DESIGN AND APPLICATIONS IN DIESEL ENGINEERING

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Preface

When preparing an appropriate introduction to this book, I thought 'Why not deviate from the norm and relate my own growing association with the diesel engine?'. After all, a life cycle such as mine is very much analogous to that of the diesel cycle.

Compression and accumulation of knowledge starting from childhood days when my father took me to visit his remote village (Mar Yaco) in the midst of the rugged Northern mountains of Mesopotamia. I recall visiting the village blacksmith where I noticed some old engines and gadgets. One small engine apparently awaiting repair attracted my attention. My father called it a diesel but he said that farmers in that part of the country had been known to produce their own innovative engines, sometimes made from hard wood as well as metal. This simple conversation was imprinted in my memory till it started to make more sense when I later studied the history of the Land of the Two Rivers which is the cradle of civilization. Further compression of knowledge was to follow from completing my university studies in mechanical engineering in England and later from my considerable training and engineering experience with some bias towards engine maintenance and applications at Daura Oil Refinery in Iraq.

Ignition. Attendance at a special intensive four-month course on diesel engineering in 1968 at the UNIDO Oil Engine Research Insitute, VUNM, Prague, instructed me and further enlarged my experience. Subsequently, I was fortunate to work with one of the leading diesel advocates, Professor Theo Priede, at the Institute of Sound and Vibration Research in Southampton University. Both VUNM and Priede ignited my latent love for engines and the diesel type in particular.

Combustion. My awareness of this aspect grew because I continued to develop diesel knowledge at ISVR Southampton, Lucas CAV and Loughborough University, and through my own consulting activities with Haddad Technical Consultancy Services. Of course, many catalysts served to strengthen my commitment but I feel that my wife, Basima, deserves special mention for her unfailing support through thick and thin.

Expansion. In spite of the fact that my associates, my research students and I have, between us, completed much diesel engine research, there remains much to be done. We all hope to continue this expansion process for many years to come.

Acknowledgements. Naturally, a number of establishments and persons have been instrumental in assisting me with this process:

UNICEG: Universities Internal Combustion Engines Group: for providing the opportunity to enhance the propagation of I.C.E. knowledge.

Loughborough University: for providing me with the opportunity to run intensive post-experience courses and facilities for research and teaching expertise.

The Center for Professional Advancement: for providing the opportunity to propagate my courses worldwide.

Dr. Neil Watson: my co-editor for his invaluable contribution towards these two books.

Mr. Ellis Horwood: our publisher for his constant encouragement and advice.

The earlier, companion volume (Principles and Performance in Diesel Engineering) presented a basic introduction to the theoretical and operational background, so initiating the publication of these two complementary books on diesel engineering. In the author's view, it is becoming apparent that yet a third volume is needed to include other advanced aspects of this branch of engine technology.

And finally, on the eve of my departure to the United States, I look forward to further developments at Western Michigan University, and in the diesel engine industry in the U.S.A.

As for *Exhaust*, I would rather like to believe this will not happen; but a life cycle is just like a diesel cycle: it has to come to an end some day, allowing for another cycle to begin . . . and so on. Perhaps my exhaust stroke should be left to the imagination and speculation of the reader.

S. D. Haddad

1

Some basics of high speed diesel design

Martin H. Howarth, Atlantic Research Associates

This is a very wide title and could only be properly developed in a complete book rather than a single chapter. However, many aspects of diesel engine design are covered by other chapters in this volume such as those on structure and noise, lubrication and wear, exhaust emissions, stress analysis, bearing loadings and fuel/air mixing. This chapter therefore deals with the following design concepts:

1. Engine Cycles.
2. Combustion Systems.
3. Thermal Stresses.
4. Motoring Losses.
5. Overall Design.
6. Timing Drives.
7. Cylinder Head and Gasket.
8. What's New?

1. ENGINE CYCLES

Although two-stroke high speed diesel engines are manufactured and although they offer a greater potential of power/weight ratio and power/space ratio than four-stroke engines, their various problems have meant that they are scarcely considered in the small engine field and little development work is in progress. Therefore only four-stroke engines are considered here. The engines as we know them today have been under development for more than 50 years but are still subject to continuing refinement, and new developments are necessary to meet more exacting requirements as they arise.

The four-stroke diesel engine lends itself extremely well to supercharging and this offers great advantages to the manufacturer by extending the output range of any one basic engine design. Supercharging is therefore likely to extend down the engine size range even to the smallest sizes, whether it be by means of a turbocharger, a pressure wave supercharger or a newly developed type of positive displacement supercharger. The effect of supercharging on diesel engine design is mostly a matter of minimizing heat flow and thermal stresses and the injection equipment. Fundamental design changes are not involved.

Turbocharging is undoubtedly the most attractive way of increasing engine output and that is the reason that it figures quite largely here. As far as the designer is concerned the effect of turbocharging reflects on:

Manifolding–inlet and exhaust
Heat Flow
Maximum Cylinder Pressures
Lubrication

Apart from the bonus it provides in greater output and greater specific output, a turbocharger is in many instances an excellent silencer.

A more questionable feature is whether turbocharging actually results in lower cost per kilowatt of output. One thinks that it ought to do so but figures published recently (that may not have been representative) did not suggest that the cost of a turbocharged engine compared favourably with the cost of a larger, naturally aspirated engine.

The principle of a pressure wave supercharger is shown in Fig. 1. In addition to the design requirements listed above for the turbocharger, it is also necessary to provide a mechanical drive. Even though the drive has little power to transmit, its provision is a considerable nuisance and is only likely to be regarded as acceptable if the supercharger can provide quite substantial advantages such as improved low speed torque.

Early forms of pressure wave supercharger, far from providing any silencing effect, were appallingly noisy. This has been improved by arranging the gas passages in helical form and not as shown in the figure.

As regards supercharging by mechanically driven pumps, the position is not particularly encouraging. A drive transmitting considerable power must be provided and there is likely to be a drop in overall efficiency of the engine/supercharger combination. Recently there seemed to be interest among component manufacturers to develop more efficient compressors for use as superchargers and this might change the situation. Unfortunately, that interest seems to have waned.

Other methods of improving the four-stroke cycle have been, or are being, investigated. Of these, the diesel Wankel need not distract us now. The so called 'adiabatic engine' in which the aim is to keep the heat inside the engine by the use of ceramic materials and thus improve thermal efficiency and avoid the need for a cooling system is still in its infancy. Although this may well be a most significant development, generally accepted design principles have not yet been

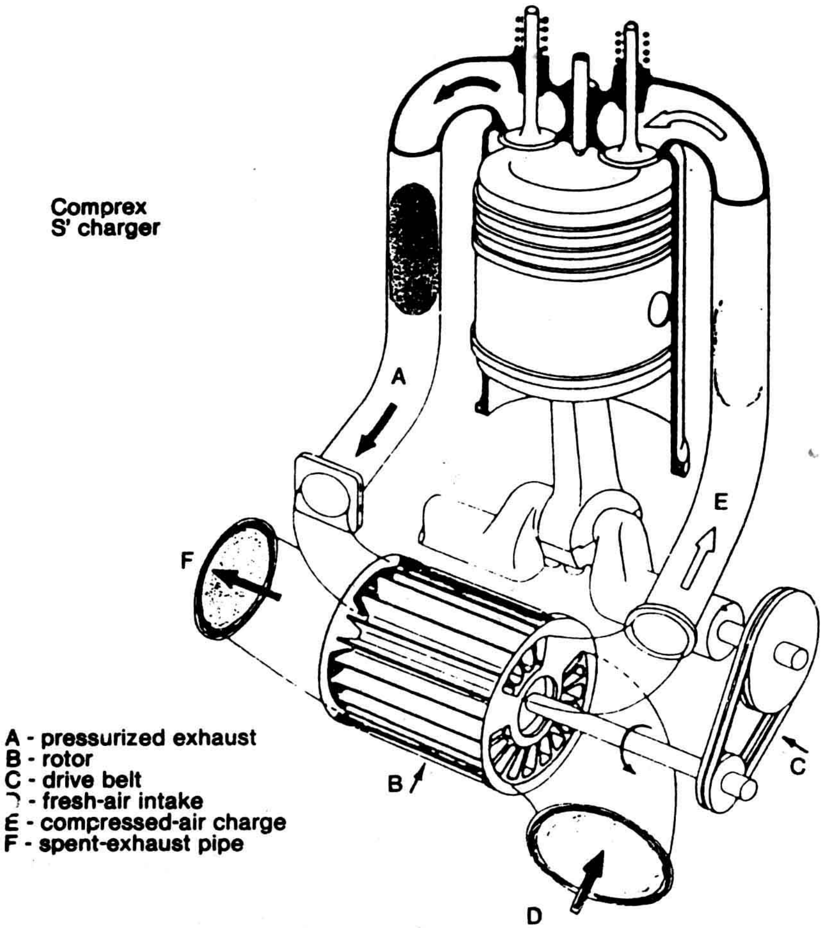

Fig. 1 – Principle of pressure wave supercharger.

established and it is too early to deal with the subject now. However, much research and development work is currently in progress.

This chapter therefore is confined to four-stroke engines of quite conventional form.

2. COMBUSTION SYSTEMS

Both direct injection (DI) and indirect injection (IDI) combustion systems may properly be considered as having high speed capability. It is well known that the

IDI system has at present greater speed capability and has little difficulty in operating up to the highest rotational speed necessary even for a vehicle. The DI engine at moderate speeds offers some 15% better fuel economy than the IDI and great efforts are being made to extend its speed range to equal that of the IDI without subsequent loss of its good economy and other virtues. The practical speed range of DI engines has been limited to about three to one and this means that the DI engine has not yet made inroads into the passenger car market. The high speed DI engine's problem falls into one of fuel and air matching.

At this stage it is perhaps worth considering the sort of time scale that has to be allowed for injection and the establishment of combustion.

Figure 2 shows a typical timing diagram for a four-stroke engine operating at 3000 rpm. The time available for injection is 1.1 milliseconds and combustion, which has to start before injection is complete, lasts only about 1.4 milliseconds.

At such a speed, satisfactory conditions could be achieved at present by all three current types of direct injection/combustion chamber combination. That is to say, a pump, pipe and injector plus multi-hole nozzle and toridal chamber, or

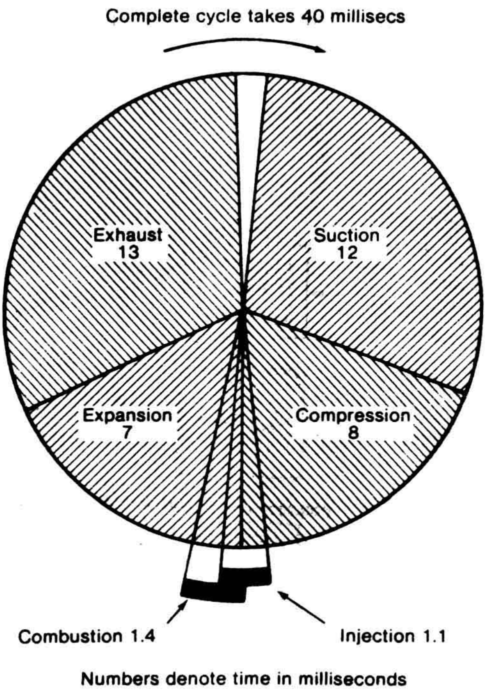

Fig. 2 – Four-stroke diesel engine: cycle of events at 3000 rpm.