CHAPTER 2 – OPERATING CYCLE

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Operating Cycle – Four Stroke

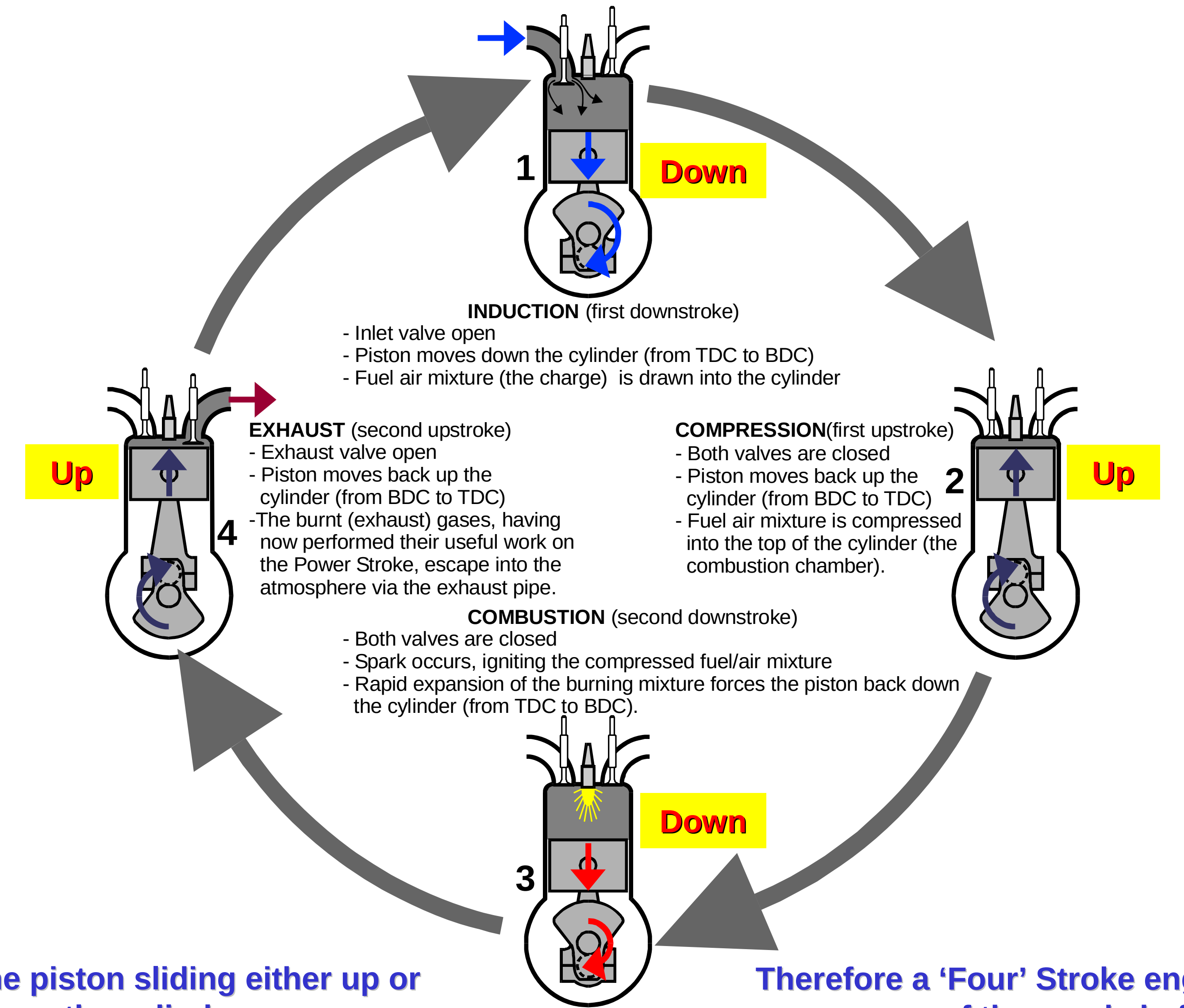
The four stroke piston engine is so called because to complete one operating cycle, the piston must travel along the cylinder four times as follows: -

Induction	**Down**	**Suck**
Compression	**Up**	**Squeeze**
Power	**Down**	**Bang**
Exhaust	**Up**	**Blow**

That means that one cycle is completed for every *two* revolutions of the crankshaft.

This is explained in greater detail in the following pages.

The four stroke cycle is also referred to as the ‘Otto’ cycle, named after Nicolaus Otto, a German engineer who produced the first functioning engine using the four stroke cycle.



1 'Stroke' = the piston sliding either up or down the cylinder

Therefore a 'Four' Stroke engine is 2 revs of the crankshaft

Operating Cycle

Operating Cycle – Four Stroke Cycle

The illustration below shows the four strokes and the two revolutions of the crankshaft i.e. one complete cycle.

However, the four parts to the cycle i.e. Induction, Compression, Power, and Exhaust do not start and stop at Top Dead Centre and Bottom Dead Centre.

For instance, Induction actually starts whilst the piston is still travelling upwards and Compression occurs in less than the distance travelled in one stroke.

The reasons for this are: -

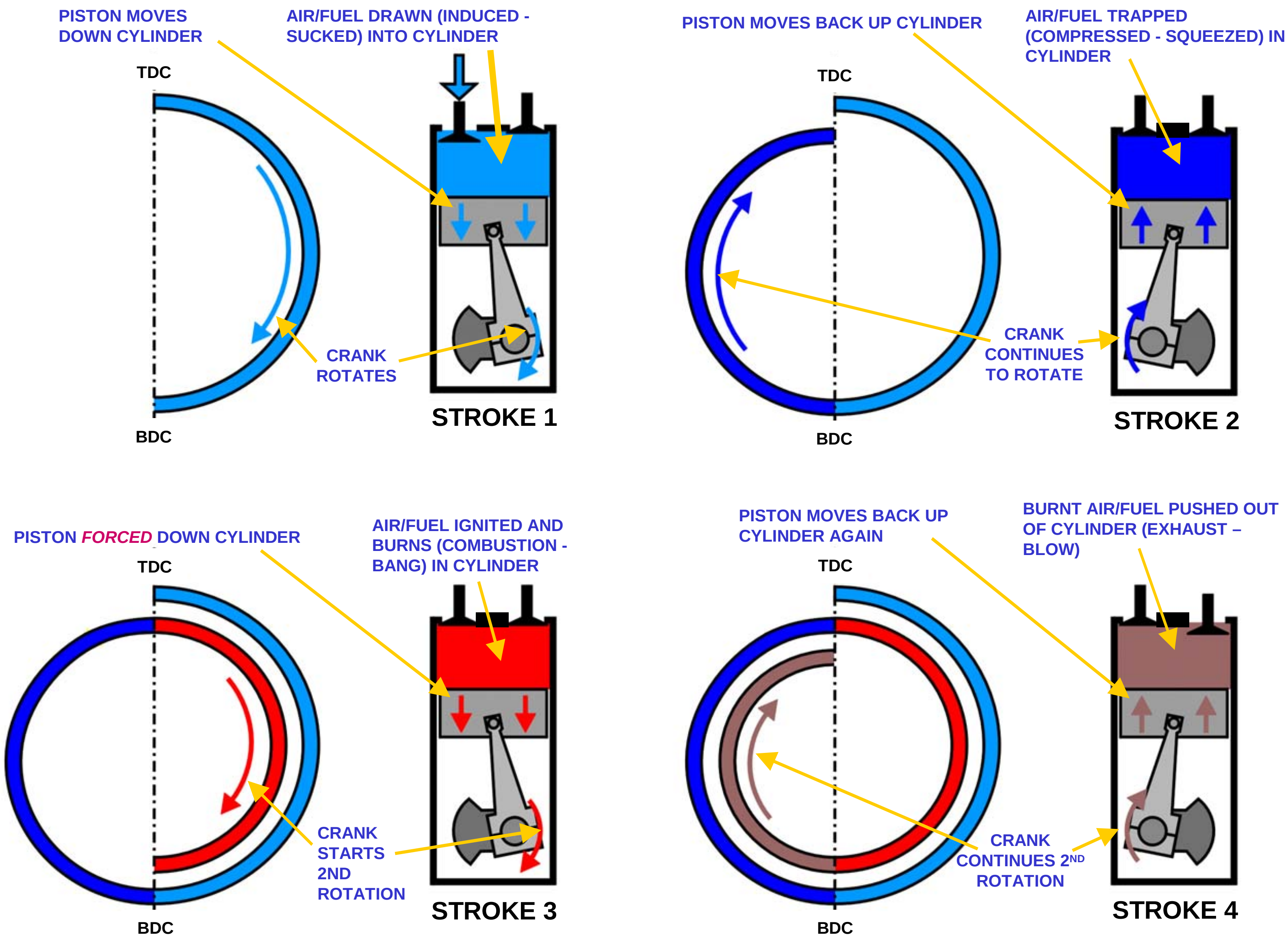
1. Combustion is not instant – it is a rapid burning process.

2. Valve operation is also not instant – it is impossible to get the valves to open/close instantly at TDC or BDC. This is because the rotating cams which are driven by the crankshaft need to have a gradual change in the lobe depth to be able to rotate; a step change would simply cause destruction of the valve mechanism.

Another point to note is that the mechanical timing of the valves is optimum only for a narrow band of RPM (most probably a cruise level RPM) where the engine spends most of it’s operating time.

However, engine manufacturers are continually striving for improvements in efficiency, i.e. getting more power out of the engine for the least fuel consumption.

This is the reason manufacturers are introducing various intricate methods to control items such as the valves to be optimum over a wider range of RPM, and to improve the opening and closing times.



Operating Cycle

OPERATING CYCLE – Valve Timing

The following is a description of the engine operating cycle based on the rotation (angular position) of the crankshaft – beginning at the start of the induction stroke.

30 Deg before TDC

Inlet valve begins to open – start of induction

At this point the exhaust valve is closing and the last of the exhaust gases are being pushed out of the exhaust valve by the rising piston.

Top Dead Centre – Induction Stroke

Piston gets to the highest point in the cylinder and then starts to travel downwards. Suction effect pulls in fuel/air mixture.

15 Deg after TDC

Exhaust valve fully closes – end of previous exhaust stroke, and induction stroke continues.

Bottom Dead Centre – Compression Stroke

Piston reaches lowest position in the cylinder – compression stroke starts.

15 Deg after BDC

Inlet valve closes - end of induction stroke, fuel/air mixture trapped in the sealed cylinder above the piston, start of compression.

30 Deg before TDC – (one revolution completed)

Spark Plug energized and ignition occurs – trapped and compressed fuel/air mixture starts to burn.

Top Dead Centre - Power Stroke

Heat from combustion starts to expand the trapped and compressed fuel air/mixture - full combustion does not take place instantly. Piston is forced down the cylinder by gradually increase pressure rise due to heat expansion of the gases.

15 Deg before BDC

The exhaust valve starts to open – end of power stroke, burnt gases start to escape through the exhaust valve.

Bottom Dead Centre – Exhaust Stroke

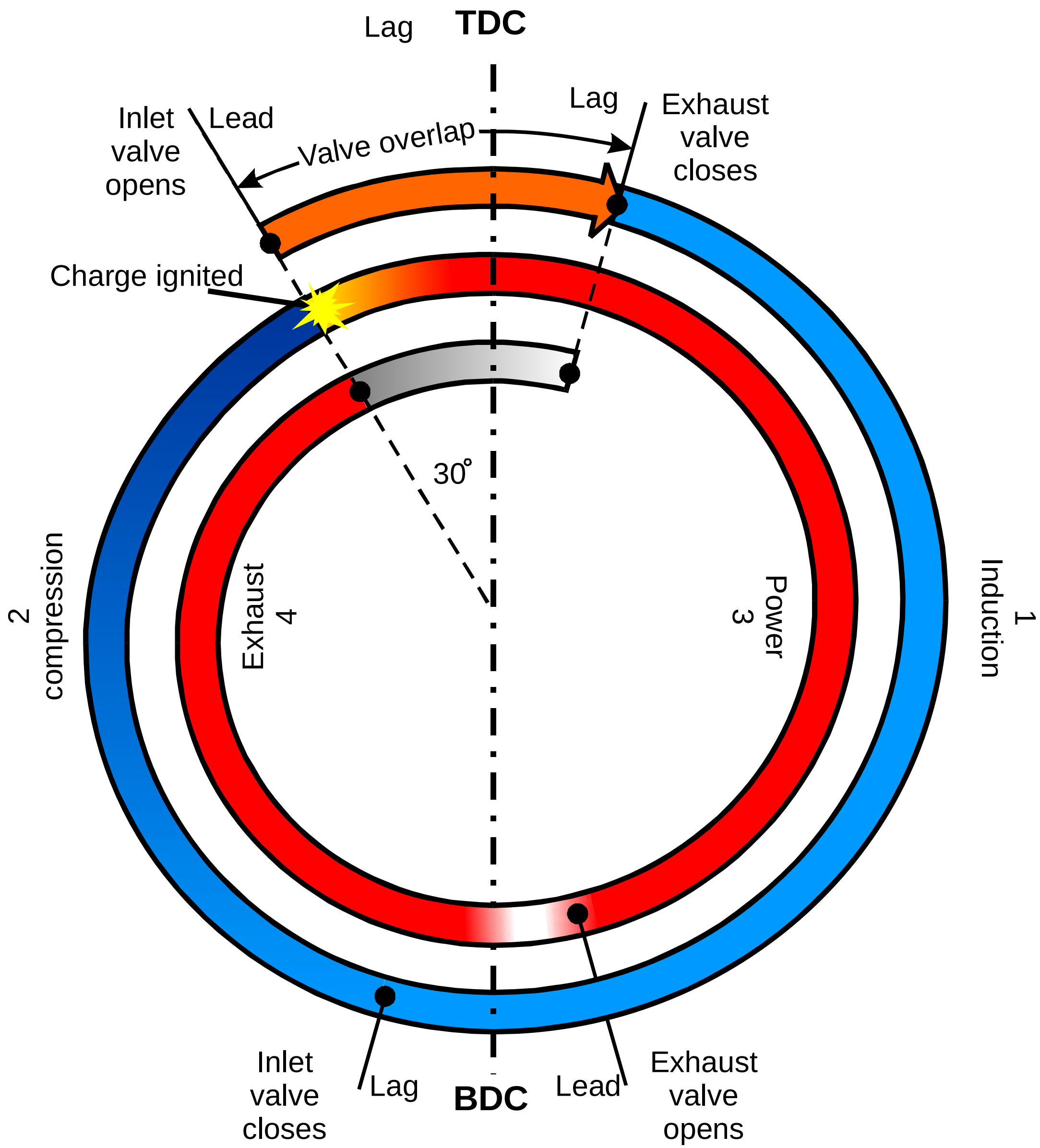
Piston reaches lowest position in the cylinder and starts to rise – piston pushes burnt gases out of the exhaust valve as it rises.

30 Deg before TDC

At this point the exhaust valve is closing and the last of the exhaust gases are being pushed out of the exhaust valve by the rising piston.

Inlet valve begins to open – start of induction

And the process starts all over again and continues until the power to the ignition system is switched off.



Operating Cycle

OPERATING CYCLE - Valve Timing (continued)

The following is a description of various crankshaft angles and other features.

TDC – Top Dead Centre

The absolute top limit of piston travel, a position when the centres of the crankshaft, the crankpin (*above* the crankshaft) and the piston are all in line.

This position gives maximum compression.

BDC Bottom Dead Centre

The absolute bottom limit of piston travel, a position when the centres of the crankshaft, the crankpin (*below* the crankshaft) and the piston are all in line.

This position gives maximum volume in the cylinder.

Compression Ratio

This is the ‘Swept Volume’ i.e. the difference between the space above the piston at BDC and TDC.

Engine Size

The volume in the cylinders when the piston is at BDC multiplied by the number of cylinders.

I.e. an engine described as a **1 Litre inline 4** describes a four cylinder engine, all cylinders inline with each other, with each cylinder having a quarter litre capacity.

The various engine layouts are described in a later section.

Valve Lead

A valve operating angle *before* either TDC or BDC.

Valve Lag

An valve operating angle *after* either TDC or BDC.

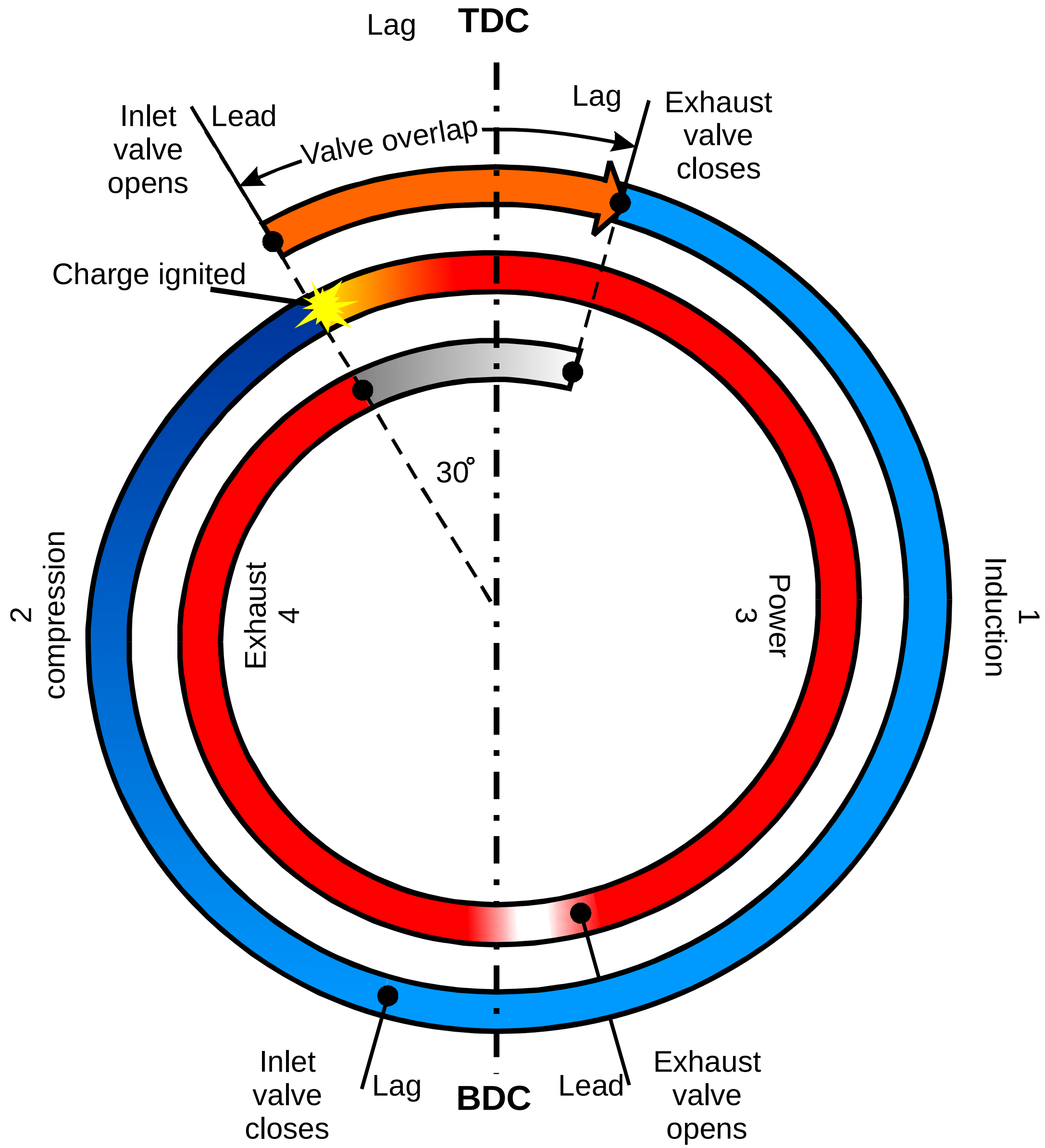
Valve Overlap

Occurs between 30 degrees before and 15 degrees after TDC where both valves are partially open; the exhaust valve is closing and the inlet valve is opening.

Ineffective Crank Angle

An arc of travel at TDC and BDC where there is very little piston movement.

If you consider an arc of rotation over 30 degrees (15 degrees before TDC or BDC, and 15 degrees after), the up and down movement is very slight compared to the same 30 degree arc of rotation at the 3 o’clock and 9 o’clock positions.



Operating Cycle

OPERATING CYCLE – Firing Order

What we have looked at so far is the operating cycle as it takes place in one cylinder.

This cycle however operates in the same sequence in all cylinders, no matter how many.

It is necessary to ensure that all cylinders in an engine fire at different times irrespective of the number of cylinders, this is to even out the loads on the moving parts and make the engine smoother when running.

Just imagine what would happen in a 4 cylinder engine if the cylinders fired all at the same time

1. The moving parts would subjected to 4 times the load and would need to be that much stronger (and heavier) or it would disintegrate.
2. The fuel and inlet manifold would need to be bigger to cope with four times the fuel flow during the simultaneous induction strokes.
3. Similarly the exhaust would need to be bigger to cope with four times the flow at the simultaneous exhaust strokes.

All the above would make for an efficient, heavy and impractical engine with high vibration.

It can be seen in the Mechanical Arrangement section that pistons 1 and 4 move up and down together, and at the same time 2 and 3 also move up and down together. This allows for the mass of the moving parts to counter balance each other, i.e. two pistons go up whilst two pistons go down.

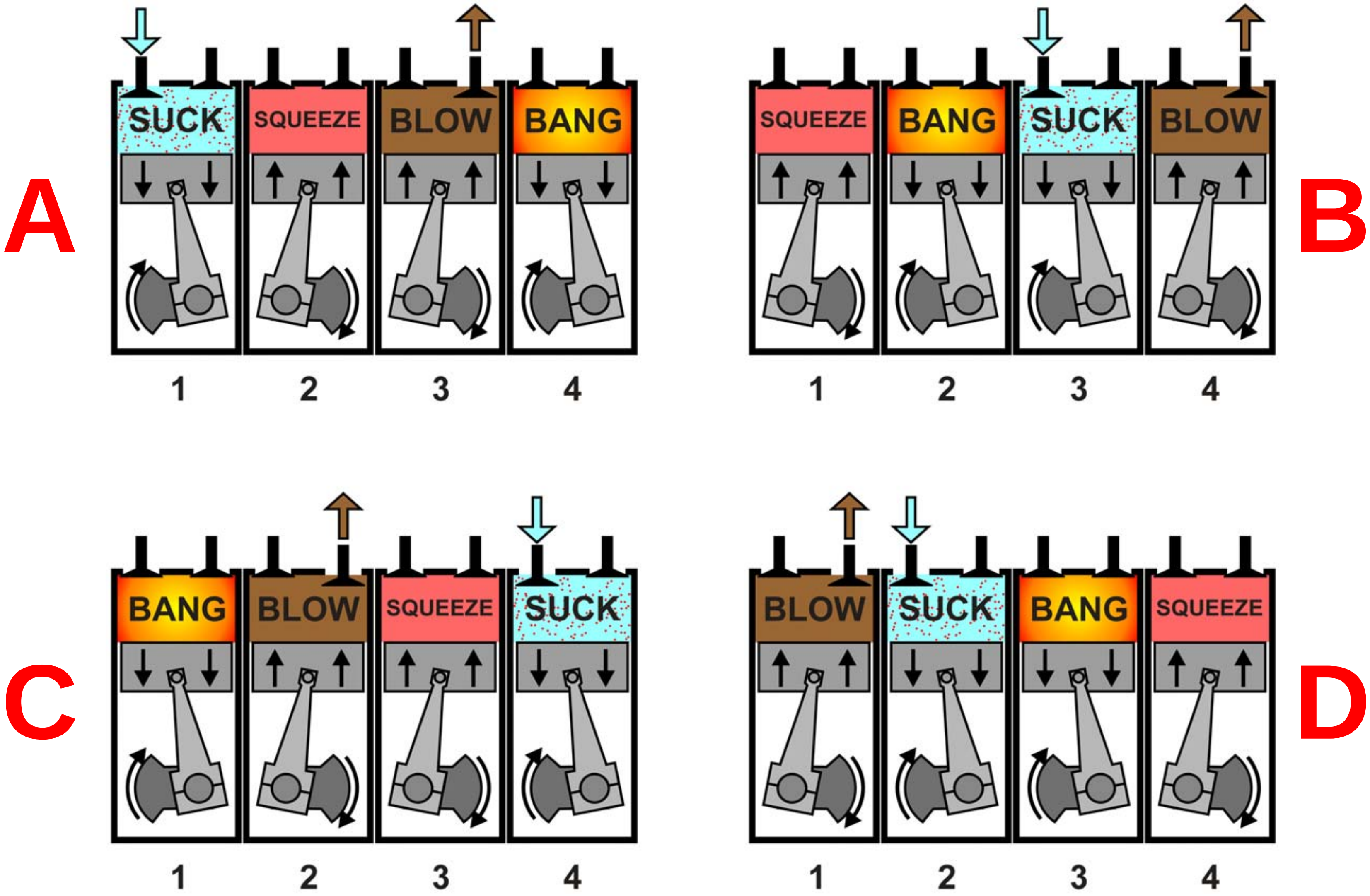
The timing in the individual cylinders (look at the combustion stroke) ensures that there are two power strokes per revolution of the crankshaft.

In a four cylinder engine the firing order is 1,3,4 2.

The illustration below shows the firing order for the engine and the correct sequence of the cycle for each cylinder.

Follow the diagrams in the A, B, C, D sequence.

Additionally, follow the sequence of events in any one cylinder and it you will see that it follows the suck/squeeze/bang/blow cycle.



Operating Cycle

OPERATING CYCLE – Firing Order (Continued)

The illustration below shows the same firing order and cyclic sequence as the previous illustration, but looking from above, and includes the inlet and exhaust systems.

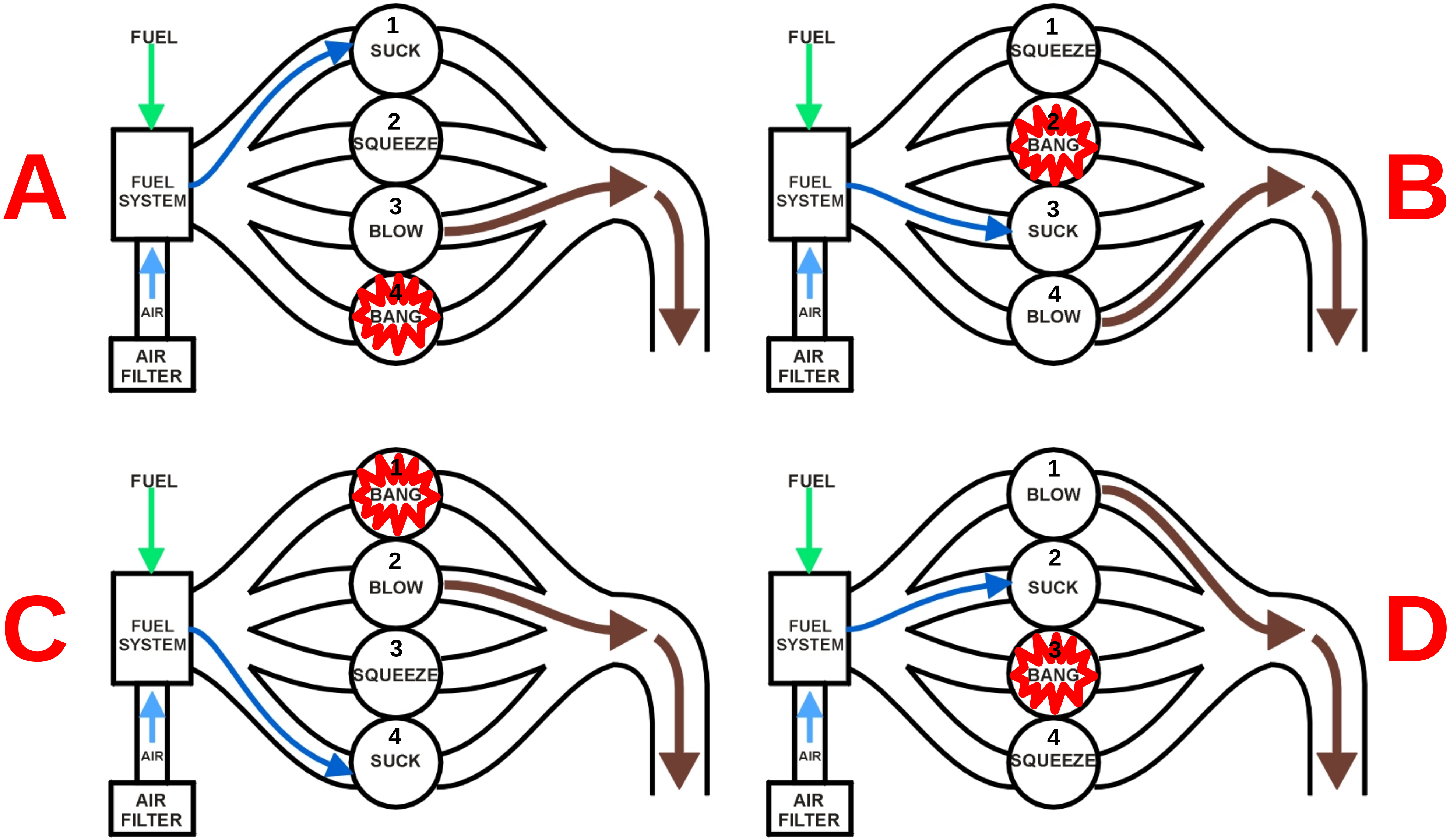
It can be seen that everytime there is an induction stroke, there is a ‘pulse’ of fuel/air mixture drawn through the inlet system; and similarly, everytime there is an exhaust stroke, there is a pulse of burnt gases through the exhaust system.

Hold your hand about 150mm (do not go any closer and be careful not to breathe the fumes) away from an exhaust pipe whilst the engine is running at ‘tick-over’, and the exhaust pulsing can be readily felt, it can also be heard as a continuous pop-pop-pop sound.

Follow the diagrams in the A, B, C, D sequence.

The combination of the cyclic sequencing and the firing order, and add to this the effect of the flywheel, ensure a smooth running engine.

Some engine manufacturers also include ‘Balancing Shafts’ within the engine. These are shafts with integral counter balance weights, but have nothing to do with the engine operating cycle. They are included to further smooth out any imbalances or vibration in the engine.



Operating Cycle