COMBUSTION ENGINES

AN INTRODUCTION TO THEIR DESIGN, PERFORMANCE, AND SELECTION

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Contents

Preface

Engines and pumps are common engineering devices which have become essential to the smooth running of modern society. Many of these are very sophisticated and require infrastructure and high levels of technological competence to ensure their correct operation. For example, some are computer-controlled, others require stable, three-phase electrical supplies, or clean hydrocarbon fuels. This project focuses on the identification, design, and construction of various engines. Noise, vibration and harness performances have also been evaluated with further suggestions given to improve current systems.

Introduction

Diersel engines constitute a major source of power for ships, buses, and trains as well as road machinery. About one-fifth of total energy consumption in the United States goes toward operating these engines, and hence demand for them is growing fast, compared to gasoline engines. Sales of vehicles using diesel engines reached a peak during the 1980s in the United States due to major oil crises, as depicted in Figure 1. Various projections at that time had predicted that an increase of about 20% in sales would be achieved by the end of the decade. However, variations in fuel costs, falling prices of petrol and various problems associated with the operation of diesel engines led to a fall in their overall sales.

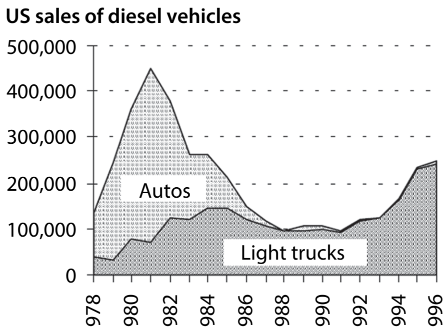

Figure 1 Trend in sales of various diesel engine based automobiles in the United States.

Gasoline engines use a spark ignition system for the initiation of fuel reaction, unlike diesel engines, which are based on the compression ignition of fuel-air mixture. Diesel engines operate at higher compression ratios, thus allowing more useful work output during the course of their operation. Combustion in these types of engines can be made to take place away from chamber walls, thus helping in reduction of the overall heat release rate. In addition, there are various throttling as well as pumping losses associated with the opertion of petrol engines. These are some of the major reasons for their lesser cycle efficiency when compared with diesel engines. Overall fuel efficiency of a diesel engine may be over 40% higher in the case of medium-sized engines and 50% for larger ones (which are generally used in marine propulsions).

The factors discussed above have hence led to a renewal of interest by various automotive companies in the development of diesel engines. Sales data of diesel engine based automobiles in Europe have indicated that about a quarter of new automobiles were powered using these engines. In France, diesel engines accounted for almost half of total engine sales. Sales of diesel engine based cars in Japan have almost tripled.

This work sheds light on the development of combustion engines with a specific focus on NVH performance of engines. We hope the information provided in the text will be useful for undergraduate and graduate students on various automotive courses.

1

Introduction to Combustion Engines

1.1 Historical Background

Most of the very earliest internal combustion engines of the 17th and 18th centuries can be classified as atmospheric engines. These were large engines with a single piston and cylinder, the cylinder being open on the end. Combustion was initiated in the open cylinder using any of the various fuels which were available. Gunpowder was often used as the fuel. Immediately after combustion, the cylinder would be full of hot exhaust gas at atmospheric pressure. At this time, the cylinder end was closed and the trapped gas was allowed to cool. As the gas cooled, it created a vacuum within the cylinder. This caused a pressure differential across the piston, atmospheric pressure on one side and a vacuum on the other. As the piston moved because of this pressure differential, it would do work by being connected to an external system, such as raising a weight [1]. Some early steam engines also were atmospheric engines. Instead of combustion, the open cylinder was filled with hot steam. The end was then closed and the steam was allowed to cool and condense [2]. This created the necessary vacuum. In addition to a great amount of experimentation and development in Europe and the United States during the middle and latter half of the 1800s [3], two other technological occurrences during this time stimulated the emergence of the internal combustion engine.

In 1859, the discovery of crude oil in Pennsylvania finally made available the development of reliable fuels which could be used in these newly developed engines. Up to this time, the lack of good, consistent fuels was a major drawback in engine development [4]. Fuels like whale oil, coal gas, mineral oils, coal, and gun powder which were available before this time were less than ideal for engine use and development. It still took many years before products of the petroleum industry evolved from the first crude oil to gasoline, the automobile fuel of the 20th century [5]. However, improved hydrocarbon products began to appear as early as the 1860s and gasoline, lubricating oils, and the internal combustion engine evolved together [6]. The second technological invention that stimulated the development of the internal combustion engine was the pneumatic rubber tire, which was first marketed by John B. Dunlop in 1888 [7]. This invention made the automobile much more practical and desirable and thus generated a large market for propulsion systems, including the internal combustion engine [8]. During the early years of the automobile, the internal combustion engine competed with electricity and steam engines as the basic means of propulsion. Early in the 20th century, electricity and steam faded from the automobile picture—electricity because of the limited range it provided, and steam because of the long start-up time needed.

Thus, the 20th century is the period of the internal combustion engine and the automobile powered by the internal combustion engine as shown in Figures 1.1–1.3 [9]. At the end of the century, the internal combustion engine was again being challenged by electricity and other forms of propulsion systems for automobiles and other applications [10].

During the second half of the 19th century, many different styles of internal combustion engines were

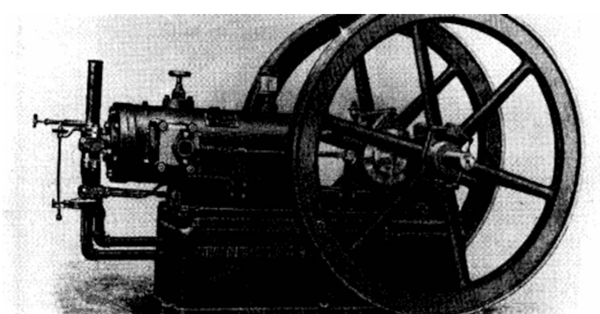

Figure 1.1 Charter engine.

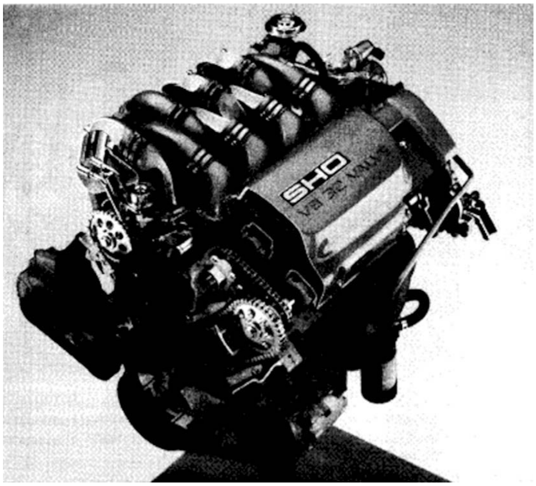

Figure 1.2 Ford engine.

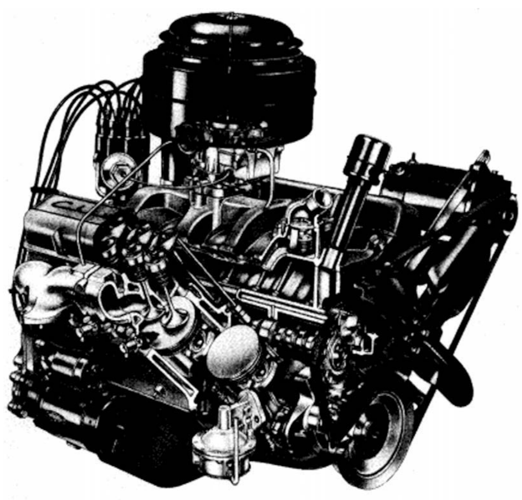

Figure 1.3 Chevrlot engine.

built and tested [11]. These engines operated with variable success and dependability using many different mechanical systems and engine cycles. The first fairly practical engine was invented by J. J. E. Lenoir [12]. During the next decade, several hundred of these engines were built with power up to about 4.5 kW (6 hp) and mechanical efficiency up to 5%.

In 1867, the Otto-Langen engine, with efficiency improved to about 11%, was first introduced, and several thousand of these were produced during the next decade. This was a type of atmospheric engine with the power stroke propelled by atmospheric pressure acting against a vacuum [13]. During this time, engines operating on the same basic four-stroke cycle as the modern automobile engine began to evolve as the best design. Although many people were working on four-stroke cycle design, Otto was given credit when his prototype engine was built in 1876 [14]. In the 1880s the internal combustion engine first appeared in automobiles [15].

Also in this decade the two-stroke cycle engine became practical and was manufactured in large numbers. By 1892, Rudolf Diesel had perfected his compression ignition engine into basically the same diesel engine known today. This was after years of development work which included the use of solid fuel in his early experimental engines [16].

Early compression ignition engines were noisy, large, slow, single-cylinder engines. They were, however, generally more efficient than spark ignition engines. It was not until the 1920s that multi-cylinder compression ignition engines were made small enough to be used with automobiles and trucks [17].

1.2 Classifications [18]

Internal combustion engines can be classified in a number of different ways:

1. Types of Ignition (a) Spark Ignition (SI). An SI engine starts the combustion process in each cycle by use of a spark plug. The spark plug gives a high-voltage electrical discharge between two electrodes which ignites the air-fuel mixture in the combustion chamber surrounding the plug. In early engine development, before the invention of the electric spark plug, many forms of torch holes were used to initiate combustion from an external flame. (b) Compression Ignition (CI). The combustion process in a CI engine starts when the air-fuel mixture self-ignites due to high temperature in the combustion chamber caused by high compression.
2. Engine Cycle (a) Four-Stroke Cycle. A four-stroke cycle experiences four piston movements over two engine revolutions for each cycle. (b) Two-Stroke Cycle. A two-stroke cycle has two piston movements over one revolution for each cycle.

Three-stroke cycles and six-stroke cycles were also tried in early engine development [19].

3. Valve Location [20] – As seen from Figure 1.4, Valves in head (overhead valve), also called I Head engine. (b) Valves in block (flat head), also called L Head engine. Some historic engines with valves in block had the intake valve on one side of the cylinder and the exhaust valve on the other side. These were called T Head engines.

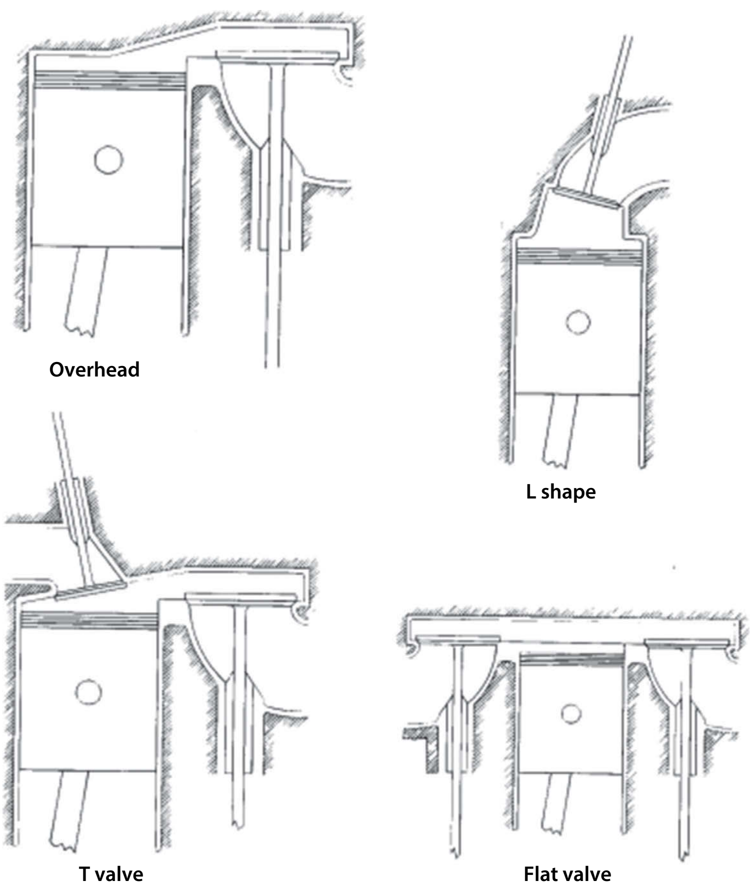

Figure 1.4 Engine classification by valve location.

(c) One valve in head (usually intake) and one in block, also called F Head engine; this is much less common.

4. Design of Engine [21] – (a) Reciprocating. Engine has one or more cylinders in which pistons reciprocate back and forth. The combustion chamber is located in the closed end of each cylinder. Power is delivered to a rotating output crankshaft by mechanical linkage with the pistons. (b) Rotary-Engine is made of a block (stator) built around a large nonconcentric rotor and crankshaft. The combustion chambers are built into the nonrotating block.
5. Position and Number of Cylinders of Reciprocating Engines [22] – As seen from Figure 1.5 various systems can be-

(a) Single Cylinder. Engine has one cylinder and piston connected to the crankshaft.

(b) In-Line-Cylinders are positioned in a straight line, one behind the other along the length of the crankshaft. They can consist of 2 to 11 cylinders or possibly more. In-line four-cylinder engines are very common for automobile and other applications. In-line six and eight cylinders are historically common automobile engines. In-line engines are sometimes called straight (e.g., straight six or straight eight).

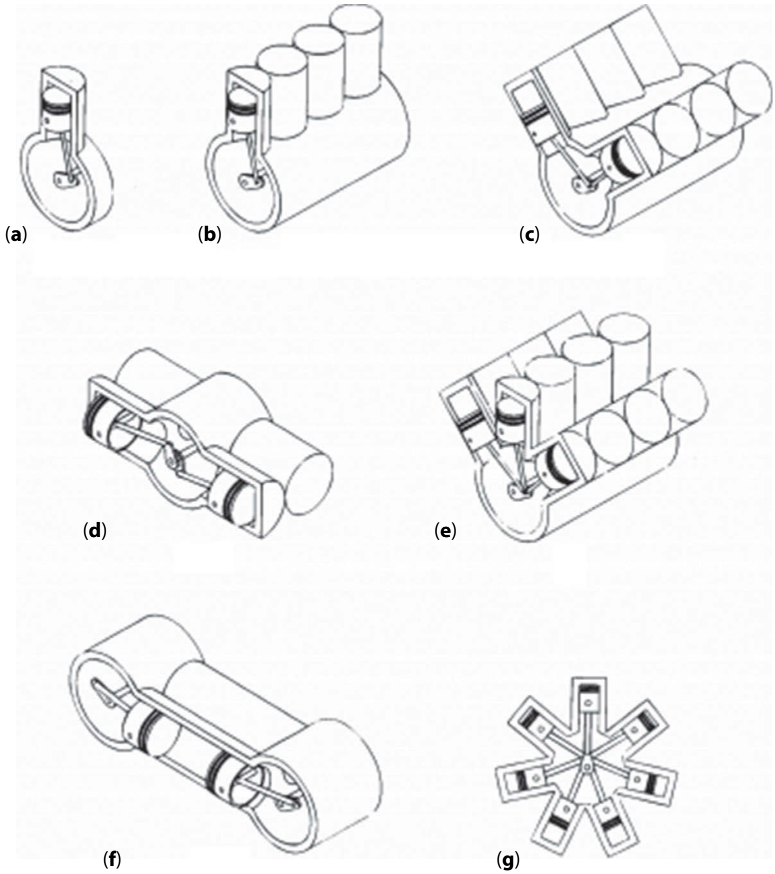

Figure 1.5 Various engine arrangements (a) Single, (b) In line, (c) V block, (d) Opposed cylinder, (e) W type, (f) opposed piston, (g) Radial.

(c) V Engine – Two banks of cylinders at an angle with each other along a single crankshaft. The angle between the banks of cylinders can be anywhere from 15° to 120°, with 60°–90° being common. V engines have even numbers of cylinders from 2 to 20 or more. V6s and V8s are common automobile engines, with V12s and V16s (historic) found in some luxury and high-performance vehicles.

(d) Opposed Cylinder Engine – Two banks of cylinders opposite each other on a single crankshaft (a V engine with a 180° V). These are common on small aircraft and some automobiles with an even number of cylinders from two to eight or more. These engines are often called flat engines (e.g., flat four).

(e) W Engine-Same as a V engine except with three banks of cylinders on the same crankshaft. These are not common, but some have been developed for racing automobiles, both modern and historic. Usually 12 cylinders with about a 60° angle between each bank.

(f) Opposed Piston Engine – Two pistons in each cylinder with the combustion chamber in the center between the pistons. A single-combustion process causes two power strokes at the same time, with each piston being pushed away from the center and delivering power to a separate crankshaft at each end of the cylinder. Engine output is either on two rotating crankshafts or on one crankshaft incorporating complex mechanical linkage.

(g) Radial Engine – Engine with pistons positioned in a circular plane around the central crankshaft. The connecting rods of the pistons are connected to a master rod which, in turn, is connected to the crankshaft. A bank of cylinders on a radial engine always has an odd number of cylinders ranging from 3 to 13 or more. Operating on a four-stroke cycle, every other cylinder fires and has a power stroke as the crankshaft rotates, giving a smooth operation. Many medium- and large-size propeller-driven aircraft use radial engines. For large aircraft, two or more banks of cylinders are mounted together, one behind the other on a single crankshaft, making one powerful, smooth engine. Very large ship engines exist with up to 54 cylinders, six banks of 9 cylinders each.

1.3 Engine Components [23]

The following is a list of major components found in most reciprocating internal combustion engines as shown in Figure 1.6:

1. Block – Body of engine containing the cylinders, made of cast iron or aluminum. In many older engines, the valves and valve ports were contained in the block. The block of water-cooled engines includes a water jacket cast around the cylinders. On air-cooled engines, the exterior surface of the block has cooling fins.

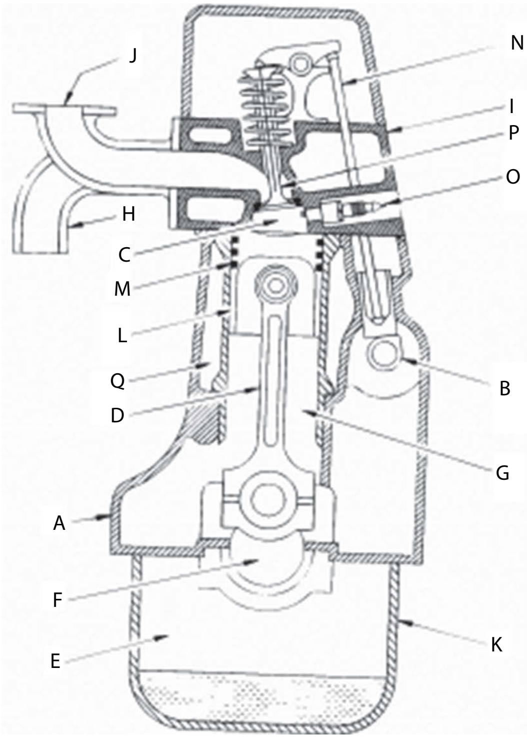

Figure 1.6 Parts of engine – Cross section of four-stroke cycle S1 engine showing engine components; (A) block, (B) camshaft, (C) combustion chamber, (D) connecting rod, (E) crankcase, (F) crankshaft, (G) cylinder, (H) exhaust manifold, (I) head, (J) intake manifold, (K) oil pan, (L) piston, (M) piston rings, (N) push rod, (O) spark plug, (P) valve, (Q) water jacket.

2. Camshaft [24] – Rotating shaft used to push open valves at the proper time in the engine cycle, either directly or through mechanical or hydraulic linkage (push rods, rocker arms, tappets). Most modern automobile engines have one or more camshafts mounted in the engine head

(overhead cam). Most older engines had camshafts in the crankcase. Camshafts are generally made of forged steel or cast iron and are driven off the crankshaft by means of a belt or chain (timing chain). To reduce weight, some cams are made from a hollow shaft with the cam lobes press-fit on. In four-stroke cycle engines, the camshaft rotates at half engine speed.

3. Carburetor [25] – Venturi flow device which meters the proper amount of fuel into the air flow by means of a pressure differential. For many decades it was the basic fuel metering system on all automobile (and other) engines. It is still used on low-cost small engines like lawn mowers but is uncommon on new automobiles. Catalytic converter Chamber mounted in exhaust flow containing catalytic material that promotes reduction of emissions by chemical reaction.
4. Combustion chamber [26] – The end of the cylinder between the head and the piston face where combustion occurs. The size of the combustion chamber continuously changes from a minimum volume when the piston is at TDC to a maximum when the piston is at BDC. The term "cylinder" is sometimes synonymous with "combustion chamber" (e.g., "the engine was firing on all cylinders"). Some engines

have open combustion chambers which consist of one chamber for each cylinder. Other engines have divided chambers which consist of dual chambers on each cylinder connected by an orifice passage. Connecting rod – Rod connecting the piston with the rotating crankshaft, usually made of steel or alloy forging in most engines but may be aluminum in some small engines.

5. Connecting rod bearing [27] – Bearing where connecting rod fastens to crankshaft. Cooling fins – Metal fins on the outside surfaces of cylinders and head of an air cooled engine. These extended surfaces cool the cylinders by conduction and convection.
6. Crankcase [28] – Part of the engine block surrounding the rotating crankshaft. In many engines, the oil pan makes up part of the crankcase housing. Crankshaft – Rotating shaft through which engine work output is supplied to external systems. The crankshaft is connected to the engine block with the main bearings. It is rotated by the reciprocating pistons through connecting rods connected to the crankshaft, offset from the axis of rotation. This offset is sometimes called crank throw or crank radius. Most crankshafts are made of forged steel, while some are made of cast iron.