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## Preface

Traditionally, the study of internal combustion engines operation has focused on the steady-state performance. However, the daily driving schedule of automotive and truck engines is inherently related to unsteady conditions. In fact, only a very small portion of a vehicle's operating pattern is true steady-state, *e.g.*, when cruising on a motorway. Moreover, the most critical conditions encountered by industrial or marine engines are met during transients too. Unfortunately, the transient operation of turbocharged diesel engines has been associated with slow acceleration rate, hence poor driveability, and overshoot in particulate, gaseous and noise emissions. Despite the relatively large number of published papers, this very important subject has been treated in the past scarcely and only segmentally as regards reference books. Merely two chapters, one in the book *Turbocharging the Internal Combustion Engine* by N. Watson and M.S. Janota (McMillan Press, 1982) and another one written by D.E. Winterbone in the book *The Thermodynamics and Gas Dynamics of Internal Combustion Engines, Vol. II* edited by J.H. Horlock and D.E. Winterbone (Clarendon Press, 1986) are dedicated to transient operation. Both books, now out of print, were published a long time ago. Then, it seems reasonable to try to expand on these pioneering works, taking into account the recent technological advances and particularly the global concern about environmental pollution, which has intensified the research on transient (diesel) engine operation, typically through the Transient Cycles certification of new vehicles.

For a number of years now, the vast majority of diesel engines have been turbocharged and this trend is sure to continue. Although turbocharging the diesel engine is beneficial because it increases its (specific) brake power, and also because it provides better fuel economy and reduced CO<sub>2</sub> emissions, it is the turbocharged diesel engine that suffers way more than its naturally aspirated counterpart from poor transient response. This originates in what is known in the engine community as 'turbocharger lag', which is the key factor responsible for the slow speed response and heavy exhaust emissions. Consequently, the turbocharged diesel engine will be the focus of analysis in this book, with the behavior of its naturally aspirated counterpart highlighted only on specific aspects (*e.g.*, cold

starting). As a matter of fact, the title of the book could well have read *Turbocharged Diesel Engine Transient Operation*.

Although there are many operating schedules experienced by diesel engines that can loosely be termed transient, we have focused on the most influential ones in terms of engine performance and exhaust emissions, namely load acceptance, acceleration and cold starting, as well as their combinations, most notably in the form of Transient Cycles.

Emphasis in the book is placed on the in-cylinder thermodynamic discrepancies, exhaust emissions and methods of improving transient response. However, it has been our intention to cover the subject from all relevant aspects; consequently, the interested reader will be able to find information on areas of 'lesser popularity' such as second-law (exergy, availability) analysis, compressor surging or crankshaft torsional deformation during transients. Although automotive applications are usually the main case studied, industrial or marine engines' transient response is dealt with too. Moreover, the analysis is thermodynamics rather than control oriented. Control matters are only briefly discussed, mainly in Chapter 6, where the effects of the various control strategies on the engine transient response improvement are pinpointed.

The book is organized as follows: in Chapter 1, an introduction to transient diesel engine operation is given, highlighting various typical load acceptance and acceleration schedules of both automotive and industrial/marine engines, and detailing the importance and different evolution pattern of transient operation compared with steady-state conditions. Chapter 2 describes the complex thermodynamic issues of transient operation (located in the fuel injection mechanism, heat transfer, combustion, air-supply and exhaust gas recirculation processes), starting, of course, with the discussion of the fundamental turbocharger lag problem. Chapter 3 focuses on the dynamic issues encountered during transients, namely friction overshoot, components stress and crankshaft torsional deformation. Chapter 4 discusses briefly the experimental procedure involved in transient diesel engine research, addressing in more detail the instantaneous particulate matter measurement techniques and the heat release analysis of transient pressure data. Chapter 5 deals with the very important aspect of exhaust emissions during transients, and Chapter 6 with the various methods developed over the years for reducing the turbocharger lag phase and improving transient response. Chapter 7 focuses on other aspects of transient conditions, namely cold starting, operation when the turbocharger compressor experiences surge and low-heat rejection engine operation. Chapter 8 provides an alternative coverage of the subject through the perspective of the second law of thermodynamics. Finally, Chapter 9 summarizes the various modeling approaches developed over the years for the simulation of transient operation.

This book is the outcome of many years of research on the subject and it is intended to serve as a reference for engineers and researchers but it should also be useful to (post-graduate) students as a supplementary text. It is expected that the reader is already familiar with (basic) aspects of internal combustion engine operation. Consequently, when dealing, for example, with the combustion development during transients, only a brief reminder is provided at the beginning of the section concerning some fundamental features of (steady-state) combustion,

and afterwards we focus on the discrepancies and special behavior noticed during transients that diversify the operation from steady-state conditions. Wherever possible, we provide experimental results to support our analysis. There are a few points, however, where this was not feasible due to lack of relevant experimental work (*e.g.*, transient operation when the turbocharger compressor experiences surge or crankshaft transient torsional deformation).

At this point, we would like to express our thanks to the various publishers and companies, who have granted permission to reproduce figures and photos from their publications. In particular, the assistance of Messrs Jörg Albrecht of MAN Diesel SE, Elmar Gasse of Daimler AG, Chris Nickolaus of Cambustion Ltd, John Zambelis of Isuzu Motors Greece, Martin Stenbäck of Lysholm Technologies AB, Günther Krämer of BorgWarner Turbo Systems and Masayasu Kondo of Mitsubishi Heavy Industries Europe Ltd is greatly appreciated.

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