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Reducing emissions by optimising the fuel injector match with the combustion chamber geometry for a marine medium-speed diesel engine

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ABSTRACT

The effects of seven matching parameters of a fuel injector and combustion chamber geometries on nitrogen oxide (NO_x), soot and specific fuel oil consumption (SFOC) were investigated by means of a parametric study. The study was carried out on four different engine loads, i.e. L25 (25%), L50 (50%), L75 (75%) and L100 (100%) loads. The injection-related parameters were found to have more prominent influences as opposed to the combustion chamber geometries. Then, a multi-objective genetic algorithm (MOGA) method was proposed in order to identify a set of optimal designs for the L100 load. The emissions and performance of these optimal designs were also examined and compared on the other three engine loads. Finally, an optimal design which meets the IMO (International Maritime Organization) Tier II NO_x emissions regulations (research shows it is impossible to meet Tier III NO_x emissions regulations solely on the basis of the optimisation of the combustion progress) and which has the best fuel economy was singled out.

1. Introduction

Marine diesel engines play an indispensable role in shipping. Their extensive application as main propellers or generators mainly relies on their high reliability and fuel economy. However, intolerable pollutions caused by them are gaining increasing focuses worldwide. Compared to automotive diesel engines, marine diesel engines exhaust much lower CO, CO_2 and HC emissions, and conversely generate severely deteriorated NO_x emissions. As a result, the IMO expressly referred to the NO_x emissions in the revised Annex VI of MARPOL (Pueschel et al., 2013), as shown in Table 1. Tier II NO_x emission regulation came into force for engines mounted on a ship constructed on or after 1 January 2011. It stipulated the reduction of NO_x up to 20% by comparing to Tier I regulations in the global area. The more stringent Tier III regulations were applied for engines installed on a ship constructed on or after 1 January 2016, operating in the ECAs. It requires a NO_x reduction of 80% from Tier I. Tier II regulations are still applied for ships operating outside of the ECAs.

In view of the challenge posed by stringent emission regulations, some existing technologies are applicable, for example, the EG), the SCR, the 2-stage TC system together with an extreme Miller cycle, the dual fuel engine or the nature gas operation (Christer, 2013; Steffe et al., 2013). However, some existing marine diesel engines installed on old ships can only meet

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Nomenclature

2D	two dimensional
BTDC	before top dead centre
CFD	computational fluid dynamics
CO	carbon monoxide
CO_2	carbon dioxide
d003	connection length
D2	a test cycle for NO_x emissions
DoE	design of experiment
ECAs	emission control areas
EGR	exhaust gas recirculation
GA	genetic algorithm
h001	bowl radius
HC	hydrocarbons
HPCR	high-pressure common rail
IMO	international maritime organization
KIVA	a Fortran-based CFD software
L100	full engine load
L25	25% engine load
L50	50% engine load
L75	75% engine load
MARPOL	the international convention for the prevention of pollution from ships
MOGA	multi-objective genetic algorithm
NLPQL	non-linear programming by quadratic Lagrangian
NO_x	nitrogen oxides
NPL	nozzle protrusion length
Piso	pressure implicit split operator
r002	toroidal radius
SA	spray angle
SFOC	specific fuel oil consumption
Simple	semi-implicit method for pressure linked equations
Sobol	quasi-random low-discrepancy sequences
SOI	start of injection
SCR	selective catalytic reduction
SR	swirl ratio
TC	turbocharging
TDC	top dead centre
v001	the distance from the centre of toroidal surface to the piston top surface
v002	clearance
v003	crown centre height

Functions and variables

x	n-dimensional parameter vector
f	function
j	variable
k	objective
N	maximum objective numbers
$\vec{x}^*$	Pareto design
$\vec{x}_j$	arbitrary design

Units

CA	crank angle
deg	degree
g/kWh	grams per kilowatt-hour
L	litre
kW	kilo Watt
mm	millimetre
r/min	rotates per minutes