International Journal of Research in Advent Technology, Vol.2, No.11, November2014
E-ISSN: 2321-9637

Performance Analysis of Opposed Piston Engine Using Computational Fluid Dynamics

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Abstract- A Computational Fluid Dynamics (CFD) simulation of an opposed piston Internal Combustion (IC) engine, also known as the Nu Stroke engine, has been developed. The thesis focuses on the design and analysis of this particular engine using ANSYS CFX, a commercial CFD tool. The engine geometry is modelled and meshed in ANSYS Workbench V14.5 to minimize any exporting errors that may creep in and cause serious mesh issues during mesh deformation simulation. A further improved CFD model with multiple inlet and exhaust ports is then applied. The in-cylinder flow fields and pressure waves observed show significant vortex generation and heat transfer through the gas and combustion chamber walls.

Index Terms- Opposed piston engine, profile change, CFD.

1. INTRODUCTION

The present modelling of the engine using CFD techniques, and the analysis are the first attempts of this kind for this particular engine. The advantage of polynomial cam profile in controlling the performance of this engine is observed to be outstanding. The analysis of the obtained pressure and temperature, and the in- cylinder mid-plane pressure and velocity streamline plots show that both the spreadsheet model and CFD model agree qualitatively.

These observations lead to a conclusion that the project, if extended further with experimental analysis, will give results that are comparable to the spreadsheet and CFD model results. The current work successfully presents a numerical simulation of an opposed piston engine. This study has enough potential to boost further research attempts in similar engine configurations, as they opposed piston engines have not been widely used nowadays in industries due to difficulties in attaining a successful design and balancing issues despite of the fact that they are low cost and less complicated engines.

At this stage of the thesis, experimental results are not available for a more extensive validation, but at a later stage, if possible, this could be done to validate the current CFD model. Further extensive research on similar engine configurations with the help of good computing facilities and CFD simulation tools would make it possible to develop a successful, designer-friendly, and eco-friendly engine, which could eventually set up a new revolution in the entire engine industry.

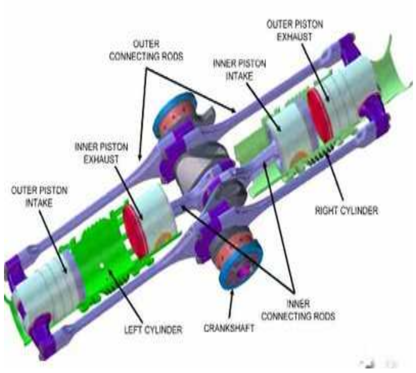

Fig.1 opposed piston engine

2. METHODOLOGY

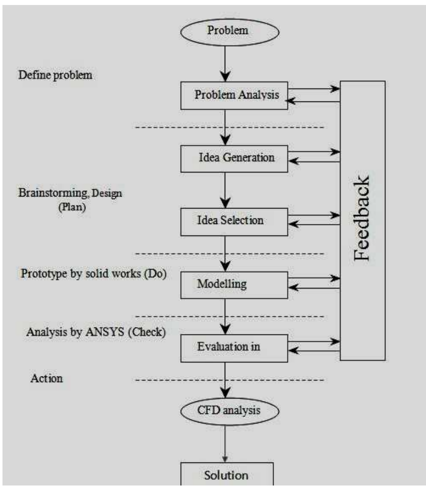

Fig.2 Process Methodology

3. OBJECTIVES

- To project the capability of CFD techniques

to model and analyse IC engine processes,
- To compare the spreadsheet analytical model and the CFD model.
- To discuss the advantages of using polynomial profile cam-plate over sinusoidal profile cam-plate for the Opposed Piston IC engine,
- To discuss the advantages of using multiport engine configuration over the uniport engine design,
- To introduce the concept of modelling combustion using Domain Source Model (DSM), and
- To discuss CFD combustion modelling using the Burning Velocity.

The scope of the thesis is limited to CFD simulation of the Opposed Piston gasoline engine which is a unique design. The study can be extended to experimental analysis to validate the CFD and analytical models. The methods of combustion analysis discussed in this thesis can be used in the future for analysis of IC engines and combustors, and the results from this method can be used as benchmark values for comparison.

4. DESIGN CHALLENGES IN OPPOSED PISTON ENGINES

Even though Opposed Piston engines deliver higher efficiency and better performance compared to the conventional engines, the difficulties in developing a fool-proof engine are many. Some of the prominent disadvantages and limitations of Opposed Piston engines are discussed here. As mentioned earlier, the Opposed Piston engines are lengthy, either in the vertical direction or in the horizontal direction. Only an experienced person can work on these engines as the piston motions and spark ignition in case of multiple sparks need to be synchronized. Another challenge is, whether the two-stroke Opposed Piston engine can meet modern emission and sound regulations. According to the Powell Engine Company (Powell, 2006), these problems have been rectified in the Nu Stroke engine by using easily replaceable and cheaper parts for the engine, and the exhaust emission is controlled by using stratified charging .

5. COMPARISON OF ENGINE MODELS

Here, the in-cylinder pressure and mass flow rate through ports are compared based on piston motion configuration. Separate analysis is performed for the uniport and multiport models with sinusoidal and polynomial cam-plate guided piston motions. From Fig.3, it is clear that both models predict the expansion. The sinusoidal profile-guided piston motion predicts a higher peak pressure compared to the polynomial profile guided piston motion configuration even if they have same stroke length. The reason could be that in the case of sinusoidal profile guided motion, the piston motion curve is steeper, the amount of mass inflow is less, and consequently the temperature predicted inside the cylinder is higher. These can lead to a higher pressure inside the cylinder. However, the profile of both the pressure curves is almost similar. The mass flow rate at the inlet and outlet ports of the uniport model for sinusoidal and polynomial profile-guided piston motion configurations are shown in Fig.5. The polynomial cam-plate engine ports close after the sinusoidal cam-plate engine ports close, and again they open prior to the sinusoidal cam-plate engine ports. This helps to draw in more air and increase the volumetric efficiency that helps to achieve lean mixture possible in polynomial profile guided piston motion engines.

6. CFD ANALYSIS

The polynomial profile-guided piston motion is achieved in CFX using the piston motion values obtained in the spreadsheet model from polynomial expressions generated for the cam-plate profile. CFX allows the user to take data input from spreadsheet files as functions. The advantage of using polynomial cam profile is that the engine designer has full control over the configuration of the engine. For instance, a longer stroke during exhaust for better exhaust gases removal, or a longer stroke at TDC to extract maximum power and to ensure complete fuel burning etc.

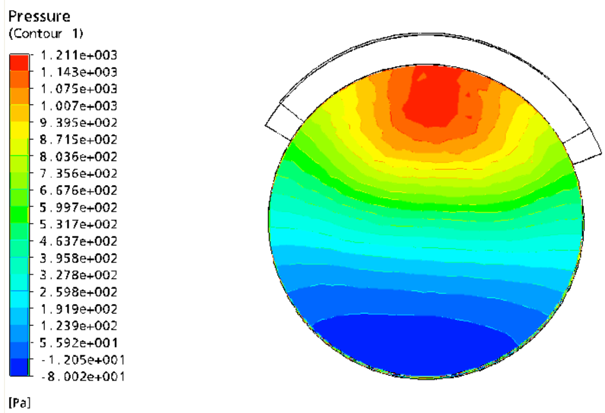

Fig.3 Pressure contours at cylinder mid-plane (1°CA)

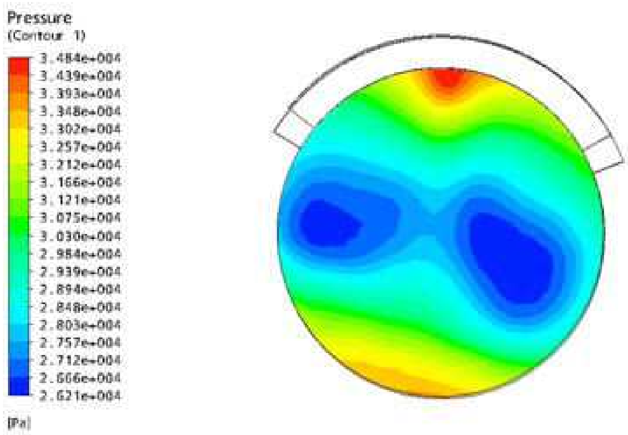

Fig.4 Pressure contours at cylinder mid-plane (45°CA)

This theory is widely covered in the previous study by the author that mainly discussed the spreadsheet modelling (Thomas, 2008).The series of plots in shows the contours of pressure at a middle plane inside the engine cylinder. Shows high pressure at the top of the cylinder, and this is due to the gas inflow when the pistons are at BDC. As pistons come close to TDC the pressure is seen to be distributed uniformly inside the cylinder, and higher values of pressure are observed close to the cylinder wall. At 180^{o}CA, the low pressure spot visible at the center of the cylinder is due to the vortex flow inside the cylinder. As the pistons move back to BDC the high pressure spot is observed to shift downwards.

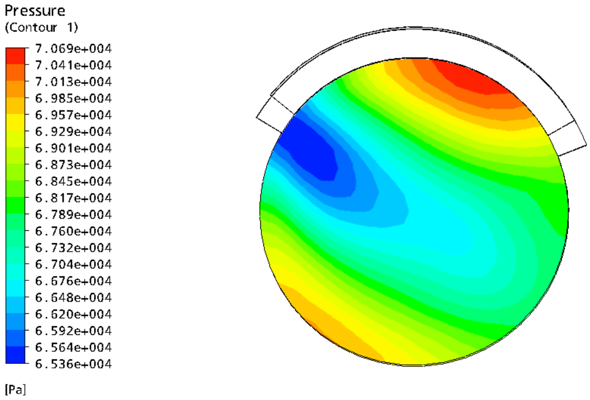

Fig.5 Pressure contours at cylinder mid-plane (90°CA)

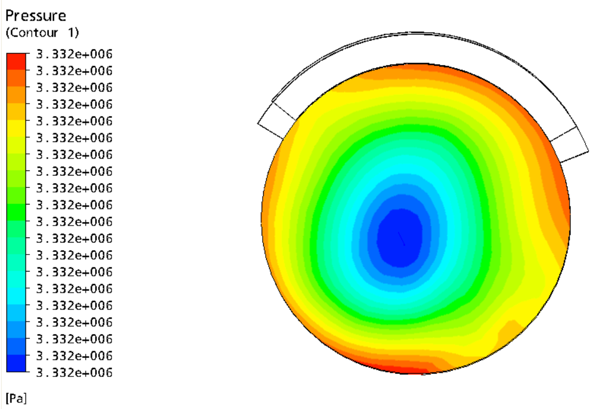

Fig.6 Pressure contours at cylinder mid-plane (180°CA)

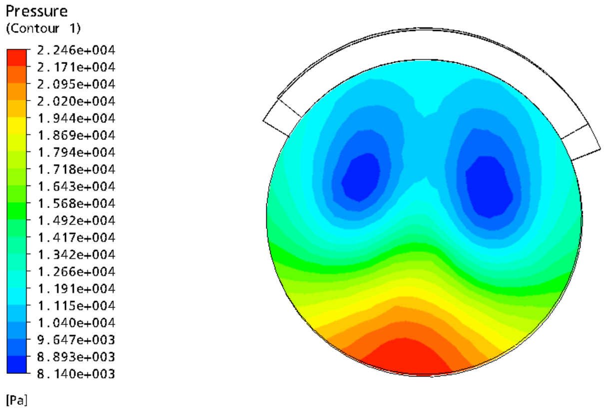

Fig.7 Pressure contours at cylinder mid-plane (245°CA)

7. SUMMARY

The advantages of a polynomial profile guided piston motion over sinusoidal profile guided piston motion is discussed and verified. The performance of multiport and uniport engine models are compared, discussed and verified. The multiport model was seen to be the best choice as it offers better volumetric efficiency, better cooling of engine parts using inlet air stream and allows lean mixture combustion. The multiple port models was found the best choice from the viewpoint of practical application of the engine model as otherwise will result in piston locking as discussed earlier. The CFD simulation of the cam plate engine is achieved and combustion is modelled using DSM model.

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