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Design and Study of Swirl Injector of Pulse Detonation Engine

Navdeep Banga[1], Kanika[2]

[1]Strategic and Defense Analyst, Research Scholar, Department of Aerospace Engineering, IKG Punjab Technical University, India
[2]Department of Aerospace Engineering, MRSPTU, India

***Abstract*— *Future Indian Air force and Navy Capabilities indicate the need for a supersonic cruise missile. Therefore, there exists a need for a low cost, light-weight, and efficient means of supersonic propulsion. In this paper my main emphasis on Pulse Detonation Engine, in pulse detonation engine humphey cycle is used ,PDE has thermodynamic efficiency greater than 50% as compared to 35% for present day propulsion technology constant-pressure Brayton cycle currently in use in gas turbines/ramjets/scramjets. Pulse Detonation Engines (PDE's) represent an upcoming new approach to propulsion and with the simplicity of its construction; PDE's produce thrust more efficiently than the current engines and produces a higher specific thrust. Since current rocket engines require heavy and expensive pumps; with mechanical simplicity and thermodynamic efficiency PDE's offer a viable alternative to reduce the cost of launching spacecraft.*

Keywords*— *detonation engines, detonation, PDE, PDE ignition, swirl injector.

I. INTRODUCTION

DRDO is currently developing and working on pulse detonation engine(PDE) as a low-cost, simple, light-weight, and efficient means of supersonic propulsion. The PDE concept has a higher thermodynamic efficiency than the constant-pressure cycles. Detonation is a self-sustaining combustion process that leads to the formation of supersonic combustion products. The wave front produced by the detonation process, is at supersonic speeds, which compresses the unburned fuel and mixture ahead of the wave front. This further compresses the unburned fuel-oxidizer mixture and leads to detonation. Whereas In the process of deflagration the burning of fuels through flames will be moderately simple and gentle and the under the similar condition we observe that main typical that is nothing but the travelling characteristics of this flame will be at subsonic stage. On comparison of deflagration and detonation, detonation is found to be more effective in the terms of pressure and velocity obtained. The PDE concept has a higher thermodynamic efficiency than the constant-pressure cycles currently in use, such as turbojets, ramjets, and scramjets. A major problem in the development of this type of engine is increasing the propulsive efficiency to acceptable level.

Pulse Detonation Engine

Pulse Detonation Engine typically consists of a sufficiently long tube which is filled with fresh fuel-oxidizer mixtures and ignited by sufficiently strong energy source. Flame initiated by ignition must in relatively short time accelerate to detonation velocity, so the transition from deflagration to detonation must happen in relatively small distance. Detonative combustion produces high pressure which is converted to thrust. After all mixture is consumed by detonation, combustion products have to be evacuated from the tube and fresh mixture must be quickly resupplied, and the cycle is repeated. Typical frequency of such engine operation is usually in range of dozen Hertz.

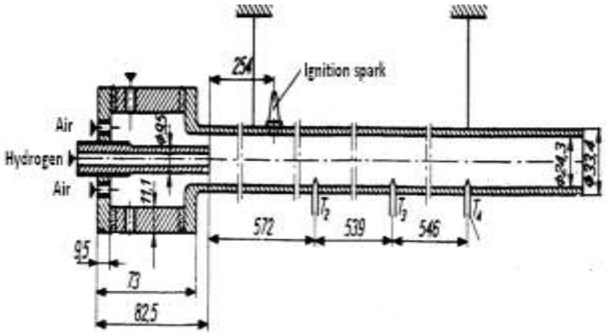
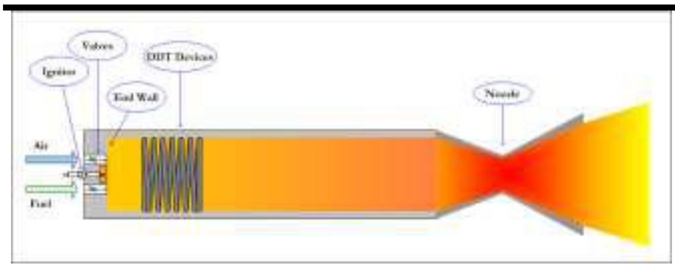


Fig.1: Design of Pulse detonation engine

PDE can operate in wide flight Mach number, ranging from 0 and up to M4+, but the engine operates in a pulsed mode, so the thrust is varying in time and the detonation must be initiated each time. The system is complicated because fast purging and refilling are required. Also the engine is operating in the stoichiometric condition (due to necessity of fast initiation of detonation), and the frequency is relatively low. If the pulsed detonation could be applied for turbojet combustion chambers, it would be necessary to add an extra air to decrease the temperature before the first turbine stage. Also the production of NOx would be high.

Schematic of the PDE showing the main components

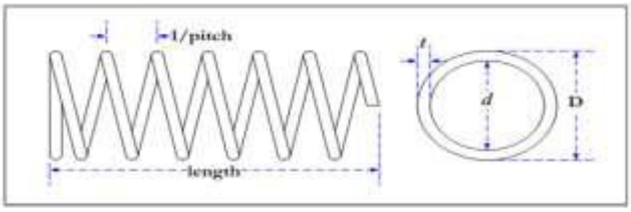


Pre-detonator:-The pre-detonator design was chosen because of its simplicity. At the cost of a small amount of oxygen carried on board, the pre-detonator provides an effortless means of igniting the propane-oxygen mixture quickly with low energy sparks, and makes it possible to transmit an accelerated detonation wave into a less energetic fuel-air mixture.

Shchelkin Spiral*:*-The pre-detonator has the option of being fitted with a long Shchelkin spiral. The spiral is welded to a flange that enables it to be bolted to the flange of the pre-detonator. The Shchelkin spiral is used to over-drive the detonation wave so that it may be successfully transmitted through the nozzle without decoupling.

II. DDT DEVICES

The deflagration-to-detonation transition (DDT) is a process by which a deflagration flame front is gradually accelerated to form a supersonic detonation wave. As the flame is pushed downstream by the expansion of the burnt gases behind it, the flame front becomes curved and wrinkled by the effects of the boundary layer in front of the flame, flame instabilities and turbulence. As a result, the surface area of the flame grows which increases the rate of reaction of the fuel and oxidizer. Thus, the rate of release of energy is amplified causing the flame front to be accelerated at an even faster rate. Finally, the increased energy release leads to the formation of one or more localized explosions and the transformation of the flame into a detonation wave.

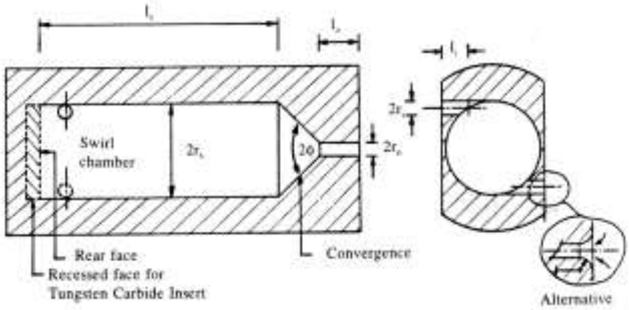


Nozzle:

The nozzle was designed to transmit the detonation wave with minimal loss of velocity. It was found that larger diverging angles or abrupt transition of area cause detonation waves to decouple, due to the excessive curvature of the detonation wave and the cooling of the flow due to the rapid expansion.

Main Combustion Chamber with Swirl Injector Block: The carbon steel collars hold pressure and optical transducer ports and contain orifices for water to circulate through them, and also provide additional strength to the tube. The combustor tube is covered with a layer of sheet metal in between the collars, forming a water cooling jacket. Water is pumped in through four tubes bored into the wall of the main flange on the left and the water exits the cooling cavity through four tubes welded to the last collar on the right hand side of the tube. At the left hand end of the main combustor is the swirl injector block, which has four ports through which a fuel-air mixture is pumped in.

Analysis of swirl injector in pulse detonation engine- Swirl injectors are used in liquid rocket, gas turbine, and diesel engines to improve atomization and mixing efficiency. The circumferential velocity component is generated as the propellant enters through helical or tangential inlets producing a thin, swirling liquid sheet. A gas-filled hollow core is then formed along the centerline inside the injector due to centrifugal force of the liquid sheet. Because of the presence of the gas core, the discharge coefficient is generally low. In swirl injector, the spray cone angle is controlled by the ratio of the circumferential velocity to the axial velocity and is generally wide compared with non-swirl injectors.The basic internal geometry of the pressure swirl injector consists of a main cylindrical body called the swirl chamber. At, or near, the upstream end of the swirl chamber (the closed end or 'top' face) are attached the inlets. The inlets are one or more cylindrical or rectangular channels positioned tangentially to the swirl chamber. At the opposite end of the swirl chamber, the 'open' end, there is a conical convergence. Toward the apex end of the cone there is a cylindrical outlet, concentric with the swirl chamber.

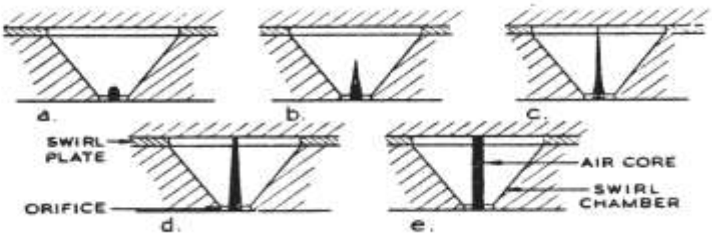


Swirler –

The swirlers used to impart rotation to the airflows were of particular importance. In order to obtain a symmetrical flow, swirlers must be machined to within very tight tolerances. Swirl vanes may be flat, or they may be curved in a variety of ways. No matter what the type of swirler used, however, it is essential to machine the assembly very precisely. The types of machining operations available to produce swirlers are somewhat limited, and, if the swirlers are assembled from separate part, the difficulty of assembling them correctly increases dramatically. For this investigation, twisted-vane swirlers were employed, as these are compact, can be inserted directly into an air duct, and can be machined from a single piece of stock, without any further assembly steps. In order to machine twisted-vane swirlers, aluminum blanks were first turned down to the precise diameters required. The blanks were initially simple cylinders, with sections cut to two diameters: one that let them fit tightly into sleeve for the next step in the machining process, and one that matched t +3.602he required final diameter of the swirler. The centers of the blanks were then bored out to the required inner diameter necessary for each swirler. A special rotating assembly, attached to a precision stepper motor, was then attached to a vertical milling machine.

Internal flow of swirler

The air-core is usually seen to initiate from the outlet orifice, where the pressure is already ambient, as one gradually increases the injection pressure From some observations the air-core is also seen to initiate simultaneously from the upstream face of the swirl chamber. Thus the two ends of the air-core along the axis are not initially joined. The initiation of the air-core at the upstream end of the swirl chamber is likely to be due to one or more of the following mechanisms. Firstly, as the liquid, initially under pressure, enters the swirl chamber, then dissolved gases within the liquid come out of suspension and are buoyed inwards toward the low pressure region on the swirl chamber axis. Secondly, there maybe an intermittent seepage of the ambient gas from the outlet along the axis to the back face, possibly in the form of small bubbles. Figure below is a diagram showing the air-core formation for an atomizer with a short swirl chamber and a negligible length outlet. There is seen to be no air-core formation initiating from the upstream face in this instance. The presence of an air-core ensures that the body of liquid within the nozzle is in the form of an annulus and that the passage of a liquid particle through the nozzle will thus describes helical path.



providing a swirl rotational motion to the fuel inside the injector. The key advantage of hollow cone sprays is the high area to volume ratio, which can lead to the required level of atomization without large penetration lengths. Swirl injectors are used in liquid rocket, gas turbine, and diesel engines to improve atomization and mixing efficiency. The circumferential velocity component is first generated as the propellant enters through helical or tangential inlets producing a thin, swirling liquid sheet. A gas-filled hollow core is then formed along the centerline inside the injector due to centrifugal force of the liquid sheet. Because of the presence of the gas core, the discharge coefficient is generally low. In swirl injector, the spray cone angle is controlled by the ratio of the circumferential velocity to the axial velocity and is generally wide compared with non-swirl injectors.

Pulsating Flow with Swirl Injectors

The spray and acoustic characteristics of a gas/liquid swirl coaxial injector are studied experimentally. Self-pulsation is defined as a pressure and flow rate oscillations by a time-delayed feedback between liquid and gas phase. Self-pulsation accompanies very intensive scream and this strong scream affects atomization and mixing processes. So, the spray and acoustic characteristics of self-pulsation are different from those of general swirl coaxial spray. The liquid and gas velocity is selected as the variables of injection conditions and recess length is chosen as the variable of geometric conditions. By shadow photography technique, spray patterns are observed in order to investigate the macroscopic spray characteristics and determine the onset of self-pulsation. For acoustic characteristics, a PULSE System was used. Using He-Ne laser and photo detector system frequencies of spray oscillations are measured. And self-pulsation boundary with injection conditions and recess length is obtained. From the experimental results, the increase of recess length leads to the rapid increase of the sound pressure level. And characteristic frequency is mainly dependent on the liquid velocity and linearly proportional to the liquid velocity. The frequency of spray oscillation is the same as that of the acoustic fields by self-pulsation.

III. CONCLUSION

To replace other injectors such as (air blast ,orifice ,etc) used in the pulse detonation engine ,we have studied the concept of swirl injector. The swirl injector will increase the atomisation of the fuel by adding the centrifugal force of the swirler and thus inreasing the efficiency of the engine.We have worked in a steady mode with this swirl injector but still the research is to be done on pulsating mode ie. It has to worked on different frequencies such as 8 Hz ,25 Hz and 50 Hz. I have stuided the basic concept of swirl injector and designed it .For testing this swirl injector I have also designed a set up box for it in which various parameters such as spray cone angle ,mass median daimeter (MMD) and mixing is done.Still the results are accurate but more research is to be done on this swirl injector for reaching the exact results.

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