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PRIFYSGOL METROPOLITAN ABERTAWE

Advanced Engine Technology

Lecture 4: Spark Ignition Combustion Process and Detonation

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Contents

- Introduction
- The three phases of combustion
 - Delay Period
 - Rapid pressure rise period
 - After burning period
- Ignition timing and engine speed
- Detonation

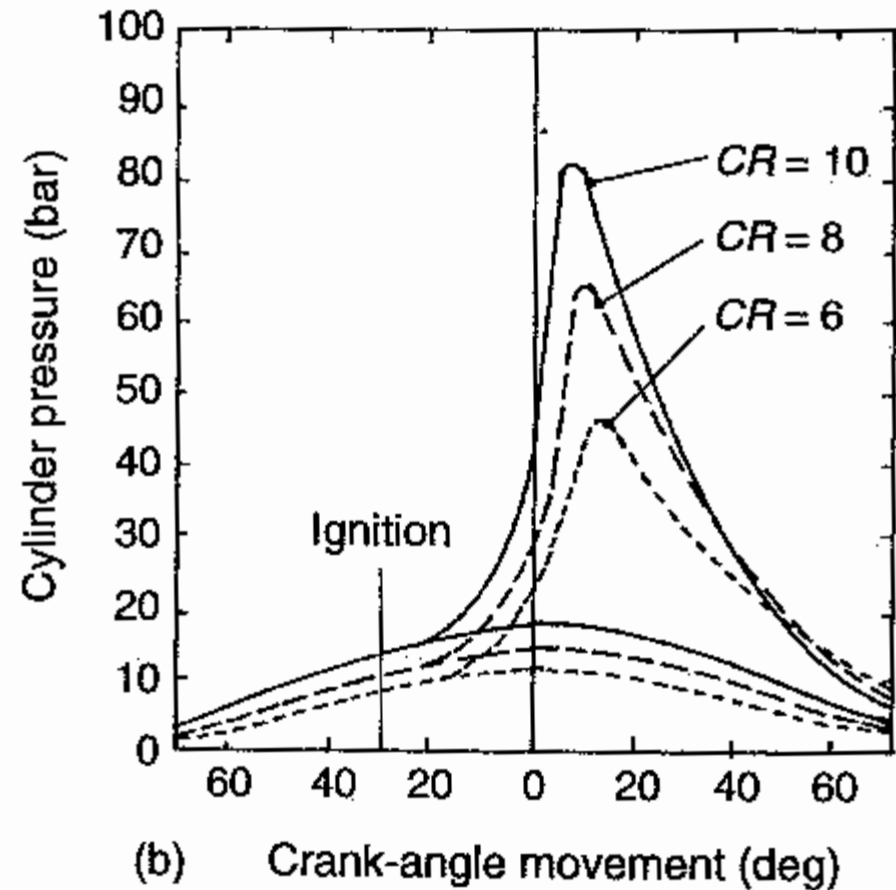
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Introduction



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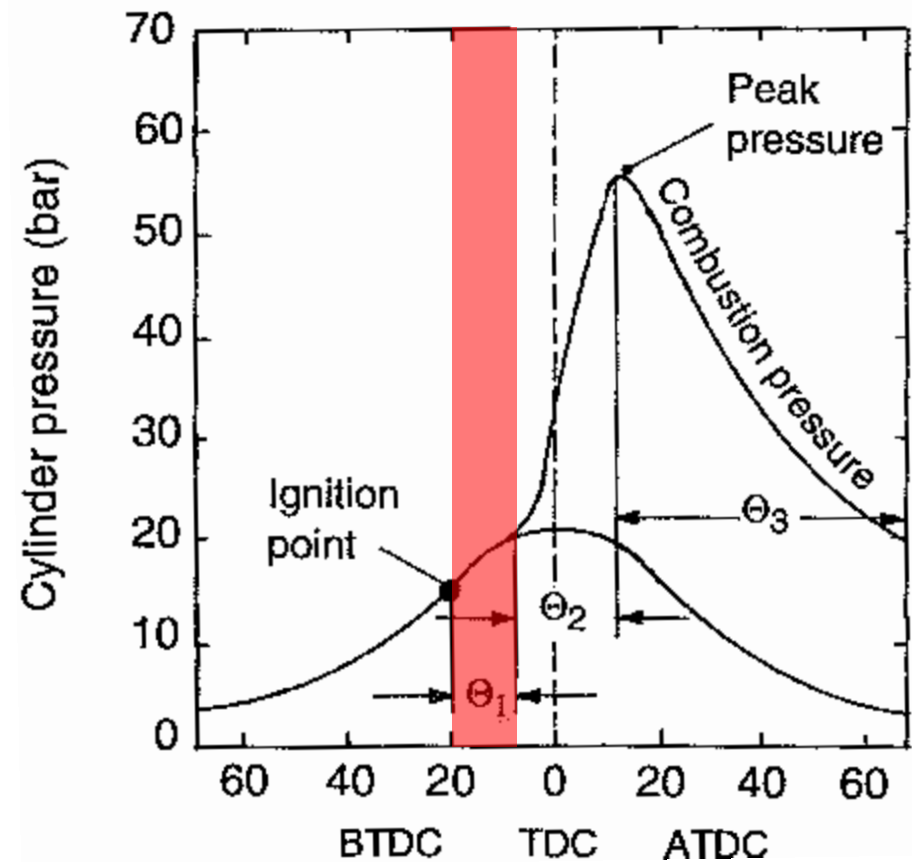
- Combustion phase gives large peak in cylinder pressures
- Combustion period has 3 phases
 - Delay period
 - Rapid pressure rise
 - After burning period



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Introduction

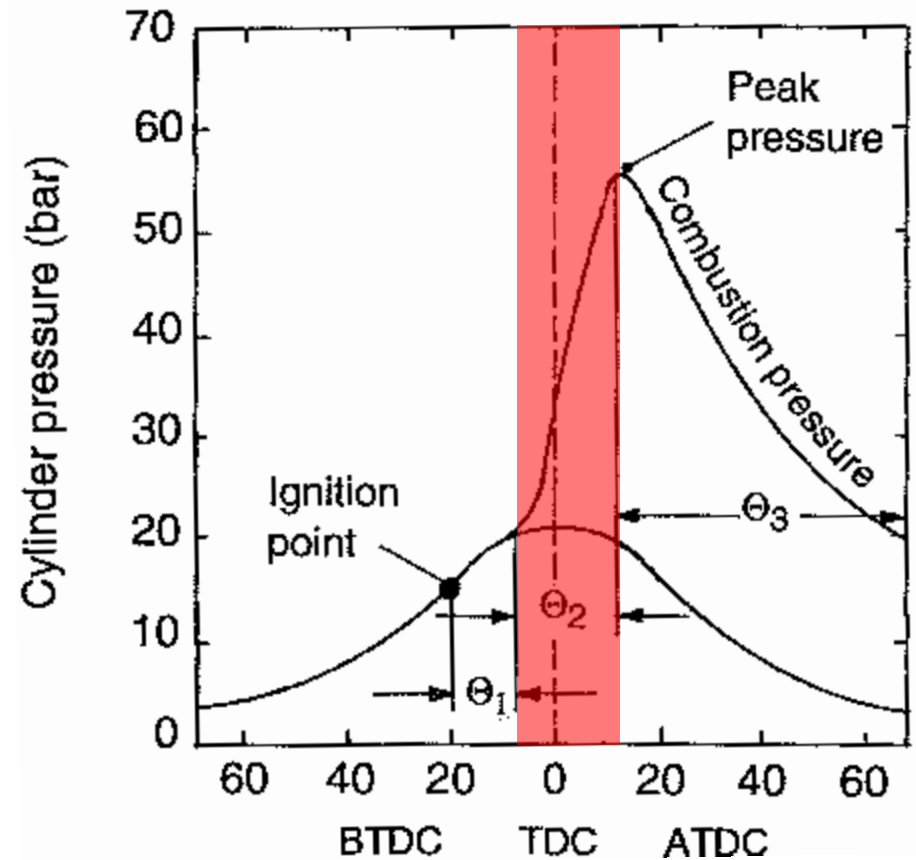
- Delay period (θ_1)



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Introduction

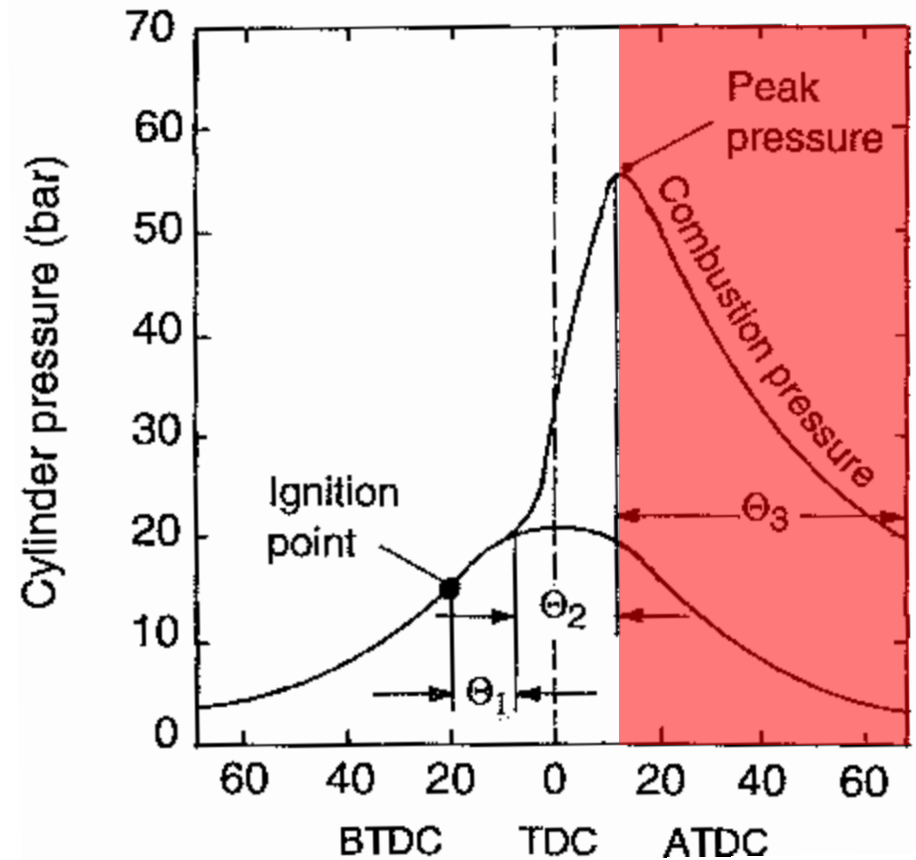
- Delay period (θ_1)
- Rapid pressure rise (θ_2)



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Introduction

- Delay period (θ_1)
- Rapid pressure rise (θ_2)
- After burning period (θ_3)



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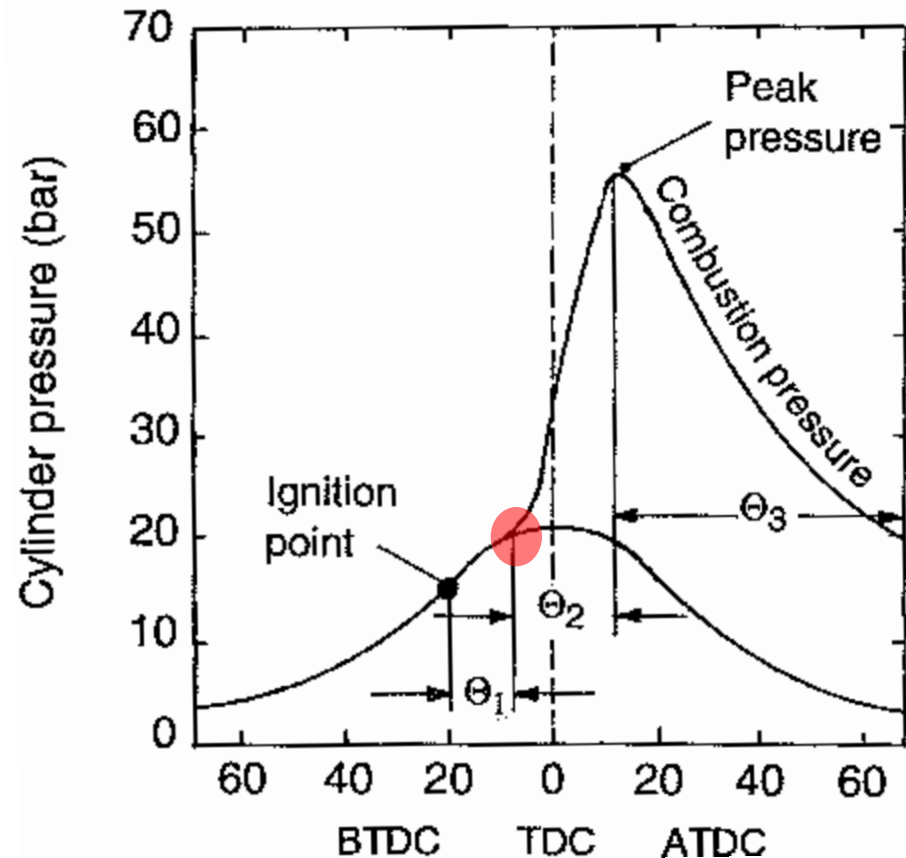
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Delay Period



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- Starts when spark plug ignites mixture
- Ends when flame starts to release the heat energy of the fuel
- i.e. when the cylinder pressure rises above normal compressive pressure



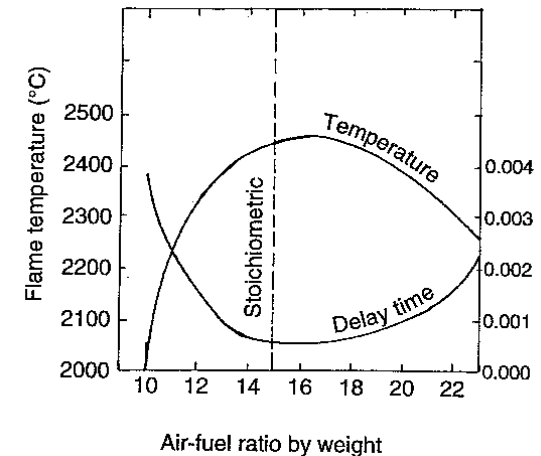
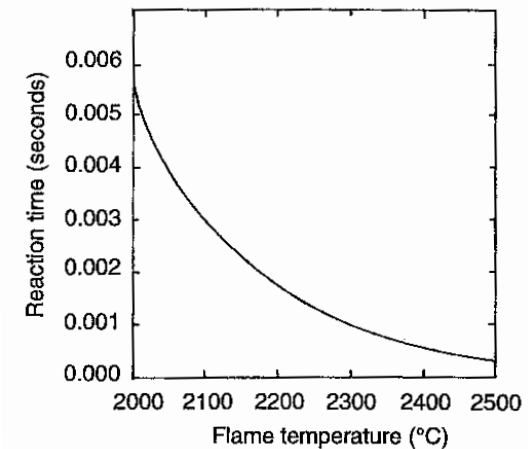
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Delay Period



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- Duration dependent on:
 - Temperature of flame at spark plug
 - Fuel type/composition
 - Temperature & pressure of charge
 - Thoroughness of mixing of charge
 - Strength of charge mixture



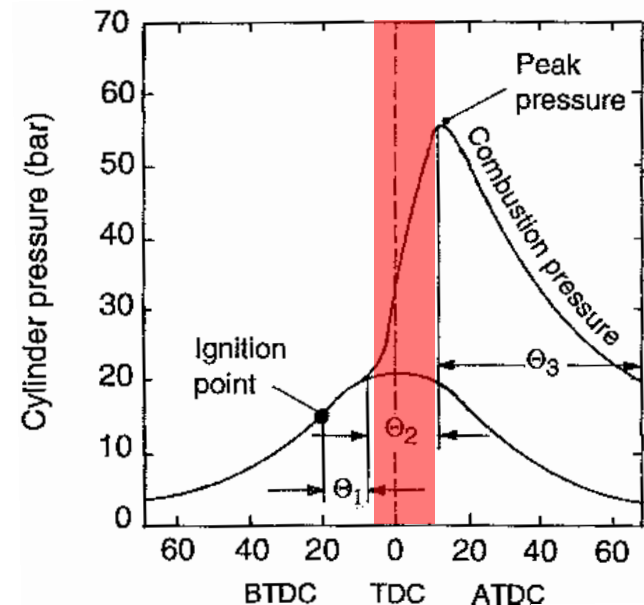
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Rapid Pressure Rise



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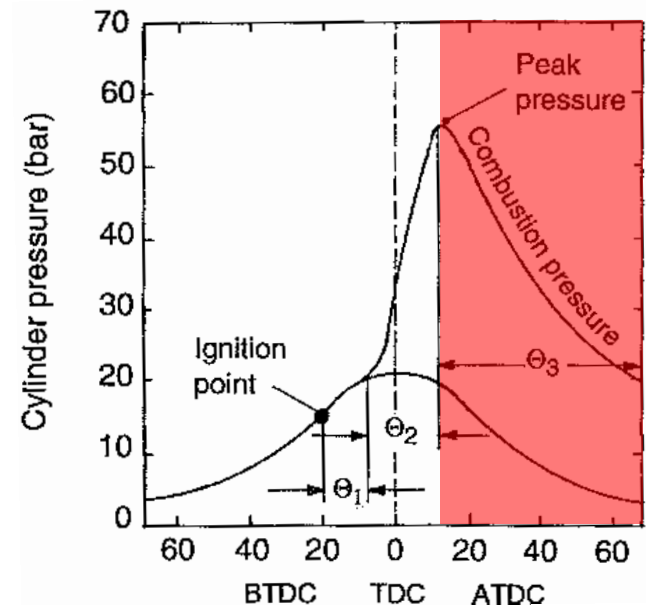
- Runs from initiation of flame front until the flame front has spread to the cylinder walls and peak pressure has been reached
- Time for this phase depends mainly on intensity of the turbulence / state of agitation of mixture – a highly turbulent mixture burns more rapidly
- Turbulence rises roughly linearly with engine speed thus the duration of this period is approximately constant in terms of crank rotation (not time!)



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After Burning Period

- After flame front reaches cylinder walls, some 25% of the charge remains unburnt
- It is now more difficult for remaining oxygen to react with the petrol vapour, so the rate of burning slows (*after burning*)
- Heat is lost through cylinder walls, head and piston crown
- Volume increases as piston moves down bore
- Hence rapid drop in pressure



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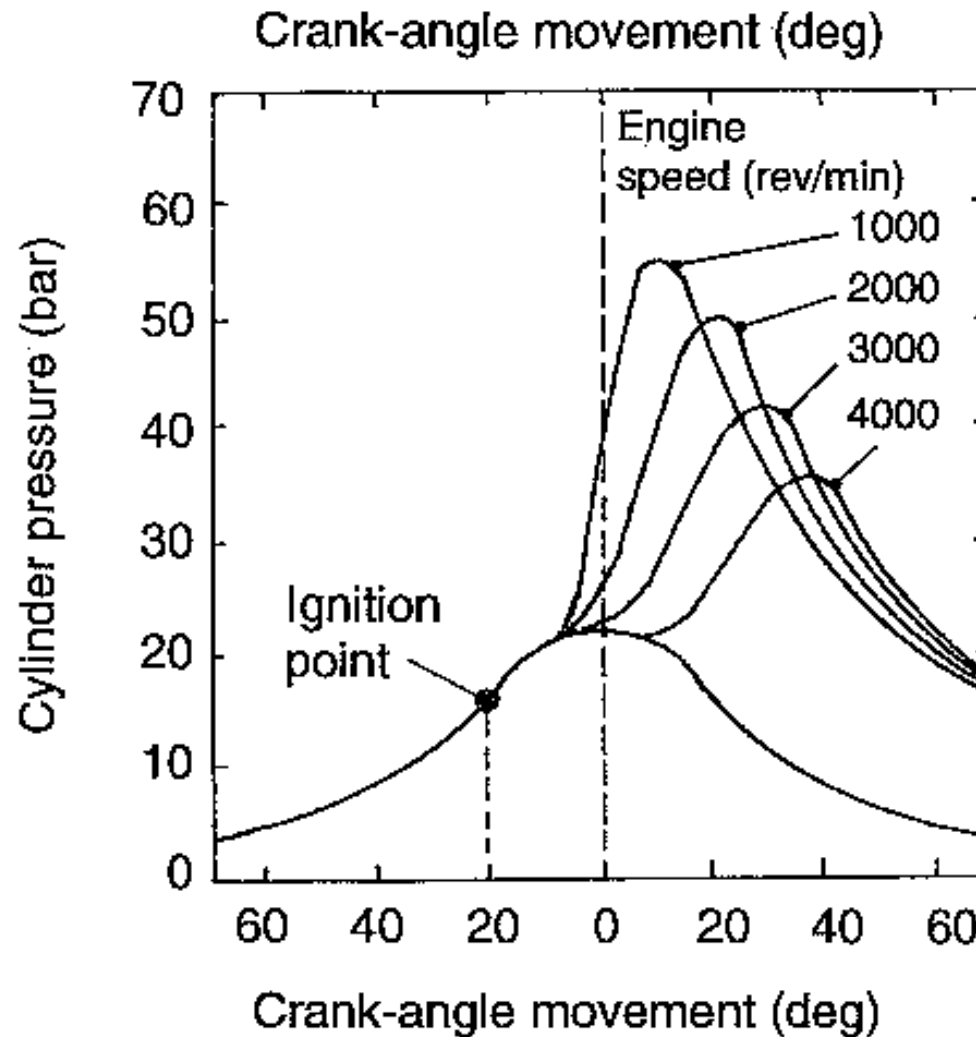
- When engine speed rises, there is less time for cylinder to dissipate heat from each stroke, so the delay time period reduces
- However, in terms of crank angle the delay period increases (with the square root of engine speed – i.e. Less than monotonically)
- Turbulence increases in proportion to engine speed, and the time interval of the rapid pressure rise period reduces (in crank angle terms it remains roughly constant)
- Thus if ignition advance is fixed to produce peak pressure at about 10 ATDC at low speed, then as speed increases peaks will occur later in cycle, and have smaller magnitude

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Ignition Timing



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**Fixed Ignition
Timing @ 20
degrees BTDC**

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Ignition Timing

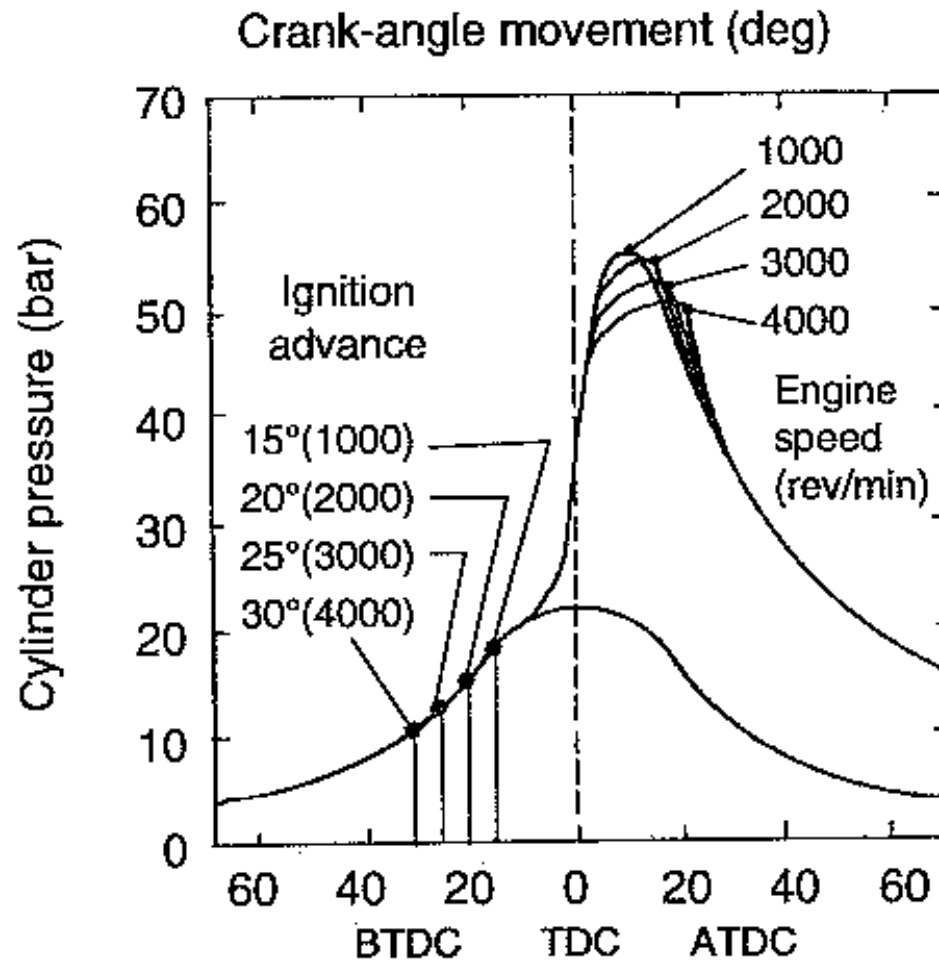
- To avoid this, ignition is advanced by the same amount as the delay period increases as engine speed increases
- Position of pressure peak remains roughly constant
- Magnitude of pressure peak drops slightly due to reducing volumetric efficiency at high speeds
- Automatic variation of firing point with speed can maintain engine torque to a far greater degree than static ignition

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Ignition Timing



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**Speed-dependant
ignition advance**

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Ignition Timing

Mechanical Advance



Load - High Octane Timing Map

	8	16	24	28	32	36	40	44	48	52	56	64	72	80	88	96
400	15	25	20	15	5	5	5	5	5	5	5	5	5	5	5	5
800	15	40	32	28	25	21	12	8	7	4	2	2	2	2	2	2
1200	15	38	30	30	30	28	22	19	16	14	14	14	14	13	13	13
1600	28	40	38	38	37	34	29	22	22	24	19	17	17	16	17	17
2000	35	40	44	42	40	37	34	26	22	25	25	20	15	15	15	16
2400	35	45	45	40	38	36	34	31	29	28	32	26	20	20	20	18
2800	35	45	45	41	39	35	33	32	32	32	32	30	23	20	20	20
3200	35	44	44	44	39	35	33	32	32	31	29	30	26	21	21	20
3600	35	37	41	42	40	35	34	33	31	30	29	28	23	21	21	20
4000	35	37	41	43	40	37	36	33	31	31	31	29	23	22	21	20
4400	35	37	41	43	40	38	36	33	30	29	27	27	22	22	21	20
4800	35	37	41	43	40	37	34	33	30	29	28	27	26	22	21	20
5200	43	43	43	43	40	38	35	33	29	28	28	27	26	22	21	20
5600	43	43	43	43	40	38	36	33	29	28	28	27	26	22	20	19
6300	43	43	43	43	40	38	34	31	29	28	28	26	25	21	20	19
6900	43	43	43	43	40	38	33	30	26	25	23	22	24	21	19	19

■ Open Loop ■ Closed Loop

Electronic Ignition via ECU



Vacuum advance

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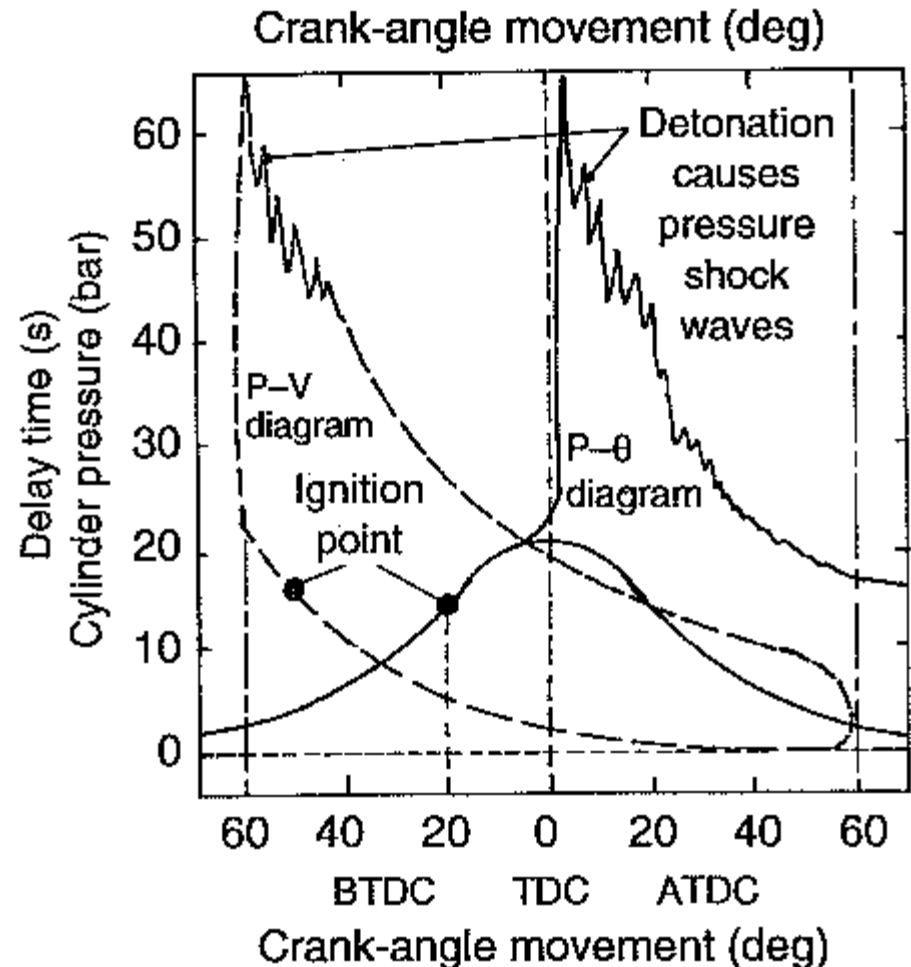
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Detonation

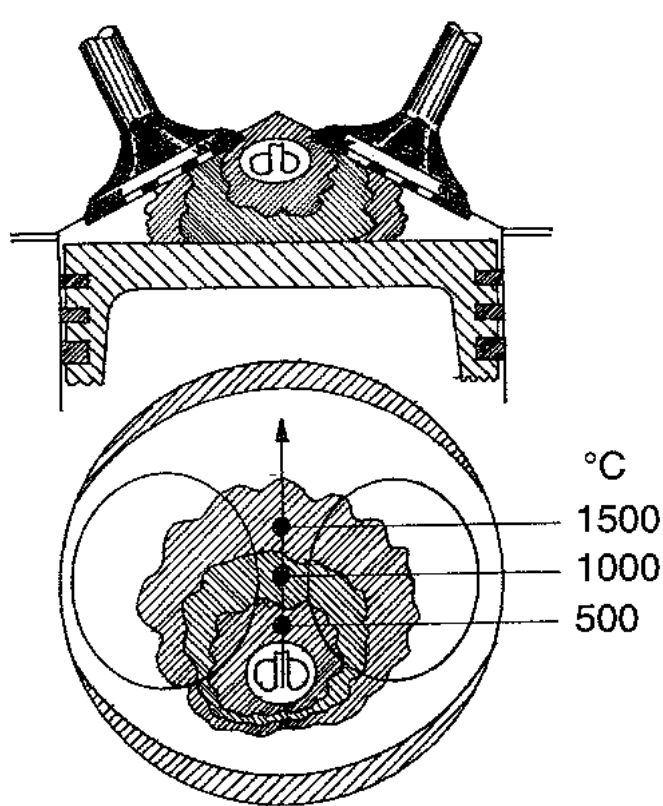
- “Knock”, “Pinking”
- The creation of a pressure wave within cylinder travelling at high velocity which excites cylinder walls into vibration
- Metallic knocking or high pitched pinging sound
- Typically 500Hz
- Due to uncontrolled combustion



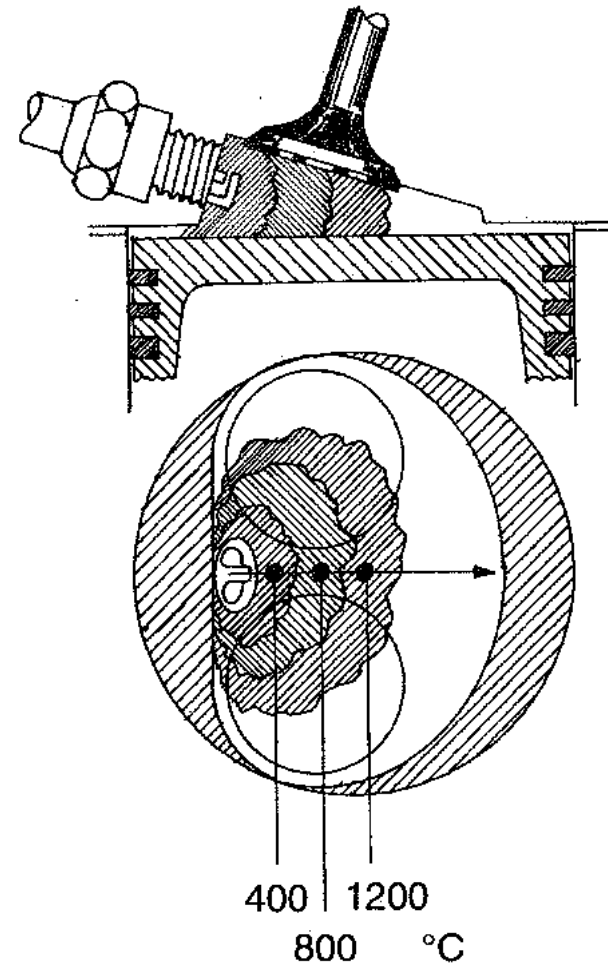
- In combustion process, spark plug ignites fuel / air mixture
- Flame front travels outwards towards cylinder walls through mixture
- If flame travels slowly, and the distance it travels is long, there is sufficient time for heat to conduct to the unburnt mixture ahead of the flame front, raising its pressure
- When this unburnt “end mixture” reaches a high enough temperature and pressure, it will spontaneously ignite
- The resulting explosion produces pressure shock waves which give the characteristic “knock”

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Detonation



Slow Burning Long Flame



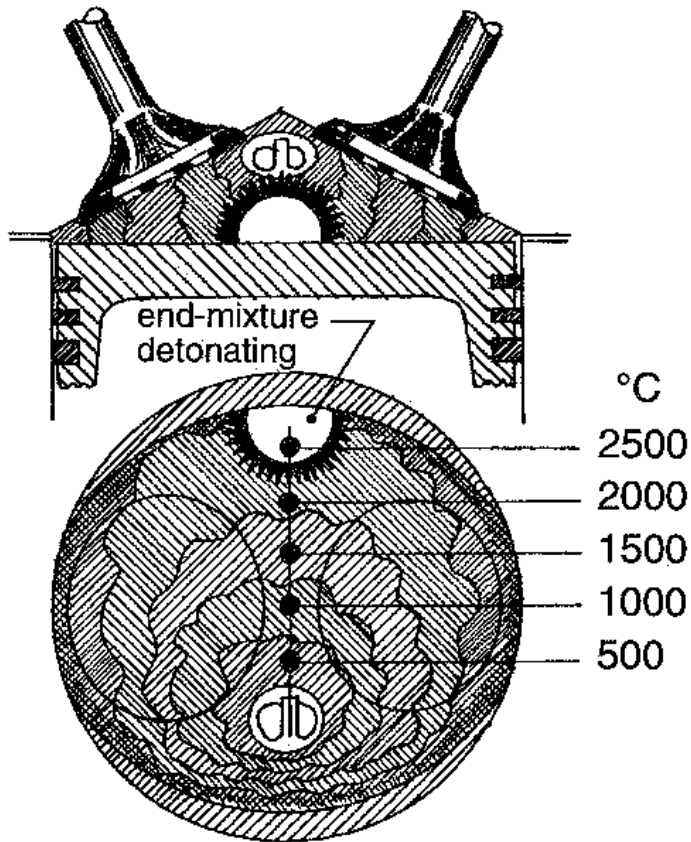
Fast Burning Short Flame

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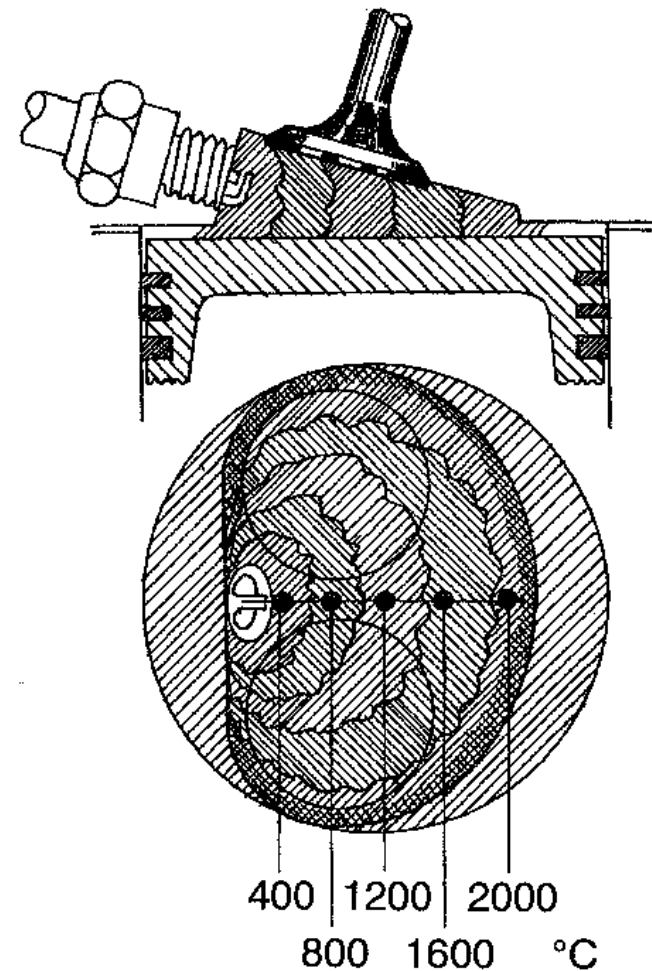
Detonation



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Slow Burning Long Flame



Fast Burning Short Flame

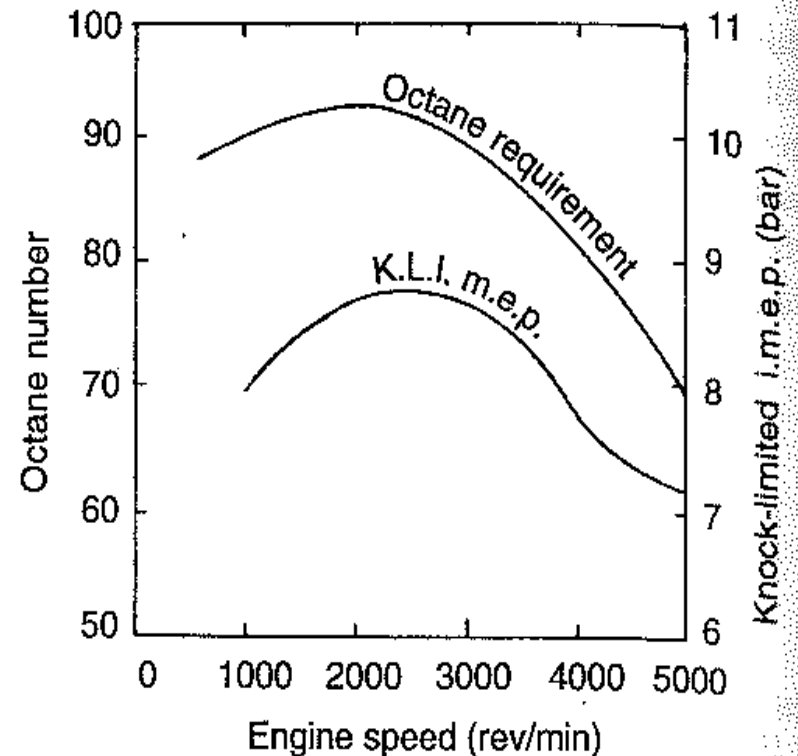
- If the flame speed is fast enough, and the flame path short, there is insufficient time for the unburnt mixture to become dangerously overheated
- Thus, detonation may be controlled by:
 - Increased turbulence / speed of flame travel
 - Reduced flame path and increased quench area
 - Raised octane value (knock resistance) of the fuel

- Effects of detonation
 - Scour away the protective layer of stagnant gas which is present on the combustion chamber surface
 - More heat is transmitted through the chamber wall
 - Mean chamber temperature is increased
 - This can cause pre-ignition
 - Erodes the oil film which lubricates cylinder walls
 - Reduced lubrication of cylinder walls (more dry and mixed lubrication, less full film conditions)
 - Increased friction and wear
 - Detonation shockwaves on piston can cause vibration on gudgeon pin, piston bosses and con rod small end bearings
 - Destroys lubrication
 - Increased wear

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Detonation

- Effect of engine speed
 - Low speed
 - More time for flame front to preheat end mixture
 - Promotes detonation
 - High speed
 - Volumetric efficiency decreases
 - Conditions (pressure) less severe (would reduce detonation)
 - Less time for heat to dissipate (would increase temperatures)
 - Net effect however is a reduction in detonation



- Factors which promote detonation
 - High compression ratios
 - Low octane fuels
 - Long flame path from point of ignition
 - Over-advanced timing moves cylinder peak pressure towards TDC, meaning maximum pressure is higher than normal
 - Slightly rich (10%) air/fuel mixture raises temperatures and pressures
 - Inadequately cooled combustion chamber
 - Excessive carburization of combustion chamber and piston crown