Internal Combustion Engines – MAK 4070E

Principles of Engine Operation

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Information

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Course Plan

- Principles of SI and CI engine operation, 2-stroke engines, 4-stroke engines
- Ideal standard cycles, thermal efficiencies, comparison, deviations
- Classification of engine fuels
- Characteristics of engine fuels, knock resistance, ignition tendancy, ccombustion chemistry (air excess ratio, calorific value, adiabatic flame temperature, dissociation)
- Real engine strokes, induction stroke, volumetric efficiency
- Compression stroke, combustion in SI engines and influencing parameters
- Abnormal combustion, parameters influencing knock and early ignition
- Combustion in CI engines, parameters influencing ignition delay
- Expension and exhaust strokes, exhaust emissions
- Mixture preparation in SI engines
- Carburator fundamentals, fuel injection, control of A/F ratio
- Mixture preparation in CI engines, injection pumps, injectors
- Fuel injection systems in Diesel engines, Atomization, combustion chamber types in Diesel engines
- Engine characteristics and performance.

Assessment Criteria

	Percentage
Quiz	5 x 10 = 50 %
Final examination	50 %

References

Textbook

- Heywood, J.B., Internal Combustion Engine Fundamentals, McGraw Hill Book Company, New York, 1988.
- Soruşbay, C., IC Engine, Lecture Notes, İ.T.Ü., 2001 (soft copy).

Other References

- Soruşbay, C. et al., İçten Yanmalı Motorlar, Birsen Yayınevi, İstanbul, 1995.
- Pulkrabek, W.W., Engineering Fundamentals of the Internal Combustion Engine, Prentice Hall, New Jersey, 1997.
- Stone, R., Introduction to Internal Combustion Engines, Macmillan, London, 1994.
- Other references given in the list (see web page of the course)

Internal Combustion Engines – MAK 493E

Principles of IC Engine Operation

- Introduction
- Operation principles
- Classification of engines
- Four-stroke and two-stroke engines
- SI engines, CI engines

Introduction

Internal Combustion Engines (IC-engines) produce mechanical power from the chemical energy contained in the fuel, as a result of the combustion process occuring inside the engine

IC engine converts chemical energy of the fuel into mechanical energy, usually made available on a rotating output shaft.

Chemical energy of the fuel is first converted to thermal energy by means of combustion or oxidation with air inside the engine, raising the T and p of the gases within the combustion chamber.

The high-pressure gas then expands and by mechanical mechanisms rotates the crankshaft, which is the output of the engine.

Crankshaft is connected to a transmission/power-train to transmit the rotating mechanical energy to drive a vehicle.

Spark ignition (SI) engines – Otto or gasoline engines

Compression ignition (CI) engines – Diesel engines

Introduction

Most of the internal combustion engines are reciprocating engines with a piston that reciprocate back and forth in the cylinder.

Combustion process takes place in the cylinder.

There are also rotary engines

In external combustion engines, the combustion process takes place outside the mechanical engine system

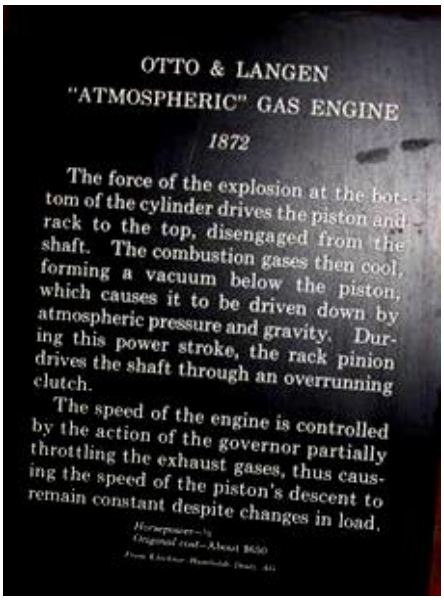
Early History

Atmospheric engines

Earliest IC engines of the 17th and 18th centuries are classified as atmospheric engines.

These are large engines with a single cylinder which is open on one end. Combustion is initiated at the open cylinder and immediately after combustion, cylinder would be full of hot gases at atmospheric pressure. The cylinder end is closed at this time and trapped gases are allowed to cool. As the gases are cooled, vacuum is created within the cylinder causing pressure differential across the piston (atmospheric pressure on one side and vacuum on the other side). So piston moves due to this pressure difference doing work.

Early History

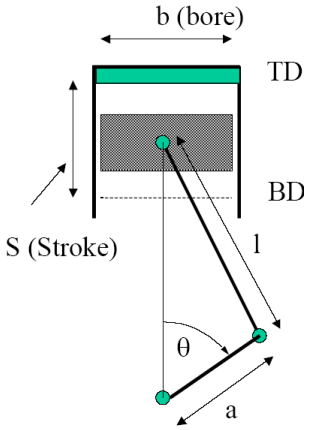


Early History

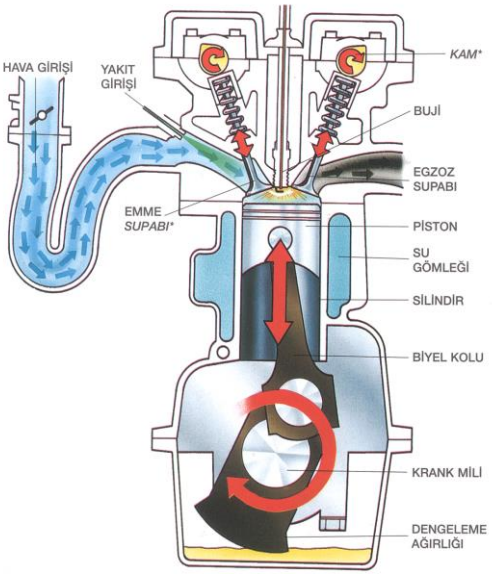
Huygens (1673)	developed piston mechanism
Hautefeuille (1676)	first concept of internal combustion engine
Papin (1695)	first to use steam in piston mechaanism
“Modern” engines	using same principles of operation as present engines – previously no compression cycle
Lenoir (1860)	driving the piston by the expansion of burning products - first practical engine, 0.5 HP later 4.5 kW engines with mech efficiency up to 5%
Rochas (1862)	four-stroke concept was proposed
Otto – Langen (1867)	produced various engine improved efficiency to 11%
Otto (1876)	Four-stroke engine prototype built, 8 HP and patented
Clark (1878)	Two-stroke engine was developed
Diesel (1892)	Single cylinder, compression ignition engine
Daimler/Maybach (1882)	Incorporated IC engine in automobile

Introduction

V_C	clearence volume
V_D	displacement volume
V_T	total volume
D	bore
L	stroke
TDC	top dead center
BDC	bottom dead center

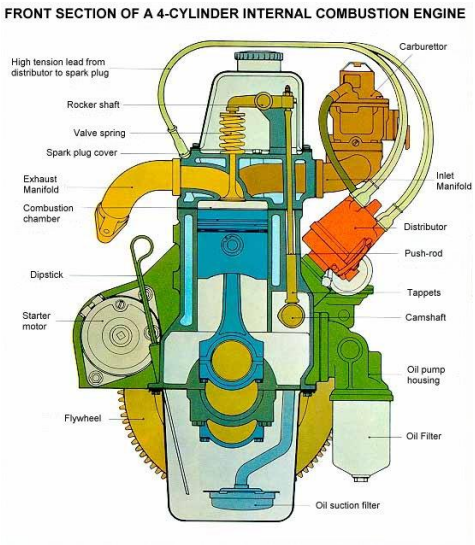


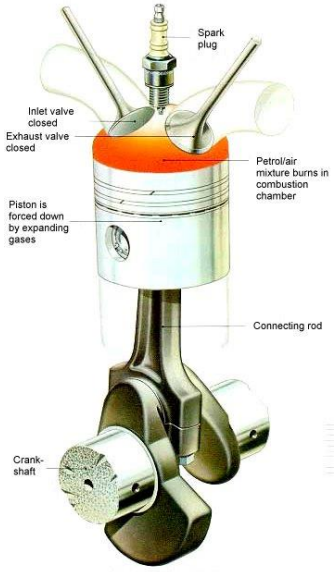
Introduction



A single cylinder
4-stroke engine

Introduction



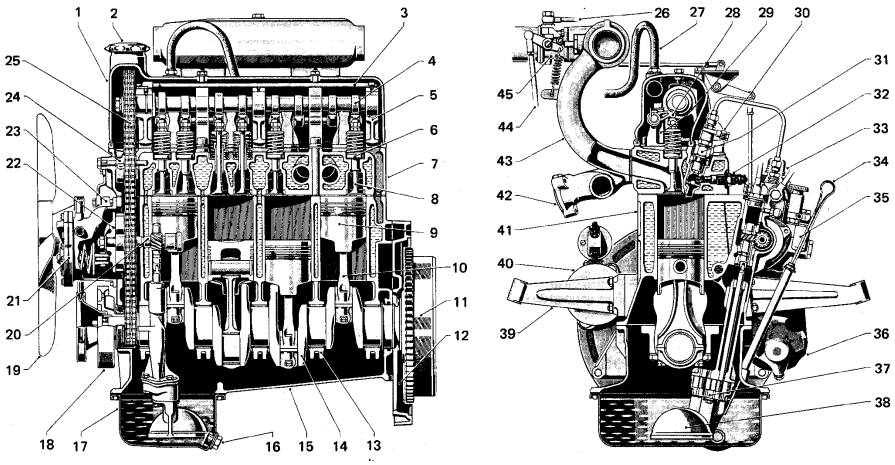


Introduction

a single cylinder, 4-stroke engine

Introduction

a Diesel engine



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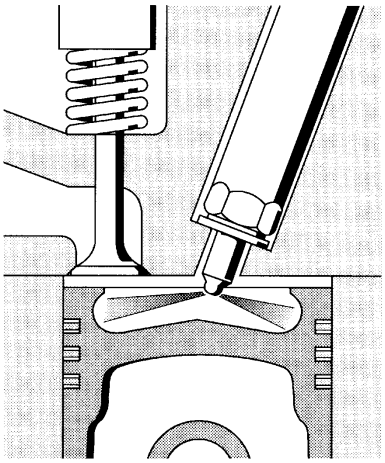

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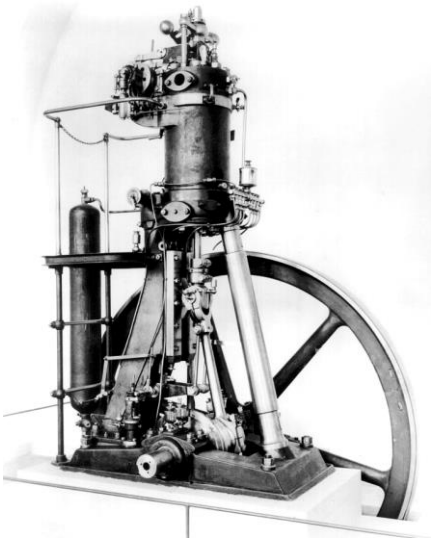


Classification of Engines

By application

motorcycles, scooters, 0.75 – 70 kW, SI, 2- and 4-stroke
passenger cars, 15 – 200 kW, SI and CI, 4-stroke
light commercial vehicles, 35 – 150 kW, SI and CI, 4-stroke
heavy commercial vehicles, 120 – 400 kW, Diesel, 4 zamanlı

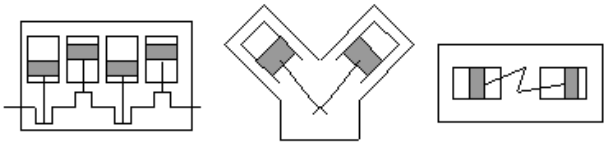
locomotives, 400 – 3 000 kW, CI, 4-stroke
ships, 3 500 – 22 000 kW, CI, 2- and 4-stroke
airplanes, 45 – 3 000 kW, SI, 4-stroke

stationary engines, 10 – 20 000 kW, CI, 2- and 4-stroke

Classification of Engines

Basic engine design

Reciprocating engines, subdivided by arrangement of cylinders



Rotary engines

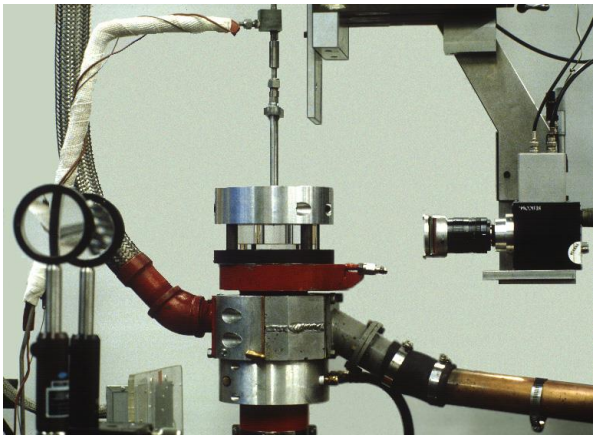
Classification of Engines

Single-cylinder engine

Otto gasoline engine

Classification of Engines

Single-cylinder “test engine”

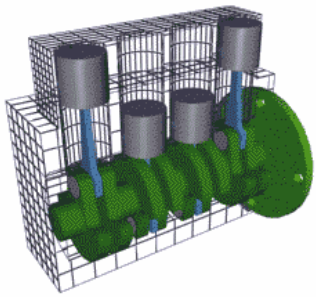


Classification of Engines

In-line engine

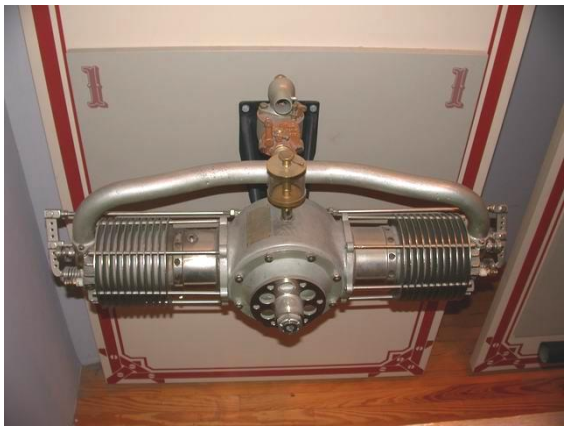
Classification of Engines

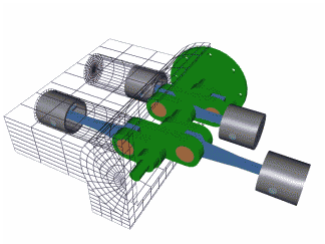
In-line engine



Classification of Engines

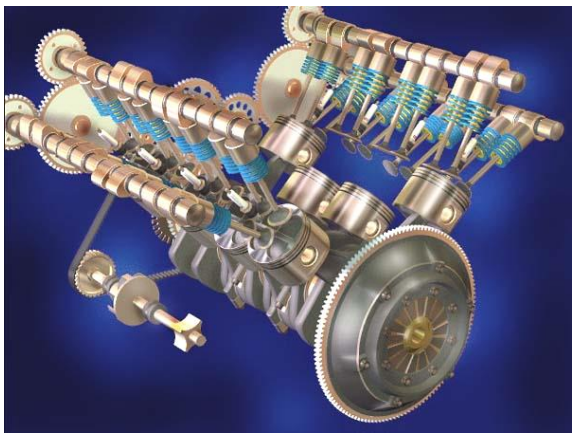
Opposed piston engine

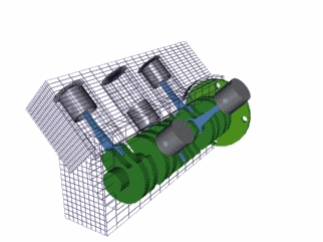




Classification of Engines

V - engine





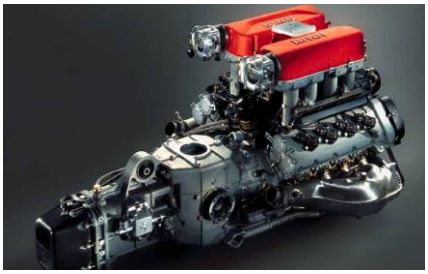
Classification of Engines

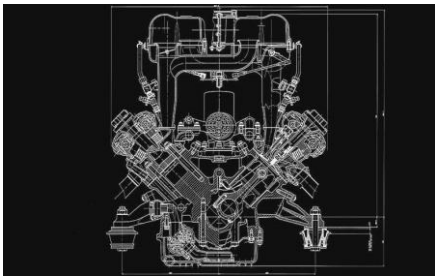
V – engine

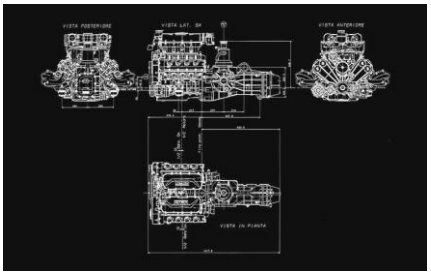
Ferrari V8 90º engine

360 Modena 3586 cc

Bore/Stroke 85/79 mm
294 kW (400 hp) @ 8500 rpm
373 Nm @ 4750 rpm







Classification of Engines

Ferrari V8 90º engine

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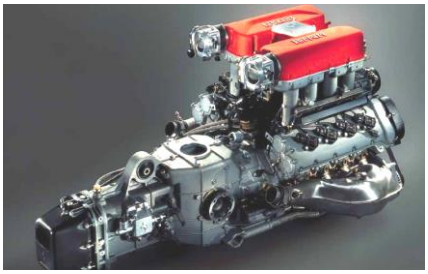
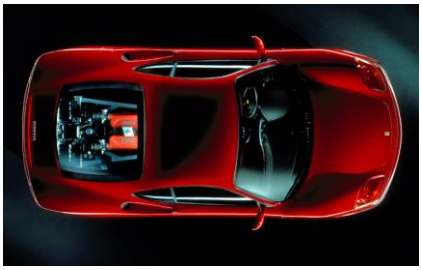
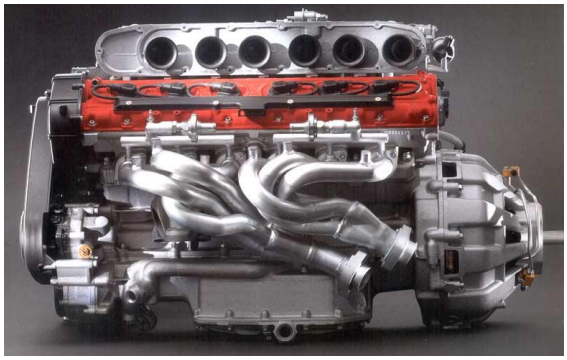




Classification of Engines

V – engine

Ferrari V12 65º engine 375 kW (485 hp) @ 7000 rpm
550 Barchetta Pininfarina 568.5 Nm @ 5000 rpm
Bore/Stroke 86/75 mm 5474 cc

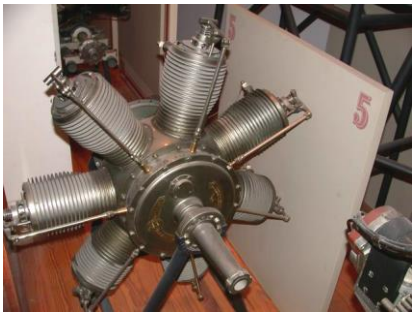


Classification of Engines

Radial engine

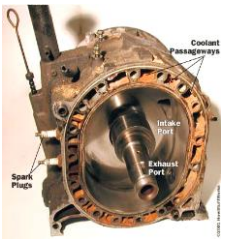
Classification of Engines

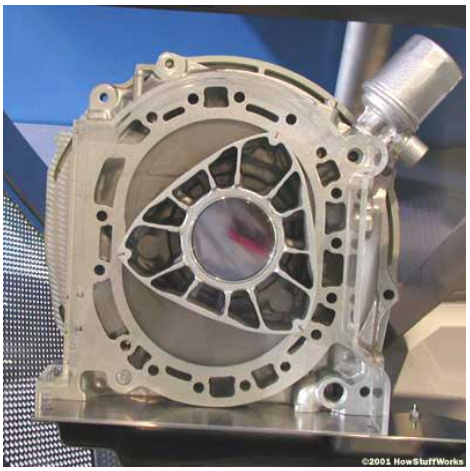
Radial engine



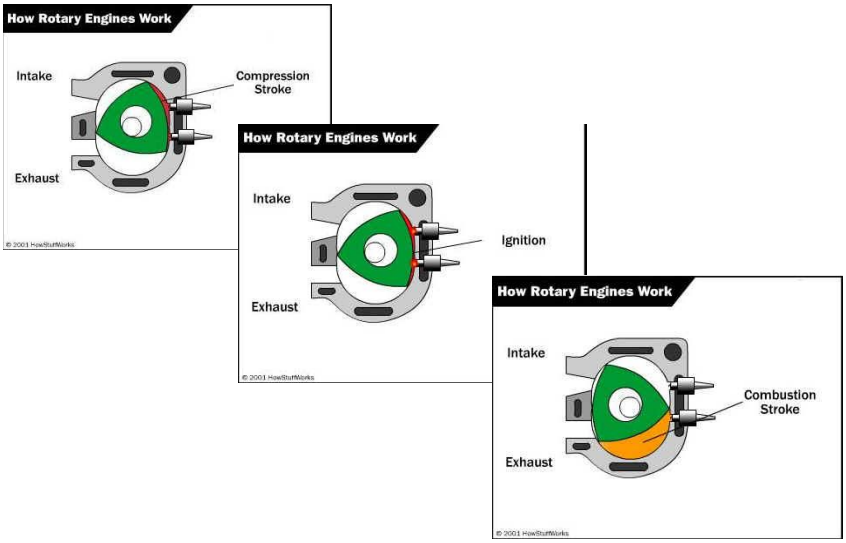
Rotary Engines

Wankel engine (Felix Wankel, prototype in 1929, patented double rotor in 1934)





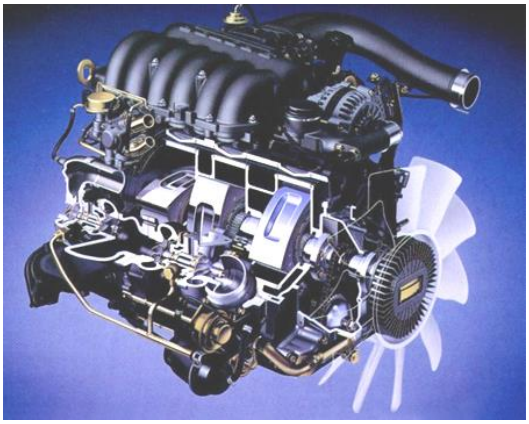
Rotary Engines



Rotary Engines

Mazda Rx-8
250 hp engine

Triple rotor engine by Mazda



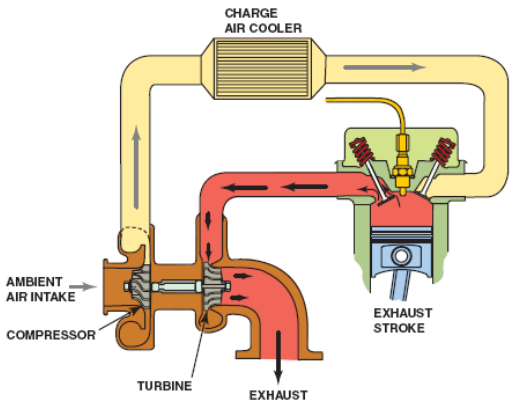
Classification of Engines

Working cycle

four-stroke cycle, complete cycle in 720 ^{O}CA
naturally aspirated, supercharged, turbocharged

two-stroke cycle, complete cycle in 360 ^{O}CA
crankcase scavenged, supercharged, turbocharged

Classification of Engines



Turbocharched engine

Classification of Engines

Method of ignition

SI engines, mixture is uniform (conventional engines), mixture is non-uniform (stratified-charge engines)

ignition is by the application of external energy (to spark plug)

CI engines, ignition by compression in conventional engine (Diesel engine), pilot injection of fuel in gas engines (eg, natural gas and diesel fuel – dual fuel engines)

Classification of Engines

Engine speed

low speed engines, 100 – 600 r.p.m.

ships, stationary engines

medium speed engines, 800 – 1500 r.p.m

generally Diesel engines, small marine applications, stationary engines, earth moving vehicles

high speed engines, 2500 – 8000 r.p.m.

passenger cars

Classification of Engines

Method of cooling,

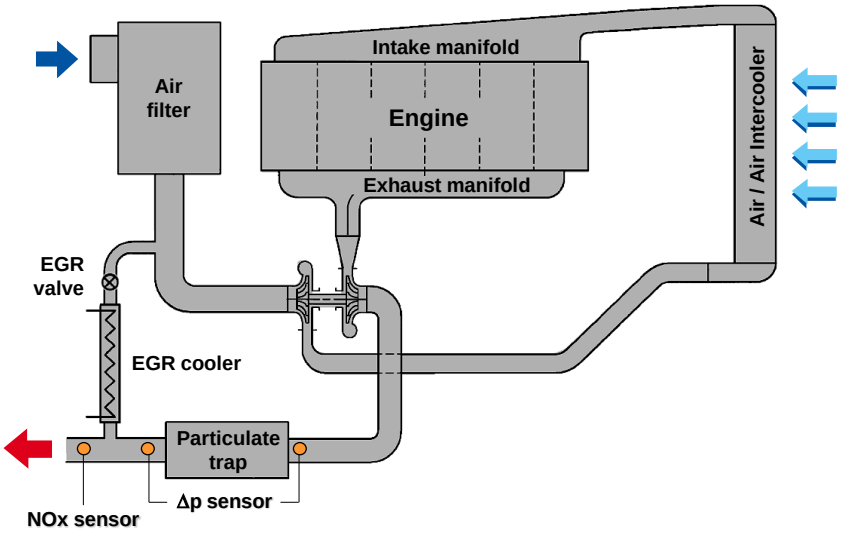
- liquid cooled, water cooled engines
- air cooled engines

Classification of Engines

Air intake process,

- naturally aspirated engines
- supercharged engines
- turbocharged engines
- crankcase compressed

Turbocharger with EGR system



Classification of Engines

Fuel used,

- gasoline engines
- diesel engines
- natural gas (CNG and LNG), methane, LPG engines
- alcohol engines
- hydrogen engines

Classification of Engines

natural gas engines

Classification of Engines

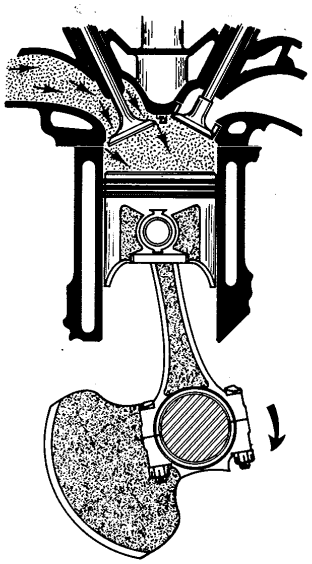
natural gas engines

Four-stroke SI-Engines

Intake stroke

Starts with the movement of the piston from TDC to BDC, while drawing fresh charge (air + fuel mixture) into the cylinder through the open inlet valve.

To increase the mass inducted, inlet valve opens for a period of 220 – 260 ^{O}CA



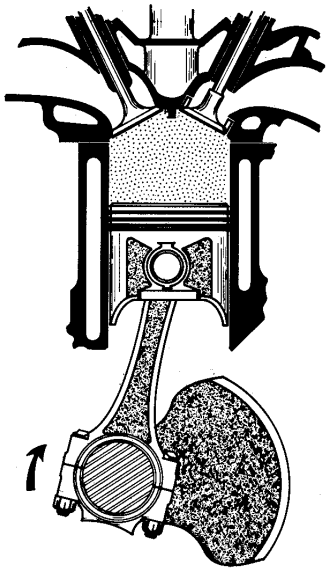
Four-stroke SI-Engines

Compression stroke

when both valves are closed, the mixture inside the cylinder is compressed to a small fraction of its initial volume by the movement of the piston (12:1).

Towards the end of compression stroke, combustion is initiated by a spark at the spark plug and cylinder pressure rises rapidly.

At the end of compression the gas temperature is around 550 – 700 K and pressure is 1.0 – 1.4 MPa

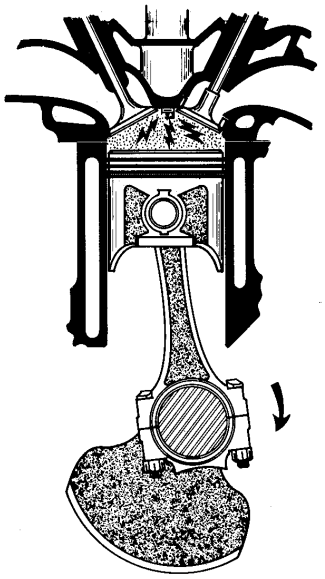


Four-stroke SI-Engines

Power and expansion stroke

Combustion starts with the ignition of the mixture, usually before TDC. During combustion process high temperature, high pressure gases push the piston towards BDC and force the crank to rotate.

Maximum temperature of 2200 – 2300 K and pressure of 3 – 7 MPa is reached in the cylinder.



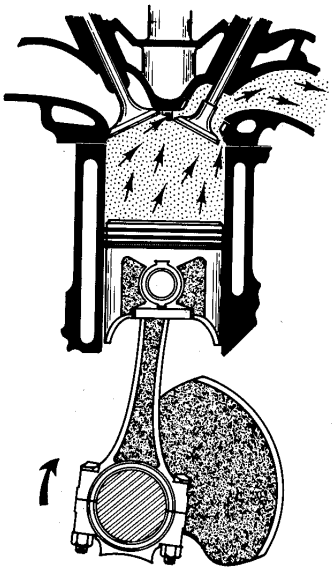
Four-stroke SI-Engines

Exhaust stroke

The burned gases exit the cylinder through the open exhaust valve, due to the pressure difference at first and then swept by the piston movement from BDC to TDC

Exhaust valve closes after TDC (stays open for 210 – 265 ^{O}CA)

At the end of exhaust stroke gas temperature is 700 – 1000 K and gas pressure 0.105 - 0.11 MPa



Four-stroke Cycle

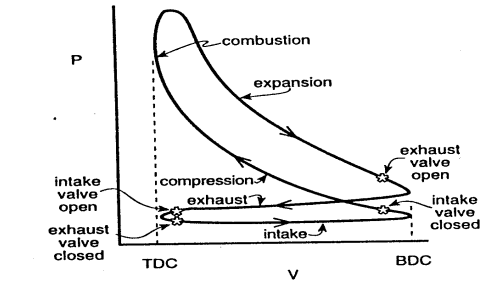
CLOSED DIAGRAM

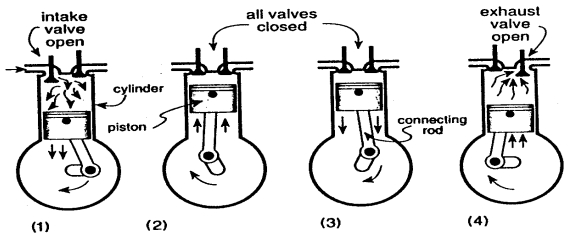
INTAKE STROKE (1)

COMPRESSION STROKE (2)

POWER-EXPANSION STROKE (3)

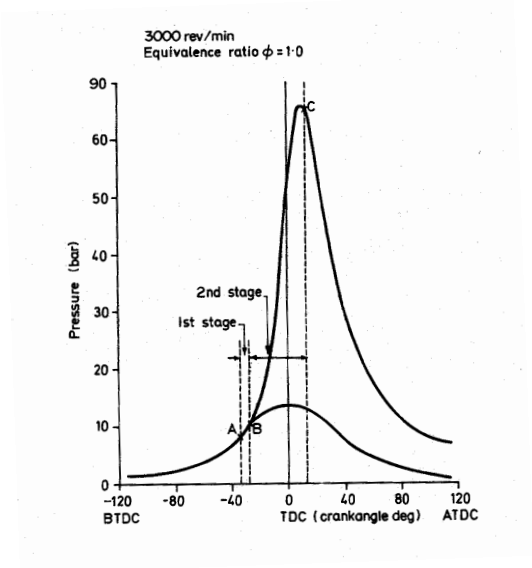
EXHAUST STROKE (4)





Combustion in SI-Engines

OPEN DIAGRAM



Four-stroke CI-Engines

Intake stroke

Starts with the movement of the piston from TDC to BDC, while drawing only air into the cylinder through the open inlet valve. The cylinder pressure is 0.085 – 0.095 MPa

To increase the mass inducted, inlet valve opens for a period of 220 – 260 ^{O}CA

Compression stroke

When both valves are closed, cylinder contents are compressed (14:1 – 24:1).

At the end of compression the gas temperature is around 900 - 1200 K and pressure is 3.0 – 5.0 MPa

Four-stroke CI-Engines

Power and expansion stroke

Combustion starts with the injection of the fuel spray into the combustion chamber, usually before TDC with certain injection advance. There is ignition delay before combustion starts.

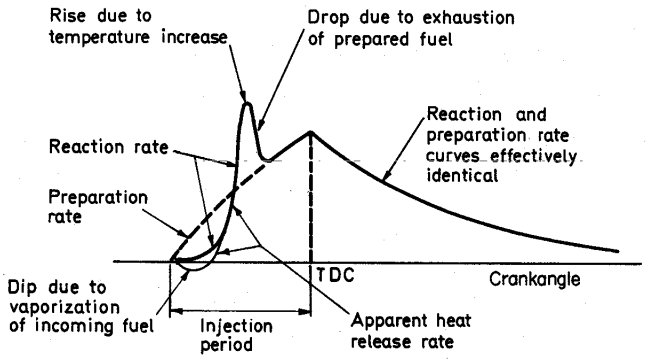
During combustion process high temperature, high pressure gases push the piston towards BDC and force the crank to rotate.

Maximum temperature of 1700 – 2100 K and pressure of 4 – 8 MPa (IDI engines) and 7 – 10 MPa (DI engines) is reached in the cylinder.

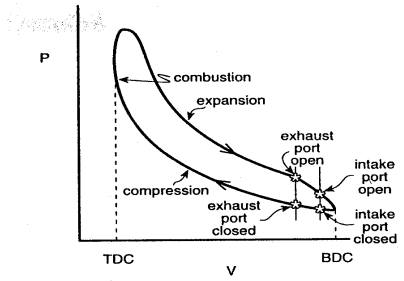
Exhaust stroke

Exhaust valve opens and combustion products exit cylinder. The stay open for 210 – 265 ^{O}CA. The gas temperature is around 1000 - 1100 K and pressure is 0.4 – 0.5 MPa

Combustion in CI-Engines

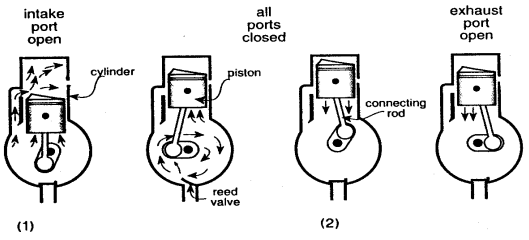


Two-stroke Cycle

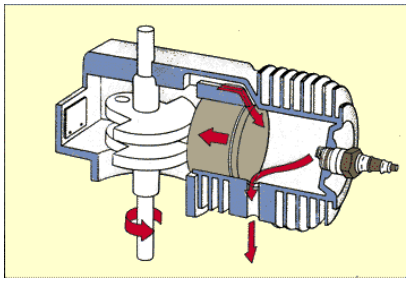


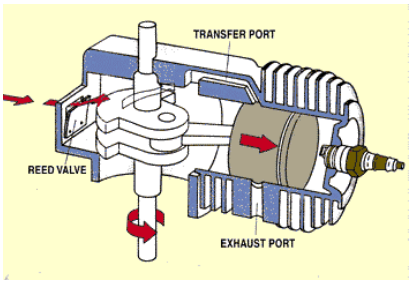
COMPRESSION STROKE (1)

POWER-EXPANSION STROKE (2)



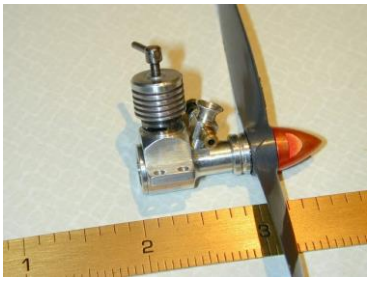
Two-stroke Engine





Two-stroke Engine

Two-stroke Engine



Two-stroke Engine