DEVELOPMENT AND ANALYSIS OF PULSE DETONATION ENGINE (PDE) WITH FUEL-AIR PREMIXED INTAKE SYSTEM

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ABSTRACT

This research is on experimental studies of the pulse of detonation engine (PDE) at High Speed Reacting Flow Laboratory (HiREF) where the pulse detonation engine was equipped with a new design of a fuel-air premixed intake system. Pulse detonation engine is a power conversion device with simple mechanism and yet efficient. A premixed intake system is fabricated and assembled with a detonation tube with dimension of 50 mm inner diameter and 600 mm in length. Stoichiometric condition of fuel-air mixture for repetitive high-speed combustion is prepared for the pulse detonation engine with operating frequency system of 5Hz. Fuel and oxidizer are injected using gas injectors into air flow in intake system manifolds that connected to mixing chamber and detonation tube. The pressure produced in the tube is measured using pressure transducers located along the detonation tube. The pulse detonation engine model is evaluated with thermodynamics theory models; Ideal pulse detonation engine (PDE), Brayton cycle and Humphrey cycle. The thermodynamic cycle efficiency of the pulse detonation engine is analyzed and compared with non-premixed pulse detonation engine for evaluation. The simulation result indicated that ideal PDE operates at 0.24 thermal efficiency. The ideal pulse detonation engine is predicted to produce 276.3 N with generated impulse up to 68.5 s in stoichiometric condition of propane and air mixtures.

ABSTRAK

Penyelidikan ini adalah mengenai kajian eksperimen enjin letupan berdenyut (PDE) di makmal aliran tindak balas berkelajuan tinggi (HiREF) di mana enjin letupan berdenyut dilengkapi dengan system pengambilan alat pracampuran bahan api dan pengoksida yang baru. Enjin letupan berdenyut adalah alat penukaran kuasa dengan mekanisme mudah tetapi berkesan. Sistem pengambilan pra-campuran dibuat dan dipasang ke tiub letupan berdimensi 50 mm diameter dalam dan 600 mm panjang. Enjin letupan berdenyut dengan kekerapan tembakan system operasi disediakan untuk pembakaran berkelajuan tinggi berulang untuk campuran bahan api dan pengoksida dalam keadaan stoikiometri pada 5 Hz. Bahan api dan pengoksida disuntik menggunakan penyuntik gas ke dalam aliran udara di manifold sistem pengambilan yang bersambung dengan kebuk pencampuran dan letupan tiub. Jumlah tekanan yang dihasilkan diukur menggunakan transduser tekanan yang berada di sepanjang tiub letupan itu. Enjin letupan berdenyut model dinilai dengan menggunekan kitaran termodinamik model teori; Enjin letupan berdenyut ideal, kitaran Brayton dan kitaran Humphrey. Kecekapan kitaran termodinamik daripada enjin letupan berdenyut dianalisis dan dibandingkan dengan enjin letupan berdenyut bukan pracampuran untuk penilaian. Hasil simulasi menunjukkan bahawa PDE ideal beroperasi pada 0.24 kecekapan haba, η_{th}. Enjin letupan berdenyut ideal telah diramalkan untuk menghasilkan 276.3 N dengan impuls yang dijana sehingga 68.5 s dalam keadaan stoikiometri untuk campuran propana dan udara .

TABLE OF CONTENTS

LIST OF TABLE

LIST OF FIGURES

LIST OF SYMBOLS

Ø	-	Equivalence ratio
D	-	Tube's internal diameter (m)
d	-	Blockage passable diameter (m)
νx,i	-	Velocity (m/s)
P	-	Pressure (Pa)
ρ	-	Density (kg/m3)
MW	-	Molecular weight (kg/kmol)
MS	-	Mass flow rate (kg/s)
Ma	-	Mach number
MCJ	-	Chapman-Jouguet Mach number
c	-	Speed of sound (m/s)
q	-	Heat addition (J/kg)
R	-	Specific gas constant (J/kg-K)
νD	-	Detonation velocity (m/s)
CJ	-	Chapman-Jouguet point
Cv	-	Constant-volume specific heat (J/kmol)
Cp	-	Constant-pressure specific heat (J/kmol)
γ	-	Specific heat ratio (Cp / Cv)
υ	-	Specific volume (m^3/kg)
h	-	Enthalpy (J/kg)
λ	-	Detonation cell width (mm)
S	-	Obstacle spacing (m)
Isp	-	Specific impulse (s)
A	-	Tube cross section area (m^2)
g	-	Gravititional acceleration (m/s^2)
Δx	-	Horizontal deflection
V	-	Tube volume (m^3)

LIST OF APPENCIDES

CHAPTER 1

INTRODUCTION

1.1 Research Background

Much interest to utilize pulse detonation engine technology for propulsion system [14] [21] and power generation [40] has been seen in the past twenty manufacture and low in maintenance. Implementation of the pulse detonation engine in commercial application requires continued development in research to achieve sustained and reliable technology. One of the challenges in developing a pulse detonation engine is to have a fast and efficient mixing of fuel and oxidizer and sustain detonated in a controlled fuel-air mixture [27]. Fast and efficient mixing related to the time of mixing between fuel and oxidizer to achieve a homogenous mixture where high frequency operation of the pulse detonation engine can be achieved. The design of fuel/air intake system is proposed to contribute for premixed mixture process and perform better performance than previous non-premixed pulse detonation engine generations. Moreover, the control system's ability in detonation ignition and parameter conditions can affect the pressure velocity of the thrust.

There are two types of combustion occurs in pulse detonation engine function mechanism which are Deflagration and detonation that separated by degree of velocity. Detonation is one of combustion mode where the phenomenon occurs in a thermodynamic properties such as pressure and temperature react and increase sharply across the detonation wave. On the other hand, deflagration is a common combustion mode in the combustion process and the flame propagates in transonic velocity of less than 10 m/s. Deflagration is the conventional type of combustion in internal combustion engine. Deflagration occurs in slow reaction and slow combustion with pressure nearly constant during the process.

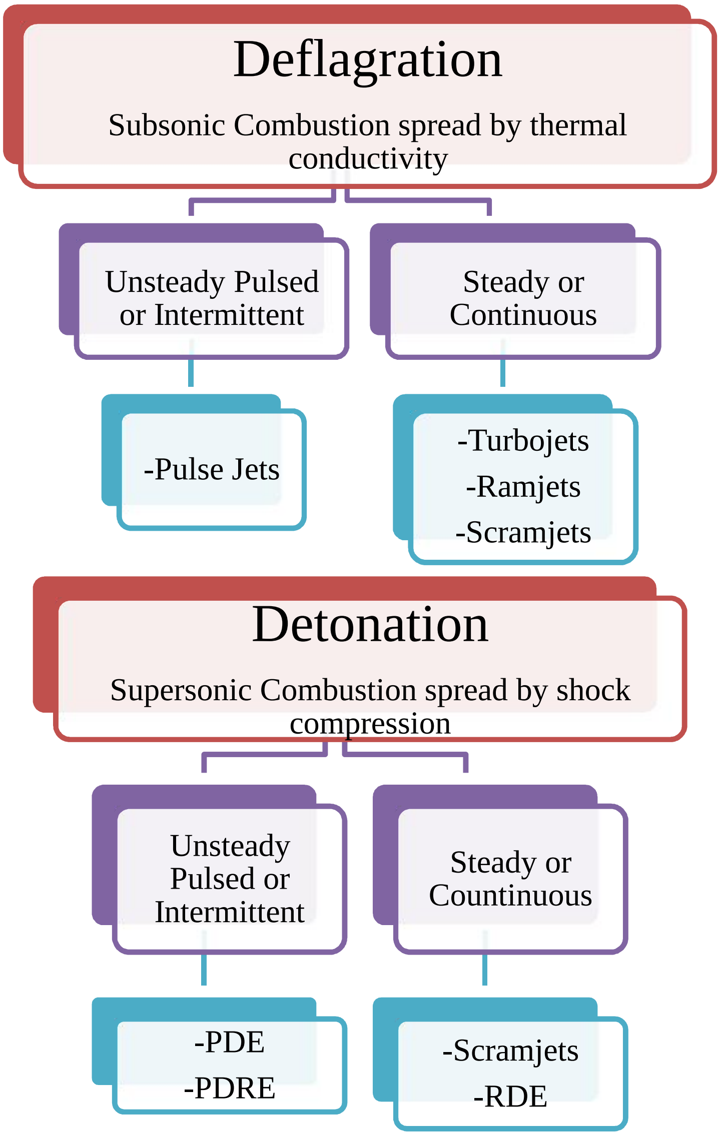

Figure 1.1 Combustion modes [42]

Fuel-air premixed combustion is a process where mixing of fuel and air is done before the mixing is applied heat and combustion occurs [20]. Fuel and air ratio based on equivalence value [30], Ø produce the required mixture for combustion process in a controlled manner. Detonation characteristics of pulse detonation engine by different mixing reactions for premixed and non-premixed resulting different effect on pressure force of detonation waves as different detonation characteristics of pulse detonation engine. The pulse detonation engine is designed and initiated with repetitive detonation wave within a short time cycle for fast and homogeneous mixing of component in the detonation chamber. The pulse detonation engine cycle is applied with deflagration to detonation transition (DDT) mechanism in the ignition process. Premixed intake system for fuel/air in the pulse detonation engine is a much different system from previous studies in HiREF where non-premixed based pulse detonation engine is used to operate and requires further analysis in thermodynamic models to understand the pulse detonation engine model.

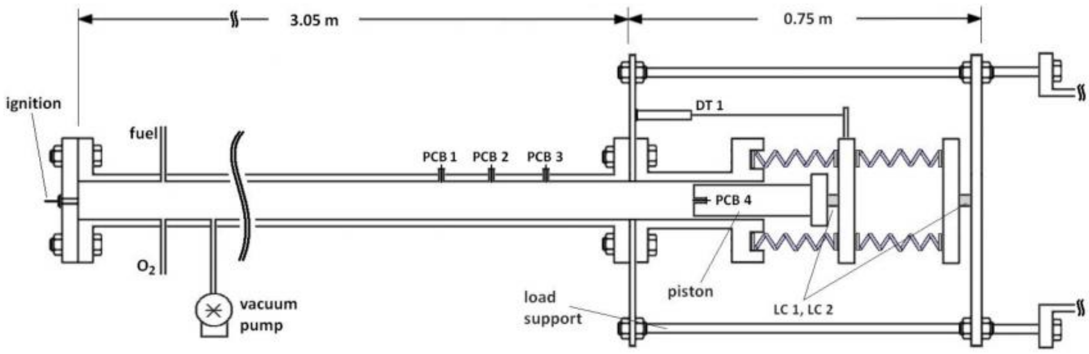

Figure 1.2 Linear system of power generation pulse detonation engine with piston [41]

Figure 1.3 ‘TODOROKI’ test engine developed by Nagoya University in 2006 [21]

1.2 Problem Statement

The utilization of high-speed combustion phenomena into pulse detonation engine system operation generates potential in propulsion system. Without application of moving parts such as compressor, pulse detonation engine produce high pressure of impulse as thrust generated from detonation wave propagates to the open end of detonation tube. A constant thrust can be achieved to power propulsion purpose by repetitive detonation combustion using suitable configuration. Development of the pulse detonation engine with designing operation and configuration leads to optimal performance result. Design of pulse detonation engine intake system is based on the real - design of the propulsion induction system for fuel/air mixture. Further study on previous successes of repetitive pulse detonation engine configuration is the benchmark for this pulse detonation engine study. The Premixed intake system supplies constant volume and pressure process to achieve a uniform, homogenous mixture in fuel and air. Prediction of high operation pulse detonation engine is estimated from consistent output performance at optimum level.

There are a few factors needed to be considered to improvement premixed intake system in the pulse detonation engine. Previous study non-premixed combustion has a low chemical reaction in fuel/air mixture and operates at a low operating frequency. Low efficiency of mixing the composition in the feeding system limits the full maximum of pulse detonation engine potential. High operation pulse detonation engine that operates with fast combustion process and high operation frequency, the pulse detonation engine requires an upgrade in feeding system design and combustible mixture [5]. Non-premixed combustion is producing combustion at lower than maximum combustion ability. The Premixed intake system strategy offers higher and faster chemical reaction in high-speed combustion system.

The pulse detonation engine is differentiated from its steady-flow counterparts [34] is by the engine level of thermodynamic efficiency [2]. Analysis of thermodynamic cycle is difficult and complex to evaluate. Assumption in thermodynamic analysis, such air-cold assumption is one of the methods to evaluate the thermodynamic cycle of an engine. Thermodynamic cycle efficiency is analyzed and compared to Humphrey, Brayton and Chapman-Jougent model [33]. High thermodynamic cycle efficiency of the pulse detonation engine leads to further saving in fuel consumption compared to non-premixed pulse detonation engine.

This study is to make thermodynamic cycle efficiency pulse detonation engine using premixed is better efficiency than conventional non-premixed pulse detonation engine. This effort is to maximize the fuel-efficiency in feeding system where mixing composition is one of design tool options. Non-premixed combustion is only producing a non-uniform combustion form and lower than maximum combustion ability. But, the application of this concept in pulse detonation engine to maximize the potential efficiency will be explored.

1.3 Research Objectives

The objective of the study is to develop a fuel-air premixed intake system of the pulse detonation engine based on fuel-air ratio, which will boost the efficiency of the thermodynamic cycle. The designed pulse detonation engine will be analyzed and evaluated to determine efficiency potential using thermodynamic theory models. The research also covers the comparison between premixed and non-premixed pulse detonation engine results.

1.4 Scope of Research

The scope of this research is to design and develop pulse detonation engine with a fuel-air premixed intake system and determine the thermodynamic cycle of the pulse detonation engine. It also compares the designed new intake system with existing non-premixed pulse detonation engine.

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