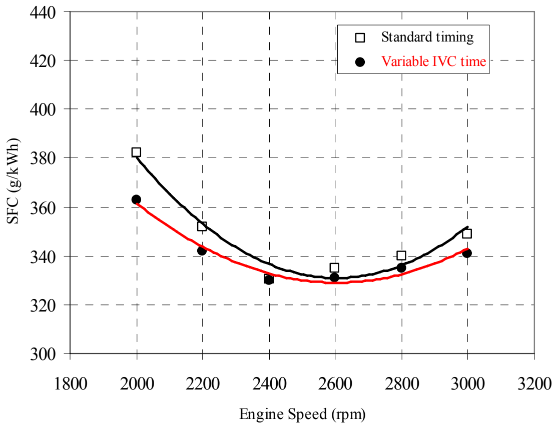

Fig. 8. Variation of SFC with engine speed for the standard and variable IVC time

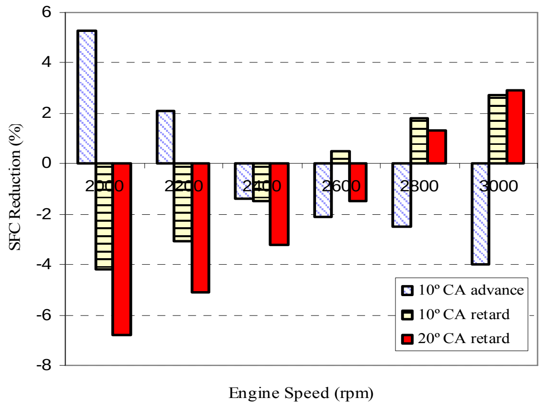

Fig. 9. Relative variation of SFC reduction with engine speed with respect to the standard timing

The variations of CO and HC emissions reduction with engine speed are shown in Fig. 10 and Fig. 11. CO emissions was decreased at 2800 rpm and 3000 rpm engine speeds when the IVC time was retarded. As shown in Fig. 11, HC emissions was reduced only at 3000 rpm engine speeds when the IVC time was retarded. However, it was increased at low and middle engine speeds.

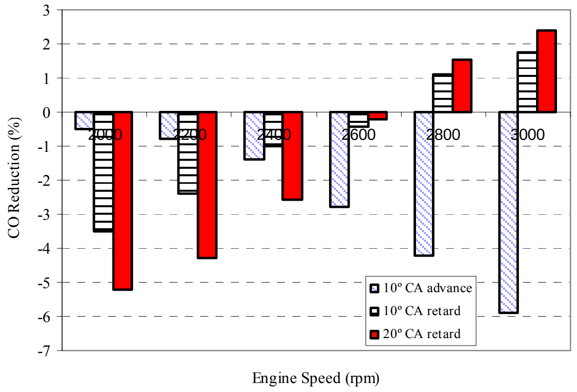

Fig. 10. Relative variation of CO emissions reduction with engine speed with respect to the standard timing

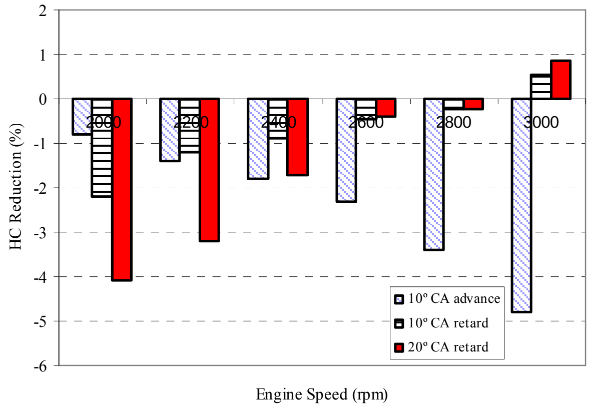

Fig. 11. Relative variation of HC emissions reduction with engine speed with respect to the standard timing

4. CONCLUSIONS

In this study, a variable valve control mechanism that can vary IVC time was designed and manufactured. IVC time was varied in a range of 38º CA aBDC to 78º CA aBDC. Exhaust valve opening and closing time, intake valve opening time and lift were not varied. Depending on the engine speed, brake torque, volumetric efficiency, SFC, CO and HC emission variations were investigated. Based on the experimental study, the following results were obtained:

1. When variable IVC time was applied, the brake torque, volumetric efficiency and SFC were improved at all engine speeds.
2. Volumetric efficiency and the brake torque were rapidly decreased and SFC was increased when the retardation of IVC time

exceeds 30 ºCA according to the standard timing at the low to high engine speed range.

3. CO and HC emissions were reduced only at high engine speeds.
4. The variation in IVC time was achieved by the motion of the camshaft axially while leaving the tappets stationary. This system, with its simple mechanism, is suitable to be used in SI engines with single overhead cam (SOHC). The future work will be focused on the hydraulic mechanism to provide the axial motion of the camshaft automatically, depending on the engine speed.

ABBREVIATIONS

aBDC	after bottom dead center
bBDC	before bottom dead center
aTDC	after top dead center
bTDC	before top dead center
CA	crankshaft angle
CO	carbon monoxide
IVC	intake valve closing
HC	hydrocarbon
MBT	maximum brake torque
SFC	specific fuel consumption
SI	spark ignition
SOHC	single over head cam
VVT	variable valve timing
WOT	wide open throttle

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