DESIGN AND CFD ANALYSIS OF PULSE JET PROPULSION ENGINE

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ABSTRACT:

Pulse jet engines or Pulsejets are family of internal combustion engine that have few or no moving parts. The project design and analysis of pulsejet engine is based on thrust produce in form of pulses. This is a powerful jet unit and one which can be made by anyone with access to lathe and welding facilities with few or no moving parts. The main purpose to design pulse jet engine is to produce high amount of thrust by performing analysis on jet engine. These engines are an efficient and simple way to convert fuel into heat. Pulsejets are used today in target drone aircraft, home heating equipment, fog generation purpose and many more. The reason they are called pulse jets, is due to how they produce intermittent pulses of thrust. The Main Purpose of this project is to design PJ15 pulse Jet Engine and analysis it on different Mass Flow rate at different Pressures. Pulsejets can be fitted with specially shaped ducts called Thrust Augmenters, which increase thrust output by harnessing aerodynamic forces, exhaust gas heat, and providing a reactive surface for high velocity pulses of exhaust to pull in additional air and transfer momentum to it. The pulse jet body will be designed and analysis will be done using the SOLID WORKS 2014.

INTRODUCTION:

A pulsejet engine (or pulse jet) is a type of jet engine in which combustion occurs in pulses. A pulsejet engine can be made with fewer no parts and is capable of running statically (i.e. it does not need to have air forced into its inlet typically by forward motion). Pulsejet engines are a lightweight form of jet propulsion, but usually have a poor compression ratio, and hence give a low specific impulse. One notable line of research of pulsejet engines includes the pulse detonation engine which involves repeated detonations in the engine, and which can potentially give high compression and good efficiency.

![Fig 1.1 PROCESS OF COMBUSTION]

1. LITERATURE REVIEW:

Current research status Although in pilot tests and technical reports of pulse combustion dryers, short drying time, high energy efficiency and product quality are generally reported, there are few theoretical studies of the pulse combustion drying process. Liu et al (2001) demonstrated experimentally that the pressure amplitude and the oscillating frequency Literature Review 38 of the unsteady flow, generated by Helmholtz pulse combustor, enhanced the convective heat transfer coefficient. Smucerowicz (1999) carried out research...
Pulse combustion spouted bed drying of particles is a new concept proposed here. This concept is motivated by the fact that the pressure drop of spout bed is generally about several thousand Pascals, which is in the range of pressure oscillation in pulse combustion flow. Thus, pulse combustion can, in principle, be used in spouted bed drying. There are numerous experimental works on “conventional” spouting bed drying of different materials, such as for grains (Madhiyanon, et al, 2002), dispersed materials (Devahastin, et al, 1998; Berghel, 2005; Wachiraphansakul, 2005), paste-like materials on inert bodies (Kutsakova, 2004), slurries and solutions (Tia, et al, 1995), etc. However, the knowledge of flow characteristics in such contactors is still limited. There are several experimental studies which investigated the particle flow pattern in spouted beds. Yokogawa (1970) measured particle velocities in a half-cylindrical vessel using a high speed video camera. However, the effect of the smooth flat wall on the motion of particles is now known to be non-negligible. Benkrid and Caram (1989) used a fiber optic technique to measure particle velocities in the annulus of a full column and concluded that there is a plug flow zone in the upper part of the annulus. He et al (1992) observed dead zone boundaries in a 0.91 m diameter column. He et al (1994a and b) used a fiber optic probe system to obtain the profiles for vertical particle velocities in spout, annulus and fountain regions of a full column spouted bed. Roy et al (1994) measured the particle velocities in a spouted bed using a γ -ray emitting particle tracking technique. These experimental results have improved our understanding of the mechanism of spouting. 

on in-situ analysis of the mechanism of the pulse combustion spray drying process. Smucerowicz (1999) and Wu et al (2002) have conducted CFD modeling of the pulse combustion spray drying process. Experimental and simulation results showed the complex nature of the pulsating flow in the drying chamber and the very rapid decrease of material moisture content in the intensive drying. Wu et al (2002) have also conducted experiments in which the pulsating gas jet from pulse combustor was used to directly atomize and dry the slurry (a solution of 10 \% NaCl).

Impinging jets are encountered in many practical applications because of their high heat and mass transfer rates (Zumbrunmen, et al, 1993; Azevedo, et al, 1994). Flow pulsation can considerably affect the jet expansion, mixing and entrainment. Thus, pulsating jets should have high potential to enhance the heat transfer performance of such flows compared to their steady counterparts. Liewkongsataporn et al (2006b) investigated numerically the effects of jet pulsation amplitude and impingement zone geometry on net heat flux enhancement factors. They found that for pulsating jet impingement, an enhancement on heat transfer can be achieved only in the case, wherein the amplitude ratio of jet velocity oscillation must be great enough so that heat transfer during positive cycle would be able to compensate for lower heat transfer during negative cycle. This is a preliminary result and needs further investigation. Also, in Liewkongsataporn et al’ experiments (2006a), the drying rate is evaluated averagely based on the whole paper sheet; the local drying rate in paper sheet is unknown. Information about the local drying rate contributes to the design of impinging jet dryer where an array of pulse jets is used.
2. THEORETICAL BACKGROUND:

2.1 Pulse combustion:

Historical development Pulse combustion is not a new concept. Heat-excited acoustic oscillations were first reported by Higgins in 1777, who observed the so-called hydrogen “singing” flames in tubes (Tyndall, 1897). Later, in 1859, Rijke discovered that strong acoustic oscillations appeared when a heated metallic grid was positioned in the lower half of a vertical tube opened at both ends (Lord Rayleigh, 1945). The pulse combustor with mechanical valves was first built by Esnault-Pelterie in France in 1906 and it was used as a drive for a gas turbine. In 1909, Marconnet constructed the first pulse combustor with an aerodynamic valve for propulsion. Although his basic patent was for a mechanically-valved unit, his design (Figure 2.1) is similar to many aero-valved current units. It consisted of two diffusers: inlet and outlet. The recirculation of fuel and air flows in this configuration resulted in the specific combustion chamber where the combustible mixture was ignited by spark plug. In 1931, Paul Schmidt obtained a German patent on the pulse combustor shown in Figure 2.2. A new feature of this combustor is the injection of the fuel downstream of the mechanical valve rather than upstream of it (Putnam et al., 1986). This design of essentially uniform cross section through the combustion chamber and resonance tube became known as the Schmidt design. The pulse combustion technology developed by Schmidt was utilized to produce thrust for propulsion of the German V-1 “buzz” flying bomb during the Second World War (or the Cruise missile in more modern terms) (Wojcicki, 1962).

Fig 2.1 Marconnet pulse combustor

Fig 2.2 Schmidt pulse combustor

In the following years, the interest in pulse combustion declined due to relatively poor specific fuel consumption, and low specific thrust produced by pulse combustors compared with the more modern thrust producers such as the turbojets or turbofans. A major development in the field of pulse combustor was made in the 1950’s when the mechanical valves were replaced by an inertial gas valve. Since the 1970’s, the pulse combustion technology has been re-examined for use in different applications, e.g. boilers, heat exchangers, dryers, etc, where high combustion efficiency and low toxic components of the combustion gases is necessary.

2.4 Merits and limitations:

Compared with steady combustion, pulse combustion offers the potential for higher efficiency of the combustion process and heat transfer rate with lower pollutant emission (Dec et al., 1992). Some of the
key features are presented in Tables 2.1 (Sonodyne Industries Inc, 1984).

**Comparison of steady -state and pulse combustion:**

<table>
<thead>
<tr>
<th>Process parameters</th>
<th>Steady -state</th>
<th>Pulse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustion intensity (kW/m³)</td>
<td>100-1000</td>
<td>10000-50000</td>
</tr>
<tr>
<td>Efficiency of combustion</td>
<td>80-96</td>
<td>90-99</td>
</tr>
<tr>
<td>Losses due to chemical underburning (%)</td>
<td>0-3</td>
<td>0-1</td>
</tr>
<tr>
<td>Losses due to mechanical underburning (%)</td>
<td>0-15</td>
<td>0-5</td>
</tr>
<tr>
<td>Temperature level (K)</td>
<td>2000-2500</td>
<td>1500-2000</td>
</tr>
<tr>
<td>CO concentration in exhaust (%)</td>
<td>0-2</td>
<td>0-1</td>
</tr>
<tr>
<td>NOx concentration in exhaust (mg/m³)</td>
<td>100-7000</td>
<td>20-70</td>
</tr>
<tr>
<td>Noise produced (dB)</td>
<td>85-100</td>
<td>110-130</td>
</tr>
<tr>
<td>Convective heat transfer coefficient (W/m²K)</td>
<td>50-100</td>
<td>100-500</td>
</tr>
<tr>
<td>Time of reaction (s)</td>
<td>1-10</td>
<td>0.01-0.5</td>
</tr>
<tr>
<td>Excess air coefficient</td>
<td>1.01-1.2</td>
<td>1.00-1.01</td>
</tr>
</tbody>
</table>

3.1 DESIGNING OF PULSE JET ENGINE:

PJ15 pulsejet engines have been designed and constructed in order to provide Power and reliability, Light weight, Ease of assembly and maintenance, a choice of fuel systems, extended reed valve life, throttle able (injected version only). These engines are the result of a comprehensive development program that has produced a number of innovative new designs. These simple, effective, light-weight engines can be put to many different uses including Powering model airplanes, boats, cars, etc. Basically an enhanced Schmidt tube design, these engines have an enlarged combustion zone, straight tailpipe and divergent tail cone. The valving system uses a mix of traditional petal-valves and two unique features perfected after almost two years of research and development.
4. CFD ANALYSIS ON PULSE JET ENGINE: CFD Analysis has to done for the given design of Pulse Jet Engine PJ15 based on different Mass Flow Rate conditions at different pressures. Based on analysis, construct a table with results obtained at different conditions [7].

4.2 At a Mass flow rate of 10kgs/s:

4.2.1 5 bars of pressure:

By applying the input conditions the velocity and pressure contour can be seen at mass flow rate of 10kgs/s of 5 bar of pressure.

Velocity graph at 5 bar pressure at Mass flow rate of 10kgs/s

By applying the input conditions the velocity and pressure contour can be seen at mass flow rate of 10kgs/s of 5 bar of pressure.

4.2.2 10 bars of pressure: Inlet boundary conditions:

By applying the input conditions the velocity and pressure contour can be seen at mass flow rate of 10kgs/s of 10 bar of pressure.

In the similar way analysis of PJ Engine has been done on different mass flow rates at different pressures and detailed values have been noted in the below table.
5. RESULTS:
For 10kgs (mass flow rate)

<table>
<thead>
<tr>
<th>Massflow rate[10kgs]</th>
<th>Maximum pressure</th>
<th>Maximum velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>5bar</td>
<td>108</td>
<td>630</td>
</tr>
<tr>
<td>10bar</td>
<td>120</td>
<td>650</td>
</tr>
</tbody>
</table>

For 15kgs (mass flow rate)

<table>
<thead>
<tr>
<th>Massflow rate[20kgs]</th>
<th>Maximum pressure</th>
<th>Maximum velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>5bar</td>
<td>110</td>
<td>630</td>
</tr>
<tr>
<td>10bar</td>
<td>125</td>
<td>635</td>
</tr>
</tbody>
</table>

For 20kgs (mass flow rate)

<table>
<thead>
<tr>
<th>Massflow rate[20kgs]</th>
<th>Maximum pressure</th>
<th>Maximum velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>5bar</td>
<td>113</td>
<td>630</td>
</tr>
<tr>
<td>10bar</td>
<td>128</td>
<td>682</td>
</tr>
</tbody>
</table>

6. CONCLUSION:

- Designing and analysis of pulse jet engine is done in solid works software
- CFD analysis is done on pulse jet engine at three different mass flow rates with two different pressures i.e.; 10kgs, 15kgs and 20kgs with 5 bar and 10bar pressures.
- By performing the analysis on the PJ15 Pulse Jet Engine, we can conclude that by increasing mass flow rate the velocity can be increased.
- The Mach number of the Jet engine can be increased with different pressure and mass flow rate which is mainly important using target drone aircraft, flying control line model aircraft
- The Pulse Jet Engine is a new technology, though they are functioning from 19th century. The pulse jet engines have many advantages over the other engines for propulsive purposes and can be more reliable.
- Pulse jet engine is the best option due to its pulsating firing nature. This inherent characteristic of intermittent pulses create good amount of thrust and same utilized for fumigation purpose to get better coverage.
- There is a scope of conducting further research on Pulse Jet Engines to increase the Mach number by brining modifications to design and analyzing the design to required needs.

References:

- [i]. Experimental investigations into the operational parameters of a 50 centimeter class pulsejet engine – Ordon, Robert Lewis., 2006.

- [xiii]. History of German Guided Missile Development, - Benecke,T.H., Quick,A.W., AGARDograph No 20, pp 375-418, 1947.