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Comparison of Direct and Metamodel Based Optimization in the Coolant Jacket Design of an IC Engine

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Abstract

This paper focuses on the conjugate heat transfer analysis of an I4 engine, and discusses optimization of the coolant passages in engine coolant jackets. Direct Optimization approach integrates an optimizer with the numerical solver. This method of optimization is compared with a metamodel-based optimization in which a metamodel is generated to aid in finding an optimal design. The direct optimization and metamodel approaches are compared in terms of their accuracy, and execution time.

1. Introduction

Increased customer demands combined with stringent fuel economy regulations have driven the need for higher power density engines. Higher power generation is associated with increased heat released. Increased heat release demands effective and efficient rejection of heat to meet the thermal management as well as temperature distribution requirement. One of the critical components of the thermal management system is Internal Combustion Engine. To maintain the engine components at acceptable temperatures the generated heat needs to be removed in an effective manner.

Heat generated by the IC engine is removed by coolant circulating through passages in cylinder head and engine blocks termed as coolant jackets. Due to complicated topology of these passages, designing the water jackets for optimum coolant flow and velocities is a very challenging task. An ideal water jacket would have sufficient amount of coolant flow rate in critical areas to remove heat and result in desired temperature distribution without adversely affecting pressure drop. A higher pressure drop across the water jacket results in overall increase of power consumption. Higher component temperatures compromise structural integrity of the engine which results in Thermomechanical fatigue failures.

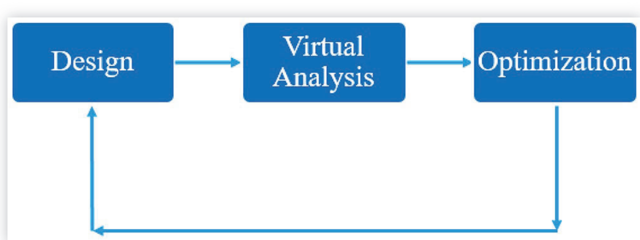
Conjugate Heat Transfer (CHT) analysis has been successfully employed recently in automotive industry for numerical prediction of metal temperatures in IC engines [1-6]. In CHT analysis, thermal field of engine is predicted by solving energy equation for fluid and solid domains simultaneously. Multiple commercially available softwares are capable of predicting entire thermal map of an engine using CHT.

The possibility of predicting coolant and metal thermal map simultaneously using CHT has made it a powerful tool in early design phase and throughout development of IC engines. CHT coupled with optimization tools opens a gateway for upfront design of coolant jackets. Due to stringent target requirements on flow and temperature, coolant passage design optimization often turns out be a multi-objective problem. The conflicting goal of maximizing flow, and minimizing pressure drops makes this a very intriguing problem in Optimization field. Optimization has widely been used in design and development of engines and vehicles [8-17].

As shown in the flowchart below (Figure 1) design and optimization of water jacket is a multistep process. It starts with a design typically based on past experience, manufacturing feasibility and meeting minimum design requirements. This design is evaluated via CHT for temperature distribution and analyzed to determine any shortfalls. The design then goes through optimization process resulting in a product which meets all the requirements and design targets.

The optimization process starts with a well-established baseline analysis. Based on the resulting temperature map, areas of concerns such as high temperature zones and enablers, such as coolant passages, gasket holes, for improvement are identified. The enablers, known as design parameters form the input to the optimization study. To fully comprehend the influence of design parameters, a full factorial study which entails modifying each parameter at a time, is required. This approach is time consuming and hence has limited applications, especially as the number of parameters increase.

FIGURE 1 Design optimization process workflow



Direct optimization approach solves the same problem using a closed loop approach. It eliminates approximation and thus any errors associated with it. It is thus a better approach in terms of accuracy. However, metamodel based optimization is beneficial in terms of time due to the possibility of evaluating all the design points in parallel.

For the current problem, metamodel based optimization generates a better design compared to direct optimization. The time taken by the metamodel approach is also 50% less than direct optimization. The predicted temperatures also match with measured data.

Both the approaches demonstrated in this paper can be used as a powerful analysis tool in early design phase and throughout the development of an engine as it provides great insight into the behavior of the dynamics of the system without the need for physical testing. For this particular application metamodel based optimization approach outperformed direct optimization.

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