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An Introduction to Engine Testing and Development

Richard D. Atkins
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Introduction

How does one describe the internal combustion engine? My grandfather, a renowned mechanical engineer, defined it for me as “the infernal confusion engine.” Now, many years later, with countless research and development projects behind me, I believe that he was possibly more accurate than he ever envisaged.

Simply put, the internal combustion engine is an energy conversion device that converts thermal energy (heat) into mechanical energy. When hydrocarbon fuel is burned in air, some of the chemical energy contained in the fuel is converted into work. The nitrogen trapped in the cylinder is heated by the energy released when the carbon and hydrogen in the fuel react with oxygen in the air. That’s all there is to it.

It is generally accepted that a Dutch physicist, Christian Huygens, first formulated the principle of the internal combustion engine in 1680; however, he proposed to use gunpowder as the motive power source. In 1860, Etienne Lenoir, a self-taught mechanic, revealed to the world the first internal combustion engine that worked. For some time, engineers had understood both the low efficiency of the steam engine and the desirability of a device that would burn its fuel inside the cylinder instead of using it to produce steam as an intermediary. Many engines were designed, but Lenoir’s engine was the first recorded engine to pass the experimental stage. It was fueled by coal gas (used at that time primarily for street and home lighting). This coal gas was mixed with air and was drawn into a cylinder by withdrawal of a piston. At the midpoint, electric sparks ignited the mixture, so that only the second half of each stroke was powered. However, Lenoir’s engine was double acting, so fuel entered either side of the piston in turn. The operating principle closely followed that of the steam engine. The engine ran, but it was very inefficient, the gas was expensive, and vast quantities of gas were used (almost 3 cubic meters) to produce 0.75 kW at 100 rev/min. In addition, it had a significant noise and vibration problem, producing violent shocks at each explosion, which Lenoir attempted to damp out by the use of springs and other devices to absorb the power stroke shocks. In 1862, a railway engineer named Alphonse Eugène Beau de Rochas published a pamphlet about improvement in locomotive design, in which he suggested compounding the steam engine with gas engines. This was a significant advance, and to date, its principles have not been challenged. He stated that the gas in the engine should ignite continuously under high compression, which was instigated by making it work in four stages:

1. Stage one—Intake during one whole stroke of the piston
2. Stage two—Compression during the following stroke
3. Stage three—Firing at the dead point, and expansion during the third stroke
4. Stage four—Expulsion of the burned gases from the cylinder

Thus, Beau de Rochas presented the principle of the four-stroke engine as we understand it today. However, he never undertook to construct an engine on these lines nor to present a paper to his peers. As frequently happens in life, quite independently of Beau de Rochas, Nikolaus August Otto, a German traveling salesman who was fascinated by all things technical and was blessed with an inquiring mind, took up the invention. The
problem of enabling the engine to run efficiently by controlling the richness of the gas/air mixture presented a great challenge. Otto produced an engine in which the expulsion drove the piston upward into a vertical cylinder, where the contraction of the spent fuel as it cooled produced a vacuum, into which atmospheric pressure and gravity forced the piston back. This followed the system used by the steam-driven beam engines of the eighteenth century. The engine worked, and while it was better than the Lenoir design, it still was a vibrating, noisy, and inefficient device.

Tradition has it that one day in 1875, Otto was watching a smoking chimney, and his imagination was caught by the smoke that first emerged in dense plumes and then gradually dissipated into the air. His supposition was that it should be possible to introduce a rich fuel/air mixture to the point of ignition, where it would be cushioned from the piston by a much thinner layer of inert air next to it. This principle of stratification was almost certainly, in this instance, incorrect. However, to produce it, Otto reinvented the four-stroke cycle as Beau de Rochas had envisaged it (but henceforth was called the “Otto cycle”) and embodied it in his “silent Otto engine” of 1876, which was a tremendous success, 2 kW at 180 rev/min. The engine utilized a very dangerous open flame ignition system to fire the coal gas fuel that Otto was using. (Lenoir used an advanced spark ignition system.) In parallel with Otto’s work, an Austrian inventor named Siegfried Marcus in 1867 had invented a carburetor to convert liquid petroleum into flammable gas.

In 1861, Otto patented a two-stroke engine that ran on gas. Otto and his partner, a German industrialist named Eugen Langen, built a factory and worked on improving the engine. Their two-stroke engine won a gold medal at the 1867 World’s Fair in Paris. The company was named N.A. Otto & Co., which was the first company to manufacture internal combustion engines. The company exists today as Klockner-Humboldt-Deutz AG, the oldest company manufacturing internal combustion engines and the world’s largest manufacturer of air-cooled diesel engines.

In May 1876, Otto built the first four-stroke piston cycle internal combustion engine. This was the earliest practical alternative to the steam engine. In the next ten years, more than 30,000 of the engine were sold. This engine was the prototype of all combustion engines that have since been built. The operating principle of the engine was named the “Otto cycle” in honor of Nikolaus Otto. The design of the engine consists of four strokes of a piston, which draw in and compress a gas/air mixture within a cylinder. This process results in an internal explosion. Otto’s gas/motor engine had the patent number 365,701. In 1862, Alphonse Beau de Rochas, a French engineer, had patented the four-stroke cycle. However, Otto was the first to build a four-stroke cycle engine. Nevertheless, in 1886, Otto’s patent was revoked when Beau de Rochas’ patent was revealed. Nikolaus August Otto died on January 26, 1891.

Meanwhile, Gottlieb Daimler constructed a very light engine using Otto’s model and attached one of them to a bicycle. This became the world’s first motorcycle. Karl Benz built his first three-wheeled automobile employing Otto’s engine. Daimler also constructed an automobile using Otto’s engine. The firms of Daimler and Benz merged and manufactured the famous Mercedes-Benz vehicles. George Brayton, an American engineer, developed a two-stroke kerosene engine in 1873, but it was too large and too slow to be commercially successful.

In 1885, Gottlieb Daimler constructed what generally is recognized as the first modern high-speed internal combustion engine. Small and fast with a vertical cylinder, the engine used gasoline inducted via a carburetor. In 1889, Daimler introduced a four-stroke
engine with mushroom-shaped valves and two cylinders arranged in a “V” configuration, having a much higher power-to-weight ratio. With the exception of electric starting, which would not be introduced until 1924, all modern gasoline engines are descended from Daimler’s engines.

The internal combustion engine as we understand it has been with us now for some 120 years. With the advent of computer-aided design systems, flow visualization, and highly advanced mathematical models, one would think it would be possible to design and manufacture the ideal engine the first time, every time. If only this were the case.

There is no doubt that fantastic advances are being made at an accelerating rate, but the internal combustion engine is an extremely complex device, requiring a sound understanding of many disciplines. With ever diminishing world oil stocks and increasingly stringent government legislation worldwide, the challenges facing the automotive engineer have never been greater.

Downsizing, the intelligent use of new technologies, and incorporation of these into cost-effective vehicles will present the automotive engineer with stimulating and challenging work for decades to come. My purpose in writing this book is to present some of the basic principles required in the testing and development of the internal combustion engine powertrain system, thus giving the new automotive engineer the basic tools required to meet these challenges.

Richard D. Atkins
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