Before we take a detailed look at how the slide valve engine works, I think it would be a good time to first look at some of the important major items we will be discussing, namely the 'D- SLIDE VALVE' and the 'ECCENTRIC' and ECCENTRIC STRAP.

The 'D SLIDE VALVE'

Take a look at FIG 9a

Here we see a cross section through a typical 'D Slide valve', so named because of its appearance/resemblance to the letter 'D' laid on its side.

It is shown in its CENTRAL or MID- position on the valve seat (port face) of the cylinder with which it is associated, as defined by the line X-Y, which is the position from which all critical valve, and valve gear, dimensions are measured.

The valve seat (port face) is defined by the line A-B.

The steam PORTS and transfer passages to each end of the cylinder are shown designated as SP, and with the EXHAUST PORT designated as EP.

The curved cavity under the valve, designated EC, is the exhaust cavity and its height should be such that it allows free passage to the exhausting steam without restriction. This height should be, at the very least, equal to the width of the steam ports but typically is made about ¾ the width of the exhaust port (EP).

'O' and 'O' are known as the BRIDGES.

You will observe that the valve flanges, a-b and c-d, are shown extending beyond the steam ports EP in both directions which introduces a couple of new terms to become familiar with, namely OUTSIDE and INSIDE LAP, and these, as will be seen in later discussions, prove to be very important.
The distance, by which the edge of the valve flange extends beyond the outer edge of the steam port, when the valve is in its CENTRAL position, is called the OUTSIDE LAP.
In the diagram, e and e represent the OUTSIDE LAPS for the two ends of the valve.

The distance, by which the edge extends beyond the inside edge of the steam port, when the valve is in its CENTRAL position, is called the INSIDE LAP and is represented on the diagram by f and f for the two ends of the valve.

A slide valve with no LAP, either INSIDE or OUTSIDE, would be known as a LINE on LINE valve and the flanges would have a width equal to SP.
Such a valve, as will be seen shortly in the following discussions, cannot produce early CUT-OFF of the steam, which would be necessary for expansive working, however, it can, and is used, for some applications, which will be covered later in the series.

Eagle eyed readers, or a certain OZZIE, will note that the way the valve is being driven, in fig 9a, differs from that shown in FIG 8, have no fear, it is all in order.

There are several methods used for this, and the ones shown in the two diagrams represent different approaches. Both types are used extensively, as are several others.

The object is to be able to move the valve, from side to side (or up and down on a vertical engine/valve) along its seat with a negligible amount of end play, which would detract from motion accuracy, but at the same time allowing the valve to have sufficient vertical movement to permit steam pressure to press the valve onto the valve seat and maintain a good steam seal, even after many hours of running.
The method used must also allow for the position of the valve to be adjusted so as to be in the correct position relative to the piston, crankshaft, and eccentric etc.

In fig 8, the valve steam, or valve rod, passes through a slot, cast into the top of the valve, which is both wide enough and deep enough to permit this vertical movement and the positional adjustment is made via the threaded section with nuts and lock nuts at either end of the valve.
This would be internal (inside the steam chest) adjustment.

The method shown in fig 9a uses a closely machined strap, or BUCKLE, which fits over a mating machined area at the top of the valve, and completely surrounding it.
The machining tolerances are such that the valve can lift up and down vertically, to maintain correct contact with the port face, but with little or no end float.
The valve stem/valve rod is rigidly attached to the BUCKLE, either welded to it, or cast with it, and machined as required, and the adjustment would take place outside the steam chest, using e.g. a sleeve connector arrangement having left hand and right hand threads at opposite ends, and which would be located in the valve stem, between the valve chest and the valve crosshead, or may even be part of, or incorporated into, the valve crosshead.

This, would you believe, would be termed external adjustment.

Occasionally, both methods of adjustment are provided on an engine.

The SLIDE VALVE itself would generally be a cast iron or bronze casting.

Ok, lets look at the next items, which often causes some confusion.

The ECCENTRIC and ECCENTRIC STRAP/ROD.

The purpose of the ECCENTRIC is to convert the ROTARY motion of e.g. a crank shaft or shaft, into a reciprocating motion, with which to drive e.g. a piston or a valve/valve gear, or any other device requiring linear mechanical motion.

It was invented by WILLIAM MURDOCK, a Scottish engineer and patented in 1799.

Initially its main application was on the mine pumping engines of the time, but eminent engineers of the times, such as Stephenson, acknowledged its merits and quickly adopted it for use in railway locomotives, industrial steam engines and marine steam engines in the early/mid 1800’s and it remains in use to this day.

In marine steam engines, it is most often associated with the VALVE motion, but can also be found driving water pumps, for boiler feed water, or oil and air/vacuum pumps.

Basically, it consists of a metal disc surrounding the shaft, but having its diametric centre offset from that of the shaft, to which it is attached usually by means of a key, or collar, and bolts.

Take a look at fig 9b.

This shows such an ECCENTRIC, or to be more precise, ECCENTRIC SHEEVE, attached to a shaft with a key.
From here on, the word ECCENTRIC will be used, cos I'm lazy.

Ignoring the ECCENTRIC STRAP and ECCENTRIC ROD, for the moment, and concentrating on the circular ECCENTRIC and SHAFT…..

You will observe that the small circle representing the crankshaft is not in the middle of the circles depicting the outer edges of the ECCENTRIC, but is offset towards the bottom, in the diagram.

The actual centre of the CRANKSHAFT is shown as 'Q', however, the centre of the ECCENTRIC is offset from this and is shown as 'O'

If the shaft is rotated around its centre 'Q' then the point 'O' (the eccentric centre) would describe the circle a'- b', which is known as the ECCENTRIC CIRCLE.
The diameter of this circle is the ECCENTRIC THROW and, clearly, is twice the offset between the two centres.

The offset distance 'Q' – 'O' is known the ECCENTRIC RADIUS or ECCENTRICITY.

If a small crank, as shown on the left side of fig 9b, having an offset equal to 'Q' – 'O' were attached to the end of the crankshaft, it would describe exactly the same circle as the eccentric centre, and would impart exactly the same motion.

The outside diameter of the ECCENTRIC is largely determined by the axle/shaft to which it is attached, and must be made large enough so that after all the boring and turning operations have been carried out on it, sufficient material remains at the small part, close to the shaft, to maintain adequate strength and yet prevent the surrounding ECCENTRIC STRAP from touching the shaft.

The ECCENTRIC, is generally made from steel or cast iron and, after careful machining, is fitted to the shaft using a keyway and key, to prevent rotational movement around the shaft, and is firmly clamped in place using suitable bolts.

On occasion the ECCENTRIC or ECCENTRICS, sometimes they are in pairs as will be seen latter, are cast along with (integral) the shaft and the whole thing is then machined as one unit, however, for servicing/maintenance reasons it is not general practice.

To the casual observer, the sight of a fairly large dia lump of rotating metal, understandably, conveys the message that the motion imparted is equally large, however, as shown above, this is not the case, but it, never the less, remains the single most confusing part to visualise/understand.

So why not fit a crank instead?

The answer to this is quite simple, since, more often than not, the amount of offset required, and hence the throw required, is less than the diameter of the main shaft.

It would, therefore, be virtually impossible to machine the crank into the shaft in such a way as to retain sufficient strength in the shaft to contend with the rotational forces involved; quite simply the shaft would break.

Having said this, it is possible to include a small crank at each end of the shaft, although not actually part of the shaft, and valve gears such as, e.g. Walschaert or Baker, do use them, however, their use is more generally associated with the outside cylinders of a railway locomotive (the required cranks, known as return cranks, are then attached to the main crankpins, on the outside of the main connecting rods), with any remaining inside cylinders (yes some railway locomotives had 3 or even 4 cylinders) using one of the ECCENTRIC driven valve gears, such as STEPHENSON or perhaps a RADIAL valve gear such a JOY. These additional cylinders and associated valve gears would be located between the chassis frames of the locomotive and hence are generally not easily seen, and the valve gear is driven via one of the main wheel axles, and which, incidentally, may not necessarily be the same one the pistons drive.

The ECCENTRIC STRAP/ROD.

These items are the equivalent of the BIG END and CONNECTING ROD as would be associated with the main engine cylinders and crankshaft.

The ECCENTRIC STRAP is generally cast from bronze, but may be cast iron with bronze linings, and it is the equivalent of the BIG END of the main connecting rod. As with the main connecting rod big end, it is normally a 2-part item with its joint line being across the centre of the major outside diameter of the ECCENTRIC.
The two parts completely surround the ECCENTRIC and are prevented from slipping off of the ECCENTRIC by means of either a raised central lip, or a pair of outer raised lips.
In the former case, the STRAP would have a central groove machined into it, this groove being the same width and depth as the raised central lip + a little running clearance (sort of a circular key really).
In the later case, the 2 outer lips would be machined to be a little larger in outside dia. than the ECCENTRIC, thus creating a recess into which the STRAP could locate.
The 2 halves are joined together, and held in place, by a pair of clamp bolts passing straight through the STRAP as shown in the diagram.

Often the STRAP halves would joined with some removable shims placed between the two halves when they are clamped together, these could then be reduced in number when it became necessary to adjust for wear.
Naturally, an allowance for their inclusion would need to be made when initially machining the STRAP.

The ECCENTRIC ROD is the part that connects the ECCENTRIC STRAP with the VALVE CROSSHEAD and thus performs the same task as the main CONNECTING ROD.

Generally, there is some means included by which the overall length of the ECCENTRIC STRAP/ROD may be adjusted to the final required length.

When a valve is driven by an ECCENTRIC, or a small crank for that matter, the valve and valve gear are adjusted so that the steam port is just about to open when the PISTON is at the end of its stroke, either top or bottom dead centre.
The fact that a valve can have LAP will make a considerable difference to this, as will be seen shortly.

Another term often come across is another NEW ONE, namely LEAD.

A valve is said to have LEAD when the steam port is actually opened just before the PISTON reaches the extreme end of its stroke.
This can be beneficial in high-speed engines by allowing the inlet transfer passages to fill with steam to full boiler pressure prior to the piston reaching the end of its stroke, thus avoiding the slight drop in pressure, which would otherwise occur if the valve opened later.

On some small marine engines, such as those used for small pleasure boats, the valve was sometimes adjusted so that it opened after the PISTON had passed the end of its stroke, i.e. NEGATIVE LEAD.
This was often the case where the engine may have to be manually turned over a dead centre in order to start it (e.g. a single cylinder engine) where it was desirable to avoid kickback.

The amount/distance the valve is open, or not, as the case may be, when the PISTON is at the extreme end of its travel, is termed the STEAM LEAD, and it may be POSITIVE or NEGATIVE.

The amount of STEAM LEAD required would be added to the LAP dimension, when initially setting the valve and valve gear.

Ok, that just about covers all the bits so lets have a look at how it all works: -

First off we will look at the sequence of events when using a slide valve of the LINE on LINE type…. i.e. one with no LAP and also with no LEAD

NOTE WELL…. In the diagrams that follow, it should be noted that they are not, in any way, to scale, but are deliberately distorted in that the ECCENTRIC centre dimension (offset) is exaggerated, also the main CRANK radius is not true to the stroke length and the rod lengths are not true to size and may, indeed, vary between the individual diagrams.

These distortions were made to make the diagrams easier to view/understand and serve only to observe, and hopefully more clearly, the relative positions of the slide valve, the various items of valve gear, and other engine parts, at specific, important, times during the cycle of events.

In this sense they are no less accurate.

Take a look at fig 10.

This shows a single DOUBLE ACTING cylinder having an OUTSIDE ADDMISSION (steam admission is controlled by the outside edges of the valve) slide valve having neither LAP or LEAD. I.e. a LINE on LINE valve.

The CRANKSHAFT centre is at ‘S’

The ECCENTRIC centre is at ‘c’, making the ECCENTRIC THROW 2 x ‘S’-‘c’.

The Crankpin is at ‘d’

The Main CROSSHEAD is at ‘b’

The valve stem CROSSHEAD is at ‘a’.

Rod ‘a’ –‘ c’ represents the ECCENTRIC ROD.

Rod ‘b’- ‘d’ represents the main CONNECTING ROD.

The direction of rotation is to be CLOCKWISE and the various components will move in the directions as shown by the arrows.

So let us now follow the sequence of events through one complete revolution of the CRANKSHAFT.

In fig10A: - the PISTON is in the TOP DEAD CENTRE position and about to begin its stroke and the slide valve is in its CENTRE position with neither the steam or exhaust ports being open, but just about to open.

As can also be seen, the ECCENTRIC centre ‘c’ is set at a 90degree angle to the crank; in other words, the ECCENTRIC is said to lead, or precede, the CRANK by 90degrees. (Eccentric lead = 90 degrees)

The slightest clockwise rotation of the CRANK will cause the ECCENTRIC centre ’c’ to move away from the cylinder, which in turn will cause the valve to move to the right.
The LEFT OUTER edge of the valve will open the left port to STEAM and the right port is opened to EXHAUST by the RIGHT INNER edge of the valve.

The steam entering the left port pushes the piston along the bore and any steam, which may be in the cylinder to the right of the PISTON from a previous stroke, will be expelled via the right port into the EXHAUST CHAMBER/PORT.

In fig 10 B: - the ECCENTRIC centre ‘c’ has now moved to its furthest extreme right position and the valve is now in its fully open position.
The piston has moved to approx it’s mid-position along the cylinder.

It would be exactly in its central position if the effects of angularity of the connecting rod were ignored. We will meet this angularity issue, and its effects, again in future instalments.

To continue: -

At this point any further rotation of the CRANK will cause the valve to change direction and begin to close the ports again, however, the piston remains moving in the same direction.

The cycle continues with the PISTON moving towards the bottom of its stroke and with the VALVE now moving in the opposite direction, progressively closing the steam and exhaust ports

In fig 10C: - The PISTON has now completed it stroke with the CRANK ‘d’ at its extreme right position (BOTTOM DEAD CENTRE) and the VALVE has JUST closed both the steam and exhaust ports again and the engine is ready to start the other half of its revolution cycle.

As the CRANK continues its rotation and passes through BOTTOM DEAD CENTRE, the VALVE now opens the RIGHT port to the STEAM and the LEFT port is opened to EXHAUST and the PISTON is driven back along the bore.

After 90 degrees of rotation from the position in fig 10C we arrive at fig 10 D: - where the valve is now at it’s extreme left position and the ports are again fully open.

Further rotation now causes the VALVE to reverse its direction again and, just as with the previous stroke, it begins closing the STEAM and EXHAUST ports. With further progress through the remainder of the stroke we arrive at fig10 E: - with the PISTON back at TOP DEAD CENTRE and just about to change direction and with the VALVE back at its CENTRAL position with all ports JUST having closed.

The cycle, fig 10 A – fig 10 E repeats as further revolutions continue.

The sequence diagrams in fig 10 show us conclusively that, with no LAP or LEAD, the slide valve permits the steam to be admitted to the cylinder for the FULL STROKE of the engine and, as a consequence, that there can be no steam CUT_OFF, and therefore, no useful EXPANSIVE use made of the steam.

In conclusion the following is now evident: - with a plain D SLIDE VALVE of THE LINE on LINE format, operated by a single ECCENTRIC, there can be no CUT-OFF of admitted steam until the end of the stroke, and thus, no useful work from expansion of the steam can be obtained.

Apart from a slight reduction in steam losses, generally associated with the more exposed rubbing/sliding surfaces, this is clearly no better than the results obtained from the oscillating engine, but what if: - the VALVE has LAP?

Take a look at fig 11 and fig 11a.

It may also be of use to have the HYPOTHETICAL INDICATOR DIAGRAM fig 4 from an earlier chapter available, as some reference will be made to this in the discussion that follows.

Fig 11 A; - shows the same single cylinder etc and again the PISTON is at TOP DEAD CENTRE (TDC), however, this time you will notice that the slide VALVE is no longer shown as closing both ports, and is also in a slightly different position to that shown in fig 10 A.

This VALVE has both OUTSIDE and INSIDE LAP.

The other major thing to observe is the effect that the LAP has had on the position of the ECCENTRIC, which is now no longer set at 90degrees to the CRANK.

So what is going on?

As before, it is necessary for the VALVE to be in a position where the STEAM inlet port is just about to open (no steam LEAD is being used in this example), and in order for this to be achieved it is necessary to move the VALVE to the right, away from its CENTRAL position, to bring the LEFT outside steam edge in line with the outer edge of the left steam port.
No, this is not done by shortening the valve stem, or by adjusting the valve on the stem; but is accomplished by rotating the ECCENTRIC centre ‘c’ away from its original 90degree position (‘c^{1}’ on the diagram fig 11 A) to a new location (‘c’ on the diagram fig 11 A) some further number of degrees ahead of the CRANK. (Eccentric lead now = 90 degrees + lap degrees)

The actual additional angular advance (lap degrees) required being dictated by the OUTSIDE LAP distance of the VALVE.

Notice also that the right port is already partially open to EXHAUST, allowing steam on this side of the PISTON to exit to the atmosphere via the EXHAUST PORT.
This early exhaust opening is a direct result of the additional valve displacement attributed to/by the OUTSIDE STEAM LAP.
Whilst the size of the exhaust port is limited my practical mechanical considerations, the exhaust path is not entirely free and therefore some pressure will be present on the exhaust side of the PISTON. The early, partial, opening does, however, provide the advantage of reducing the internal cylinder pressure on the exhaust side of the PISTON, which will now meet with less backpressure during its subsequent power stroke.

Back to fig 11A: -

The slightest clockwise rotation of the crank will cause the VALVE to open the left STEAM PORT and the PISTON begins its stroke. This is actually point ‘A’ on the

HYPOTHETICAL INDICATOR DIAGRAM (fig 4). And is the start of the ADMISSION phase.

The stroke progresses through fig 11 B where you can see that the right port is now fully open to exhaust and continues through to fig 11 C.

Here you can see that the ECCENTRIC centre has now reached its maximum travel and that the left steam port is also now fully open.
Any further rotation will now cause the ECCENTRIC to begin closing the VALVE again, even though the piston has not yet reached its mid point of travel.

As the stroke continues, with the PISTON moving in the same direction, but with the VALVE now moving in the opposite direction, we arrive at fig 11 D.

This is another important point in the cycle.

You can clearly see that although the PISTON still has a fair way to go, to the end of its stroke, the VALVE has just CLOSED the left port to STEAM.
This is the elusive CUT-OFF point we have been looking for and is shown as point ‘B’ on the HYPOTHETICAL INDICATOR DIAGRAM (fig 4).

From here, until the end of the stroke the PISTON is now pushed only by the EXPANSION of the steam already admitted to the cylinder.
Notice also that the right port (exhaust) is also now almost about to close.

In fig 11 E: - Is reached only a few degrees further on from fig 11 D and also represents an important point in the cycle.

You can see that the inner right edge of the VALVE has JUST CLOSED the right port to EXHAUST, which is point ‘D’ on the HYPOTHETICAL INDICATOR DIAGRAM (fig 4) and it is the start of the COMPRESSION PHASE.

From this point on, until the end of this stroke, any remaining steam on the right side of the PISTON will now be compressed until it approaches the boiler steam pressure.

In fig 11 F: - The stroke has now progressed almost to its end, and you will see that the inner LEFT edge of the VALVE has JUST begun to open the left end of the cylinder to EXHAUST.

This is the end of any meaningful EXPANSION and is termed the point of RELEASE.
On the HYPOTHETICAL INDICATOR DIAGRAM (fig 4) this is Point ‘C’, and is the final important point in the complete cycle.

A few degrees more of travel brings the PISTON to the end of its stroke as shown in fig 11 G.

Here the PISTON is at BOTTOM DEAD CENTRE (BDC) and about to begin its return stroke, the right outer edge of valve is in line with the outside edge of the right port and just about to open the right port to STEAM.

The steam from the previous stroke is exhausting through the left port and the CRANK and ECCENTRIC are both diametrically opposite their positions in fig 11 A.

The sequence fig 11 A, through fig 11 G, now repeats for the return stroke with the exception that the original VALVE, PISTON and ECCENTRIC directions are reversed.

The Effects of LAP.

By careful study of the diagrams (fig 11 A, to fig 11 F) the effects of varying the LAP should be seen.
For example: - in fig 11 D, it should be evident that if the OUTSIDE LAP were less, then the VALVE would not close the left port when its centre was in the position shown; as a consequence, the PISTON, and the ECCENTRIC would have to move further ahead in the stroke before the VALVE could move back far enough to close the port. This, of course, would mean the CUT-OFF would take place later in the stroke and shorten the EXPANSION. Conversely, if the VALVE had a greater amount of OUTSIDE LAP, then the VALVE would CUT-OFF the steam earlier in the stroke, thus extending the EXPANSION.

Hence, increasing the OUTSIDE Lap means an earlier CUT-OFF and an increase in EXPANSION, while a decrease in OUTSIDE LAP would result in a later CUT-OFF and a decrease in EXPANSION.

When considering the effects of INSIDE LAP: - in fig 11 E, if the INSIDE lap had been less, then the EXHAUST would not have been closed so soon, as a consequence the COMPRESSION would have begun later; on the other hand, had the INSIDE LAP been greater, then the COMPRESSION would have begun earlier.
Fig 11 F: - shows us that with a diminished INSIDE LAP, the opening of the EXHAUST, (RELEASE) would take place earlier; while with an increased INSIDE LAP, the RELEASE would have taken place later in the stroke.

Hence, increasing the INSIDE LAP increases COMPRESSION and delays RELEASE, and a decrease in INSIDE LAP results in a decrease in COMPRESSION and an earlier RELEASE.

Clearly then, the task of designing a slide valve having LAP, and an appropriate eccentric to drive it with, for an engine employing expansive working, requires the design engineer to have considerable amount of information regarding the precise timing requirements.

On the other hand, a slide valve without LAP, of the LINE on LINE type would only require the design engineer to know the width of the steam and exhaust ports and their spacing on the valve seat (port face).
The required ECCENTRIC would only need to have an eccentric radius equal to the width of the steam ports.

In part 6 of this tome; we will take a look at the requirements for reversing a slide valve engine and also another type of valve, namely the PISTON VALVE, we will then go on to study the STEPHENSON LINK valve gear which employs 2 eccentrics and a lot more bits…… He He.