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Optimization of Scallop Design for Cylinder Head of a Multi-Cylinder Diesel Engine for Reduction of Combustion Deck Temperatures and Simultaneously Enhancing Combustion Deck Fatigue Margin

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Abstract

Thermal fatigue crack failure is becoming the most important aspect in modern cylinder head design as modern engines are striving towards higher peak cylinder pressures. Thermal cracks are developed in the cylinder head due to thermal gradients generated because of operating conditions. Paper scope comprises analytical and experimental study on reduction of combustion deck temperature and enhancing combustion deck fatigue margin of a diesel engine through introduction of scallop on the combustion face.

There are methods such as cooling jacket optimization, faceplate insertion, scallops and other measures to reduce the temperatures on the combustion deck. Among these Scallop optimization is selected as a measure to make thermal fatigue crack resistant cylinder head because changing cooling water jacket design will cause change in castings for the cylinder head which may increase the development cost whereas introducing scallop will require just extra machining feature which does not require any major casting design modifications in cylinder head design. Since there is a material removal from the combustion face hence there will be reduction in High cycle fatigue (HCF) strength in water jacket location as well, therefore it is a trade-off between temperature reduction and fatigue strength if scallop is introduced.

Optimum scallop dimensions will be obtained from Design of Experiment (DOE) for reducing temperatures and these should also simultaneously meet the required water jacket HCF fatigue margins. Finite Element Models (FEA) will be calibrated through thermal mapping performed on the cylinder head to increase the accuracy.

Initially, Baseline and concept cylinder head models were analyzed through FEA and models were calibrated by thermal survey performed on both cylinder heads. Water jacket HCF fatigue margins should be reduced as minimum as possible along with reducing combustion deck temperature. Maximum % reduction in water jacket HCF fatigue margin was ~6.5% and combustion deck fatigue margin was enhanced up to 6%.

Introduction

Engines can be defined as a device for converting energy into useful work. The goal of any engine is to convert chemical energy into "mechanical force and motion". In internal combustion (IC) engine chemical energy of fuel is used which is generated through exothermic reactions taking place during combustion and hence evolved energy is used to do work [10].

Cylinder head is one of the important components of IC engines because:

- It contains combustion pressure
- Route air/fuel into and out of the cylinder in most efficient manner
- Support components (spark plug, valve train, fuel injectors, and pumps)
- Route fluids (oil, coolant and sometimes fuel to injectors)
- Support other engine accessories and bracket

Thermal management of the cylinder head is very important. High temperatures on cylinder heads can make designs prone to thermal fatigue cracks. There are various methods by which one can reduce fatigue failure in cylinder heads. Combustion face of the cylinder head is the bottom surface of the cylinder head which is exposed to very high thermal gradient and the advent of crack is from the combustion face [1]. Scalloping of combustion face has been used to improve

TABLE 5 HCF Fatigue margin comparison at water jacket

Locations on Lower water jacket floor	% Difference of HCF margin between scalloped and non-scalloped head
A	-2.38
B	-3.50
C	-5.04
F	-3.17
G	-0.45
H	-0.72
I	-3.60
J	-0.48
K	-0.69
L	-0.00
M	-5.88
N	-6.67
O	-4.80
P	-0.74
Q	-1.63

Conclusions

- Optimization of scallop design was performed based on Radius (Fillet radius of cut), Depth of cut and Diameter. Results of optimization revealed that Depth of cut has the highest impact on scallop functionality.
- Scalloped cylinder head of concept design meets the required HCF fatigue and combustion deck fatigue margin. Hence, meets the required targets also reducing the combustion deck temperature at critical locations. Although flux and temperature were higher in concept design (since brake power was increased) through scalloping of cylinder head combustion deck fatigue margin for worst case cylinder was improved by 7% and became equivalent to baseline design without any other modifications in cylinder head.
- Maximum reduction in HCF fatigue margin observed was 6.67% with respect to non-scalloped concept cylinder head. Fatigue margin was reduced due to material removal but still better than a known minimum margin of benchmark product.
- Valve bridges on combustion face get severe thermal stresses as compared to other locations on combustion deck.
- Introduction of scallop is most favorable if a major design modification in cylinder head design is not required.
- Favorable locations for scallops are around injector bore and valve bridges.
- Scallop reduces material from the combustion face which affects the fatigue life but also increases conductive heat transfer which reduces combustion deck temperatures as well. Hence, an optimized scalloped cylinder head is favorable for eliminating fatigue cracks.

Future Work

Further improvement on scallop design to optimize more with respect to thickness and combustion deck fatigue margin and improve HCF fatigue margin at water-jacket locations and correlate with experimental validation (Component, Engine and application level testing).

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