

Internal Combustion Engines – ME 422 Yeditepe Üniversitesi

## **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**
- **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
- Expansion and exhaust strokes, exhaust emissions
- **Mixture preparation in SI engines**
- **Mixture preparation in CI engines**, injection pumps, injectors
- **Engine characteristics and performance.**

## References

### Textbook

- Pulkrabek, W.W., Engineering Fundamentals of the Internal Combustion Engine, Prentice Hall, New Jersey, 1997
- Soruşbay, C., IC Engine, Lecture Notes (Power Point)

### Other References

- Soruşbay, C. et al., İçten Yanmalı Motorlar, Birsen Yayınevi, İstanbul, 1995.
- Heywood, J.B., Internal Combustion Engine Fundamentals, McGraw Hill Book Company, New York, 1988.
- Stone, R., Introduction to Internal Combustion Engines, Macmillan, London, 1994.
- Other references given in the list (see web page)

## Internal Combustion Engines – ME422

### 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 occurring 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



### OTTO & LANGEN "ATMOSPHERIC" GAS ENGINE 1872

The force of the explosion at the bottom of the cylinder drives the piston and rack to the top, disengaged from the shaft. The combustion gases then cool, forming a vacuum below the piston, which causes it to be driven down by atmospheric pressure and gravity. During this power stroke, the rack pinion drives the shaft through an overrunning clutch.

The speed of the engine is controlled by the action of the governor partially throttling the exhaust gases, thus causing the speed of the piston's descent to remain constant despite changes in load.

*Horsepower—13  
Original cost—About \$650  
From Kitchener—Hutchinson—Dunn, 1911*

## Early History

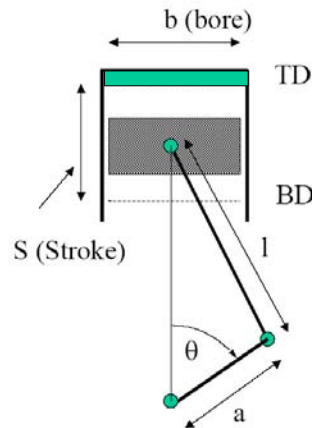
Huygens (1673)	developed piston mechanism
Hautefeuille (1676)	first concept of internal combustion engine
Papin (1695)	first to use steam in piston mechanism
<b>"Modern" engines</b>	using same principles of operation as present engines – previously no compression cycle
Lenoir (1860)	driving the piston 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

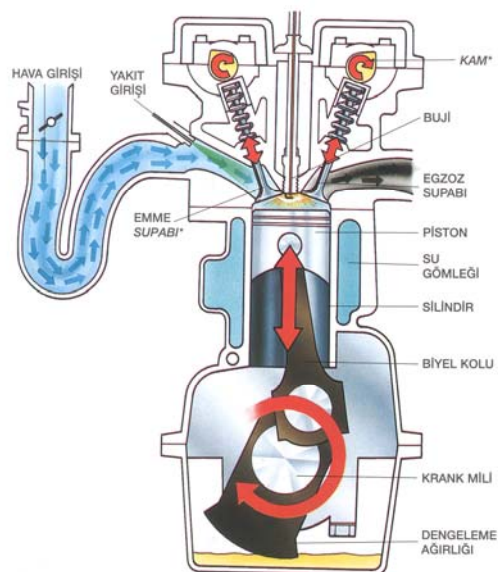
$V_C$  clearance volume  
 $V_D$  displacement volume  
 $V_T$  total volume

$D$  bore  
 $L$  stroke

TDC top dead center  
 BDC bottom dead center



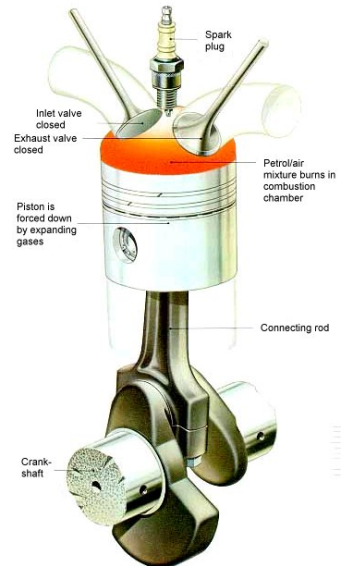
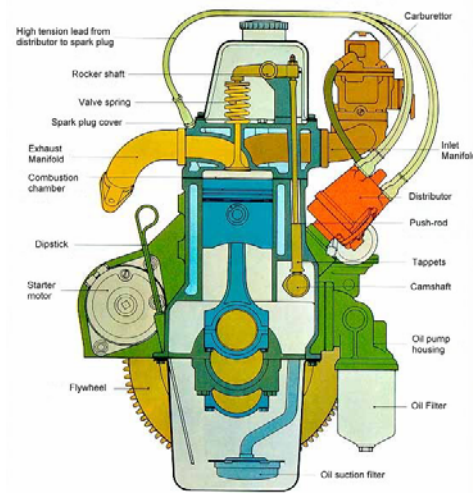
## Introduction



A single cylinder  
 4-stroke engine

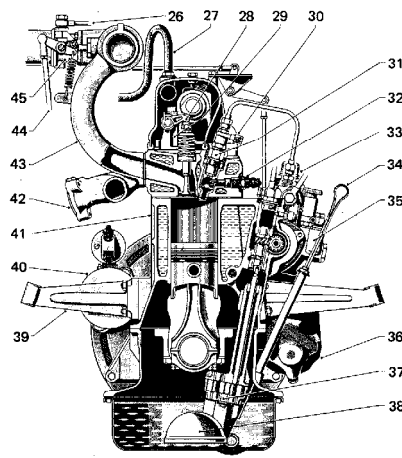
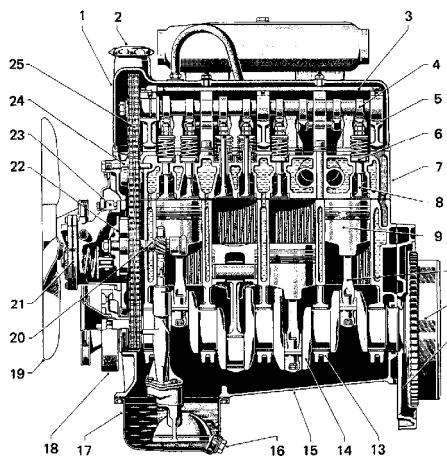
## Introduction

FRONT SECTION OF A 4-CYLINDER INTERNAL COMBUSTION ENGINE

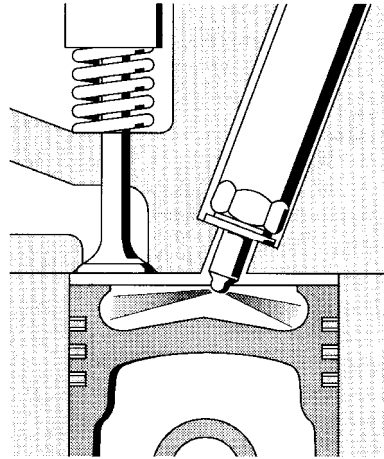


## Introduction

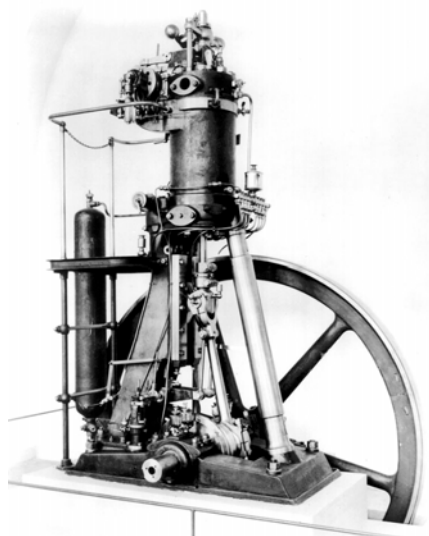
### Diesel engine



## Introduction



## Introduction





## 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

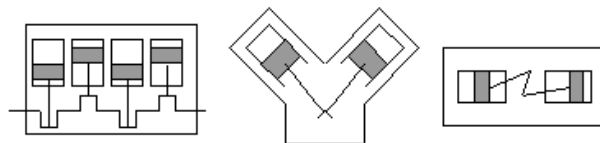
locomotives, 400 – 3 000 kW, CI, 4-stroke  
ships, 3 500 – 22 000 kW, CI, 2- and 4-stroke  
airplanes, 45 – 3 000 kW, SI, 4-stroke

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

## Classification of Engines

### Basic engine design

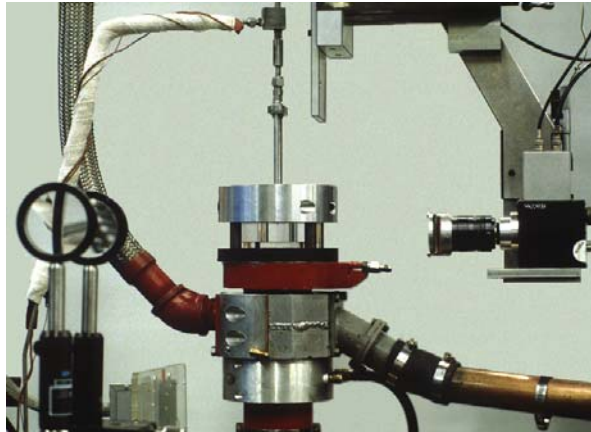
Reciprocating engines,  
subdivided by arrangement of cylinders



Rotary engines

## Classification of Engines

Single-cylinder "test engine"



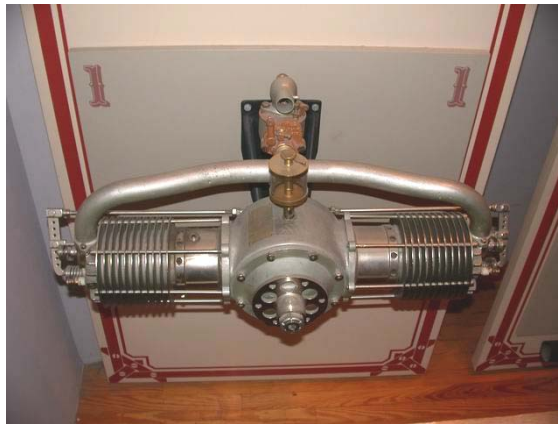
## Classification of Engines

In-line engine



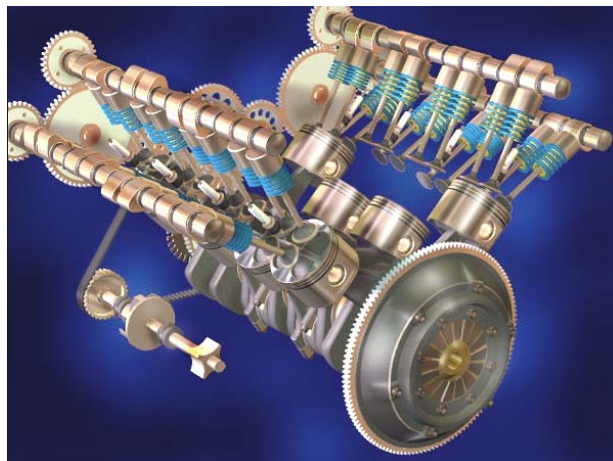
## Classification of Engines

Opposed piston engine



## Classification of Engines

V - engine



## Classification of Engines

### V – engine

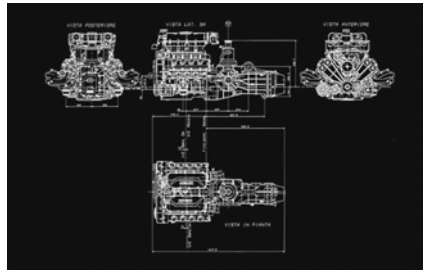
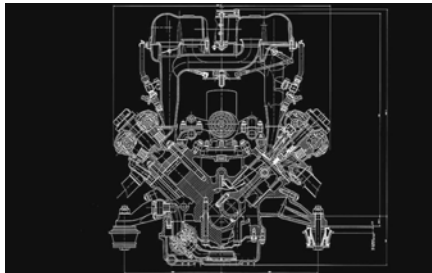
Ferrari V8 90° engine

360 Modena 3586 cc

Bore/Stroke 85/79 mm

294 kW (400 hp) @ 8500 rpm

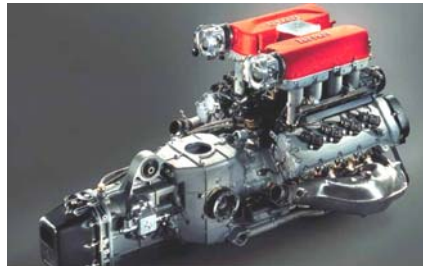
373 Nm @ 4750 rpm



## Classification of Engines

Ferrari V8 90° engine

360 Modena 3586 cc



## Classification of Engines

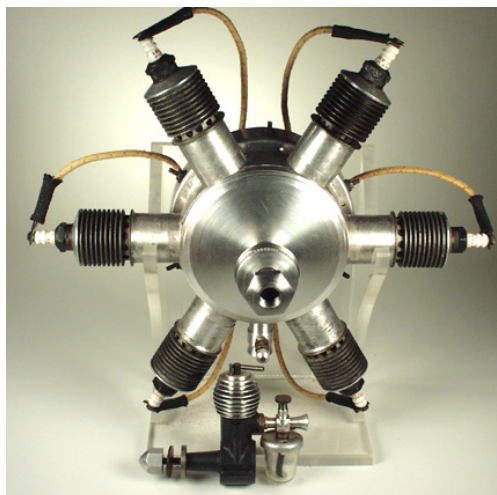
### V – engine

Ferrari V12 65° 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



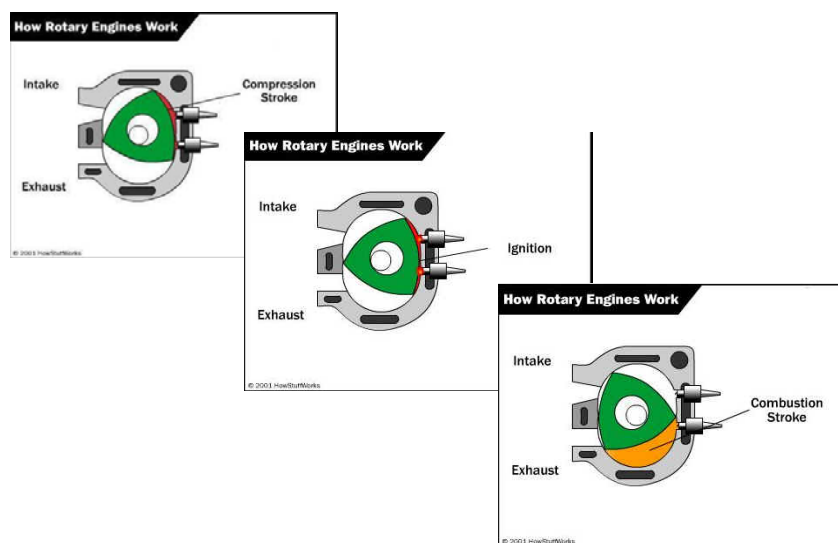
## Rotary Engines

### Wankel engine

Felix Wankel, prototype in 1929, patented double rotor in 1934



## Rotary Engines

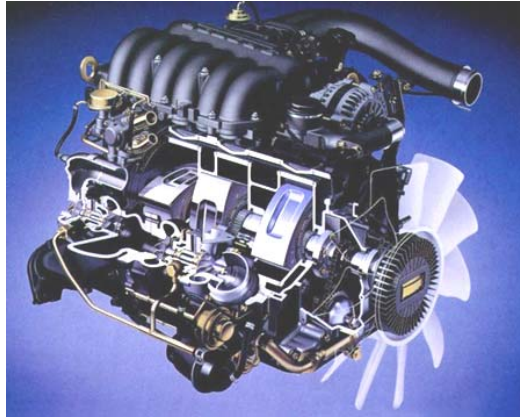


## Rotary Engines

**Mazda Rx-8**  
250 hp engine



**Triple rotor engine by Mazda**



## Classification of Engines

### Working cycle

**four-stroke cycle,** complete cycle in 720 °CA  
naturally aspirated, supercharged,  
turbocharged

**two-stroke cycle,** complete cycle in 360 °CA  
crankcase scavenged, supercharged,  
turbocharged



## 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. (revolutions per second)  
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,**

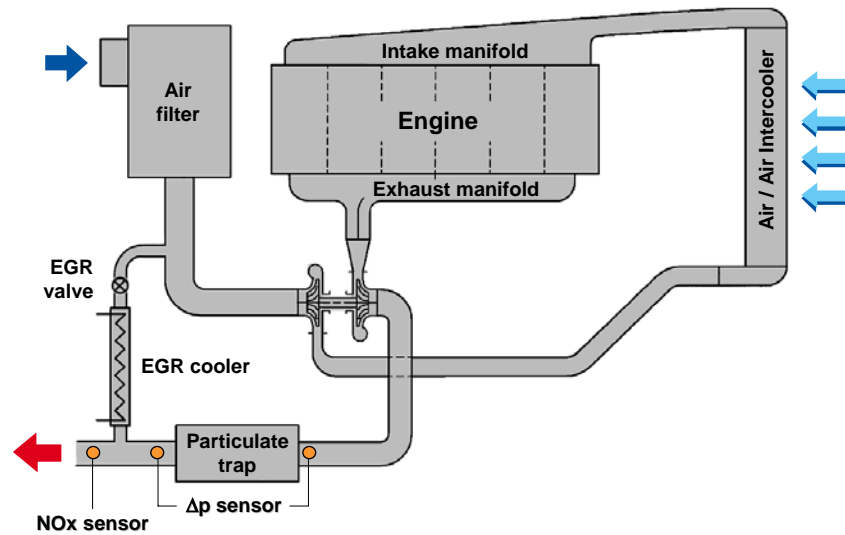
naturally aspirated engines

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

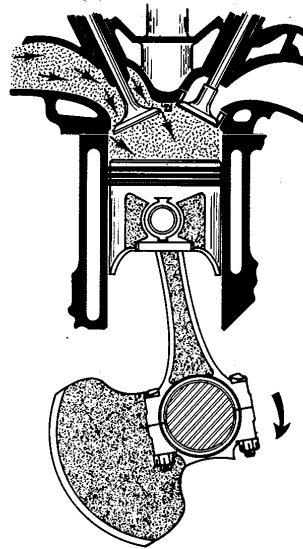


## Four-stroke SI-Engines

### 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  $220 - 260^\circ\text{CA}$



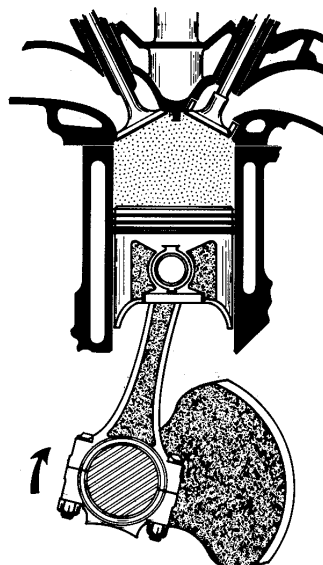
## Four-stroke SI-Engines

### 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  $550 - 700\text{ K}$  and pressure is  $1.0 - 1.4\text{ MPa}$



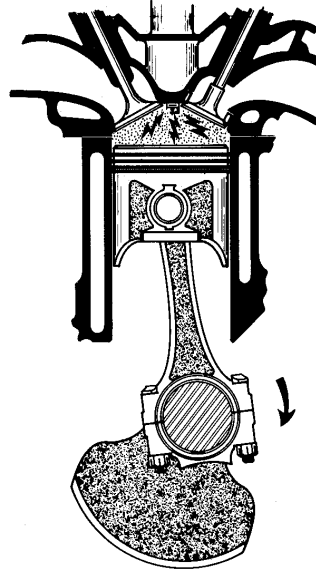
## Four-stroke SI-Engines

### 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.



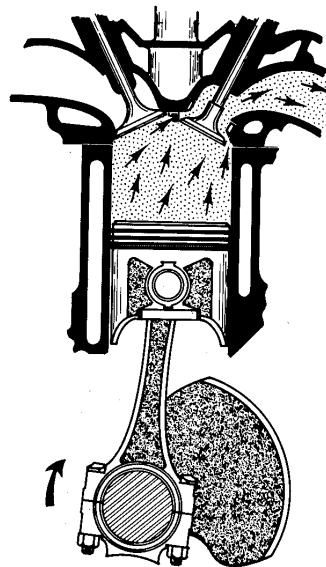
## Four-stroke SI-Engines

### 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 °CA)

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



## Four-stroke Cycle

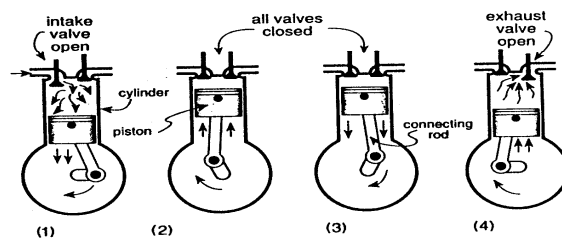
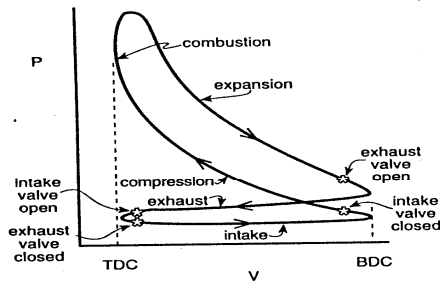
### CLOSED DIAGRAM

INTAKE STROKE (1)

COMPRESSION  
STROKE (2)

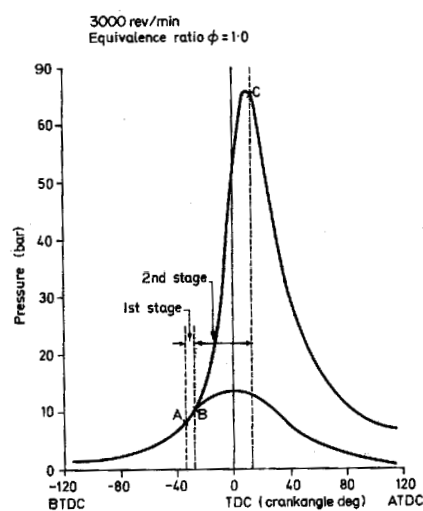
POWER-EXPANSION  
STROKE (3)

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 °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.

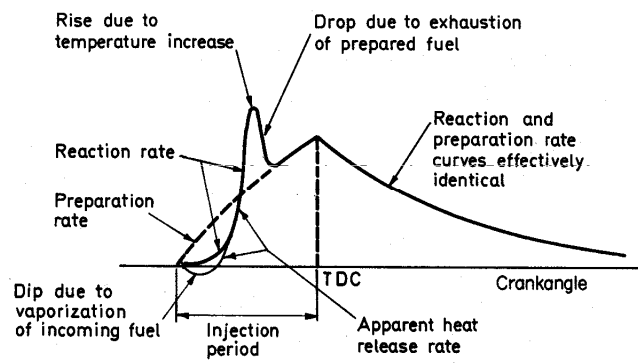
During combustion process high temperature, high pressure gases push the piston towards BDC and force the crank to rotate.

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 °CA. The gas temperature is around 1000 - 1100 K and pressure is 0.4 – 0.5 MPa

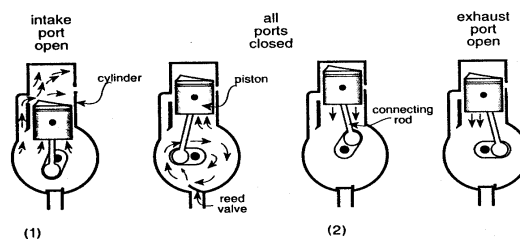
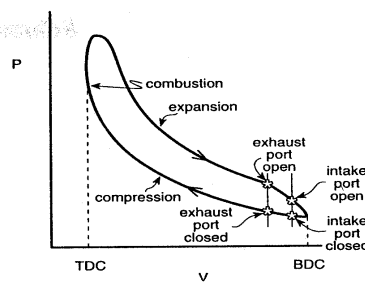
## Combustion in CI-Engines



## Two-stroke Cycle

COMPRESSION  
STROKE (1)

POWER-EXPANSION  
STROKE (2)





## Two-stroke Engine

