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Methodology for Combustion Analysis of a Spark Ignition Engine Incorporating a Pre-Chamber Combustor

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ABSTRACT

With an increasing global awareness of the need to conserve fuel resources and reduce carbon dioxide emissions, the automotive sector has been seeking gains in engine efficiency. One such method for achieving these gains on a spark ignition (SI) engine platform is through lean burn operation. Ultra-lean operation (λ>2) has demonstrated the ability to increase thermal efficiency and significantly reduce emissions of nitrogen oxides (NOx) due primarily to lower mean gas temperatures. Turbulent Jet Ignition (TJI), a pre-chamber-based combustion system, is a technology that enables ultra-lean operation. TJI is also an effective knock mitigation system due to the distributed nature of main chamber ignition, resulting in rapid burn rates.

Pre-chamber combustors such as that utilized in TJI have been studied extensively for decades, but the interaction of the combustion events between the two chambers is not well understood. Additionally, current in-cylinder pressure transducer-based combustion analysis is limited in its effectiveness at capturing TJI combustion characteristics, particularly start of combustion (SOC) in the main chamber. This can lead to misleading heat release results and incomplete understanding of ignition and chamber interaction. This study analyzes the limitations of current combustion analysis techniques to characterize TJI and proposes a new methodology for combustion analysis.

An optical engine is used to qualitatively assess pre-chamber jet formation and the subsequent main chamber ignition events. This data is synthesized with that of a single cylinder metal engine counterpart providing empirical heat release information. Utilizing high speed pressure transducers in both pre-chamber and main chamber, the validity of heat release data is explored within the context of the optically observed combustion process. A computational fluid dynamics (CFD) model is employed as an explanatory tool for the pre-chamber combustion event and the gas exchange process between the chambers. Informed by qualitative optical engine data, empirical heat release data, and CFD, this study seeks to produce a new methodology for combustion analysis that is applicable not only to TJI but to most pre-chamber-based SI combustion systems. Further accurate understanding of the interaction of the combustion events between the chambers and the gas exchange process can lead to optimum pre-chamber design and operation, and enable system scalability.