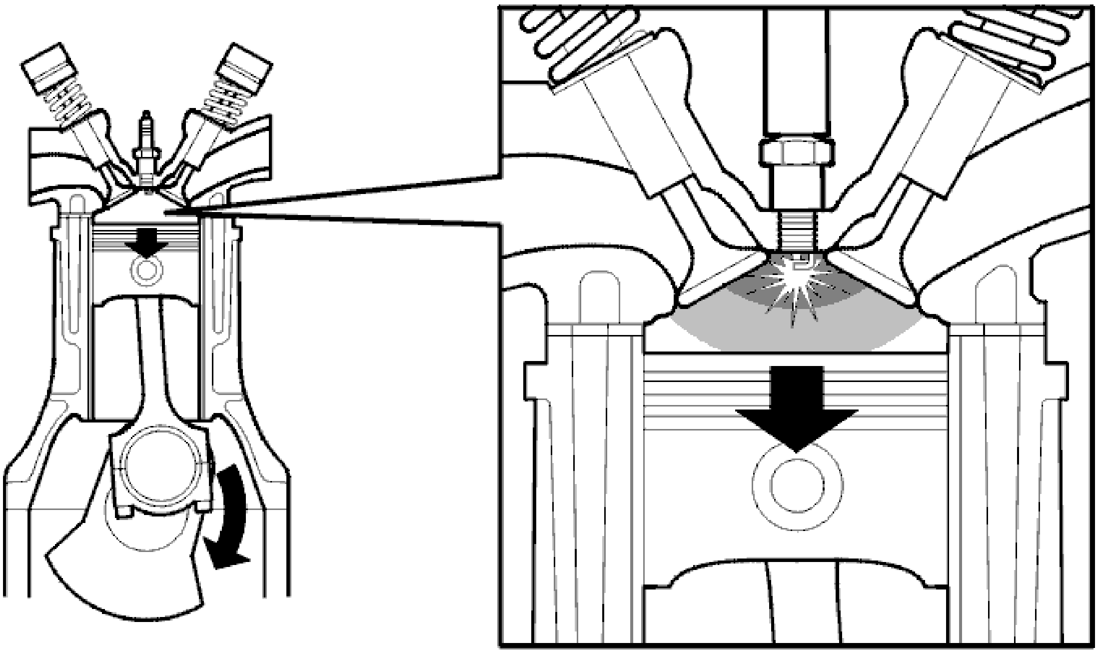
Combustion theory



The mixture burns!

Car engines develop power through the combustion of fuel.
Two things are required for this. Oxygen taken from the air and heat to begin the combustion. The heat in gasoline engines (also called otto engines) comes from a spark plug providing a spark (heat). When combustion begin a flame spreads from the spark plug at a speed of approximately 30 m/s. The entire combustion takes only approximately 2m/s (2/1000 s).

In order for the combustion to be as efficient as possible a number of things are required, including: - The correct relationship between fuel and air.

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- Sparking at the correct time.
- That the fuel is finely spread and well mixed with the air.

It does not just require a thorough fuel and ignition system but also optimum design of the intake and exhaust channels, valves (including play), camshafts and combustion chamber etc.

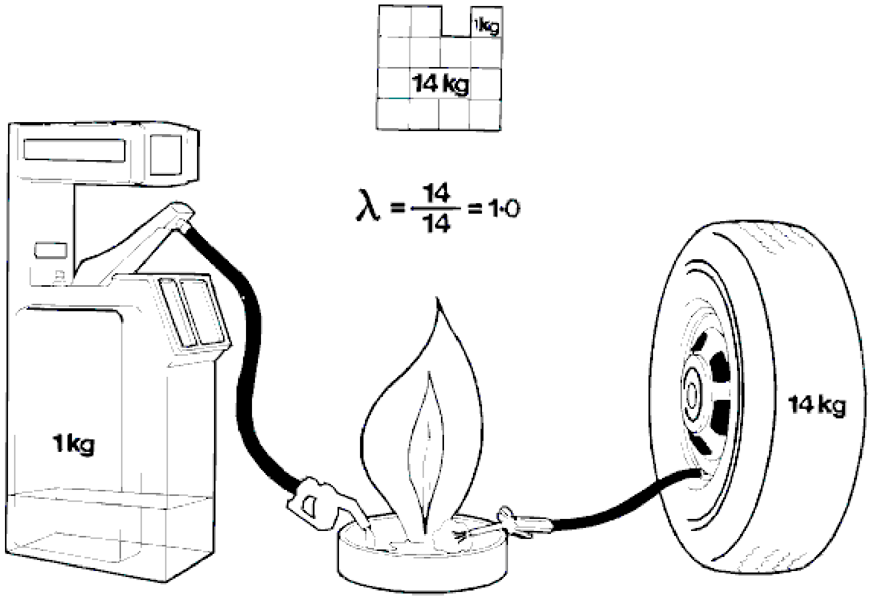
Maximum temperature at combustion: approximately 2500°C (4532°F)

Maximum pressure at combustion: approximately 60 bar

Difference between combustion and explosion

Combustion occurs at a speed of approximately 15-30 m/s.

Explosions occur at a speed of approximately 300 m/s.



How much air is consumed?

Gasoline mainly consists of different hydro-carbons (HC) and the oxygen required to burn these is taken from the air.

Theoretically approximately 14 kg of dry air is required to thoroughly burn 1 kg of gasoline. Exactly how much air is required varies depending on the air quality.

Air factor λ

If at combustion the amount of air supplied is as much as the theoretical requirement the air factor is 1. The Air factor is symbolized by the Greek letter λ (Lambda).

14 kg (supplied air mass) divided by 14 kg (theoretical requirement) = 1.00 ⇒ λ (air factor) = 1

If one operates with too little air supply (rich mixture) λ would be less than 1. With too much air supply (leaner mixture) λ will be greater than 1.

With complete combustion the residual

products will be only (H_2O) and carbon dioxide (CO_2). Unfortunately a car engine is not ideal and so there is always a little oxygen and fuel left over which completely or partially unburned.

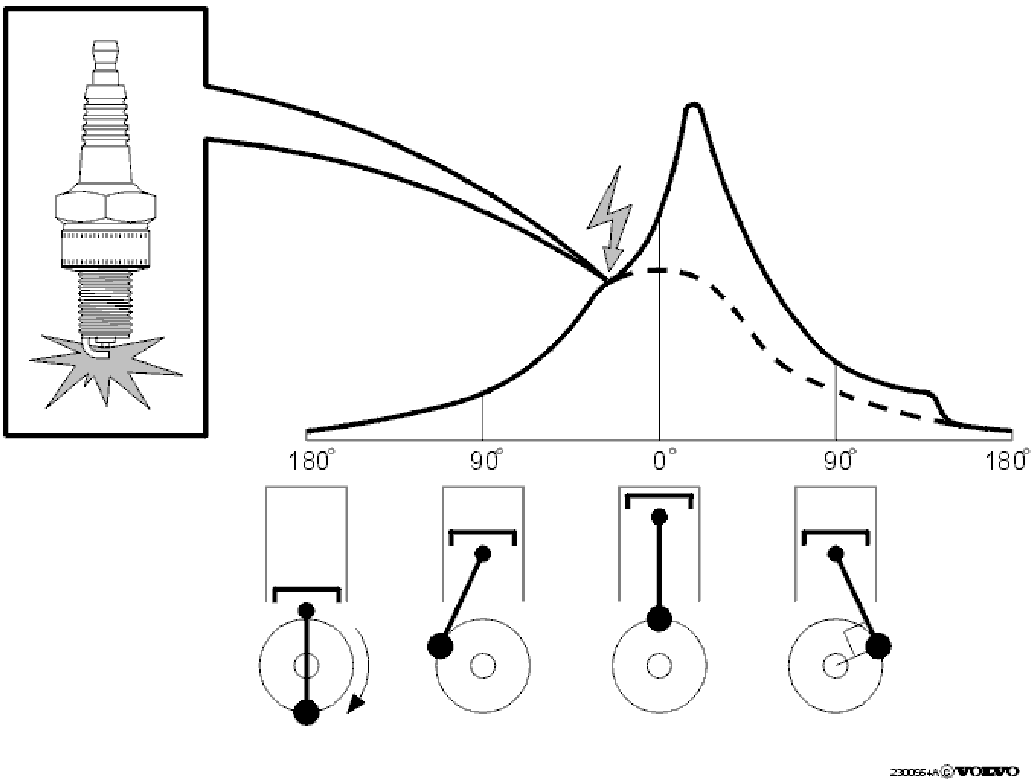
In addition the ideal ($\lambda = 1$) must be deviated from in certain circumstances, when starting the car, at wide open throttle (WOT), under acceleration for example.

What does gasoline and air consist of?

In percent weight gasoline consists of 84% C (carbon) and 14.8% H_2 (hydrogen) The rest is oxygen and nitrogen among other things.

Dry air at normal pressure consist as a volume percent of 78% N_2 (nitrogen), 21% O_2 oxygen, 0.92 argon and other noble gases and 0.03% CO_2 (carbon dioxide).

14 kg dry air at normal pressure corresponds to approximately ca 12200 dm^3 (l) if the temperature is approximately +20 °C(68°F).

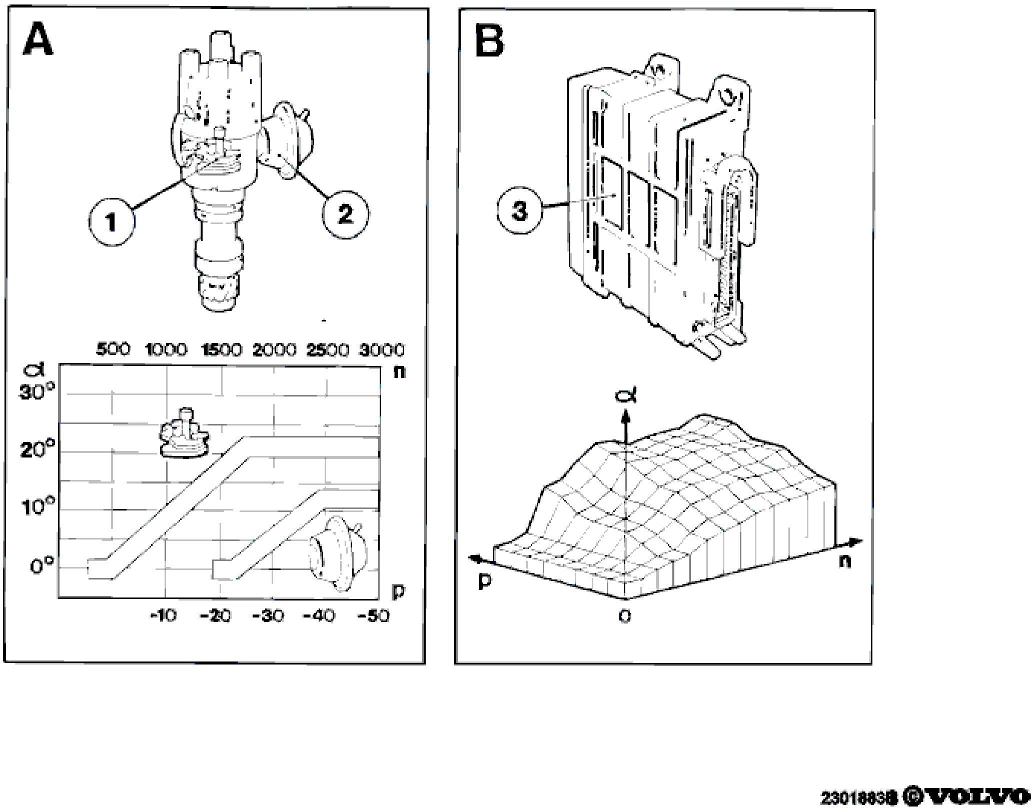


When is the best ignition setting?

The best ignition setting is when as much work as possible is taken out of the fuel/air mixture.

To extract as much energy as possible the combustion pressure should be at its greatest just after top dead center (TDC) This is to use the pressure as much as possible before the angle between the connecting rod and the crankshaft lever is 90° . After 90° angle the angle reduces again and means that the extracted power is lost.

Because combustion always takes a certain time the mixture must be ignited before top dead center (TDC) so that the pressure has time to build up.



Why are different ignition settings required depending on engine speed (RPM) and load?

Constant combustion speed

With one and the same mixture relationship between air and fuel the combustion speed (approximately 30m/s) and therefore combustion time (approximately 2 ms) are constant.

Higher engine speed (RPM) requires earlier ignition

Because the combustion speed / time is essentially constant the combustion must start earlier at higher engine speeds.

This is so that pressure has time to build up and that the maximum pressure is achieved at the correct piston position.

On breaker controlled ignition systems this is controlled by a centrifugal regulator(1).

Higher loads require later ignition

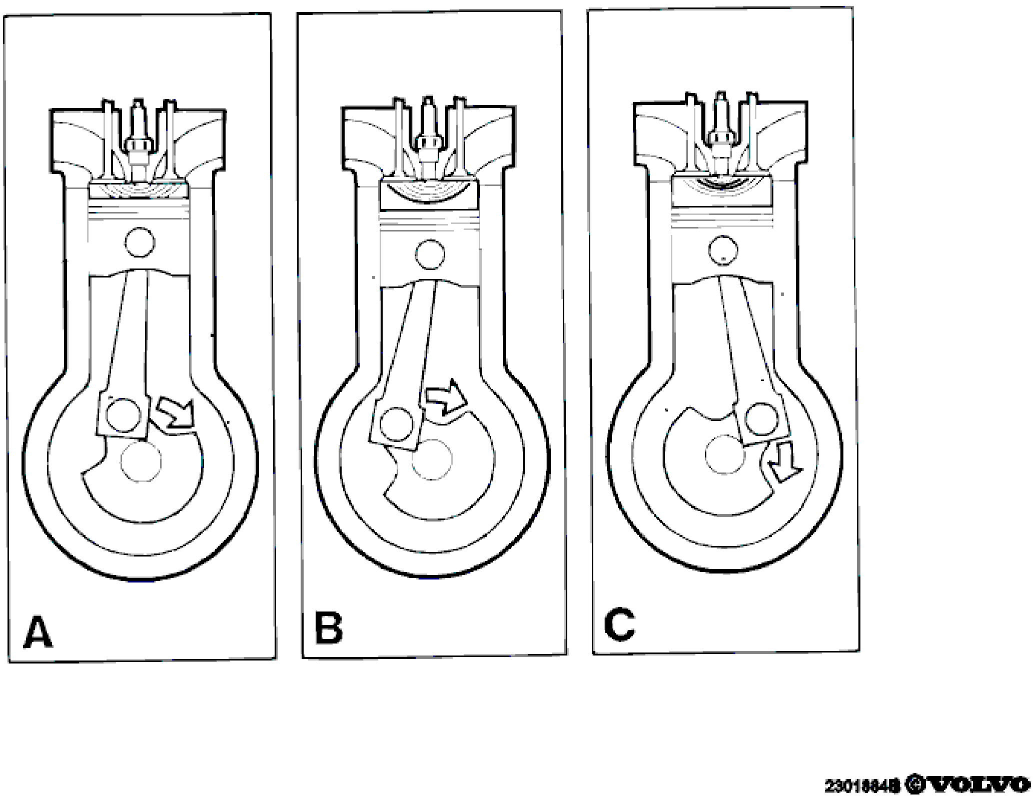
With high loads (large opening in the throttle and low engine speed (RPM)) there is a large amount of fuel/air mixture in the cylinders. This gives a high compression.

Because the combustion speed / time is essentially constant the combustion must start later at high loads. Otherwise the high compression and the large amount of mixture that is ignited will result in the combustion pressure being too high too early.

On breaker controlled ignition systems this is controlled by a vacuum controller (2).

The preprogrammed values in the control module

On electronic systems, all control is dealt with by a control module (3). This contains preprogrammed values which result in precise control. A further advantage with the electronic system is that several factors are able to influence the ignition position, for example the engine coolant temperature (ECT).



When is the correct ignition setting?

Correct ignition setting (A)

There is no set value. It varies depending on, for example, engine speed (RPM), load, the fuel air ratio and temperature.
When selecting the ignition setting, the desired handling, the design of the

combustion chamber, the idle trim quality, the condition of the engine and emission regulation etc must be taken into account.

When discussing the correct ignition setting (A), we mean an ignition setting that takes into account all the factors affected by the ignition. It is also a compromise between the need for high voltage, low fuel consumption and the cleanest possible emissions.

Early ignition (B)

Results in higher combustion temperature but lower exhaust temperature.
The combustion temperature increases because the combustion pressure is higher in the event of earlier ignition. The exhaust temperature falls because the combustion has been completed for a longer period before the exhaust valves open. More energy in the fuel is used for mechanical work and less energy is lost in the form of heat loss. In general, the aim is to regulate the ignition so that it is as early as possible while taking into account the load and engine speed (RPM).

However too early ignition result in too high combustion pressure and too high combustion temperature. It also increases the risk of self ignition, in other words the engine is knocks. Furthermore the release of exhaust gases is affected negatively and there is a risk of engine damage.

Late ignition (C)

Results in lower combustion temperature but higher exhaust temperature. The combustion temperature will be lower because the combustion pressure is lower. This is because greater amounts of energy are released when the piston is a long way down. The increase in exhaust temperature is because combustion is completed closer to the exhaust valve opening, and less mechanical efficiency is achieved. As a result more energy is converted to heat.

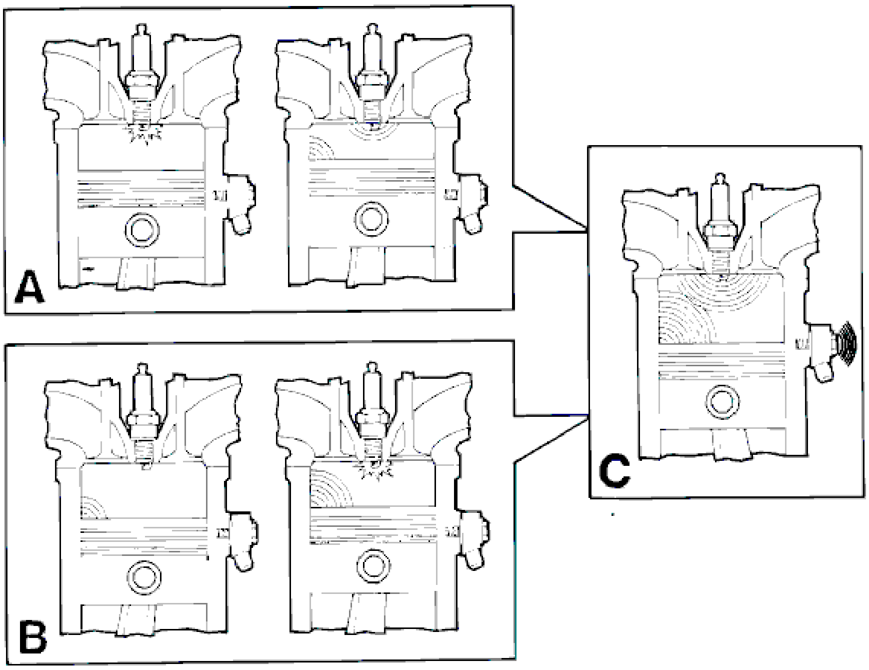
Delayed ignition results in poor power because the increase in pressure comes too late. Therefore the energy content of the fuel is poorly utilized. In addition the emissions are negatively affected and fuel consumption increases.

Different expressions used to describe

ignition settings

Earlier ignition = Ignition increase = Increased ignition advance = Ignition occurs when the piston is further from top dead center (TDC).

Later ignition = Ignition reduction = Reduced ignition advance = Ignition occurs when the piston is closer to top dead center (TDC).



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What is knocking?

Combustion normally spreads from the spark plug at a speed of approximately 30 m/s.

In certain cases self ignition can also occur in certain parts of the fuel/air mixture. Self ignition is not combustion. It is an explosion that occurs at a speed above 300 m/s. The result of self ignition is that two or more flames spread out in the combustion chamber. Knocking (harsh metallic sound) is the collisions between different flame fronts.

The effects of knocking

Knock results in an extremely quick and powerful pressure and temperature increase. A knocking series is hazardous for the engine. However a single knocking is normally harmless.

Different types of knock

Self ignition can occur before or after the spark plug has produced an ignition spark.

After the spark has been produced (A)

- When the flame front spreads out from the spark plug, the temperature and pressure increase. This can cause self ignition in another part of the fuel/air mixture. This is sometimes called "compression knock" or "ignition knock".

Before the spark has been produced (B)

- When the flame front spreads out from the spark plug, the temperature and pressure increase. This can cause self ignition in another part of the fuel/air mixture. This is sometimes called "compression knock" or "ignition knock".

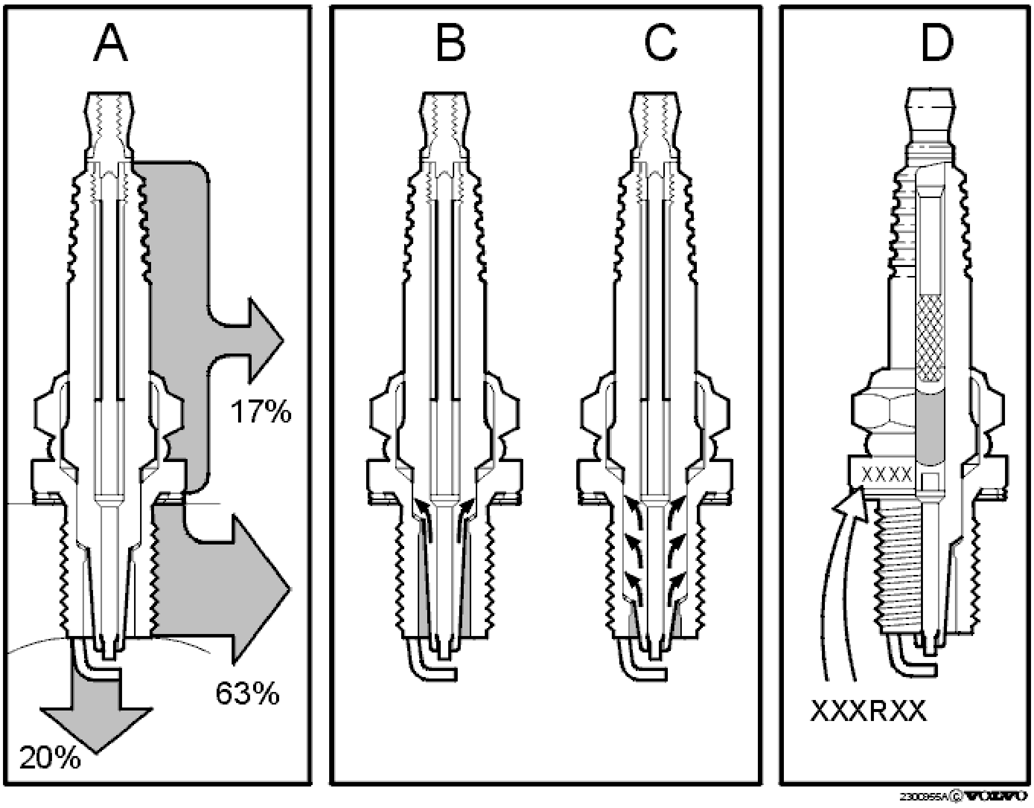
How is knock counteracted?

In principle this can be occur in two ways

- Later ignition which results in lower combustion pressure and temperature.
- Richer fuel/air mixture which results in a lower combustion temperature because the fuel cools down.

Some possible causes of knocking

- Premature ignition. Results in increased combustion pressure and increased temperature.
- Fuel with too low octane. The octane content is a gauge of the capacity of the fuel to resist self ignition.
- Too little fuel (lean fuel/air mixture). Results in a high combustion temperature. May be due to, for example, low fuel pressure, a blocked fuel filter, failure to enrichen the mixture during acceleration or at wide open throttle (WOT), or air leakage in the intake system.
- Poor fuel distribution. If the fuel is not mixed efficiently with the air, the temperature may increase in certain parts of the fuel/air mixture. This can be caused by poor swirl development. This can be due to, for example, deposits in or on the injectors or a build up of carbon either on the valves or in the combustion chamber.
- Faulty or worn spark plugs. In the event of incorrect heat range or coating the spark plugs may become too hot. As the spark plug deteriorates the distances between the electrodes increases. A higher ignition voltage is then required to produce a spark. This can affect the ignition setting.



The spark plugs must be highly tolerant

The spark plugs must be able to tolerate the rapid pressure and temperature variations which occur in the combustion chamber. During the compression phase the temperature can rise to 2500°C (4532°F) and the pressure can reach a value of 60 bar. Shortly thereafter, during the intake phase, there is little negative pressure and the spark plugs come into contact with the fuel/air mixture. The fuel/air mixture temperature may be very close to that of the outside temperature.

Correct operating temperature

The temperature of the spark plug must be approximately 400 °C (752°F). This is so to obtain a self cleansing effect which burns of any carbon.

The maximum temperature should not exceed approximately 850 °C (1562°,F) so that the spark plug does not cause self ignition.

Excess heat must be led away from the spark plug. Illustration A displays the principle of how excess heat is led away. Approximately 17% of the heat is directed to the surrounding air, 63% should be transferred to components and approximately 20% is transferred out in to the combustion chamber. For this to be achieved, it is extremely important that the spark plug is tightened to the correct torque and that any gasket is in good condition.

Correct heat tolerance

The heat tolerance indicates the heat the spark plug is able to tolerate without becoming too hot and causing self ignition.

Spark plugs are available with different heat tolerance. These are for different engine types and operating conditions so that they operate at the correct operating temperature.

Hot plugs (B) have a long insulator foot which absorbs a great deal of heat. They have little heat transfer.

Cold plugs (C) have a short insulator foot which absorbs little heat. They have god heat transfer qualities.

Ignition system disruption

When the ignition system is operating, sparks are generated at the rotor and spark plugs. This causes voltage peaks (interference pulses) which bounce back in the system. These can disrupt for example radio reception.

Ignition cables with resistance were previously used to dampen these interference pulses. Nowadays it is normal to use rotors and spark plugs with built-in resistance. This is because interference should be dampened as close to the source of interference as possible.

Spark plugs (D) with built-in resistance normally have an "R" in the type designation.

The ignition system should be able to

In order to provide a summary of what a modern ignition system must be able to do, the following is a number of numerical examples. Note that the digits are only approximate.

- Produces 25 sparks per second and for each cylinder at 6000 rpm.
- Generate a peak voltage of above 30 kV (30 000 V).
- Transfer the spark to the spark plug in 0.033 - 0.005 seconds.
- Generate a peak voltage in 0.020 - 0.004 seconds. The actual spark time at the spark plugs is only 0.00300 - 0.00047 seconds.