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# Study of Deflagration to Detonation transition length in a single cycle $H_2$-$O_2$ Pulse Detonation Engine

Mayur Anvekar[1], Venkatesh Kusnur[2], Siddalingappa P K[3]

[1]Assistant professor, Aeronautical Engineering, NMIT Bangalore, Karnataka, India

[2]Assistant professor, Aeronautical Engineering, ACSCE Bangalore, Karnataka, India

[3]Assistant professor, Aeronautical Engineering, NMIT Bangalore, Karnataka, India

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Abstract - *The pulse detonation engine is an unsteady propulsive device in which the combustion chamber is periodically filled with gaseous fuel and air mixture, a detonation is initiated, the detonation propagates through the chamber, and the product gases are exhausted. The deflagration which is subsonic must be converted into supersonic detonation which generates the shock wave. The transition is achieved by reducing the cross-sectional area inside the detonation tube. The transition length for the hydrogen oxygen mixture is studied in this paper. The transition length can be minimized by using orifice plate or perforated plate in combination with schelkin spiral. The perforated plate and orifice plates are selected based on the requirement of blockage to achieve good detonation transition. The maximum and minimum length for deflagration to detonation transition is studied in the single cycle pulse detonation engine. Pressure and velocity for different positions of schelkin spiral and plate combination are studied and comprehended.*

*Keywords: Detonation, Schelkin spiral, Deflagration, Blockage ratio, Shock wave etc….*

## 1. INTRODUCTION

The deflagration to detonation transition can be achieved using schelkin spiral with or without orifice and perforated plate. If the blockage ratio is less than the transition length will be more as the sufficient amount of air fuel mixture is not available at the upstream of the plate to have detonation [1]. The hydrogen pulse detonation engine has the same detonation cycle with the purging, filling, sparking and transition steps. The transition length should be minimized to achieve high frequency detonation which reduces the length of the detonation tube as well. The hydrogen oxygen mixture can be detonated without using the blocking obstacle also. The mixture is very reactive for small amount of spark which is ignited using conventional spark plug. The hydrogen air mixture is also very combustible but it needs the blocking obstacle which helps to achieve short transition length.

The detonation tube is selected based on the fuel air mixture flow rate and the minimum cell size [2]. The length of the tube is selected based upon the transition length which depends on the blocking obstacle placement inside the tube. The diameter of the tube must be selected based on the required amount fuel air mixture which gives the final result as thrust. The pulse detonation engine used here is single cycle and the detonation tube is filled with hydrogen and air/oxygen. The fuel and air are mixed in the mixer just before the injection into the detonation tube. The tube previously has the schelkin spiral in it and the fuel air mixture is throttled for single cycle and combusted. The combustion which is subsonic is transmitted into supersonic detonation wave which is measured interns of pressure and velocity. The detonation tube is purged using air just to clear the inside area of the detonation tube. The tube is again filled with fresh fuel air mixture to carry next stage of tests. The detonation wave is measured interns of pressure and combusted flame interns of velocity.

A detonation wave is a supersonic combustion wave consisting of a shock wave coupled with a reaction zone. The conditions behind an ideal detonation wave are dictated by the Chapman-Jouguet (CJ) condition that the flow behind the wave is sonic in a reference frame moving with the detonation velocity [2]. The pulse detonation engine has a length of a half wavelength of the resonance frequency. This means that when detonation occurs a shockwave is travelling from valves to the end of the pipe. Then the shockwave turns and go back [3].

The combustion begins from left to right in the figure 1. The deflagration transit to detonation at $X_0$ which has very high pressure showing a sudden rising spike as the pressure from I to N. The combustion begins from left to right in the above figure. The deflagration transit to detonation at $X_0$ which has very high pressure showing a sudden rising spike as the pressure from I to N.

The region N to F is reaction zone where the combustion reaction takes place which has lesser pressure region than detonation. The region FN will be having the deflagration flame which is following the detonation wave at a distance of $X_f$ [4]. The pressure in front of the detonation wave will be near to atmospheric.

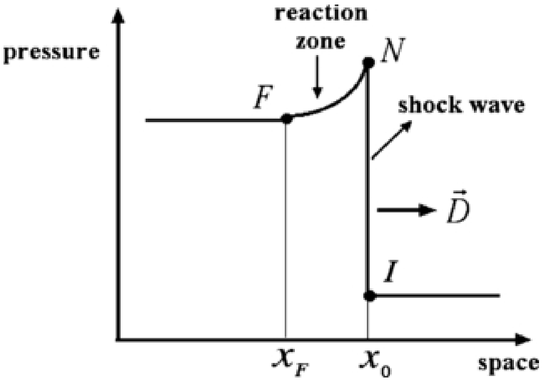


Fig- 1: Detonation physics diagram [4]

## 2. EXPERIMENTAL SETUP

In Pulse detonation engine, the detonation propagates at gallopian mode nothing but spinning mode. The detonation tube is selected based on the cell size of the fuel. The cell size is defined as the height of the cell structure and is related to the direct detonation initiation energy [2]. The detonation tube length is selected based on the deflagration to detonation transition length. As the transition length decreases the length and weight of engine reduces. The minimum length for the deflagration to detonation transition is 10 times the tube diameter. A pulse detonation engine is a multi-cycle engine. A single cycle consists of four major steps: 1) Filling of the tube with the desired mixture; 2) detonation initiation; 3) propagation of the detonation along the tube; 4) exhaust of the products to the atmosphere.

The detonation tube is purged before filling the mixture. The fuel and oxidants are mixed previously in the mixer to have pre-combustion mixture. Based upon the volume of the detonation tube the fuel oxidant mixture is filled. The non return valves are used to prevent the back fire. The conventional spark plugs are used for combusting the mixture. The combustion velocity which is subsonic is transited into supersonic detonation using schelkin spiral with orifice and perforated plate configuration. The blockage ratio of schelkin spiral is 27%-30% where as the blockage ratio of orifice plate and perforated plate.

The high blockage ratio will result in the reduction in transition length of detonation. The reaction zone will be very short in the study as the transition length is small. The small reaction zone results in the stable condition of the detonation. As the reaction zone reduces the combustion flame will move close to the detonation supersonic wave. The orifice plate and perforated plates are placed inside the tube at a distance of 60% of detonation tube diameter and the experimental study is carried. The experimental study gives the minimum transition length of the tube diameter. The pressure is measure using the piezo-electric pressure transducers which are very sensitive to the flow and can be operated for high frequencies. The supersonic shock wave hits the diaphragm of the pressure transducer which is converted into electric signal. The velocity is calculated based on processing the images taken from high speed camera. The detonation cycle duration is just 50 milliseconds and the camera will capture around 2500 frameset that time. All these frames are processed considering its pixel ratio and other properties to have the velocity of the combustion flame.

As the hydrogen is in gaseous form, there will not be any two phase difficulty in achieving detonation. The hydrogen pulse detonation engine is studied for single cycle. The detonation engine consist of a detonation tube with shchelkin spiral, ignition circuit, fuel and oxidizer tank, a mixer and solenoid valves. The fuel and oxidizer are premixed in the mixer before injecting into detonation tube. The fuel and oxidizer must be throttled and controlled flow rate should be maintained.

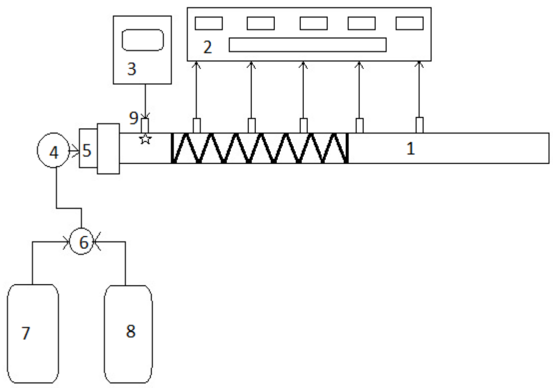


Fig - 2: Hydrogen pulse detonation engine experimental setup

1-detonation tube with shchelkin spiral, 2-data acquisition system, 3-sparking circuit, 4-solenoid valve, 5-fuel air injector, 6-mixer, 7- oxygen tank, 8- fuel tank, 9-spark plug

The fuel and oxidizer are pressurized in the tank and the flow rate is throttled using needle valves. The calibrated rotameter are used to measure the flow rate. Solenoid valve is used to make a controlled discrete flow rate. The detonation tube is purged initially using air. The calculated amount of fuel and oxidizer is sent from the mixer inside the detonation tube and solenoid valve is closed. On sparking the combustion initiates at the closed end of detonation tube and proceed further. The shchelkin spiral with orifice or perforated plate placed at some distance from head end or closed end will help to get the transition of deflagration to detonation as shown in figure 2. The high speed camera is triggered externally with the sparking circuit. The flame propagation is captured and processed to find the velocity of combustion.

A transparent detonation tube is selected to take images externally. The tube is made up of polycarbide fiber of 40mm inside diameter and 2000mm long. The shchelkin spiral of length 350mm and blockage ratio ranging from38-44% is used. Orifice plate and perforated plates are used with shchelkin spiral. A conventional spark plug is used to ignite the mixture. The transparent fiber tube will help to study the flame propagation and the creation of flame carnal. The shchelkin spiral with orifice or perforated plate configuration is kept inside the detonation tube initially at a calculated distance from the head end of tube.

The high speed camera and data acquisition circuit is connected in parallel with the sparking circuit. As and when the sparking circuits get closed, the data acquisition system and high speed camera gets triggered. The duration of image capturing and acquisition of data is initially set to the required frequency.

The calculated amount of hydrogen fuel and oxygen oxidant is supplied to detonation tube through mixer. The time taken to fill the tube is calculated based upon the tube volume and the flow rate sent. After closing the valves the sparking circuit is closed which results in sparking in spark plug. The combustion initiated and the transition from deflagration to detonation takes place with the help of shchelkin spiral. The transition can be seen in the high speed camera. The single cycle pulse detonation engine needs some millisecond time to complete its cycle.

The perforated plate and orifice plate used are of different blockage ratio. The orifice plate has a blockage ratio of 38.5% and perforated plate has a blockage ratio of 43.5%. The detonation experiment is carried at different location of shchelkin spiral inside the detonation tube. The experiment is carried for different equivalence ratios also. The conventional spark plug is used in the sparking circuit, which produces enough energy to ignite the gaseous fuel oxidant mixture. The spark circuit has 12V DC power supply and to enhance the energy small capacity coil is used. The flow rates of hydrogen and oxygen are as follows.

Table - 1: Hydrogen oxygen flow rate

| Hydrogen flow rate (lpm) | Oxygen flow rate (lpm) | Equivalence ratio Φ |
|---|---|---|
| 0.5 | 0.75 | 0.88 |
| 0.5 | 0.5 | 1.21 |
| 0.75 | 0.5 | 2.37 |

The experiment is carried out for rich, lean and stoichiometric conditions of hydrogen oxygen mixture. The different equilibrium conditions results in variation in the velocity plots. The effect of perforated plate and orifice plate also results in big change in the velocity of detonation combustion.

## 3. RESULTS &DISCUSSIONS

The velocity is much higher for bigger blockage plate and rich mixture. The effect of perforated plate is better than the orifice plate, as the orifice plate don't create obstacle at the core of tube, whereas perforated plate creates series of blockage at all the cross sectional points.

When perforated plate or orifice plate with shchelkin spiral is used for transition at different equivalence ratios, the deflagration to detonation transition takes place only at certain locations from the head end of the detonation tube. The location of shchelkin spiral with plate for good detonation is given in the following table for different equivalence ratios.

Table - 2: Transition distance for orifice plate

| Equivalence ratio φ | Distance from head end |
|---|---|
| 1.21 | 0.06m to 0.13m |
| 2.37 | 0.05m to 0.12m |
| 0.88 | 0.07m to 0.13m |

Table - 3: Transition distance for perforated plate

| Equivalence ratio φ | Distance from head end |
|---|---|
| 1.21 | 0.05m to 0.14m |
| 2.37 | 0.043m to 0.15m |
| 0.88 | 0.055m to 0.13m |

The detonation velocity and the detonation shock pressure inside the detonation tube for different equivalence ratios and different shchelkin spiral assembly is shown in following tables. For equivalence ratio of 2.5 and above, the shchelkin spiral is not required for detonation transition. Without detonating aid the transition can be achieved for 2.5 equivalence ratio for a given mass flow rate and frequency.

Table - 4: Perforated plate velocity readings for different equivalence ratio

| Equivalence ratio φ | Velocity m/s | Pressure $10^5$ N/m$^2$ |
|---|---|---|
| 2.37 | 3450 | 18.3 |
| 1.21 | 2550 | 17 |
| 0.88 | 2225 | 15.8 |

Table - 5: Orifice plate velocity readings for different equivalence ratio

 

| Equivalence ratio φ | Velocity m/s | Pressure $10^5$ N/m$^2$ |
|---|---|---|
| 2.37 | 3220 | 18 |
| 1.21 | 2180 | 16.8 |
| 0.88 | 1985 | 15.4 |

For a short range equivalence ratio, the minimum deflagration to detonation transition distance is 0.04m from the head end or closed end of the detonation tube. The distance between the shchelkin spiral and the ignition source is considered as the transition length.

## 4. CONCLUSION

The single cycle hydrogen pulse detonation engine has got different minimum transition length for different equivalence ratios and shchelkin spiral with plate combinations. For lean mixture0.88 equivalence ratio the critical transition distance is 0.05m to 0.13m by generating a velocity ranging from 1985-2225 m/s and a detonation pressure ranging from 15.4 to 15.8bar. For 1.21 air fuel ratio mixture, the transition distance keep reducing up to some critical value i.e. 0.05m to 0.14m and velocity and detonation pressure increases for a given shchelkin spiral with plate combination. The maximum pressure and velocity found in the experiment is 16.8-17 bar and 2180-2550m/s with orifice or perforated plate. For 2.37 equivalence ratio, the transition distance still reduces i.e. 0.043m to 0.15m with increase in the detonation pressure and velocity which is, 18-18.3 bar and 3220-3450m/s.

## 5. REFERENCES

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## BIOGRAPHIES

Mr. Mayur Anvekar has got degree of Bachelor of engineering in Mechanical engineering in 2011 and MTech degree in Aeronautical engineering in 2013 from VTU Belgaum, Karnataka, India.

Mr. Venkatesh Kusnur has got degree of Bachelor of engineering in Mechanical engineering in 2011 and MTech degree in Aeronautical engineering in 2013 from VTU Belgaum, Karnataka, India.

Mr. Siddalingappa P K has got degree of Bachelor of engineering in Mechanical engineering in 2012 and MTech degree in Aeronautical engineering in 2014 from VTU Belgaum, Karnataka, India.

 