

ENGINE CALIBRATION PROCESS OPTIMIZATION

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Keywords: Set-covering, Binary integer programming, Engine calibration.

Abstract: Before an engine can be scheduled in the Product Development cycle for inclusion in a vehicle, it must be calibrated in such a way that it satisfies a variety of regulatory tests over a range of conditions. The current engine calibration process involves conducting a design of experiments at a representative number of steady state points in order to satisfy all required regulatory tests; test engineers use a standard 16×16 grid with standard grid spacing and then conduct a design of experiments on a subset of those points - about 120 of them. This work explores how to reduce the engine calibration process time by finding the best 16×16 grid choice (i.e. the best spacing on both the engine speed and torque axes) and the minimum number of points on the grid to test in order to satisfy regulatory constraints around NO_x , particulate matter, noise, and fuel consumption. Our proposed method models the problem as a Binary Integer Program that simultaneously selects the best grid spacing and optimized number of points to test, while guaranteeing that all specified constraints hold. We present an example that demonstrates how we can reduce the number of necessary test points by approximately 56%.

1 INTRODUCTION

As vehicle emission and fuel economy standards continue to tighten, manufacturers respond by developing increasingly more complex engine systems with advanced control strategies. The process of calibrating such an engine (i.e. assigning the desired values to control parameters) quickly becomes a daunting task for calibration engineers. In the case of a modern internal combustion engine that may have six or more inputs (e.g. injection timings, injection quantities, intake manifold pressure, and exhaust gas recirculation rate), generating data for the calibration task is a time consuming and costly endeavor. If we consider the simple case where the response of the engine could be reasonably modeled with a quadratic function (i.e. each control factor can be understood by using three settings), and the engine speed and load regime (i.e. the range of engine rotational speed and available output torque) are each segmented by 16 grid quadrants, then the calibration engineer would be need to run $16^2 \times 6^3 = 256 \times 4,096 = 55,296$ test points: this is derived from the (number of quadrants)^{engine speed \times torque} \times (number of inputs)^{number of settings}. At roughly 5 minutes per test point, data collection alone would take over six months! Confound this with the fact that calibrations

must be developed for different operating conditions and engine operation modes, and the product development timeline quickly becomes uncompetitive.

There has been significant work using design of experiment (DoE) and mathematical optimization techniques to minimize the amount of input data needed for every given speed and load combination (e.g. (Yoshida et al., 2011), (Maloney, 2009), (Castagné et al., 2008), and (Langouët et al., 2008)); the goal is to reduce the number of input combinations to some fraction of the possible combination of inputs and settings (e.g. $6^3 = 4,096$ combinations when there are six inputs and three settings). However, this work does not address on which of the $16^2 = 256$ speed and load combinations (i.e. test points) a calibration engineer should focus their efforts, as it is not feasible to consider every combination. This selection of test points needs to be determined in such a way to satisfy testing of typical transient drive cycles needed to pass certification (i.e. the Environmental Protection Agency (EPA) Federal Test Procedure (FTP) 75 test cycle (EPA, 1977)).

Steady state (SS) engine development consists of maintaining constant speed and load for prolonged periods of time (e.g. five minutes or more). This is not, however, typical of how most vehicle owners operate their vehicles. Vehicles are usually driven in

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