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NGHIÊN CỨU ẢNH HƯỞNG CỦA GÓC ĐÁNH LỬA SỚM TỚI ĐẶC ĐIỂM QUÁ TRÌNH CHÁY VÀ HÌNH THÀNH PHÁT THẢI CỦA ĐỘNG CƠ ĐÁNH LỬA SỬ DỤNG NHIÊN LIỆU CNG BẰNG PHẦN MỀM AVL BOOST

A STUDY OF THE EFFECTS OF IGNITION TIMING ON COMBUSTION AND EMISSIONS CHARACTERISTICS OF S.I. ENGINE FUELED WITH CNG BY AVL BOOST

Nguyễn Đức Khánh, Hoàng Đình Long, Nguyễn Thành Trung

Tóm tắt

Bài báo này trình bày kết quả nghiên cứu ảnh hưởng của góc đánh lửa sớm tới diễn biến quá trình cháy và hình thành phát thải của động cơ đánh lửa cưỡng bức sử dụng nhiên liệu khí thiên nhiên nén CNG. Nghiên cứu được thực hiện trên phần mềm mô phỏng chu trình công tác của động cơ AVL Boost. Quá trình mô phỏng được tiến hành trên động cơ 4 kỳ, 4 xylanh, đánh lửa cưỡng bức, có dung tích 1.5 lít tại tốc độ 4000 vòng/phút với bướm ga mở hoàn toàn, có góc đánh lửa sớm nguyên bản -8 độ trục khuỷu (°TK). Kết quả mô phỏng cho thấy, khi tăng góc đánh lửa sớm thì áp suất và nhiệt độ trong xylanh càng tăng; áp suất chỉ thị trung bình (IMEP) và áp suất có ích chỉ thị trung bình (BMEP) có xu hướng tăng, đạt giá trị lớn nhất tại góc đánh lửa -20°TK tuy nhiên, IMEP và BMEP có xu hướng giảm khi tiếp tục tăng góc đánh lửa sớm. Phát thải độc hại của động cơ như NO_x có xu hướng tăng và thành phần HC tăng mạnh khi tăng góc đánh lửa sớm trong khi thành phần CO giảm một chút khi thay đổi góc đánh lửa sớm.

Từ khóa: động cơ CNG, góc đánh lửa sớm

Abstract

This paper presents the research results of effects of ignition timing on combustion and emissions of Compressed Natural Gas (CNG) fueled Spark – Ignition (S.I.) engines. Simulation process is conducted on AVL Boost, an advanced simulation software in Internal Combustion Engine (ICE) research field. The subject of this study is a 4-cylinder, 4 stroke, spark ignition engine with the volume of 1.5 liters at a speed of 4000 rpm and full open throttle; and its ignition timing is -8 crank angle (°CA). The results show that ignition timing has a significant influence on engine performance, combustion and emission characteristics. In specific, the maximum of gas pressure, gas temperature in cylinder has been increased with advancing ignition timing. Indicated Mean Effective Pressure (IMEP) and Brake Mean Effective Pressure (BMEP) also have been increased with advancing ignition timing to gain a maximum value at 20°CA. However, IMEP and BMEP tend to be decreased when continuously advancing ignition timing. Some toxic or harmful emissions such as NO_x and HC are sharply increased with advancing ignition timing, whereas CO emission is slightly decreased with various ignition timing.

Key words: CNG engine, advanced ignition timing

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1. INTRODUCTION

Compressed Natural Gas (CNG) has been widely used as an alternative fuel for internal combustion engine (ICE) because of its appropriate chemical properties. Its high H/C ratio leads to low level of emission comoponents and high research octane number leads to a lower knock tendency[1,3]. Due to some of its favorable physio-chemical properties, CNG appears to be an exellent fuel for S.I. engines. Moreover, standard S.I. engines can be converted to operate with CNG quite easily by adding a second fuelling system[2,3] and compressed natural gas help to reduce the dependence on crude oil[4]. However, CNG has quite slower flame velocity than gasoline, leading to longer duration of combustion (0.42 for gasoline versus 0.38 for CNG[5,6,7]), therefor, it is nesecsary to adjust for advancing ignition timing. According to Evans RL[8], ignition timing for natural gas has to be advanced between 2° and 10° CA compared to gasoline engine in stoichiometric operation condition.

In this study, a simulation model of CNG S.I. engine converted from gasoline engine has been developed and then the ignition timing is adjusted from initial value to estimate its effects on combustion process and emissions formation characteristic of the engine

2. CONTENTS OF SIMULATION STUDY

2.1. Simulation object

The object of this study is 1NZFE S.I. engine. The specifications of the engine are listed in Table. 1

Table 1. Engine specifications

Name	1NZFE
Number of cylinder	4
Type	Spark ignition
Volume	1.5 lit
Bore	75.0 mm
Stroke	84.7 mm
Compression ratio	10.5:1
Ignition timing	-8°CA/4000 rpm

2.2. Simulation methodlogy

Study was conducted on advanced technology simulation software AVL Boost. Boost is one-direction simulation software, which can simulate and calculate thermodynamic and gas exchange processes in combustion engine. The software can simulate any type of engine with different types of fuel blends with high accuracy and reliablity to make an advantage of research and design engine.

The ICE was simulated at speed of 4000 rpm, at fully opened throttle, CNG mass was controlled to keep air exceed ratio constantly equal to 1. The ignition timing was adjusted to icrease or decrease from the original point (-80CA) with interval of 40CA to analyse the effects of this parameter on combustion process and emission formation characteristic of the engine.

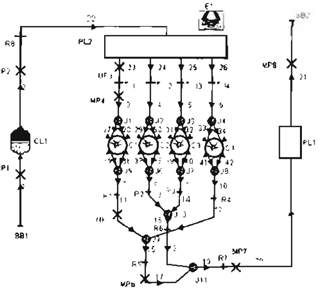
3. SIMULATION MODEL BUILDING

3.1. Engine model building

Based on theorical manual and elements included in data base and technical parameters of ICE, the model was built as shown in Figure. 1

3.2. Fuel model

Fuel blend used in study was CNG with major compositions as presented in Table. 2



Note:
SB1,2: System boundary;
CL1: Air cleaner;
I1-4: CNG Injectors;
C1-4:Cylinder;
PL1,2: Plenum;
MP1-8: Measurement points;
R1-8: Restrictor;
J1-11: Conjuntions

Figure 1. Simulation model of engine on AVL Boost

Table 2. Compositions of natural gas [9,10]

Items	Symbol	% by Vol.	%
Methane	CH_4	96,40	±0,30
Ethane	C_2H_6	2,50	±0,30
Propane	C_3H_8	0,20	±0,10
Butane	C_4H_{10}	0,07	±0,04
Carbon dioxide	CO_2	0,20	±0,10
Nitrogen	N_2	0,53	±0,10
Others	(H_2O+)	0,10	

These components were inputted

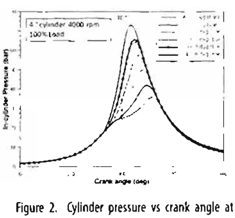


Figure 2. Cylinder pressure vs crank angle at different φ_s

into the software to calculate physio-chemical properties of CNG fuel including low heating value and stoichiometric ratio A/F.

4. SIMULATION RESULTS AND DISCUSION

The simulation results of effects of iginition timing on combustion and

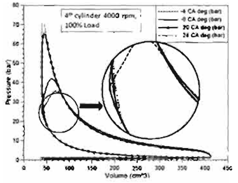


Figure 3. P-V diagram at original, optional, advancing and retarding ignition timing

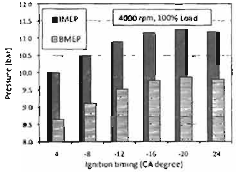


Figure 4. IMEP, BMEP and peak pressure raise at different φ_s

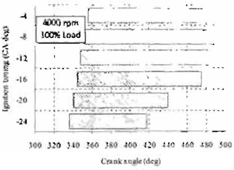


Figure 5. Combustion duration at different φ_s

emissions formation characteristic of the ICE were showed in Figure 2 to 9.

4.1. Effects of ignition timing (φ_i) on engine combustion process

It can be seen in Figure. 2, when retarding ignition timing, in-cylinder pressure decreases because combustion process starts latterly, even ATDC in the cases of -8 and -40CA. When advancing ignition timing, combustion process has been started earlier according to the variation of ignition timing. With the advancing ignition timing, in-cylinder pressure tends to be increased respectively but the losses in pumping work may be increased. It can be clearly seen in Figure. 3 and 4, which show P-V diagram, IMEP and BMEP at different ignition timings. At ignition timing of -20°CA, the IMEP and BMEP gain maximum values of 11.27 bar (increases by 7.4%) and 9.88 bar (increases by 8.3%), respectively compared to original ignition timing. However, when ignition timing is continuously advanced, these values tend to be decreased although peak in-cylinder pressure is increased. The reason is that advancing ignition timing up to -24°CA causes the combustion process to start too early BTDC, so the increase in pumping work and decrease in expansion work (Figure. 3) as results which make the decrease in IMEP and BMEP.

The variation of ignition timing not only effects in-cylinder pressure but also combustion duration of combustion process as showed in Figure. 5. It can be seen that total combustion duration (determined from the starting of combustion to 95% of fuel burned completely) has been decreased remarkably when advancing ignition timing because a lager fraction of mixture is burned completely BTDC as in-cylinder pressure and temperature has been increased (Figure .6 below)

4.2. Effects of ignition timing (φ_i) on engine emission formation

The Figures. 6 shows in-cylinder temperature at different ignition timing which is one of important factor in NO_x formation and the Figure from 7 to 9 show the concentration of NO_x, CO and HC emission versus crank angle at different ignition timings.

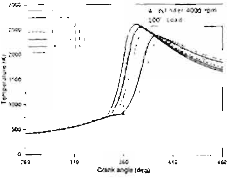


Figure 6. In-cylinder temperature vs crank angle at different φ_i

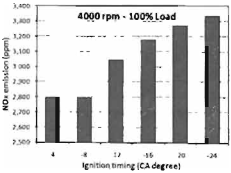


Figure 7. Concentration of NO_x vs crank angle at different φ_i

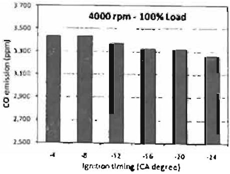


Figure 8. Concentration of CO vs crank angle at different φ_i

As above discussion, when advancing ignition timing, in-cylinder temperature increases to deliver peak value at TDC. This leads to the increase

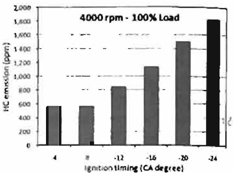


Figure 9. Concentration of total HC vs crank angle at different φ_i

in NOX emission. The increase is by value of 8.4% at 20°CA and 11.6% at 24°CA BTDC compared to original ignition timing (-8°CA).

In reverse to the variation of NO_x emission, the variation of carbon monoxide (CO) emission (a main product of uncompleted combustion) versus crank angle at different ignition timings have been decreased a little by value of 3.4% at 20°CA. The reason is that high in-cylinder pressure and temperature makes combustion more completely thereby increasing in CO emission.

The concentration of HC emission in exhausted gas, which includes of not only unburned hydrocarbon but also form crevice and lubricant oil film tend to be increased significantly and the variation tends to be more obvious at more advancing ignition timing. The reason is that the temperature in expansion in cylinder were decreased thereby the reduction of post-oxidation process efficiency when advancing ignition timing as showed in the Figure. 6 above. The increase is by value of 146% at 200CA and 203% at and 24°CA BTDC compared to original ignition timing.

5. CONCLUSION

Combustion process and emission formation characteristics of CNG fuelled S.I. engines under various ignition timing were study and the main results are summarized of follows:

In-cylinder pressure and temperature have been increased with advancing ignition timing; operation parameters including IMEP, BMEP increase to archive maximum value at -20°CA but tend to be declined if continuously advancing ignition timing due to the increase in losses pumping work and decrease in expansion work.

- Combustion duration was reduced remarkably with advancing ignition timing, thereby the increase in peak temperature in cylinder that makes NO_x emission increased.

- Total HC emissions is increased significantly because of the reduction of post-oxidation process efficiency due to the decrease of temperature in expansion process.

- CO emission was decreased a little with advancing ignition timing because of completely combustion due to high temperature and pressure in cylinder.

Phản biện khoa học: TS. Trần Đăng Quốc

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TRƯỞNG ĐẠI DIỆN VĂN PHÒNG JICA VIỆT NAM ĐẾN THĂM TRƯỜNG

Sáng 05/8/2013, ông Mutsuya MORI - Trưởng đại diện văn phòng JICA Việt Nam và ông Phương Hoàng Kim - Vụ trưởng Vụ Phát triển Nguồn nhân lực (Bộ Công Thương) đồng thời là Giám đốc Dự án JICA - HaUI giai đoạn 3 và ông Hồ Quang Trung – Vụ trưởng Vụ Hợp tác quốc tế (Bộ Công Thương), đến làm việc với lãnh đạo trường Đại học Công nghiệp Hà Nội. Tiếp nối thành công của hai giai đoạn đầu trong dự án JICA-HaUI, các bên tiếp tục trao đổi những phần công việc của giai đoạn 3, hiện đang được triển khai thực hiện tại trường Đại học Công nghiệp Hà Nội. Về phía JICA, ông Mutsuya Mori cam kết đảm bảo hỗ trợ Nhà trường về nhân lực dự án và các thiết bị máy móc cần thiết cho dự án. Về phía Bộ Công Thương, ông Phương Hoàng Kim cũng cam kết hỗ trợ và phối hợp với JICA Việt Nam để triển khai thực hiện giai đoạn 3 của dự án đạt kết quả tốt. Với kết quả của dự án JICA – HaUI giai đoạn 2 và kết quả bước đầu của dự án JICA – HaUI giai đoạn 3, các bên đều tin tưởng dự án JICA – HaUI giai đoạn 3 sẽ được trường Đại học Công nghiệp Hà Nội thực hiện thành công./.