Otto´s Four-Stroke Cycle

Chap.9 (p.163-184) & Appendix (p.339-341), Internal Fire by Lyle Cummins

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Otto´s Four-Stroke Cycle (p.163-164)

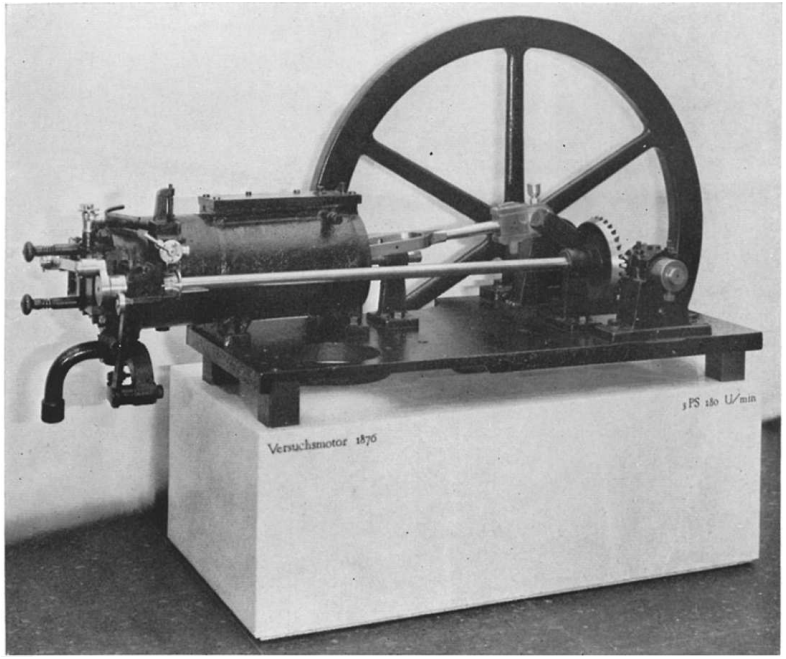
- Large numbers of units produced
  - 1876-1889: 8300, Gasmotoren-Fabrik Deutz (GER)
  - –>1888: 25000+, US; –>1882: 5000+, GBR
- 0.5-16 brake hp.
- Reuleaux convinced Otto of IC instead of hot-air engine.
- New engine must compress and then burn charge in same cylinder.
  - Accomplished by stretching the total cycle to four strokes!
  - First Lenoir test engine fired at high r_c–>violent power
  - Mixture stratification as solution.
- Transparent cylinder hand-cranked engine to study suction stroke of smoke from cigarettes (1872).
- First patent claimed more the stratification than the 4S cycle.

The optical Otto research engine

From an HCCI-presentation held by Bengt Johansson in Lund 2011.

The prototype engine - the Silent Otto (p.165-167)

- Otto and Franz Rings assigned by Langen, Daimler thought it was a waste of time.
- 6 months from idea to hardware
- The engine, functional and simple
  - $B = 0.161\text{m}$, $S = 0.3\text{m}$ –> $V_d = 6\text{L}$
  - $p_{compr.max} = 2.36\text{Bar}$ –> $r_c \approx 2$ ($p_1 = 1\text{Bar}$, $\gamma = 1.3$)
  - $N_e = 180$, $P_{max} = 3\text{bhp}$
- Improved gas ignition system consumed $\approx 2\%$ of fuel for a 4hp engine. (Fig. 9.5, p.167)
- Auxiliary camshaft turning at $0.5N_e$



The Otto prototype engine from Lynwood Bryant. Picture of Otto´s first 4S compression engine of 1876 taken by "Werkfoto Deutz" in the Klöckner-Humboldt-Deutz museum in Cologne. (also Fig. 9.2 plate)

Patent drawings

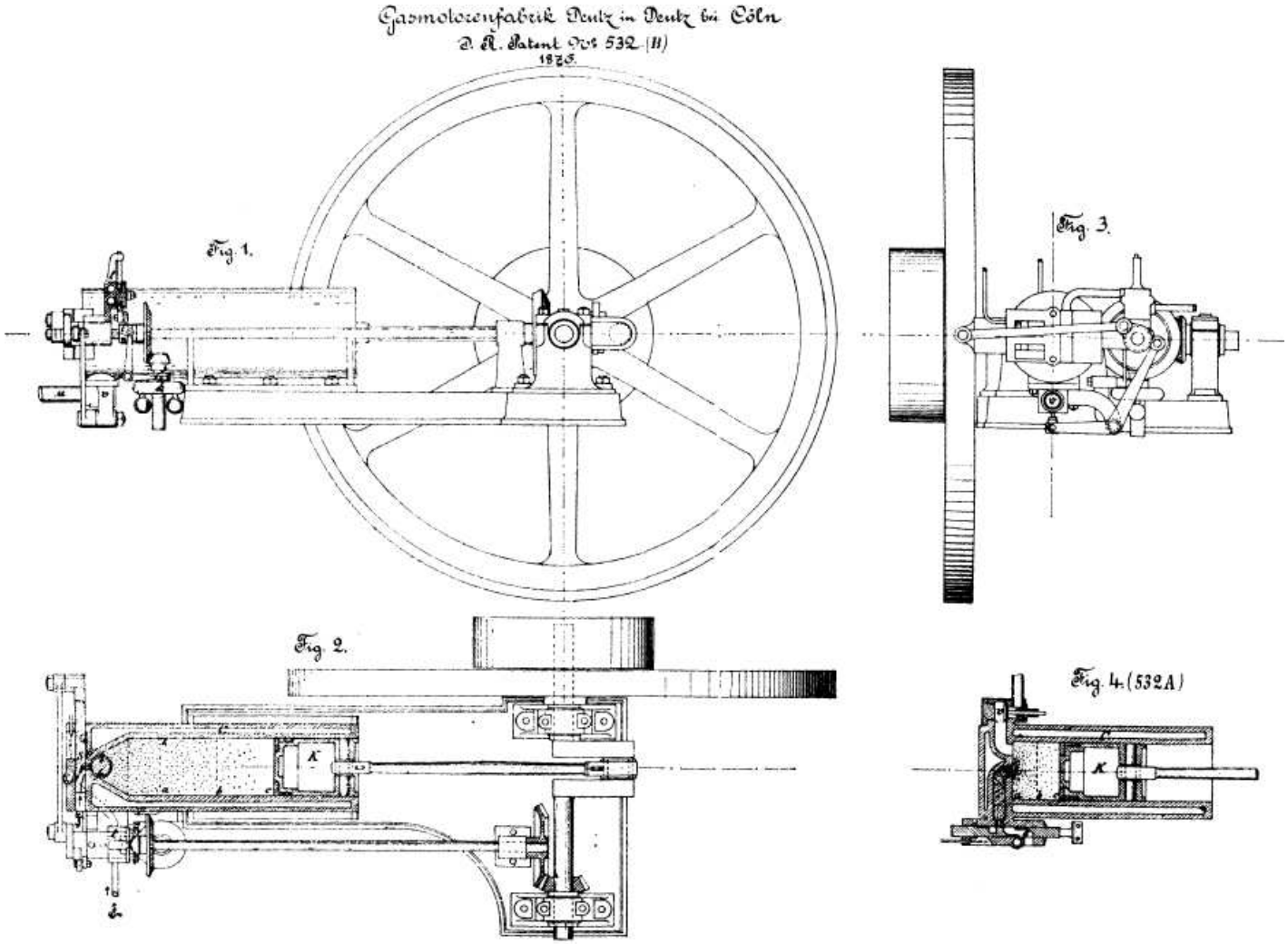


FIG. 4.—Drawings accompanying the original German patent on the Silent Otto in 1876. The stippling in the combustion chamber represents the stratified charge.

From Lynwood Bryant. Patent drawings. (also "Fig. 9.1 plate":ish)

The "Explosion canal" - igniter channel (p.168-169)

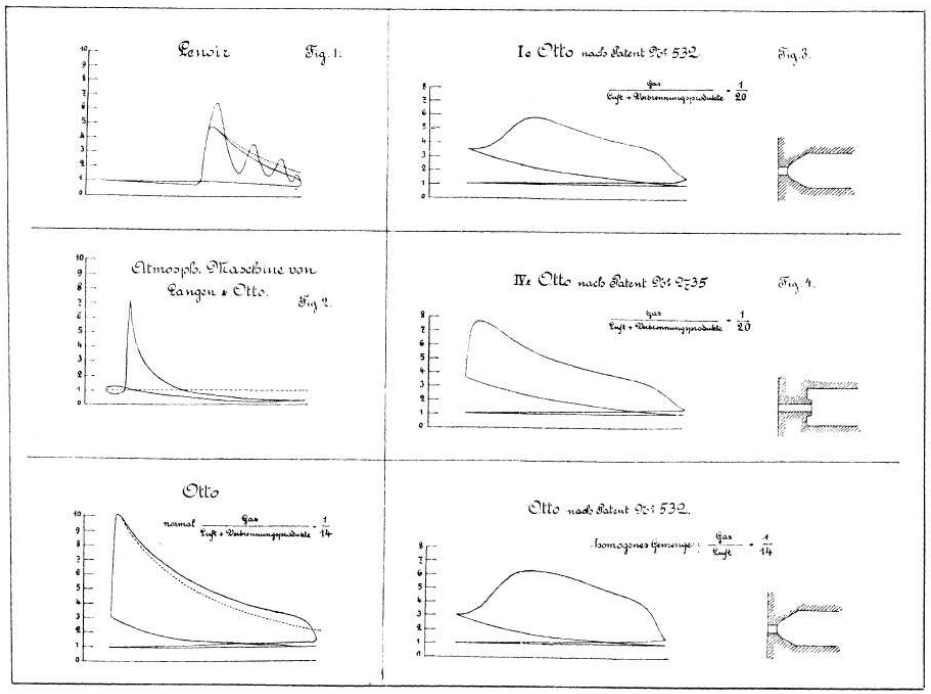


FIG. 6.—Indicator diagrams of various engines that Otto tested. The sketches attached to the diagrams in the right-hand column show the change in shape of the combustion chamber that was supposed to improve combustion of lean mixtures. (Pl. II of Eugen Langen, cited in n. 10.)

pV diagrams from Lynwood Bryant.
(also Fig. 9-7 p.169)

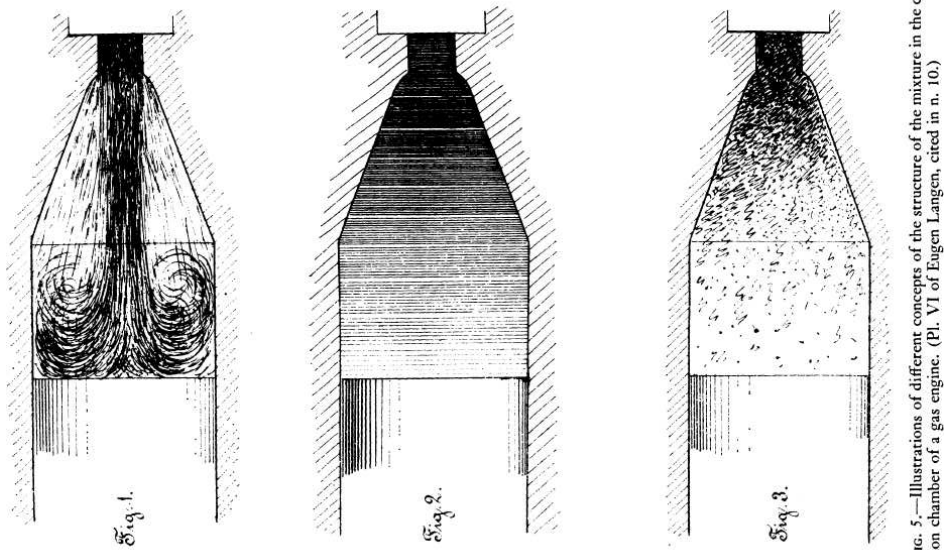


FIG. 5.—Illustrations of different concepts of the structure of the mixture in the combustion chamber of a gas engine. (Pl. VI of Eugen Langen, cited in n. 10.)

Mixture structures from Lynwood Bryant.

The "Explosion canal" - igniter channel (p.168-169)

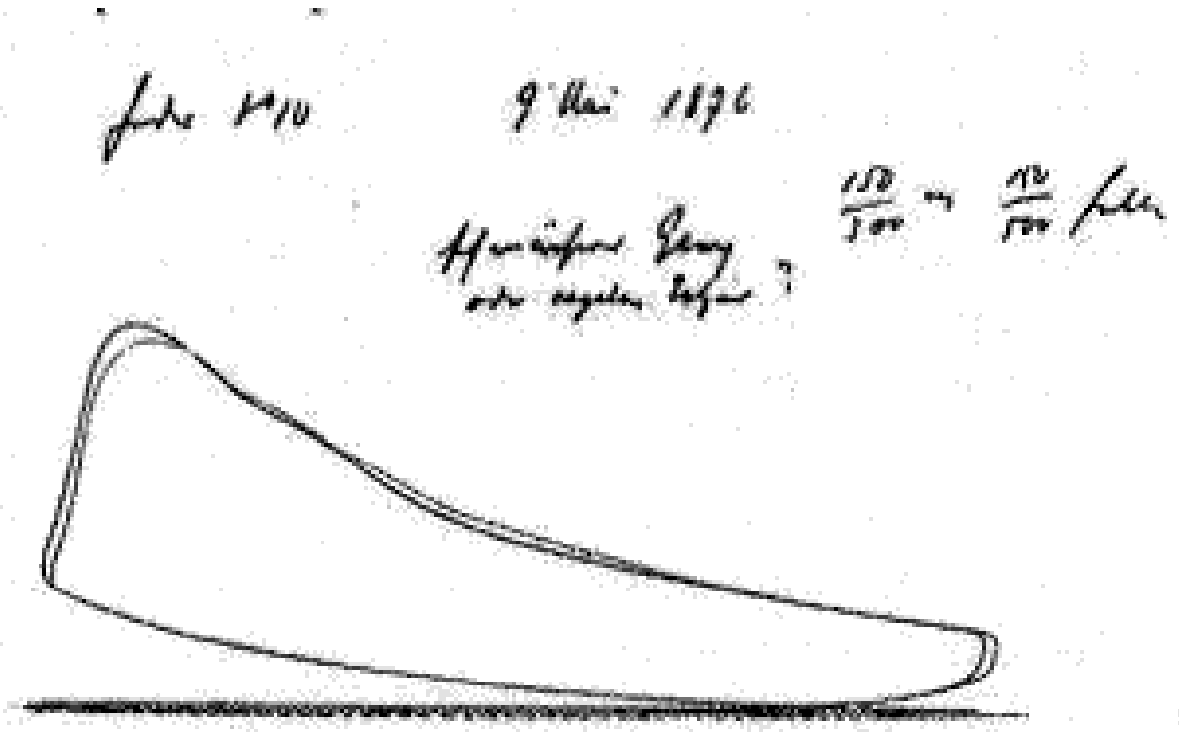


Fig. 9-9 Earliest recorded pressure-volume diagram of a four-stroke engine, made May 9, 1876. (Werkphoto Deutz)

pV diagram of Otto prototype engine from Cummins´ Internal Fire (Fig. 9.9 p.172)

The production engine (p.170-173)

- Wilhelm Maybach modified for production
  - Compression release cam for easier start. Later engines even started with compressed air.
  - Drip lubrication of slide-valve and piston.
- Independently tested
  - $V_d = [7.8 - 13]$L
  - $N_e = [157 - 158]$rpm
  - $r_c = [2.65 - 2.63]$-
  - $P_{brake} = [4.4 - 8.]$hp
  - $\eta_{mech} = [87 - 84]\%$
  - $\eta_{thermal} = [16 - 17]\%$
- $p_{max} = [7.6 - 8.3]$Bar
- $\lambda = [9 - 10] : 1$

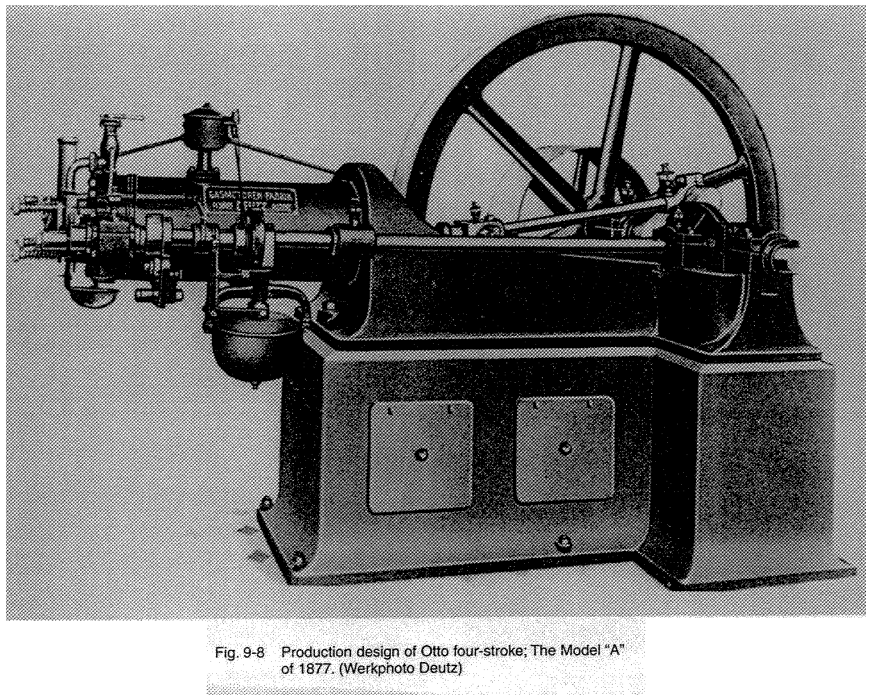


Fig. 9-8 Production design of Otto four-stroke; The Model "A" of 1877. (Werkphoto Deutz)

Fig. 9.8 plate, Cummins´ Internal Fire

2hp Otto&Langen(1884) vs. Otto(1882) (p.172)

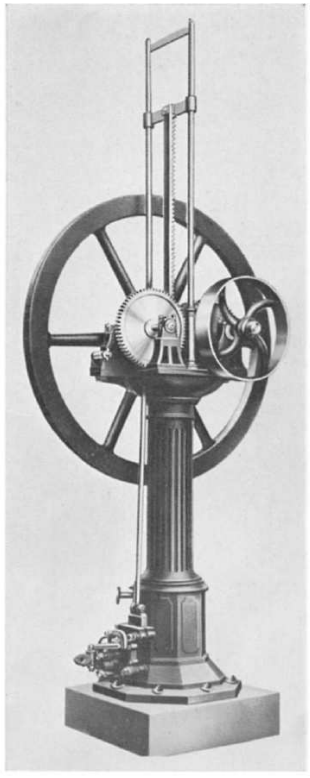


FIG. 3.—An Otto and Langen atmospheric gas engine of 1867. (Werkfoto Deutz.)

Otto&Langen engine from Lynwood Bryant.

- 1814kg
- 80.3L
- 28 power-strokes/min
- 11.2% η_{brake}

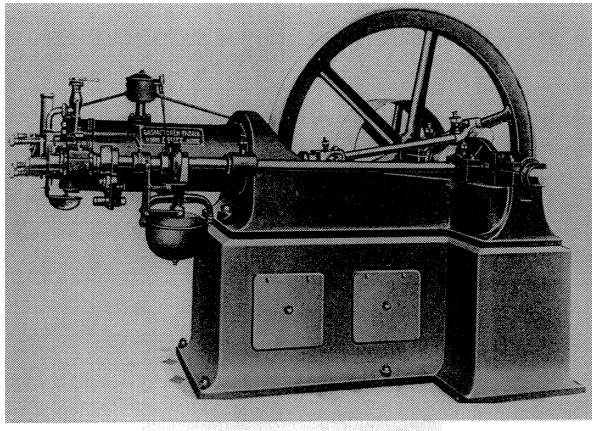


Fig. 9-8 Production design of Otto four-stroke; The Model "A" of 1877. (Werkphoto Deutz)

Fig. 9.8, Cummins´ Internal Fire

- 567kg
- 5.1L
- 80 power-strokes/min
- 14% η_{brake}

Patents in court (p.173-175)

- Patent disputes
  - Charles Linford (Eng 1882)
  - Dugald Clerk (Eng)
  - Prof. Aimé Witz (Fra)
  - Profs. Slaby and Schöttler (Ger)
- Reithmann
  - Munich clock maker
  - Built and ran own 4S engine before 1876?
  - Strangely modified to briefly run 4S cycle in patent trials
  - Deutz in the end bought Reithmann patent AND won patent trial

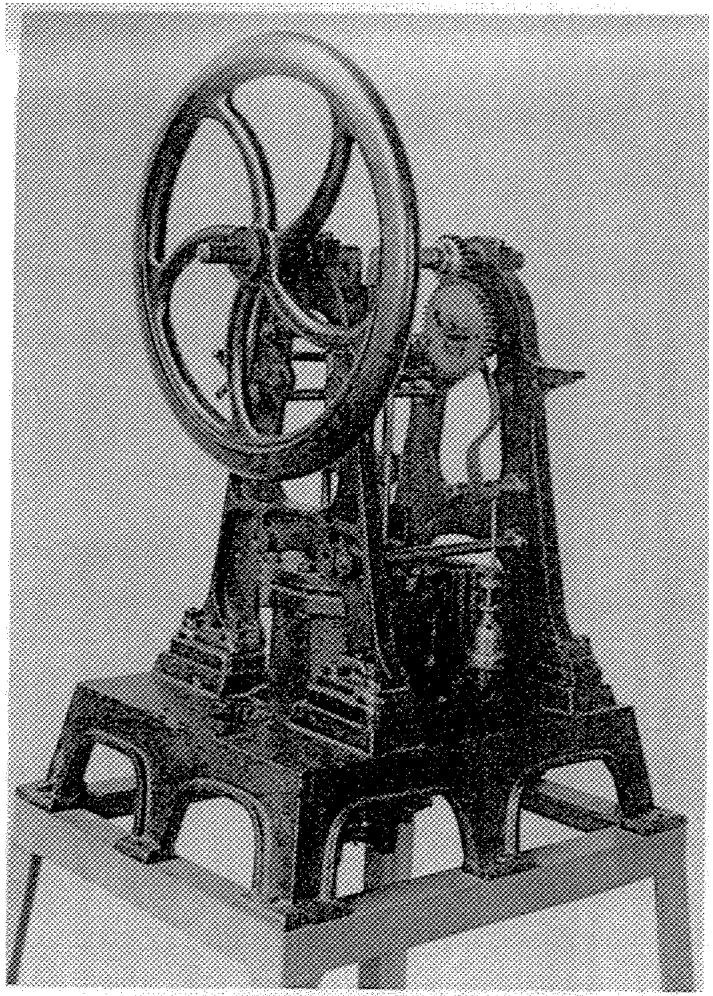


Fig. 9-10 Reithmann engine which figured in the Otto patent trials. The engine is in the Deutz Museum collection. (Werkphoto Deutz)

Fig. 9.10: Reithmann engine

Patents in court: de Rochas (p.175-176)

Alphonse Beau de Rochas (1815-1893), French engineer at transportation department, Paris

- Proposed cycle
  - Induction during outward stroke
  - Compression during return stroke
  - Ignition at TDC, followed by expansion stroke
  - Discharge of burned gases during fourth and last stroke

Fig. 9-11 Alphonse Beau de Rochas (1815-1893). (Musé du Conservatoire National des Arts-et-Métiers, Paris)

Fig. 9.11: de Rochas

Patents in court: de Rochas (appendix p.339-341)

Alphonse Beau de Rochas (1815-1893), French engineer at transportation department, Paris

- Maximize V_{cyl} given a boundary surface area
- Greatest possible working speed (for power? friction losses?
- Greatest number of expansions
- Greatest possible pressure at the beginning of expansion
- "Other things being equal, the cooling will be greater the slower the speed." Speed dependent heat transfer?
- "...and even supposing gases were combustible, it would be impossible to heat them instantaneously." Finite burn durations?
- "...as the elevation of temperature due to previous compression causes spontaneous combustion." Knock? Auto-ignition?
- "...the result will be a particular type of single-acting, or half-acting engine, so to speak..."

Fig. 9-11 Alphonse Beau de Rochas (1815-1893). (Musé du Conservatoire National des Arts-et-Métiers, Paris)

Fig. 9.11: de Rochas

The fall of the patents (p.177-178)

"He simply had the same idea at a later date as far as the court was concerned"

- First only 4S patent challenged...
- ...but later also stratification ideas.
- January 30, 1886 Deutz´s competition won complete victory
- *Interesting note:* The abandoned Otto 2S ideas, was pirated and patented under fraud in other German state. Patent then "given" to Otto when state patents were unified, even though Otto did not believe in it!

Continued engine development (p.178-182)

"Both Deutz and their licensees profited by a free exchange of information on each other´s new developments."

- Single cylinder model capable of 100hp in mid 1880s (Crossley)
- Twin engine design used to decrease engine speed variations for electric generator powering introduced
- Low tension magneto as electric ignition system introduced by Otto 1884
- Carburetors, fuel vaporized in surface carburetor by bubbling up air through a fuel reservoir.
- "AB" engine of 1885 had both systems
- 1888 Crossley adopted poppet intake valve and hot-tube ignition

(Animation of Otto engine: `http://en.wikipedia.org/wiki/Nikolaus_Otto`)

So, who was “first”?

Alphonse Beau de Rochas (1815-1893)

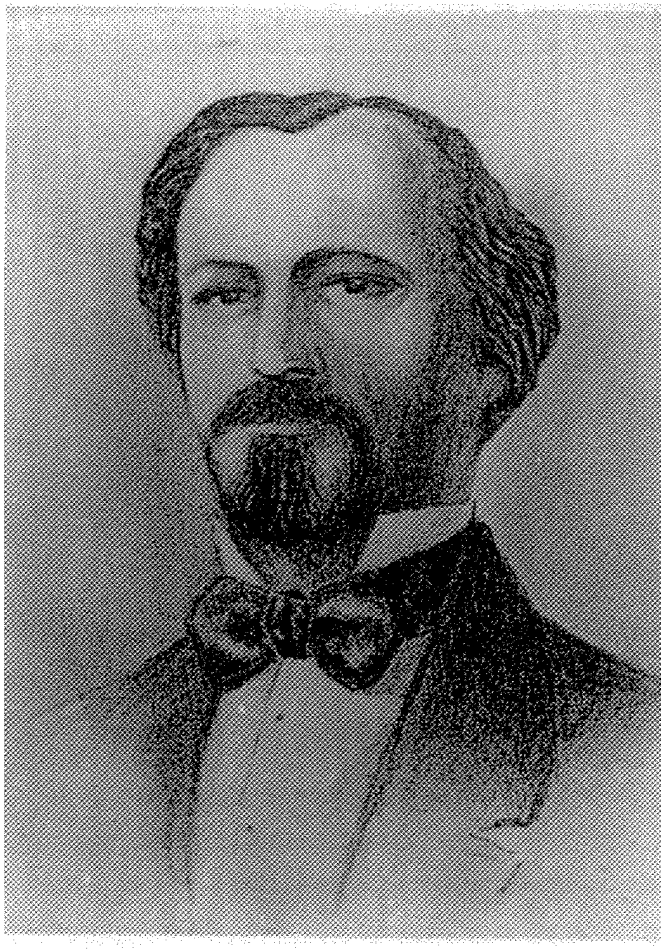


Fig. 9-11 Alphonse Beau de Rochas (1815-1893). (Musé du Conservatoire National des Arts-et-Métiers, Paris)

Nicolaus August Otto (1832-1891)