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Feasibility Study of Power Generation by Pulse Detonation Engine

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Abstract: Pulse detonation engines (PDEs) have drawn great attention because of their potential for increased specific impulse as compared to other propulsion systems i.e. gas turbine engines, ramjets, scramjets etc. Recently there have been a large number of researchers working on PDE-based hybrid engines & PDE based power generators. This paper aims to provide a review of previous & ongoing efforts to generate power through pulse detonation engine. A new concept is also discusses for power generation, which is proposed to be developed and tested for feasibility study at PEC University of Technology, Chandigarh in the Department of Aerospace Engineering.

Keywords: Pulse detonation; Deflagration; Detonation; Power generation

Nomenclature
PDE = Pulse Detonation Engine;
PDC = Pulse Detonation Combustor

I. INTRODUCTION

Because of the efficiency & simplicity of design, pulse detonation engines (PDEs) have generated much interest as a possible future high efficiency propulsion device since the early 1940's [1]. Great developments have been made in the last decade [2-4] towards the development of a Pulse detonation Engine.

An effort is being made in this paper to review the various experiments conducted by researchers to develop a system for generation of power through PDE. Most of the people have used hybrid propulsion system which incorporates PDEs with a conventional gas turbine engine as primary combustion system. Taking advantage of the detonative mode of combustion, PDE works with greater thermal efficiency as compared to the deflagrative combustion, resulting in reduced specific fuel consumption and greater specific thrust. A turbine has been integrated with PDE to extract power. The hybrid pulse detonation combustors (PDCs)-turbine system would build on the strengths of both engines to increase operating efficiency of the entire system. This pressure rise due to the detonation wave eliminates the need for the separate high pressure compression cycle that exists in a conventional gas turbine engine.

The integration of detonation tubes with a turbine is a key area that must be studied as this integration is a significant challenge that must be overcome in order to achieve a successful hybrid PDE system.

Earlier, the significant development in pulse detonation engines for propulsion have also prompted attempts to create "hybrid" gas turbine engines using detonative combustion. These developments are briefly reviewed in this paper as a prelude to the review of the pulse detonation engine as a power generator. This understanding provides insight in how to properly design and optimize a PDE power generator. Moreover a new concept for power generation through PDE is also discussed.

II. CURRENT STATUS

Deng JX et al. [5] investigated the interaction of a pulse detonation engine (PDE) with a radial flow turbine of a turbo-charger & examined whether a compressor and turbine could be used in the harsh pulsing flow of a pulse detonation engine. The cold flow test and hot detonation test were conducted. The effect of equivalence ratio on the attenuation of the detonation wave peak pressure through a turbine was investigated.

The engine was operated stably under the firing frequency with a range from 1 to 10 Hz. No pitting or discoloration were seen in the turbine for 12000 detonations. The peak pressure before the PDC exit was between 2 MPa and 3 MPa with the detonation wave speed of 1300-1500 m/s. The peak pressure and wave speed of the detonation decrease after expansion through the turbine. The turbine attenuates the strength of the wave. The peak pressure at the same location firstly increases and then decreases with increasing the equivalence ratio from 0.86 to 1.27. The maximum peak pressure exiting PDC is obtained at an equivalence ratio of 1.15. But the attenuation trend is opposite to that of the peak pressure. The peak pressure attenuations at various equivalence ratios are between 6.5 dB and 7.5 dB.

A schematic of the experimental setup was shown in Figure 1. The pulse detonation combustor (PDC)-turbine hybrid system consisted of an air inlet, a compressor, a PDC, a turbine and an exhaust nozzle. It also included fuel supply system, air supply system, ignition and frequency control system, lubrication system, measurement system, data acquisition and control systems.

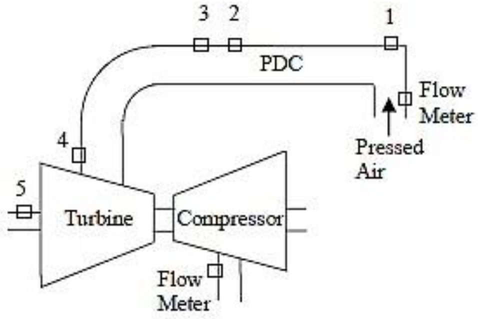

Figure 1: Schematic of experimental setup, showing locations of pressure transducers [1].

Feng LX et al. [6] investigated the power extraction of a turbine driven by a pulse detonation combustor. A radial turbine with compressor and turbocharger was integrated with PDE as shown in the Figure 2.

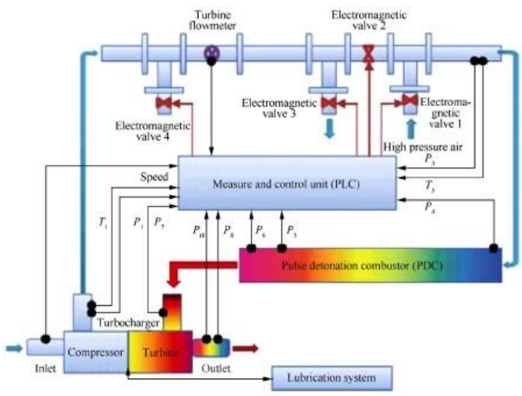

Figure 2: principle model of the experimental rig [6].

It is found that at ignition frequency of 5 Hz, the optimal equivalence ratio of fuel and air mixture is 1.01689. At that test condition the speed of the engine turbine reaches the maximum, and the flow rate of the compressor is also up to

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the highest. Two key factors that affect the speed of the turbine are found. One is the momentum difference per unit area between the turbine inlet and outlet. The other is the velocity of the gas at the turbine inlet.

Goldmeer J et al. [7] transfer function model was integrated into a thermodynamics system development and analysis tool to examine the performance of a hybrid PDC system. The model was validated against published data in the literature and then compared against a classic Brayton cycle. The model was used to examine the performance of a hybrid PDC engine. It was seen that there are multiple new parameters in hybrid engine design that must be taken into account to correctly determine overall system efficiencies. Specifically, the effect and interaction of purge and bypass flows on the total system performance must be taken into account. If the cooling needs of the system could be solved without needing an additional bypass, this could create additional performance gains.

Litchford RJ [8] developed a laboratory-scale detonation tube closed at one end and a permanent magnet assembly and an electromagnet were custom fabricated for establishing MHD interaction in the channel. All of the experiments were conducted in a single-shot mode where the system is evacuated, charged to atmospheric pressure with premixed combustibles, and ultimately detonated using a high-voltage spark discharge near the closed end of the tube. During this process, a thin membrane separates the chamber volume from the surrounding atmosphere until it is ruptured by the detonation wave. Ionization seed is introduced using an atomizing injector that is located near the open end of the detonation tube and oriented in such a way as to direct the seed spray along the length of the attached channel. The entire tube/channel assembly is suspended on rollers and preloaded against a piezoelectric-type dynamic load cell. Dynamic pressure transducers were installed in the tube to measure detonation wave strength and to provide time-of-flight measurement of detonation wave speed (Figure 3).

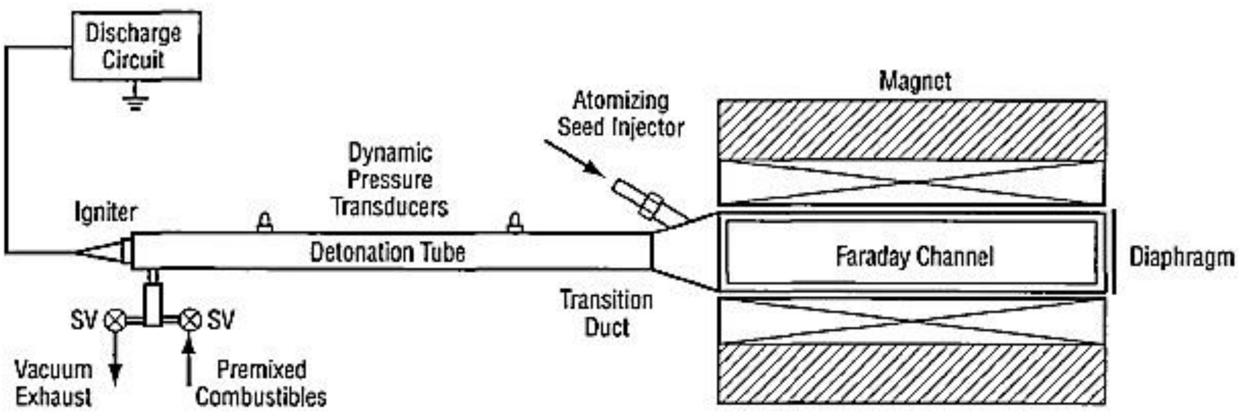

Figure 3: General schematic of laboratory-scale pulse detonation, MHD apparatus [8].

Panicker PK et al. [9] tested a PDE with a 0.75 in. and close to 1 m in length and coupled it with an automotive turbocharger driving an AC generator as shown in Figure 4. The PDE was run at 15 Hz with propane and oxygen mixtures at an equivalence ratio of 1.2. From the generator output frequency, the speed of the turbine was found to be higher than 127,000 rpm, which is below the maximum rating of 200,000 rpm. This is well within the operational range of a turbocharger on an automobile. The generator produced over 26 W of electric power, while the compressor pumped out air at a rate of 0.055 kg/s, showing that PDEs can be made to self-aspirate if combined with a turbine and compressor. The temperature of the flow exiting the turbine was measured to be over 800°C, suggesting that the flow had enough enthalpy to drive several more turbine stages.

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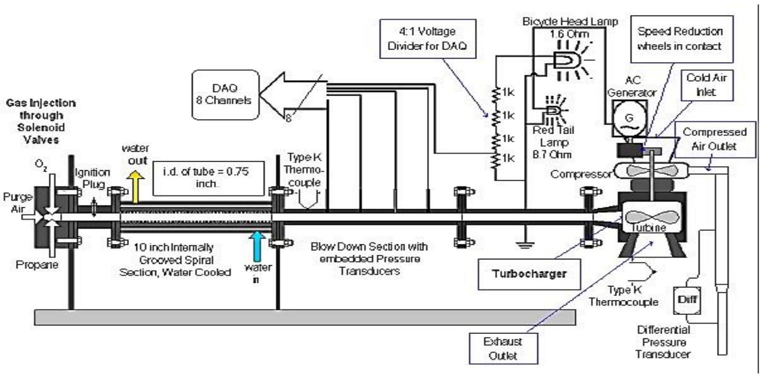

Figure 4: A schematic of the PDE, turbocharger and the generator system [9].

Power by thrust

A new concept is discussed in the next section. Where the power can be extracted through the direct thrust of the PDE. In the proposed design 2 no of the PDE combustors are fitted on a beam which can rotate freely about the vertical axis. The jet of the two combustors are in opposite direction creating a force couple. The thrust of the PDE makes the beam along with combustors rotate and produce direct power. The schematic is shown in the Figure 5 below.

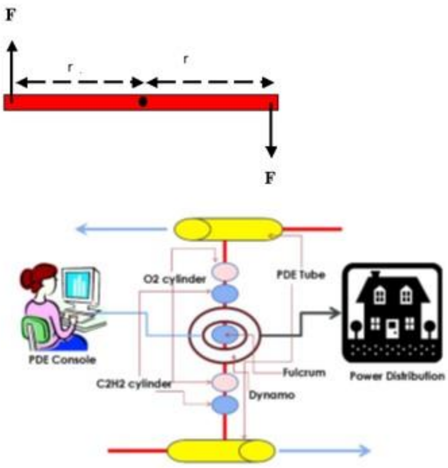

Figure 5: Conceptual diagram of power from thrust.

Power produced

PEC University of technology Chandigarh has developed a test rig for Pulse detonation testing and with acetylene and oxygen the thrust obtained was 280 N on the average in a single shot detonation. The thrust assumed on a sinusoidal curve can last for about 10ms.

The average thrust from one combustor is therefore = 280/2= 140 N

Thrust from two combustors = 280N

Assuming the frequency of detonation = 50 Hz

The average thrust per second = 280*50*10/1000= 140 N

Arm length =1m

Power = 140 Watt.

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III. CONCLUSION

It is seen that the power from the direct thrust is a very noble idea and the system simple in construction and will be reliable. However the centrifugal forces on the components will be large and depend upon the speed. The speed depend on the Moment of inertia and the drag encountered by the system. The exact analysis can be made by practically testing the integrated system.

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