Thermal and structural analysis of 4-cylinder inline engine

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Abstract

The inline-four cylinder engine or straight-four engine is an internal combustion engine with all four cylinders mounted in a straight line, or plane along the crankcase. The single bank of cylinders may be oriented in either a vertical or an inclined plane with all the pistons driving a common crankshaft. Where it is inclined, it is sometimes called a slant-four. In a specification chart or when an abbreviation is used, an inline-four engine is listed either as I4 or L4.

The main objective of the project is how to develop the prototype of four cylinder engine assembly using CAD tool SOLIDWORKS. These Engine assembly consists major components they are Piston, Connecting Rod Assembly, Crank Shaft, Cylinder head, Cam Shaft, Valves, crank case, oil tank and spark plug with required dimensions.

The components which are developed in SOLIDWORKS software and analysis are carried out in ansys work bench.

Introduction:

We almost take our Internal Combustion Engines for granted don’t we? All we do is buy our vehicles, hop in and drive around. There is, however, a history of development to know about. The compact, well-toned, powerful and surprisingly quiet engine that seems to be purr under your vehicle’s hood just wasn’t the tame beast it seems to be now. It was loud, it used to roar and it used to be rather bulky. In fact, one of the very first engines that had been conceived wasn’t even like the engine we know so well of today. An internal combustion engine is defined as an engine in which the chemical energy of the fuel is released inside the engine and used directly for mechanical work, as opposed to an external combustion engine in which a separate combustor is used to burn the fuel. The internal combustion engine was conceived and developed in the late 1800s. It has had a significant impact on society, and is considered one of the most significant inventions of the last century. The internal combustion engine has been the foundation for the successful development of many commercial technologies. For example, consider how this type of engine has transformed the transportation industry, allowing the invention and improvement of automobiles, trucks, airplanes and trains.
In Line Engine

The inline-four engine or straight-four engine is an internal combustion engine with all four cylinders mounted in a straight line, or plane along the crankcase. The single bank of cylinders may be oriented in either a vertical or an inclined plane with all the pistons driving a common crankshaft. Where it is inclined, it is sometimes called a slant-four. In a specification chart or when an abbreviation is used, an inline-four engine is listed either as I4 or L4. The inline-four layout is in perfect primary balance and confers a degree of mechanical simplicity which makes it popular for economy cars. However, despite its simplicity, it suffers from a secondary imbalance which causes minor vibrations in smaller engines. These vibrations become worse as engine size and power increase, so the more powerful engines used in larger cars generally are more complex designs with more than four cylinders.

Jerald A. Caton (2000) analysed complete version of thermodynamic engine cycle simulation for spark-ignition engine. The instructional version of cycle simulation used constant specific heats as compared to using variable properties and composition for the complete simulation. Mass fraction burned was calculated using Wiebe function. Woschni heat transfer coefficient model was used to calculate heat transfer to the cylinder gases. For the proper selection of constant properties, the global engine performance parameters and were obtained the instructional version of the simulation were in close agreement to the values obtained from using the complete version of the simulation.

Kodah et al (2000) describes a simple analysis for the prediction of pressure within a spark ignition engine. This is done by modeling the combustion process using the Wiebe function approach, which is an exponential function in the form \( m \cdot e^{-ax/y} \) to calculate the rate of fuel burned. By careful selection of \( a \) and \( m \), any spark ignition engine with any combustion chamber shape and any specified dimensions can be assessed by this model. Validity of this model has been tested by comparing the model results with those obtained from running the engine under the same operating conditions. The results obtained from the theoretical model were compared with those from the experimental data which show a good agreement. Effects of the many operating conditions, such as compression ratio, engine speed, and spark timing have also been studied in this work.

Lawrence Mianzo and Huei Peng (2000) developed the cylinder-by-cylinder model of an variable valve timing 4-cylinder engine. The model includes the

Literature review:

Ganesan (1999) had presented a comprehensive simulation producer for SI engine processes. In this literature, the simulation for compression, combustion, expansion and gas exchange process are explained, along with various heat transfer model for IC engines. A computer code for general Otto cycle, fuel-air cycle and actual cycle is presented.
cylinder and manifold mass, temperature, burned gas residual, and pressure dynamics, including combustion effects, as well as the valve actuator dynamics. The cylinder-by-cylinder model is used to obtain a cycle-averaged mapping between torque at a given engine speed and intake valve timing, which is suitable for future control design implementations.

**Main components of the engine**

**Piston**:
Piston is one of the main parts in the engine. Its purpose is to transfer force from expanding gas in the cylinder to the crankshaft via a connecting rod.

![Figure: piston](image1.png)

**Piston Rings**:
A ring groove is a recessed area located around the perimeter of the piston that is used to retain a piston ring. Ring lands are the two parallel surfaces of the ring groove which function as the sealing surface for the piston ring. A piston ring is an expandable split ring used to provide a seal between the piston and the cylinder wall.

![Figure: piston rings](image2.png)

**Connecting Rod**:
The connecting rod is a major link inside of a combustion engine. It connects the piston to the crankshaft and is responsible for transferring power from the piston to the crankshaft and sending it to the transmission. There are different types of materials and production methods used in the creation of connecting rods. The most common types of connecting rods are steel and aluminum. The most common type of manufacturing processes are casting, forging and powdered metallurgy.

![Figure: connecting rod](image3.png)

**Crankshaft**:
The crankshaft is the part of an engine which translates reciprocating linear piston motion into rotation. To convert the reciprocating motion into rotation, the crankshaft has crankpins, additional bearing surfaces whose axis is offset from that of the crank, to which the “big ends” of the connecting rod from each cylinder attach.

![Figure: crankshaft](image4.png)

**Camshaft**:
Camshaft is frequently called “brain” of the engine. This is so because its job is to open and closed at just the right time during engine rotation, so that the maximum power and efficient cleanout of exhaust to be obtained. The camshaft drives the distributor to electrically synchronize spark ignition. Camshafts do
their work through eccentric "lobes" that actuate the components of the valve train. The camshaft itself is forged from one piece of steel, on which the lobes are ground. On single-camshaft engines there are twice as many lobes as there are cylinders, plus a lobe for fuel pump actuation and a drive gear for the distributor. Driving the camshaft is the crankshaft, usually through a set of gears or a chain or belt. The camshaft always rotates at half of crank rpm, taking two full rotations of the crankshaft to complete one rotation of the cam, to complete a four-stroke cycle.

Figure: cam shaft

Modelling Of Four Cylinder Engine

connecting rod:

Piston

Crankshaft

cam shaft

Analysis:
Static structural analysis on Piston:
Load: 500N
Grey cast iron:

Static structural analysis on connecting rod
Load: 1000N
Material: grey cast iron

Results:

Static structural analysis on crank shaft
Load: 1000N
Material: grey cast iron

Aluminum alloy
Aluminum alloy

Static structural analysis on cylinder block
Pressure: 1Mpa
Material: grey cast iron

Static structural analysis on cam shaft
Load 500N
Material: grey cast iron
Aluminum alloy:

Static structural analysis on valves
Load 500N
Material: grey cast iron

Thermal analysis on piston
Thermal loads
Temperature 750°C
Material: grey cast iron

Results:
Aluminum alloy

Thermal analysis on cylinder block
Material: grey cast iron
Thermal loads
Temperature – 500°C

Aluminum alloy:

Thermal analysis on valve
Material: gray cast iron
Thermal loads
Temperature 150°C
Results:

**PISTON**
Load: 5000N
Temperature: 750deg
Radiation: 30 deg

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<th>deformation</th>
<th>strain</th>
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<tr>
<td>Grey cast iron</td>
<td>3.3093</td>
<td>0.0029467</td>
<td>3.0097</td>
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<td>Aluminum alloy</td>
<td>3.2861</td>
<td>0.0045624</td>
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**CRANK SHAFT:**
Load: 1000N

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<td>94.856</td>
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**CYLINDER BLOCK:**
Pressure: 1MPa
Temperature: 500deg
Radiation: 30deg

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<td>Aluminum alloy</td>
<td>16.849</td>
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**CAM SHAFT:**
Load: 500N

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<td>Aluminum alloy</td>
<td>34.281</td>
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**VALVES:**
Load: 500 N
Temperature: 150deg
Radiation: 22deg

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<td>Aluminum alloy</td>
<td>1.187</td>
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**Conclusion:**
Internal Combustion engine is one of the most important inventions of the last Century. It has been developed in the late 1800s and from there on it has had a significant impact on our society. It has been and will remain for foreseeable future a vital and active area of engineer research.

- Using a cad tool called solidworks “FOUR CYLINDER ENGINE ASSEMBLY “Straight In-Line order is developed including few sub-assemblies.

- This assembly consists few sub-assemblies they are Middle Crank Shaft, Connecting Rod, Piston, Valves, Cam Shaft, Belt, Valve
Springs, crank case, oil tank, cylinder head spark plug.

- The main objective of this project is to knowing of designing process using CAD tool (SOLIDWORKS) and also preparing components and assembly. This project is deals with the

- Modeling and analysis of a Four Cylinder Engine Assembly. and analysis is done using cae tool (solidworks simulation), using these software, here we chosen different type of materials for every component which are developed in cad tool.

- The materials are not existing material and materials are chosen which are better than existing materials. The main objective of analysis is to showing the heat transformations from one component to other applying boundary conditions and thermal loads are applied. This process is done for Cylinder Head, Inlet valves, Crank Shaft, piston components.

- The components having different materials. These Analysis process is done in every manufacturing industries before assembling (Individual component Analysis).

- Why because this individual analysis is to decide the capability of component before they going to work. Finally the materials which are chosen (not existing) are better in weight & thermal conduction.

- Thus analysis is carried out on inline 4 cylinder engine in ansys work bench

- Two different materials grey cast iron and aluminum alloy is applied to individual parts

- Required parameters such as stress, strain, deformation, temperature distribution and heat flux values are obtained and tabulated.

- From the results aluminum alloy is showing best results compared to grey cast iron.

References

- Ricardo (1933), “The High-Speed Internal Combustion Engine”