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CFD-based optimization of fuel injection strategies in a diesel engine using an adaptive gradient method

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Abstract

A computationally efficient computational fluid dynamics (CFD)-based optimization method with the capability of finding optimal engine operating conditions with respect to emissions and fuel consumption has been developed. The approach taken uses a steepest descent method for an adaptive cost function, where the line search is performed with a backtracking algorithm. The backtracking algorithm utilizes quadratic and cubic polynomials to accelerate the convergence, and the initial backtracking step employs an adaptive step size mechanism which depends on the steepness of the search direction. The adaptive cost function is based on the penalty method such that the penalty term is stiffened after every line search. The engine simulations are performed with a *KIVA-3*-based CFD code which is equipped with well-established spray, combustion and emission models. The application of this optimization tool is demonstrated for a non-road, medium-speed DI diesel engine which, for these simulations, utilizes a multi-orifice, asynchronous injection system. It has been demonstrated that this new injection method has a large potential for reducing emissions while maintaining a low fuel consumption. In addition, this optimization approach is computationally very efficient when good enough initial values are available.

Keywords: CFD simulations; Engine optimization; Adaptive gradient method; Asynchronous injection

1. Introduction

One of the main driving forces in today's engine research is the reduction of pollutants while keeping the fuel consumption as low as possible. A widely used method which addresses such issues is to investigate the flow, spray and combustion processes inside the cylinder and to develop strategies which will minimize the pollutants at their source. This approach is particularly suited for diesel engines where emission after-treatments are technically challenging and expensive. Over the years, methods of computational fluid dynamics

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Nomenclature

CA	crank angles
CFD	computational fluid dynamics
EPA	Environmental Protection Agency
EVO	exhaust valve opening
GA	genetic algorithm
IVC	inlet valve closure
NO_x	nitric oxide
PM	particualte mass
RPM	revolutions per minute
TDC	top dead center
SFC	specific fuel consumption
grad	spatial gradient
μGA	micro genetic algorithm
C, N, S	cost function weights
D	penalty matrix, diffusivity
F	total cost function evaluations
P	power output
L	power losses
T	temperature
X	normalized parameter space
c, n, s	cost function exponents
$\mathrm{d}V$	volume differential
f	cost, merit or penalty function
f_0	unconstraint objective function
g	constraint function
l_k	# cost function in kth line search
m	mass
n	dimension of parameter space
p	pressure
p_i	ith parameter component
p_k	kth search direction
x	normalized parameter
β	backtracking constant
δ_k	derivative in direction p_k
λ	backtracking constant
ρ	density
ζ	penalty parameter

Subscripts

g	gas
k	iteration index
l	liquid
0	target value

(CFD) have evolved into a reliable and economic tool which is now routinely used in the development of new or improved engine designs. While CFD methods are an expedient way to investigate a particular engine operating condition, they can become computationally very demanding when used in the context of engine optimization, where hundreds of such operating points may have to be evaluated. Therefore, engine optimization