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Thermal Mapping and Cooling optimization of three-cylinder SI Engine using Computer Aided Engineering

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ABSTRACT

As an appreciable amount of heat is transferred through the I. C. engine which effects the engine performance, it is therefore essential to look forward to analyze the modes of heat transfer and temperature variations in the engine components. About 35% of the total chemical energy that enters an engine is converted to crankshaft work, & about 30% of the fuel energy is carried array from the engine in the exhaust flow. This leaves about one third of the total energy that must be dissipated to the surrounding by some mode of heat transfer. Temperatures within the combustion of an engine reach values on the order 2700 K and above. Materials in the engine cannot tolerate this kind of temperature & would quickly fail if proper heat transfer did not occur. Removing heat is highly critical in keeping an engine & engine lubricant away from thermal failure. On the other hand it is desirable to operate an engine as hot as possible to maximize thermal efficiency. It must be remembered that the reliability of an engine depends not so much, it is true on the proportion of the total heat converted into useful work, but rather upon the proportion of the total heat which is not so converted & which is left over to make trouble. This means that the cooling of an IC Engine should be optimised to avoid overheating and overcooling. Efforts are taken to analyse the potential of CAE to optimize the Cooling of multicylinder SI Engine and the results are discussed.

Keywords : CAE, IC Engine, SI Engine

I. INTRODUCTION

High pressure fuel injection systems such as common rail system & electronically controlled unit injector systems are being widely used in modern heavy duty engines. They are shown to be very effective for achieving high power density with high fuel efficiency & low exhaust gas emissions. However the increased peak combustion pressure gives additional structural & thermal load to engine structure. A large portion of heat from the gases of combustion is transferred to the cylinder head & walls, piston & valves. Unless the excess heat is carried away & these parts are adequately cooled, the engine will be damaged. Satisfactory engine heat transfer is required for a number of important rea¬sons, including material temperatures limits, emissions and knocking. The temperatures of certain critical areas need to be kept below material design limits.Themaximum heat flux through the engine components occurs at fully open throttle & at maximum speed. Peak heat fluxes are on the order of 1 to 10 MW/m2. The heat flux increases with increasing engine load & speed. The heat flux is largest in the centre of the cylinder head, the exhaust valve seat &centre of the piston. About 50% of the heat to the engine coolant is through the engine head & value seats, 30% through the cylinder sleeve or walls & remaining 20% through exhaust part area. The piston and valves, since they are moving, are difficult to cool, &operate at the highest temperatures. Temperatures measurements indicate that the greatest temperatures occur at the top or crown of the piston, since it is in direct contact with the combustion gases. The temperature of the piston & valves depend on their thermal conductivity. As thermal conductivity increases, the conduction resistance decreases. resulting in lower surface temperatures for the same speed & loading, aluminum pistons are about 40K cooler than cast iron pistons.

Temperature of burned gases in the cylinder of an internal combustion engine may reach upto ten times of surface temperature and leads to great heat fluxes emitted to the chamber walls during the combustion period. Maximum metal temperatures for the inside of combustion chamber space are limited to much lower values by a number of considerations & hence cooling for the engine becomes essential.For a given mass of fuel within the cylinder, higher heat transfer by extra cooling will lower the average combustion gas temperature & pressure which in turn reduce the work per cycle transferred to the piston. Thus specific power & efficiency are reducedIt should always be remembered that abstraction of heat from the working medium by the way of cooling the engine components is a direct thermodynamic loss.

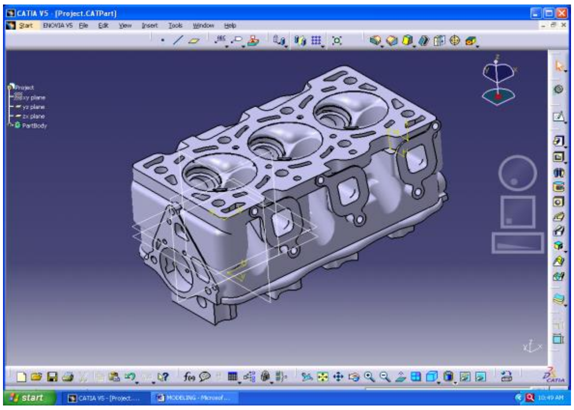
Thus it is very important to predict the magnitude of heat transfer within the engines. Hence it is the objectiveof this analysis to study temperatures distribution across the cylinder head of a three Cylinder SI Engine is and optimize it's cooling using CAE.

2. Thermal Analysis using CAE

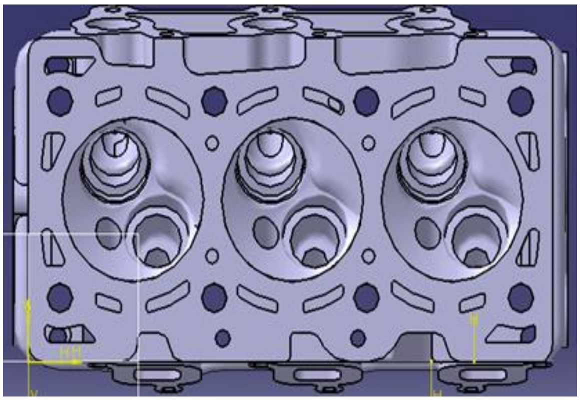
2.1 Modeling

A 3D model of a three CylinderSI Engine Head was prepared using the sketcher and part designing environments a CAD software.

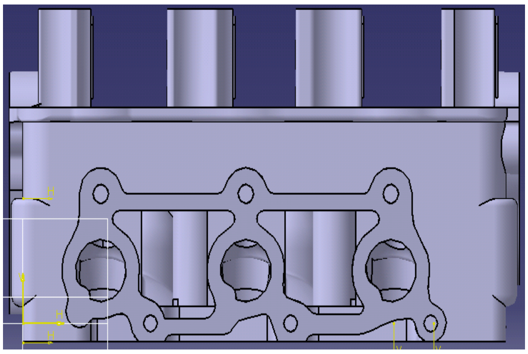
Model of 3 Cylinder SI Engine



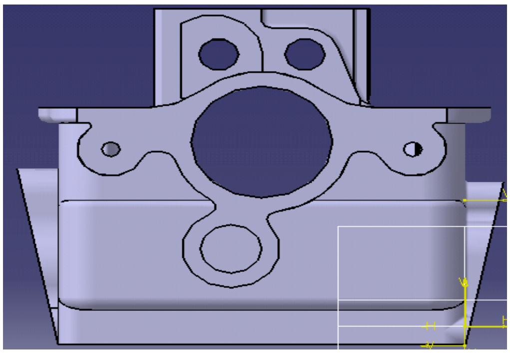
Bottom View



Side View



Front View



2.2 Meshing

Meshing can be defined as the process of breaking up a physical domain into smaller sub-domains (elements) in order to facilitate the numerical solution of a partial differential equation. While meshing can be used for a wide variety of applications, the principal application of interest is the finite element method. Surface domains may be subdivided into triangle or quadrilateral shapes, while volumes may be subdivided primarily into tetrahedra or hexahedra shapes. The shape and distribution of the elements is ideally defined by automatic meshing algorithms.

The finite element method in recent decades has become a mainstay for industrial engineering design and analysis. Increasingly larger and more complex designs are being simulated using the finite element method. With its increasing popularity comes the incentive to improve automatic meshing algorithms.
At the inception of the finite element method, most users were satisfied to simulate vastly simplified forms of their final design utilizing only tens or hundreds of elements. Painstaking preprocessing was required to subdivide domains into usable elements. Market forces have now pushed meshing technology to a point where users now expect to mesh complex domains with thousands or millions of elements with no more interactions than the push of a button.

Consumers of finite element technology such as aerospace and automotive industries have immediate needs to shorten design cycles and overall time to market. Improving the robustness, speed and quality of automatic meshers, while only a small part of the entire process, can translate into increased revenue and competitive advantage.

While there is certainly the incentive from a market-based perspective to improve finite element meshing technology, opinions on the specifics of what should be improved are diverse. Amongst users of finite element technology their has long been a debate as to what shape of element produces the most accurate result. There is the often-held position that quadrilateral and hexahedral shaped elements have superior performance to triangle and tetrahedral shaped elements when comparing an equivalent number of degrees of freedom. Use of hex elements can also vastly reduce the number of elements and consequently analysis and post-processing times. In addition, hex and quadrilateral elements are more suited for non- linear analysis as well as situations where alignment of elements is important to the physics of the problem, such as in computational fluid dynamics or simulation of composite materials. The automatic mesh generation problem is that of attempting to define a set of nodes and elements in order to best describe a geometric domain, subject to various element size and shape criteria. Geometry is most often composed of vertices, curves, surfaces and solids as described by a CAD or solids modeling package.

Many applications, use a "bottom-up" approach to mesh generation. Vertices are first meshed, followed by curves, then surfaces and finally solids. The input for the subsequent meshing operation is the result of the previous lower dimension meshing operation.

2.3 Meshed Geometry

No. of Nodes 74388
No. of Elements 75763N

2.4 Optimisation of Cooling using CAE :

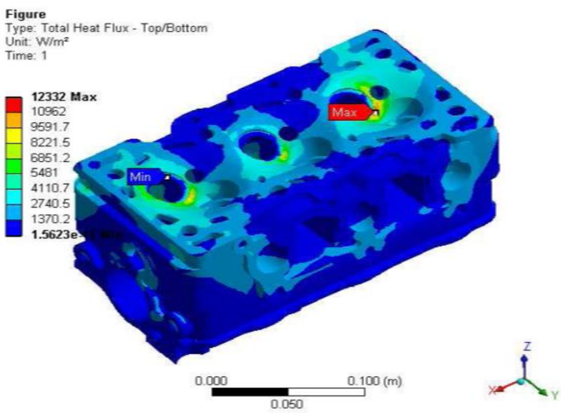
To understand the optimized cooling condition three different cases were taken. Coolant was allowed to flow at three different flow rates and the temperature distribution across the cylinder head in all three cases was observed.

Material properties of cylinder head :

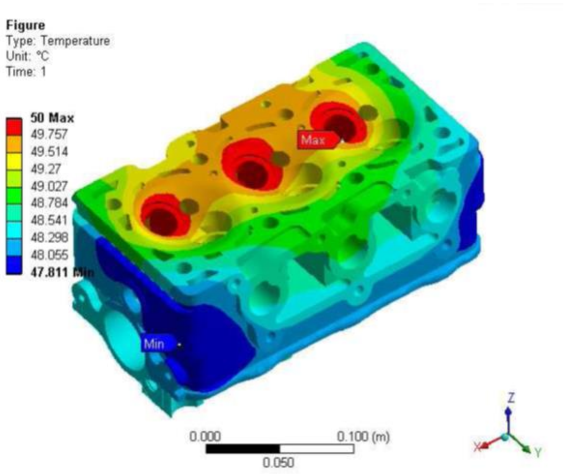
Aluminum 356.0-T6, Permanent mold cast. Subcategory: Aluminum Alloy; Aluminum Casting Alloy; Metal; Nonferrous Metal	
Material Properties	
Young's Modulus	7.24e+010 Pa
Poisson's Ratio	0.33
Density	2680. kg/m³
Thermal Expansion	2.3e-005 1/°C
Tensile Yield Strength	2.28e+008 Pa
Compressive Yield Strength	2.8e+008 Pa
Tensile Ultimate Strength	3.1e+008 Pa
Thermal Specific Heat	875. J/kg·°C
Resistivity	5.7e-008 Ohm·m

CASE I: Coolant flow rate of 90 GPM

Total heat flux distribution



Total Temperature Distribution

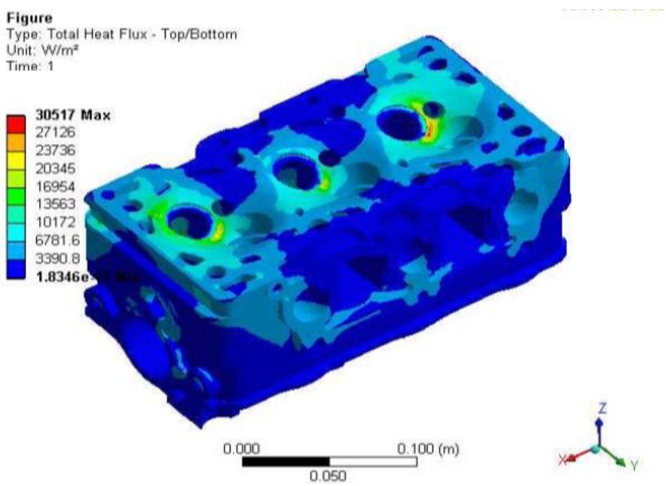


This is a thermal mapping of cylinder head for 50˚ C. the cooling rate required for this temp. is 80 GPM at this state cylinder head get overcooled.

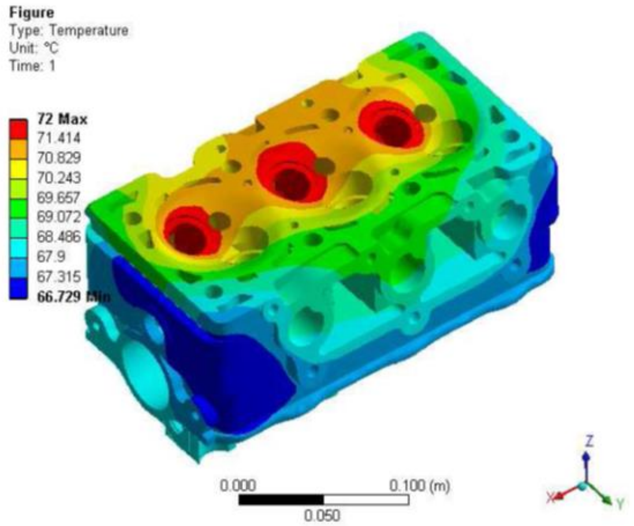
- Max. temp. = 50˚ C
- Min temp. = 47.81˚ C
- Max Heat Flux = 12332 W/m²

CASE II: Coolant flow rate of 70 GPM

Total heat flux distribution



Total Temperature Distribution



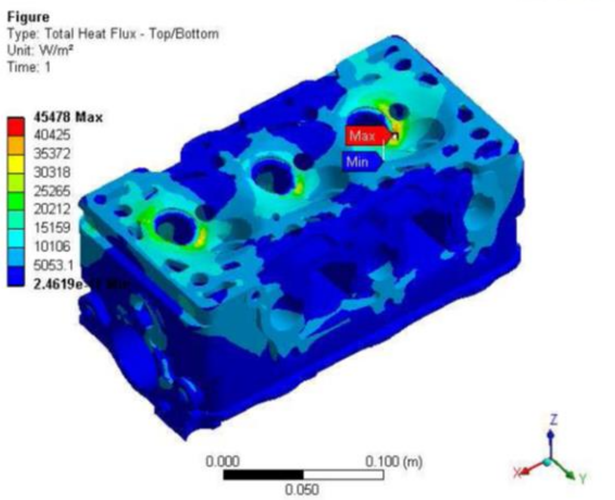
This is a thermal mapping of cylinder head for 72˚ C. the cooling rate required for this temp. is 63 GPM at this state cylinder head works efficiently.

This is optimized cooling condition.

- Max. temp. = 72˚ C
- Min temp. = 66.72˚ C
- Max Heat Flux = 30517 W/m²

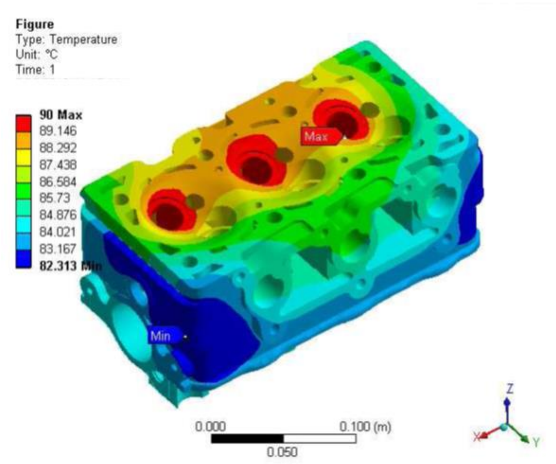
CASE III: Coolant flow rate of 50 GPM

Total Heat Flux



CASE III: Coolant flow rate of 50 GPM

Total Temperature Distribution



This is a thermal mapping of cylinder head for 90˚ C. the cooling rate required for this temp. is 49 GPM at this state cylinder head get overheated.

- Max. temp. = 90˚ C
- Min temp. = 82.30˚ C
- Max Heat Flux =45478 W/m²

II. CONCLUSION

The Three Cylinder Head S.I. engine in conventional mode is suggested to be operated at a flow rate of 63 GPM where the max. temp. 72˚ C. at the exhaust valve region. On reducing flow rate to 49 GPM the max temperature at the exhaust valve region goes to 90˚ C. where the cylinder head get overheated and for increasing the flow rate up to 80 GPM the temperature in the vicinity of exhaust valve reduces to 50˚ C. where cylinder head is overcooled.

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