Module BESTT MS2

Marine Steam Engines

Aim

There are many varieties of steam engines to be found on launches and ships: from model engineer derivatives right up to massive engines which can be several stories high. Larger vessels will have a number of engines for a range of purposes, not just propulsion. In all this diversity there is also a great deal of commonality, and it is on these common features which we will focus.

INTRODUCTION

Size of boiler in relation to the engine demands

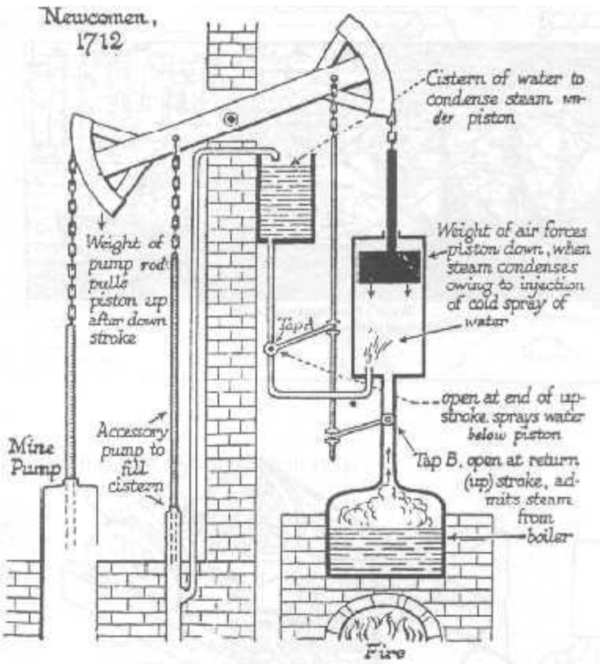
Different types of steam engine

Valve arrangements

Engine lubrication and alignment

Maintenance and serviceable parts.

The first effective steam engine was built by Thomas Newcomen in 1702 and it worked on atmospheric pressure rather than steam pressure: The large cylinder was filled with steam and then cold water was sprayed in to condense the steam. The condensing of the steam caused a partial vacuum and the pressure of air from the atmosphere drove the piston down. Because atmospheric pressure is only 15PSI (1 Bar) a very large piston is required in order to do useful work.

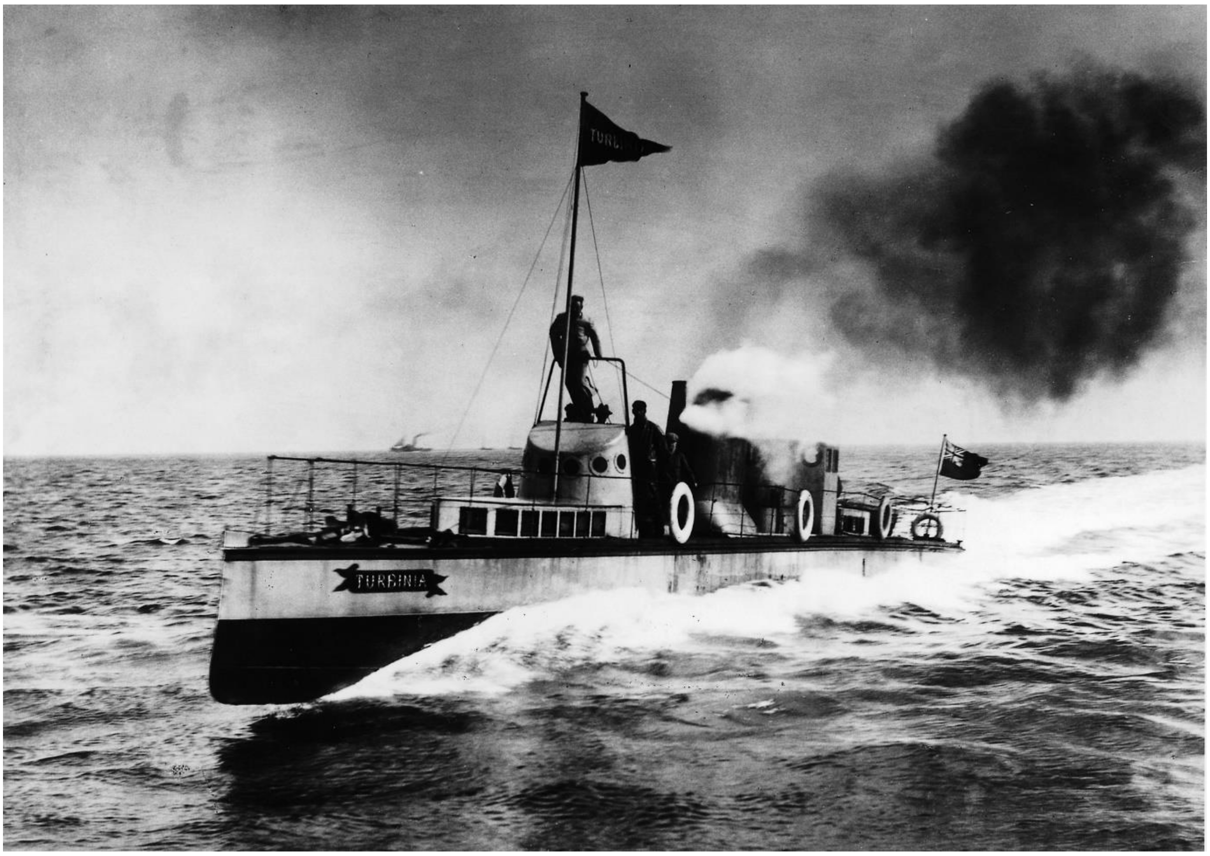


DIAGRAMMATIC VIEW OF NEWCOMEN'S ATMOSPHERIC OR FIRE ENGINE (1712)

The next significant step on the development of steam power was by James Watt who built boilers and engines which would work using the steam pressure rather than atmosphere pressure. The size of pistons, and hence the whole engine, could be much smaller which allowed these engines to be mobile.

The first locomotive was built by Richard Trevethic in 1802. Materials science and steam engineering then moved hand in hand at rapid pace and developments continued through the 19th Century.

Built in 1894, the experimental steam vessel Turbinia caused a great wave in more ways than one at the Spithead Review of the Royal Navy where she revealed herself as the fastest machine on water. Turbinia used the revolutionary type of engine: a Steam Turbine. A turbine is a sort of windmill in the steam flow and can reach very high speeds. It is much more efficient than the piston engine for many reasons and remains a technology in use in power stations and nuclear submarines today. Steam turbines fall outside the scope of the BESTT training units.



Turbinia at speed – see can be viewed at the 'Discovery' museum in Newcastle on Tyne.

The rise of internal combustion engines from the start of the 20th Century saw the decline in steam piston engines. Ever more creative ways of gaining the most efficient steam system were employed such as Triple and even Quadruple expansion engines but internal combution engines and then gas turbines grew and dominated, relegating piston steam engines to the history books. The growth in appreciation of steam heritage which has seen a rise in the use of steam engines again, albeit recreational, has enabled the preservation of some of the great variety of innovation and craftsmanship which epitomised industrty and transport of the Victorian and Edwardian eras.

Learning Outcomes

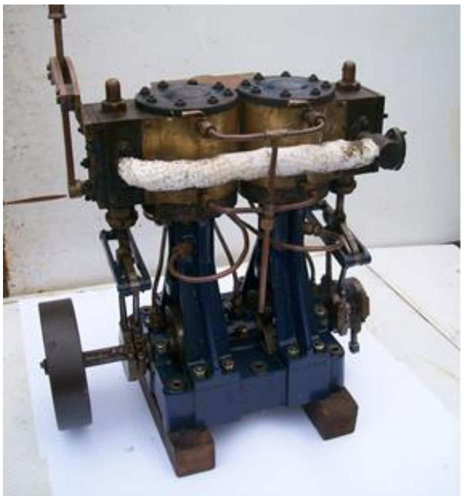
LO 1:

Different Types of Steam Engine

1. Single acting
2. Single cylinder, double acting
3. Two-cylinder, double acting (also known as twins)
4. Two-cylinder compound
5. Three-cylinder simple or compound (aka triple expansion)
6. Oscillating

One- or two-cylinder single acting: In these engines steam is provided on one side only of the piston. As a consequence these engines can be hard to start.

One-cylinder double acting: In these engines steam acts on both sides of the piston. They are one of the most popular engines in small launches with little to go wrong with them. If the piston is stopped at the very top or bottom of the travel, when steam is applied there is no turning force on the crankshaft. In small engines the movement can be started by hand. This example is a Stuart Turner 5A, probably the smallest engine likely to be seen powering a launch. In larger boats these types of engines could be linked to water pumps or force-draft fans.



Two-cylinder double acting twin: In these engines steam acts on both sides of the pistons which are of equal diameter. Generally, they are easy to start because the 2 cranks are 90^{o} to each other hence one piston is always off top or bottom 'dead centre'

Two-cylinder compound: In these engines the steam is expanded in two stages.

Stage 1: in the High Pressure (HP) cylinder where the steam from the boiler is expanded down to about ½ boiler pressure. Stage 2: The HP exhaust steam is fed into the Low Pressure (LP) cylinder where the steam is expanded down to a low pressure acting on the LP piston.

Accordingly, these engines work most effectively when coupled to a condenser and an air pump to produce a very low pressure. The air pump is therefore a crucial part of the overall system and needs to produce a vacuum ideally of at least 20 inches of mercury for the engine to function properly.

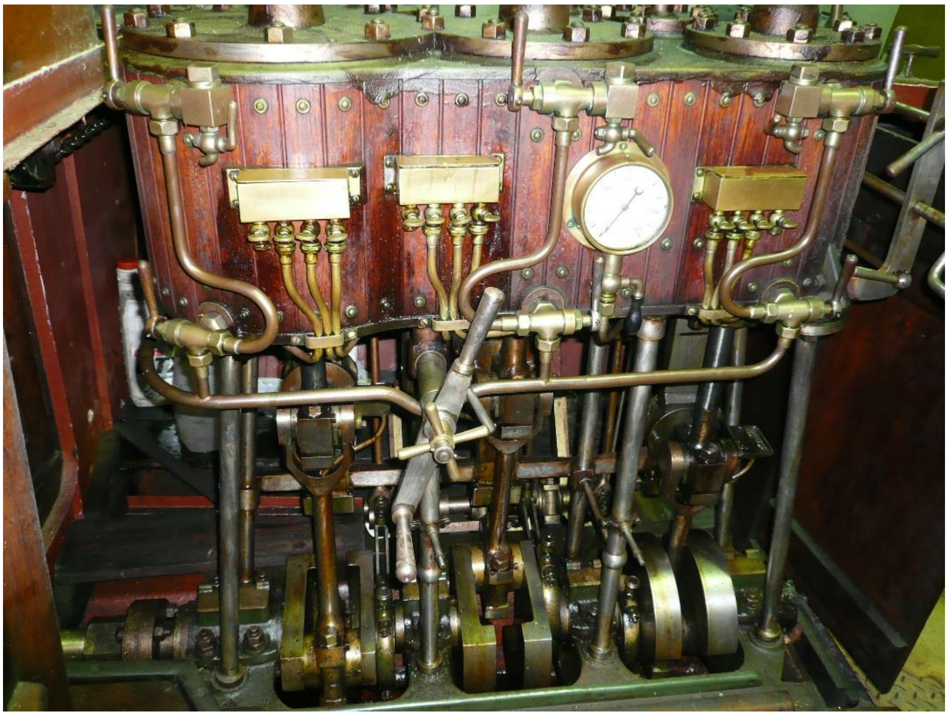
The condensing system is covered in depth in MS03.

Handling these engines, particularly on larger vessels, requires some skill with a need to make sure that the engine is never stopped with the HP piston at one extremity or the other of the cylinder as in this position no amount of steam going into the HP cylinder will start the engine. When manoeuvring it is best to stop the engine with the HP piston positioned mid stroke so that injecting steam either ahead or astern it will then make it go easily. These engines, are often fitted with a 'Simpling' valve so that, in the event of the engine getting stuck with the HP cylinder at top or bottom 'dead centre', steam can be passed briefly into the LP cylinder to start the engine.

Diagonal two-cylinder compound engine (Ex Compton Castle Paddle Steamer)

Three-cylinder compound: These engines are sometimes found in larger vessels and can either be simple expansion with three cylinders of equal diameter or triple expansion in which steam is first fed into a smaller HP cylinder, then exhausted into a slightly larger Intermediate Pressure (IP) cylinder and then into an even larger LP cylinder. These engines are less likely to get stuck but nonetheless have 'simpling' valves which allow steam to bypass the HP cylinder if the engine gets stuck and start it by putting steam either into the IP or LP cylinder directly.

There are variations in design of the three-cylinder arrangement but the most commons is for the HP to be in the middle with the LP and IP either side of it.

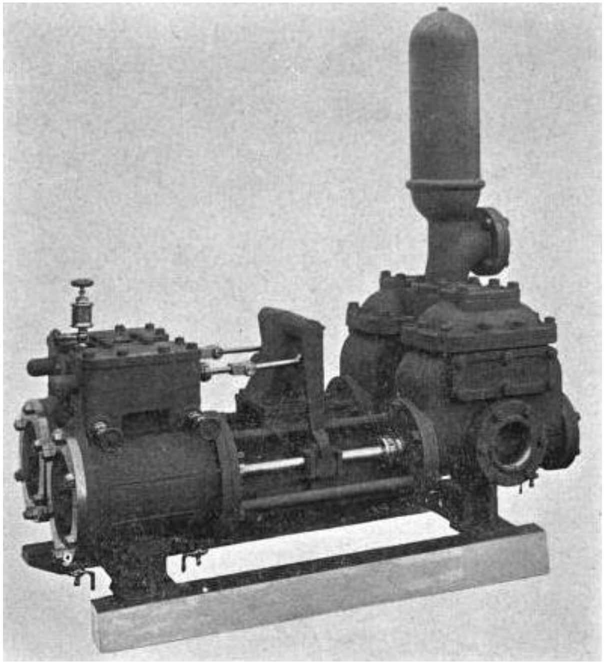


Otto's triple expansion engine (HP on Right, LP on Left). Note the wick oiler reservoirs with multiple outlets.

Oscillating engines: Any who have ever seen a child's Mamod style toy steam engine will be familiar with the idea of an oscillating steam engine where the engine is without connecting rods with the connection to the crankshaft being made by the piston rods themselves. This is achieved by the cylinders oscillating. There remains an operational fleet of nine paddle steamers at Dresden most of which have oscillating engines. For any encountering them for the first time it can be quite a shock seeing their large cylinders, which form the greater parts of their engines, starting to move on their axes giving the (entirely false) impression that the whole engine is falling over

Duplex pumps

Duplex pumps are usually pairs of double acting steam cylinders linked to pairs of double acting piston pumps. The momentum of the moving pistons and connecting rod moves links which operate the steam valves.



This duplex pump has a particularly large air chamber on the water outlet which will absorb much of the pulsing of the water pumped out as the pistons shuttle alternately back and forth. Note the drain cocks clearly visible under the steam cylinders and the small lubricator on the top of the steam valve chest. On the pump side there are large panels which appear to be easy to remove to service the one-way valves.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO1 1	Steam engines	Describe the different sorts of steam engines	Classroom	
LO1 2	Compounding	Describe the differences between simple and compound engines	Classroom	
LO1 3	Efficiency improvement	Describe how triple expansion engines work and their benefits	Classroom	
LO1 4	Simpling Valves	Describe why a Simpling Valve may be necessary	Classroom	

Learning Outcomes

LO 2

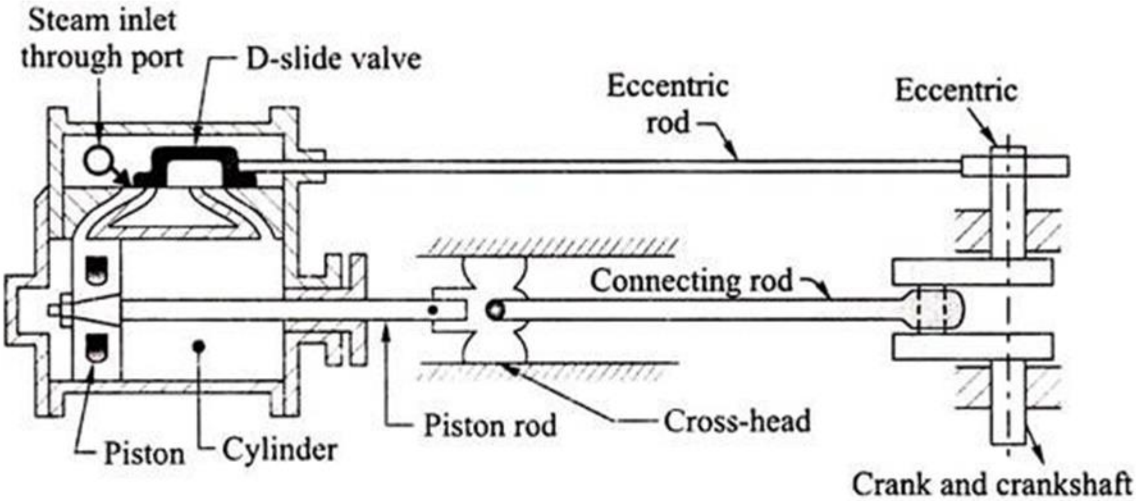
Reciprocating to Rotating

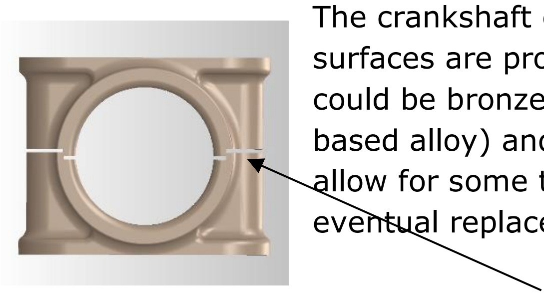
In this section we will be considering the moving parts which are common to all steam engines and associated with any movement there is likely to be friction and wear. Railway locomotives, traction engines and stationary engines will have many similar features to marine engines in this context and skills achieved in this section will be broadly transferable across the different branches of steam locomotion.

This website gives a good animated version of the principles of steam engine actions:

http://www.animatedengines.com/locomotive.html

Reciprocating simply means moving back and forwards. The steam pressure in the boiler pushes alternately on the top and bottom of a piston causing movement. This is sufficient for duplex pumps, but not for moving ships. The reciprocating movement is turned into rotating movement using a cranked shaft (crankshaft). The crankshaft is then connected to the propeller shaft or paddle wheel shaft via a flexible coupling.





The crankshaft experiences large forces and the bearing surfaces are prone to wear. In steam engines the bearings could be bronze, phosphor bronze, or 'white metal' (a tin based alloy) and they are nearly always split bearings to allow for some taking up as the surface wears away, or eventual replacement.

The split bearing housing may contain sacrificial shims which can be exchanged or abraded to close-up the loose bearing.

Between the crankshaft and the piston there are two rods: the piston rod and the connecting rod (aka con rod). The piston rod passes through a gland in the cylinder bottom cover. This gland is often packed with graphited packing and the gland will have the capacity to be tightened if steam is weeping past the gland. This should not be tightened excessively as that could introduce friction. Indeed, it is valuable to have a small amount of steam seepage to provide lubricating water for this seal. It is necessary to renew the graphited packing periodically as it will degrade over time. It is useful to measure the diameter of the piston rod at several points on its length and around its perimeter as the piston rod is susceptible to wear over time and may require replacement.

Larger engines use metallic packing which wears slowly and does not need tightening up periodically as it is spring loaded.

In order to keep the piston rod moving in perfect alignment with the piston, there is a cross-head guide. The cross-head is the junction between the piston rod and the connecting rod and the conventional junction here is a pin and yoke arrangement. The crosshead is captive and can only travel up and down the crosshead guide and this area is subject to heavy forces too and therefore subject to wear.

The connecting rod is linked to the crosshead via the crosshead pin (in the car industry this is the 'small or little end') and linked to the crankshaft at the other end of the rod via a split bearing housing (the 'big end'). Both are subject to heavy loads and wear. The wear can be assessed in three ways:

1. Under power any wear in the engine bearing surfaces is likely to lead to a 'knock' at each end of the power stroke. This may be tracked down by careful listening or by placing a firm object (eg a long screwdriver) between the suspect bearing and your ear, but this method is only applicable to the stationary Main Bearings on the crankshaft.
2. With the steam completely shut off and vented from the cylinders through the drain cocks, the various rods, housings and shafts can be gently levered to and fro whist watching and/or touching the joint to assess whether there is any play and whether it is acceptable or needs reducing.
3. Dismantle the suspect components and measure accurately with a digital calliper or micrometer.

The valve gear, and often more than one pump, can be driven directly from the main engine crankshaft. This is often achieved with eccentrics. These eccentrics have a block around them (aka eccentric strap) which will also have the capacity to be adjusted in order to account for wear. On larger engines the eccentrics will be fixed to the shaft using a key or similar, which will guarantee that the position of the eccentric cannot move in relation to the crank. However, in the smaller steam launch engines, particularly those based on model engines, the rotational position of the eccentric may be fixed using a grub screw and this position needs to be checked during routine servicing.

Duplex pumps do not have any of the wear associated with rotating members, however the valve actuating links are prone to significant wear as they are repeatedly subject to impact forces, and these contact surfaces should be inspected for wear regularly and adjusted/replaced as necessary.

Before moving on from potential wear in steam engines, it should also be appreciated that the cylinders themselves are subject to wear. After several decades of use the cylinder walls are no longer parallel. Piston rings take up some of this wear, but if it becomes excessive then steam can leak past the piston and reduce efficiency, but this will not be obvious as the escaping steam passes straight to the exhaust from that cylinder. Therefore, cylinder wear should be periodically assessed. If it becomes too bad, the cylinder will need to be rebored by a specialist and new pistons and rings manufactured.

Modern Materials

There is debate amongst those working with steam engines about whether the machinery should be restored and serviced using authentic and/or original materials or whether there is a place for modern materials. The newer materials may have improved properties to resist wear or benefits for efficiency but they are also not original. Materials such as PTFE for light bearing surfaces or valve faces can improve operation. Sintered bronze for bearing surfaces means that lubrication is more consistent. Roller bearings are now readily available and, in some applications, have far superior properties to the original solid bearings. There are also many grades of O-rings, some of which are suitable for steam which have been readily accepted by the model steam fraternity, but were not available to the original engine builders.

Ultimately the decision about materials is one for the owner, but a 'rule of thumb' exists that no changes should be made which are irreversible: should a future owner wish to revert to fully original, then this should remain achievable as far as reasonably possible. The obvious exception is that when modern materials are an improvement in safety (eg eliminating the use of Asbestos) then these changes will not be opposed by anyone. Similarly, few will object to the use of modern materials if they reduce the rate of wear on engine parts.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO2 1	Rotating movement	Explain how steam pressure can cause rotational movement	Classroom	
LO2 2	Crankshaft bearings	Dismantle a crankpin bearing housing and assess wear	Workshop	
LO2 3	Gland packing	Replace the gland packing on a piston rod	Workshop	
LO2 4	Uneven wear	Measure the piston rod for wear and eccentricity	Workshop	
LO2 5	Play in bearings	Inspect an engine and assess play in all the bearings	Workshop	
LO2 6	Cylinder wear	Measure the cylinder bore for wear	Workshop	

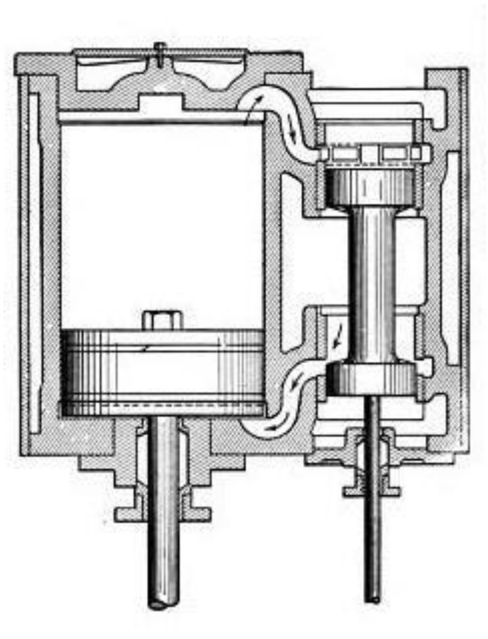
Learning Outcomes

LO 3

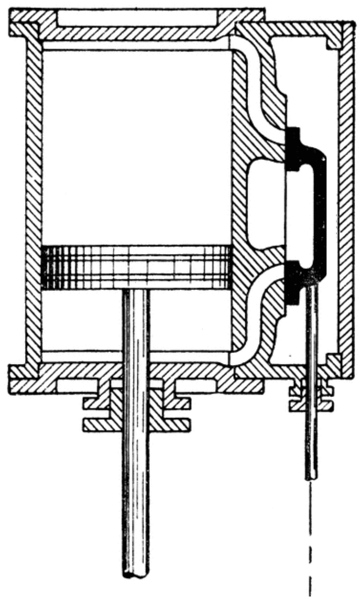
Valve arrangements & timing

1. What do the valves do?
2. Different valve arrangements
3. What adjustments are possible?
4. How is reversing achieved?

Engines have slide valves which control the entry and exit of steam to and from the cylinders. In these valves their sliding surfaces have holes to make connections between the tops and bottoms of the cylinders to control the entry and exit of the steam. The moving parts are generally either in the form of a piston or a sliding shoe which change the steam path via communicating passages.



Piston Valve



Slide Valve

This website allows you to explore the steam inlet and exhaust cycle though animations.

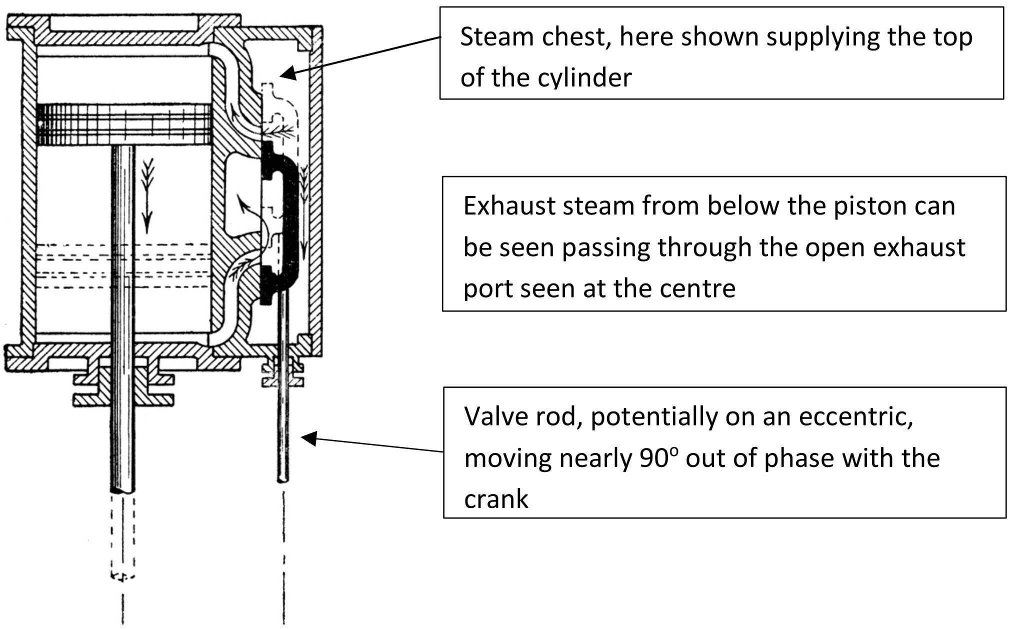
http://www.animatedengines.com/locomotive.html

Several valve-gear arrangements are presented, but the Stephenson's link is probably the most common in marine engines but there are other types which may be driven from the conrod such as Joy's or Marshall's.

The valves and cylinder position - a generalisation of a double acting single cylinder engine with a D-slide valve.

At the top of the piston stroke, the steam will be introduced to the cylinder. This will drive the piston down, and the inlet will remain open until the piston reaches 80% of the travel. The inlet valve will cut off (close) and for the reminder of the stroke the steam in the cylinder will expand and continue to impart force on the piston.

Just before the piston reaches the end of the stroke (at about 90-99% of travel) the inlet valve at the opposite end of the cylinder will open to introduce steam below the piston. This is called steam **lead**. This premature introduction means that by the time the piston has reached full travel, pressure will have built to close to maximum to force the piston back up. In addition, because the mechanical opening of the steam port is progressive, the port will be fully open while the piston is still in the early part of the stroke.



The exhaust valve release and cut-off operate in the reverse way to the inlet but typically the release and cut-off will allow for a greater period of port opening to allow the exhaust low pressure steam to escape. These ports will often be larger than the inlets to assist rapid flow and reduce back-pressure.

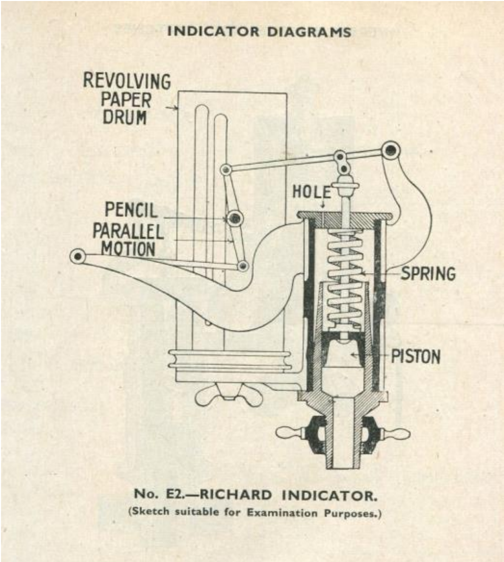
In order to allow time for the steam to expand before it is exhausted, both valves must be closed for a short period. This closure is achieved by manufacturing the valve so that there is an overlap of the inlet port. This is called the steam **lap**.

Engine designers will have worked out the lap and lead with care, as they will also have done with the release and cut-off positions. The setting of these positions is beyond the scope of this course. Issues with valve settings are not generally a problem for smaller engines on steam launches but, where occurring, can generally be addressed on a trial and error basis by making minor adjustments to the valve settings and noting improvements or reductions in efficiency. The coarse setting for the valve can be made visually with the engine cold and the valve chest cover removed: it is possible to see the inlet ports becoming progressively exposed as the valve travels. Marking the flywheel with Top Dead Centre (TDC) or removing the cylinder top cover will allow assessment of valve opening. Reams have been written on optimal timings for valve opening and closing, but in principle the following should apply for a Single Cylinder engine:

1. The opening position of the valve should be on, or a few degrees before TDC
2. This should be equal for the top and bottom valve opening - otherwise the engine will be 'lumpy'

The timing of the opening depends on the position of the eccentric (which is usually fixed by the manufacturer) and the position of the valve on the valve rod (this is adjustable to allow for taking up play in the eccentric strap).

For larger engines the general efficiency of a steam engine can be deduced by producing indicator diagrams. These are obtained by attaching a special bit of kit called an Indicator to the engine whilst it is in operation. This draws various shapes on a graph. Producing and interpreting these shapes to improve an engine's efficiency is a skilled and complex job. For those interested full details are set out in "Verbal Notes and Sketches for Marine Engineers" by J W M Southern.



The Richard Indicator

The wide differences in valve gears encountered in steam situations stem from designers initially trying to circumvent other designer's patents and latterly to reduce the drawbacks presented by different designs: problems of premature wear & fracture, asymmetry in forward & reverse running, and wire-drawing (the gradual fall in pressure in the cylinder caused by a slow rate of closure of the slide valve). Students may wish to research the differences between different valve gear types and see how the designers attempted to overcome each of these problems.

Slide Valves, Balancing and Piston Valves

Slide valves, or D valves have the pressure in the valve chest forcing them against the port plate and obviously the higher the pressure, the greater the friction force will be against the sliding valve face. This in turn will increase the loading on the link rods and eccentric strap (or alternative arrangement). Some engines counter this by having 'balanced' slide valves. This complexity involves relieving the pressure on the back of the slide valve and hence reducing friction associated wear.

A piston valve negates the problem altogether and the steam forces are completely balanced. This means wear is greatly reduced in the linkages, and the construction of these components can be lighter.

'Linking up' is a term which will be well known in locomotive circles. It involves adjusting the valve gear so that the valve travel is reduced. This means that steam input to the cylinder only happens for a small proportion of the stroke, and there is an extended time for the expansion of steam in the stroke. On a locomotive this is exploited to economise on steam use when the locomotive is not exerting a tractive force. On a ship or launch linking up is seldom employed: the engine runs under a continuous load and the propeller or paddle wheels simply rotate in proportion to steam supplied, whether via the throttle or the valve setting.

Erosion, misalignment and inspection

Over years of use the fast flowing steam can erode the edges of the valve ports and so these require periodic inspection. The valve chest and valve chest cover will be fitted with steam gasket material and this will usually require renewal once opened.

Caution: Old steam engines may have asbestos forming part of the structure of the gaskets, and if this is suspected work must stop and expert advice sought.

Inspections of valves and valve plates should pay attention to the condition of the contact surfaces, the play in the valve and valve-rod interface and the rounding, pitting or inconsistency of apertures or cut-off edges.

When the valve is being reassembled care must be taken to ensure the position of the valve on the valve rod gives symmetry of port opening.

Reversing

Different valve gears have different ways of reversing engine direction. In a Stevenson's link it is possible to bring the curved link into a different position so that a second eccentric is enabled to move the valve rod. With the Joy or Hackworth valve gear, a different pivot point is used. A slip-eccentric is another solution – this is where the eccentric can twist by 180° on the shaft.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO3 1	Valves	Describe the purpose and operation of valves	Classroom	
LO3 2	Valve types	Explain why piston valves offer an advantage over slide valves	Classroom	
LO3 3	Valve Wear	Inspect and assess valve and port plate surfaces for wear	Workshop	
LO3 4	Valve adjustment	Inside the valve chest, measure the valve travel for equality of steam inlet	Workshop	
LO3 5	Valve operation	Explain the value of steam lap and steam lead. How might these be adjusted?	Classroom	
LO3 6	Steam erosion	Describe steam erosion and examine valve ports for evidence	Workshop	

Learning Objectives

LO 4

Engine Lubrication and Alignment

It should go without saying that a good engineer is an observant engineer. Being ever attentive to the machinery and boiler, going around looking at it, wiping away excess oil and grease to keep it clean and protecting machinery with cloths and curtains whilst bunkering with coal all mean that a good engineer will pick up potential problems long before they develop into serious issues which might disable a vessel.

When machinery rotates or parts slide over one another they get hot. If oil ways become blocked resulting in a lack oil or grease reaching the surfaces then they will overheat. In extreme cases the machinery will seize up.

Types of oil

Steam cylinder oil is specially formulated to work at the high temperatures of steam machinery. It has an unusually high tallow content which enables it to retain lubricating properties and not emulsify (combine with water) in the steam chest. If an engine is built from cast iron and is running on wet/saturated steam then the graphite in the iron may be sufficient for engine and valve lubrication. This reduces the amount of oil which must be scavenged in the hotwell although most operators prefer to use oil lubrication whilst running as a precaution against wear. Either way, an internal oil coating upon shutdown will be essential to reduce internal corrosion and this can be achieved by introducing oil in the last few rotations before stopping the engine.

Engines running on superheated/dry steam will require cylinder lubrication and this is achieved by introducing oil into the steam line to the engine or into the valve chest directly. The oil must be fed in against the steam pressure which will require a displacement pump or a hydrostatic (displacement) lubricator. There are different formulations of oil for single cylinder and compound cylinder arrangements available from specialist suppliers to the steam industry such as https://www.morrislubricants.co.uk/products/classsteam/cylinder-oils.html. The website offers advice about different applications and they have regional distributors.

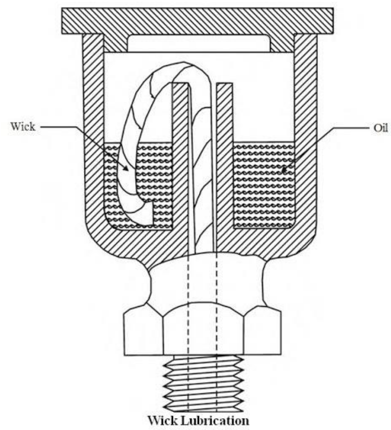
The oil which is suitable for cylinders may not necessarily be the best choice for sliding and rolling bearings. The steam cylinder oil will be very viscous at low temperatures and becomes almost like syrup on a very cold day. This may mean that the flow is inconsistent, especially through a narrow delivery pipe, depending on conditions. Some modern synthetic oils are designed to give good protection across a wide temperature range (multigrade oils) although they will not tolerate moisture as well as steam oils.

Consideration needs to be given to all these factors when selecting the right oils for the different lubrication points on a steam engine and most craft, especially the larger ones, will have a well thought out lubrication schedule which includes specific oils for each part.

Onion Lubricator

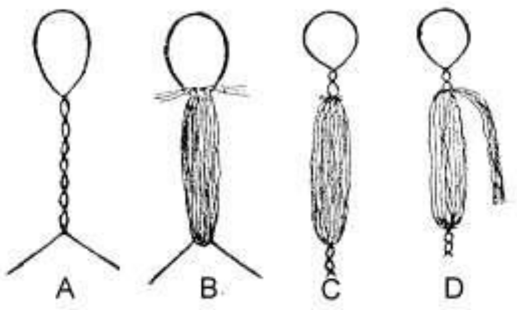
For occasional cylinder and valve lubrication the 'onion', or less politically-correctly named 'fat lady' lubricator is valuable. This oiler is fitted to the top of the cylinder or valve chest. It consists of an upper and lower valve, a reservoir and a filler cup. Opening the bottom valve whilst the top valve is closed allows the oil to enter the cylinder or valve chest even with the engine running. This is ideally performed in the last few revolutions before stopping so the internal cylinder and valve faces have a thin coating of oil to inhibit corrosion.

Wick Lubricator



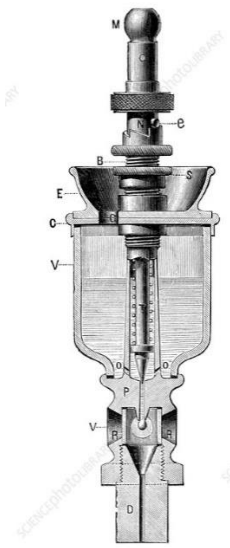
Wick lubricators rely on the combination of capillary action drawing oil along a twisted wick, and the syphon effect causing oil to be raised against gravity and then moving slowly down the delivery tube. These oilers can be made quite small and could be found on eccentric straps, main bearings on the crank shaft or on horizontally moving crossheads. The rate of flow will be more rapid at higher temperatures when the oil becomes less viscous. The lid must have a tiny hole to prevent a vacuum forming, but any water ingress can prevent the wick from working properly and can inhibit oil flow. It is recommended that the wicks are inspected at regular intervals and changed as required to maintain good operation. The oil reservoirs also need cleaning out periodically.

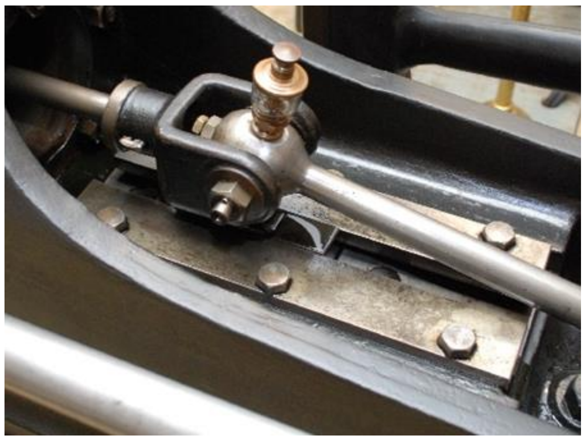
Making Oil Wicks



The strands of wire are first twisted (A). The cotton or worsted is passed round (B) until the desired thickness is obtained (not too thick or the wick will be tight in the tube and oil flow will be inhibited) with the ends at the top. Two or three twists are given to the copper wire to hold the fibres, and the ends are trimmed for plug (C) or tail (D). A less traditional method is simply to use pipe cleaners.

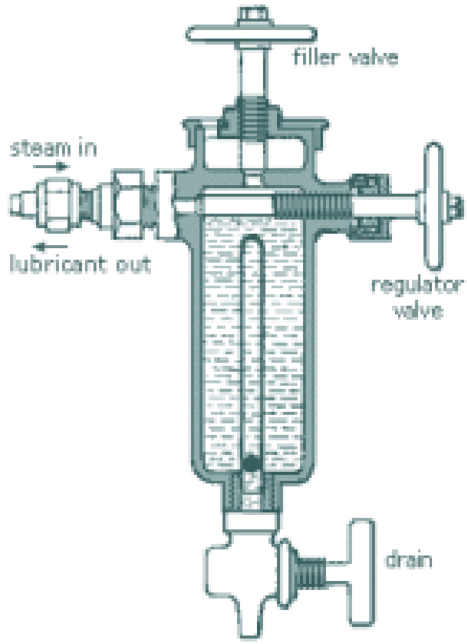
Drip





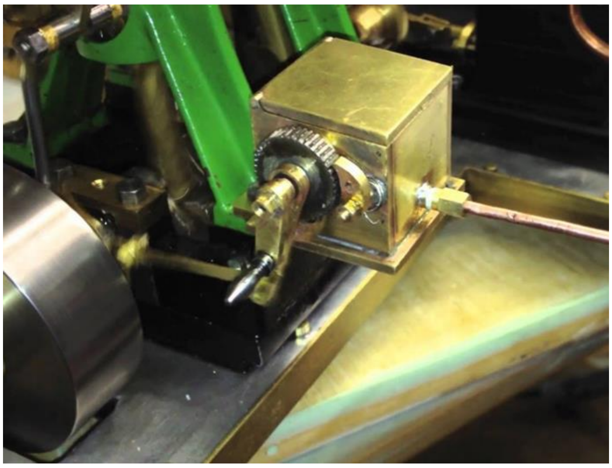
Drip lubricators are simple and reliable, with an adjustable flow rate. They are unable to lubricate against pressure, so have some limitations for their use. Because the viscosity (thickness) of oil varies with temperature, the flow-rate can also be variable.

Displacement



Displacement, or condensation lubricators are more commonly found on small engines rather than ship sized. They rely on the principle of allowing a small amount of steam to enter an oil chamber where the steam cools and condenses. The water droplets are heavier than the oil and sink, and as more steam enters and condenses, the sinking water displaces oil which is forced slowly back through the steam delivery line. Elegant in their simplicity as there are no moving parts but is it difficult to assess flow-rate, apart from being aware of how much oil has been used at the end of the day.

Pump lever, ratchet and clutch



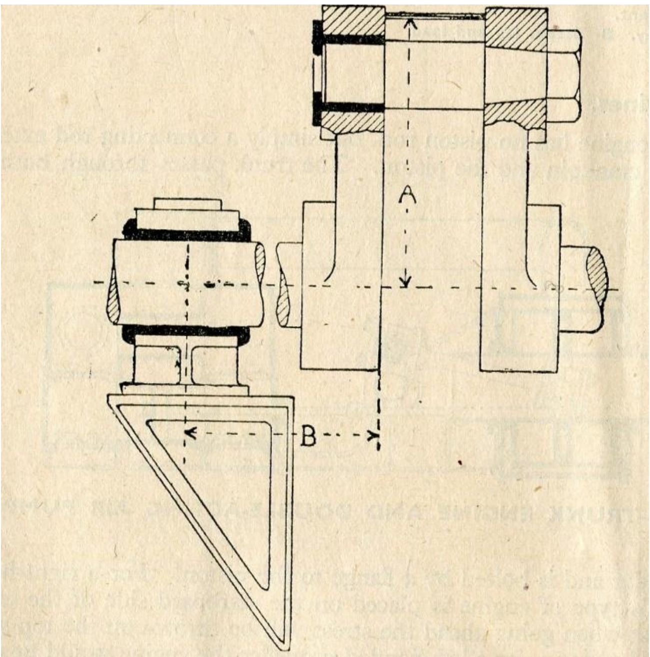
For reliable and accurate delivery of oil to bearings or the steam chest, an arm-operated piston pump can be used. These types of lubricator are also common on locomotives and traction engines. There will often be a way of adjusting flow rate by altering the arm linkages, and the flow rate is not influenced by steam pressure or ambient temperature. An elaboration of this system is to have multiple cams on a single shaft and so several pumps can be operated simultaneously. A single reservoir can lubricate bearings, crosshead slides and the steam chest.

Alignment

If engines are not properly aligned with themselves and with the shaft/s to the means of propulsion (screw or paddle) stresses will be introduced. In due course this will lead to cracks appearing in stressed parts of the machinery including, for example, in connecting rods, links gears, webs and the casting of cylinders. These need to be picked up early before engine parts fail with potentially catastrophic consequences. In all cases the underlying causes of why cracks have developed must be examined. This is likely to be due to some misalignment in the machinery but remember also that some vessels are lightly constructed themselves. All vessels will be subject to some flexing but this is more acute in vessels which are long and thin without any binding superstructure above them to hold the whole structure rigidly together and with vessels designed for shallow water work which may have minimal scantlings in order to keep their overall weight and, therefore, draught down to a minimum.

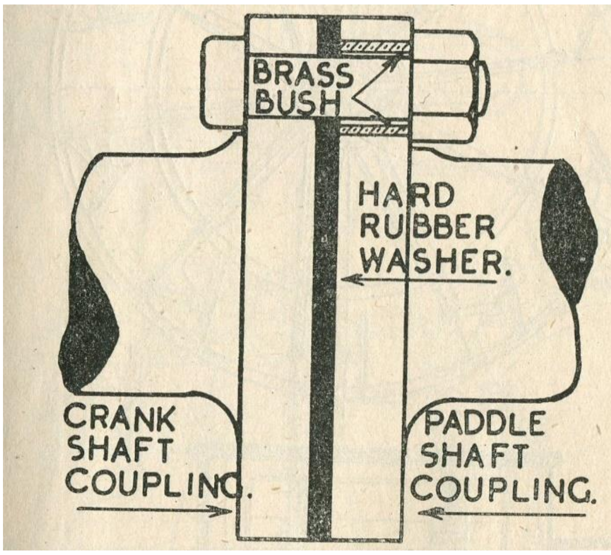
Minor cracks may be temporarily repaired by welding or bracing around them. For more serious cracks, and for all cracks in the longer term, the affected part of the machinery will need a replacement part as well as any cause(s) of misalignment or other faults addressed.

Correct engine alignment is therefore very important for all vessels. For screw driven vessels it might be relatively straightforward as the engine and propeller are connected in a straight line. However, in wooden hulls particularly there is a great deal of flexing. For paddle steamers it is inherently difficult not least because the paddle wheels are supported only on one side and hang off the end of the paddle shaft. As a result, all engines are generally built with some sort of flexible coupling in their shaft either within the engine itself where the connecting rod meets the webs or with a flexible joint where the crankshaft joins the propeller shaft or paddle shaft.



For many paddle steamer crankshafts the crankpin is only fixed to one web, and is in an easy fit in a brass bush in the other web. This allows for extra wear which takes place at the outside bearing due to the weight of the paddle wheels. The crankpin is fitted into one web with a taper and a nut and in the other web is simply a loose fit in a brass bush. This arrangement allows for the shaft wearing down outside and prevents undue stresses being thrown on the web and the pin.

To test if the outer bearing is wearing down the cranks must be placed on the top centre and the distances between the webs at the top measured by a length of stick. Then the crankshafts put on the bottom centre and the same distance again measured. If it is found that the top distance is greater than the bottom then the outer bearing will be down.



No. F8.
FLEXIBLE
COUPLING.

If the crankshaft of a paddle engine is made all in one piece like for a screw vessel that is with the webs and pins forged solid allowance for wear down is arranged by a flexible coupling fitted between the paddle shaft and the crankshaft. The coupling consists of a hard rubber disc fitted between the two flanges with the coupling bolts an easy fit in one side, the holes being made larger for this purpose. This allows for the outer bearing to wear down and prevents the inner and webs from being subject to heavy stresses in consequence.

Engines in large steel ships do not have flexible couplings between the engine and the prop-shaft. The engine is aligned exactly with the shaft when installed, therefore alignment relies on the ship's hull not distorting.

In the expanded view it is possible to see that the wick feed lubricator feeds a line which drips into a receiver cup moving up and down on the crosshead. This in turn delivers to oil to the revolving crank

VIC 56 Engine Room

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO4 1	Good Practice	Explain why a good engineer keeps the machinery clean	Classroom	
LO4 2	Lubrication	Describe the consequences of poor lubrication	Classroom	
LO4 3	Oils	Explain how temperature effects the properties of oils	Classroom	
LO4 4	Passive Lubricators 1	Replace the wick in a Wick Lubricator	Workshop	
LO4 5	Passive Lubricators 2	Service a Displacement Lubricator	Workshop	
LO4 6	Mechanical Lubricator	Service a Mechanical Lubricator	Workshop	
LO4 7	Flexible Couplings	Explain why flexible couplings are used to link engines to driveshafts	Classroom	

Learning Outcomes

LO 5

Estimating Output Power

1. Mean Effective Pressure (or average pressure)
2. Applying Power = P x L x A x N
3. Multiple cylinders
4. Brake power or Brake Horsepower

This section is for the benefit of estimating the power produced from a plant, and one can appreciate the different factors which affect engine output.

In calculating the power that an engine of given proportions will produce one important factor that we need is the mean effective pressure (MEP) on the piston. In a large commercial engine an indicator diagram would establish this information. It is difficult to produce an indicator diagram on a small engine, although it may be done electronically, and so the MEP must be estimated.

Steam engines are usually rated by indicated power which relates to the reciprocating motion of the piston and the pressure differential (ΔP) across it. During its travel down and up the cylinder ΔP will vary mainly due to the early cut off of the steam supply by the valve. Thus, the average pressure throughout the stroke has to be assessed. In a single cylinder engine typical pressures taken at five equal steps along the bore might be:-

10.5	10	4.3	0	−0.5	Bar
(155	150	65	0	−7	psi).

This gives an average of 4.9 bar (74 psi), roughly speaking 50% of the maximum (valve chest) pressure.

Therefore *P* can be taken as half the valve chest pressure.

The other simpler factors are:-

P = the mean effective pressure

L = the length of the stroke

A =the area of the piston

N = the number of revolutions per unit time.

Assuming the engine is double acting (power is produced on both the up and down stroke) the effective stroke *L* is twice the actual stroke of the engine. The force on the piston will be *P* x *A*. This gives the work per unit time produced as 2*PLAN.*

If *P* is in Pascals, *L* in metres, *A* in square metres and *N* in revolutions per second, the power will be in watts (W). In more convenient units of *P* in bars, *L* in cm, *A* in square cm and *N* in revolutions per minute (rpm), we divide by 600,000 to get the power in kilowatts (kW).

Similarly, if *P* is in psi, *L* in feet, *A* in square inches and *N* in rpm, dividing by 33,000 will give the power in horsepower (HP). Note that 1 HP is equivalent to 746 Watts.

For example:
Consider a double acting single cylinder engine with piston 3" diameter and stroke 3":

(*A*) Piston area = 7sq".

(*L*) 3" = 0.25 ft.

(*N*) 400 RPM

(*P*) Mean effective pressure = say 75 psi

2*PLAN* = 2 x 75 x 0.25 x 7 x 400 = 105,000

divided by 33,000 = 3.18 IHP (2.4kW)

If the speed is increased to 500 the IHP will increase to 4 IHP (3kW).

Vacuum

If a condenser and vacuum pump are fitted giving a modest vacuum this would add approximately 10 psi (0.7bar) to the MEP. In the last example this would increase the power from 4 to 4.5 IHP (3 to 3.4kW).

Multiple Cylinders and Compounds

In the case of twin and triple simple engines the output of a single cylinder is multiplied by 2 or 3.

In compound engines the calculation has to be done for each cylinder the results being added together. This is complicated by the difficulty of establishing the pressure drop or mean effective pressure for each cylinder, considering the vacuum on the second, low pressure (LP) cylinder only. On a large engine indicator diagrams would be taken for each cylinder individually.

Because the engine designer would plan for equal work from each cylinder an estimate can be made relating the pressures inversely to their respective areas.

For example, take a Stuart Turner 6A engine: A two-cylinder double acting engine with a 2.5″ diameter HP, a 4″ diameter LP cylinder and a stroke of 3″

Assuming an actual pressure drop from valve chest to condenser of 160 psi (150 psi. + 10 psi. for the vacuum). To get the MEP divide by 2, as explained above, giving *P* = 80 psi.

This is split inversely proportionally to the piston areas which are HP 2.5″ and LP 4″ giving 4.9 sq″ and 12.6 sq″ respectively. This ensures the MEP multiplied by the area is the same for each cylinder, ensuring they do equal work.

The total area of both cylinders is 4.9 + 12.6 = 17.5 sq″

Thus, the MEP in the first (High Pressure (HP)) cylinder will be 12.6 x 80 divided by 17.5 = 58 psi. The remaining 22 psi will be the MEP in the LP cylinder.

Now we can assess the work done in each cylinder separately

		HP	**LP**
Piston area	A	4.9	12.6
Mean Effective Pressure	P	58psi	22 psi
Double stroke (3″)	2 x L	0.5 ft	0.5 ft
Shaft speed	N	400rpm	400rpm

HP 4.9 x 58 x 0.5 x 400 = 56840 Divided by 33,000 = 1.72 IHP

LP 12.6 x 22 x 0.5 x 400 = 55440 Divided by 33,000 = 1.68 IHP
Total 3.4 IHP

(Note that the two cylinders are producing very close to the same power, as assumed above.)

Brake Power

The power developed in the cylinder (the indicated power) is rather larger than the power available on the engine output shaft, because of losses such as friction. The shaft power available is often called the *brake power* because it is the power that would be measured by a dynamometer brake on the shaft. This used to be equated to Brake horsepower. The ratio of brake power to indicated power is called the *mechanical efficiency* of the engine and for most steam engines this figure usually lies between 0.7 and 0.9. The efficiency is good because the speeds are low and there is not usually a gearbox in the drive train to absorb energy. Please do not be misled into thinking that steam plant is efficient – they are usually alarmingly inefficient but that is more to do with using steam as the working fluid in the heat cycle and this subject is beyond the scope of these materials.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO5 1	Valve chest pressure	Describe how cylinder pressure may differ from boiler pressure	Classroom	
LO5 2	Condensers	Explain how a vacuum can help engine performance	Classroom	
LO5 3	Output power	List the factors which influence the output power of an engine	Classroom	
LO5 4	Brake Power	Explain why power at the engine is not fully transferred to power at the paddles or screw	Classroom	

BESTT Marine steam maintenance and repair Module MS2

Assessment Record for: Training Centre: Year:

LO1	1	2	3	4			
Supervisor Initials and date when completed							
LO2	1	2	3	4	5	6	7
Supervisor Initials and date when completed							
LO3	1	2	3	4	5	6	
Supervisor Initials and date when completed							
LO4	1	2	3	4	5	6	7
Supervisor Initials and date when completed							
LO5	1	2	3	4			
Supervisor Initials and date when completed							