The Model SS *Simla* Engine at Riverside Museum

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1.0 Introduction. Glasgow Museums have in their collection examples of early marine steam engines including an outstanding example of a one-quarter scale model (I.D. No. T.1926.15) of the engine for the single screw steamship SS *Simla*, which is currently on display at Glasgow's Riverside Museum of Transport and Travel.

The timing of this note is appropriate, as it is 200 years since the death of James Watt, in 1819, and 250 years since his patent on the separate condenser in 1769, ref. 1 to 4. By a strange coincidence David Napier the marine engineer, and the inventor of the steam engine that powered the *Simla*, died in 1869 the same year the Suez Canal opened – a hundred years after Watt's patent.

The *Simla* engine is technically important, it was one of the early types of marine steam engine that was developed on Clydeside. The engine is of a type known as a Steeple Engine due to the crosshead guides, which stick up vertically in the air like a church steeple(1). There were other engines with this type of crosshead guide but they are not steeple engines, this will be explained in the text. The steeple engine is a type of engine also known as a return connecting rod engine. However, not all return connecting rod engines are steeple engines, again this will be explained in the text.

The steeple engine was the invention of David Napier, ref. 5, one of Clydeside's most famous marine engineers(2). He contributed to the design of steam engines and to the development of steamboat services. This Research Technical Note explains why this type of engine was developed, what were its main features, how it works and why it fell out of use.

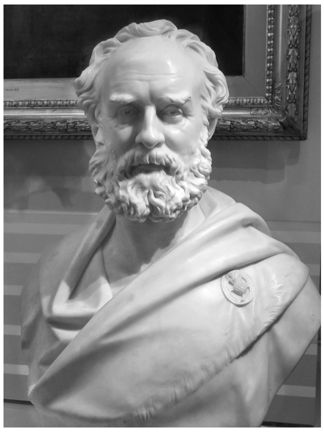
2.0 The SS *Simla*. Before going on to discuss the engine a few details of the SS *Simla* are appropriate(3)(4). Information on the *Simla* can be found in various references 8 to 13. One word of warning, not all the data is consistent, the dates of some events are inconsistent, and the tonnage, dimensions and even the horsepower of the engine is open to question. The *Simla* was an iron hull, single screw, steamship built, in 1854, on Clydeside by Tod & McGregor of Meadowside, Glasgow(5)(6), ref. 10. Their shipyard was just outside the museum on the opposite (West) bank of the River Kelvin at the junction with the River Clyde. In common with most steamships at that time *Simla* was rigged for sail(4). SS *Simla* was built for the Peninsular & Oriental Steam Navigation Company; a detailed history of this company is given in reference 14.

At the time *Simla* was built, in the 1850's, this was a difficult time for the P&O Company. Their existing ships were old, had wooden hulls and were paddle steamers. By the 1850's it was clear that iron hulls and the screw propeller were the future, although there were some issues still to be resolved(7)(8). *Simla* had a gross tonnage of 2,441 tons(10) with a length of some 330 ft. She was a large ship for her day and was powered by one steeple geared engine of 1,766 Indicated Horse Power(11) with a boiler pressure of 16 pounds per square inch(20), ref. 14. She had a speed of 11 knots, ref. 8.

The intention of the P&O Company was to use the *Simla* on their oriental route between Suez and Calcutta (the Suez Canal was not opened until 1869) but instead she was immediately used in the Crimean War for transport. She was briefly operated on the Suez to Sidney mail route in 1857. She was returned to P&O in 1858 and then used as intended on the Suez and Calcutta route. She was subsequently sold and in 1875 converted to a 4-masted sailing ship(12), ref. 8. She sank, with some loss of life, after a collision with the steamship *City of Lucknow* off the Isle of Wight in 1884(13), ref. 9.

3.0 Early Marine Steam Engines – the Things You Need to Know. The earliest attempts at utilising steam to power a ship can be traced to the late 1700's and early 1800's when engineers and others (entrepreneurs) from three countries: France, Scotland and America attempted to build practical steamboats, ref. 16. There is not time or space here to discuss these important developments. For our purposes here is what you need to know in relation to the *Simla* engine:

3.1 David Napier. The key events relating to David Napier are, ref. 5:



Bust of David Napier
by Matthew Noble 1871.

(1) As a 12 year old he saw the pioneering paddle steamer *Charlotte Dundas* at Port Dundas, Glasgow in 1803.
(2) He constructed the boiler for the PS *Comet* (1812).
(3) He had steamboats built and developed their use in sea going services (PS *Rob Roy*, c1818, Glasgow to Dublin, and later Dover to Calais).
(4) He designed and developed marine steam engines including the steeple engine.
(5) During part of his career he was assisted by experienced workmen David Tod and John McGregor who later formed their own business as Tod & McGregor, Engineers.

3.2 Steam Systems. Although the intention of this note is to discuss a steam engine it should be appreciated that the use of steam, as the working fluid, means that in reality the whole system should be considered. The main components that make up a marine steam system include: boiler, engine, feed pumps, vacuum pumps, condenser, feedwater heater, pipework and valves, thrust bearing and transmission shafting to the propeller(s) or paddle wheel(s). The fuel supply in the early steamships would be coal or wood requiring extensive bunkers. The early steam systems had a very low thermal efficiency (a few percent). The result was that a significant amount of space was required for the engine room, and the fuel bunkering and that meant less space for cargo and/or passenger accommodation. There was therefore a need to:

- Reduce the size of the engine and get more power out of it.
- Increase the efficiency of the boiler and so reduce the amount of fuel to be carried.
- Improve the transmission system by replacing the paddle with the screw for ocean going ships.

Again there is not space here to discuss these important issues. However, engineers like David Napier and his cousin and competitor Robert Napier, the shipbuilder, were inspirational in developing marine engines and shipbuilding techniques which would eventually enable steam ships to become sea-going and thus capable of crossing the world's oceans, safely and economically.

3.3 The Side-Lever and Oscillating Engines. There are many types of marine steam engines, refer: Wikipedia, Marine steam engine. There is not space here to discuss these in detail. However, the museum does have on display examples of two of the most popular types; the Side-Lever and the Oscillating engine.

The early pioneering steamships were Paddle Steamers (PS). The one that we can say with certainty that did actually work (from c1802) was the *Charlotte Dundas*. The steam engine that powered the *Charlotte Dundas* was built by the engineer William Symington, ref. 19 & 20. This engine was a horizontal double-acting engine with a piston rod and connecting rod that directly drove the crankshaft of the stern paddle wheel. This was a very practical means of powering a paddle steamer and the engine arrangement is not that far different from the near horizontal Diagonal Engine that later would become the standard power arrangement for paddle steamers like *Waverley* and the *Maid of the Loch*.

Unfortunately, due to circumstances, Symington was not able to benefit from his success with the *Charlotte Dundas*. The result was that the early paddle steamers were mostly based on a derivation of the Watt beam engine. Some were in fact beam engines, with overhead beams, and were successful as river steamers mostly in America (the Americans called them Walking beam engines). Others were less successful the weight of the beam engine with its heavy overhead beam could reduce the ship's freeboard leading to stability issues, ref. 16.

The marine engineers soon modified the Watt beam engine, with its single overhead beam, into a much more practical arrangement by moving the overhead beam into two side beams low down either side of the engine cylinder. To ensure the cylinder piston rod and horizontal crosshead maintained alignment, as the side levers rocked, there was an equivalent Watt straight-line mechanism fitted. Thus the side-lever engine was developed. This made for a compact engine and improved the stability of the ship by keeping the centre of gravity of the engine low and made sea-going service possible. The museum has the engine of the PS *Industry* (from 1828) currently on display, Figure 3. There is also a side-lever engine of the PS *Leven* (from 1823) to be seen at Dumbarton outside the Denny Tank Museum.

Another popular marine engine was the Oscillating Engine. So called because the cylinder(s) oscillated on trunnions as the crankshaft turned. There was no connecting rod, the piston rod connected directly to the crankshaft. Engines of this type were patented by Joseph Maudslay, in 1827, and perfected by John Penn. The museum has a small model of an oscillating engine currently on display, Figure 4.

3.4 The Napier Steeple Engine. David Napier built side-lever engines. However, he was an inventive engineer and he invented a marine engine that became known as a steeple engine[(1)]. A description of how he conceived the idea of the steeple engine is given in ref. 6. He patented the steeple engine in 1842 (Patent No 9439, 1842*, Improvements in Steam-Engines and Steam-Engine Boilers*), although the steeple engine was introduced in about 1831, ref. 5[(14)]. His engine became popular with Clyde paddle steamers but as we see on the *Simla* it could be adapted to drive a screw propeller for use on ocean going ships. The main features of a Napier steeple engine are, with reference to Figure 5:

(1) Cylinder(s) sit on a base frame (bedplate) at the bottom of the ship (to keep the centre of gravity low and hence improve stability).
(2) The Crankshaft is <u>above</u> the cylinder(s), with a bearing framework at mid-height.
(3) Crosshead Guides that stick up in the air (like a church steeple hence the name Steeple Engine) are above the crankshaft.
(4) Piston rod(s) are arranged to pass the crankshaft. The options were: 1 rod with a yoke wide enough to avoid the crankshaft or multiple rods (2 or 4) again spaced wide enough to avoid the crankshaft. The *Simla* engine has 4 piston rods on each cylinder.

The whole arrangement avoided heavy side-levers, had fewer working parts, a more direct (in line) drive to the crankshaft and made for a compact engine thus saving space. Other equipment such as valve gear and engine driven pumps were as normal for a marine steam engine. The working of a Napier steeple engine, based upon reference 5, is shown in the following animation link:
https://acwhyte.droppages.com/downloads/animations/Napier_Steeple_Engine_animation.gif

The steeple engine invented by David Napier was vertical in arrangement and designed principally to power commercial paddle steamers. However, with modifications there were horizontal steeple engines built (also known as a Back-Acting Engine or Double Piston-Rod Engine) for direct drive screw driven warships, ref. 16. This made a compact arrangement with a low centre of gravity and protected the crosshead guides from gunshot. One such engine from USS *Ranger* (1876) apparently still exists at the American Merchant Marine Museum, Kings Point, New York, refer: Wikipedia, Marine steam engine.

3.5 The Crosshead Guides. A feature of the steeple engine was the crosshead guides sticking up in the air. However, the steeple engine was not the only engine with crosshead guides that stick up in the air. Some side-lever engines did use guides to avoid the Watt equivalent straight-line mechanism. Examples are shown in Figures 6 to 8 including examples with wide and closely spaced guides.

3.6 The Return Connection Rod Engine. The steeple engine has piston rod(s) that emerge from the cylinder and go towards the crosshead but the connecting rod reverses direction and returns back to the crankshaft. This is a class of engine known as a return connecting rod engine (or back-acting engine), refer: Wikipedia, Return connecting rod engine. But <u>not</u> all return connecting rod engines are steeple engines. There are two models of return connecting rod engines that are <u>not</u> steeple engines currently on display in Riverside Museum:

- Figure 9 shows a model of an early steam locomotive. This was Glasgow's first steam locomotive from 1831.
- Figure 10 shows a model of a Table Engine (Americans sometimes called them Crosshead Engines and used them on river steamers).

4.0 The *Simla* Engine Model – the Details - How It All Works. The engine model is recognised as being of exceptional size and quality, Figures 1 and 2. It is around 9.4ft. (2.86 metres) in height, 6.5ft. (2.0 metres) in width and 10.6ft. (3.23 metres) in length. It is therefore as large if not larger than some actual engines, for example, it is taller than the PS *Industry* engine, Figure 3. The model is largely made of metal: cast iron, wrought iron, steel, bearing brasses, gunmetal pumps and copper piping. According to Grace's Guide, reference 13, the model was built in 1853 and was exhibited at the 1855 Universal Exposition in Paris, at the 1862 London Exhibition and at the Crystal Palace. It is then said to have been purchased by a Mr. D. Desvignes of the West London Engineering Works[(15)]. It was then purchased from Mr Desvignes by the Institutions of Engineers of Great Britain and presented to Glasgow Museums.

In its current state the model is almost complete; there are a few items missing, these will be explained in the relevant text. The detailed description of the engine model now follows. This has been greatly aided by the description of the model (No 822. Model of engines of S.S. "Simla" (Scale 1:4) Lent by G.F.G. Des Vignes, Esq., 1908.) given in the London Science Museum Catalogue, ref. 25. The working of

the engine is shown in the following animation link:
https://acwhyte.droppages.com/downloads/animations/Simla_Steeple_Engine_animation.gif

4.1 The Cylinders and Crankshaft. The engine has two cylinders[20] that sit on a base frame (bedplate), Figure 11. The cylinders are double-acting; there will be four working strokes per revolution of the crankshaft when both cylinders are working. The engine is not compound it works by simple expansion; the cylinders are supplied with steam at boiler pressure and have their own slide valves, control gear and shut-off (throttle) valve so the engine could be run on half power on one cylinder only.

There is one crankshaft with 3 cranks. The aft end of the crankshaft extends to drive a large gear wheel. This large gear drives a small pinion gear, the shaft of which drives the propeller. The crankshaft and large gear are supported by four journal bearings on a bearing frame, Figure 11. The two piston cranks are at 90 degrees to each other so at least one piston will be off dead centre enabling the engine to be started and manoeuvred. The piston crank at the forward end is a side crank i.e. it has one crank web with a side pin, Figure 12. The aft piston crank is a centre crank i.e. it has two crank webs with a centre pin between the webs, Figure 13. There is a third (central) crank, Figure 14, to drive the condenser air pumps, these will discussed in section 4.5 below.

4.2 The Piston Rods and Connecting Rods. Each cylinder has four vertical piston rods spaced to allow the rods to pass the crankshaft, Figure 15. The piston rods pass through the cylinder cover and are sealed with stuffing boxes. This was one of the disadvantages of this engine; these multiple stuffing boxes would require regular maintenance. The piston rods connect with the crosshead, which slides in the steeple guides, Figure 16 and 17. The crosshead connects with the return connecting rod to drive the crankshaft. The bearing ends of the connecting rod are secured by a wedge cotter, gib, and strap arrangement, Figure 18.

4.3 The Eccentrics. The crankshaft has a third crank, in a central position, which drives two condenser air pumps in trunks (i.e. like a Trunk engine), Figure 14. Adjacent to this crank are four eccentrics (two for the aft cylinder and two for the forward cylinder) these drive the main slide and expansion valves and bilge pumps by means of two sets of three diagonal drive rods. The aft set of eccentrics (with balance weight) and diagonal rods are shown in Figure 19. The air pumps and eccentrics are always running when the crankshaft is running, but the slide and expansion valves and bilge pumps can be disengaged (thrown out of gear) from the eccentrics by hand locking levers on the diagonal drive rods. The hand locking levers are on the side of the diagonal rods that are moving, when the engine is running, so some dexterity by the engineers would be required when operating the engine. Details of the hand locking levers and their operation are given in Figures 20 and 21.

4.4 The Slide Valve Control. Once started the engine can run automatically by means of a slide valve (main slide valve), which directs the steam to the cylinder and then to either side of the piston, to give a double-acting engine. The steam supply and the steam chest which distributes the steam to the cylinder is on the port side of the cylinder, Figure 24. Each cylinder has its own steam chest with valve gear and hand control shut-off (throttle) valve; there are also hand controls for the condenser cold water spray valves and the condenser drain/blow-through valves. These hand controls are attached to the port side of the bearing frame, Figures 22 and 23.

The details of the valves are not known but a section through a typical steam chest with a main slide valve (a D valve pattern) and an expansion valve (a gridiron pattern) is shown in Figure 25. The main slide valve does most of the work; it controls:

(1) Reversing Ahead or Astern.
(2) Directing the steam to either side of the piston to give a double-acting engine.
(3) Directing the exhaust steam to the condenser.

On this engine there is also an expansion slide valve, on the outside of the main slide valve, Figure 24. This expansion valve gives control over the amount of steam supplied to the main valve and hence to the cylinder, see Wikipedia, Expansion valve (steam engine). Adjusting the steam cut-off makes full use of the steam pressure and gives better control of the expansion of the steam in the cylinder leading to better fuel economy, Figure 26. This is done by cut-off of the steam supply as a percentage of the piston stroke, see Wikipedia, Cutoff (steam engine). After cut-off the steam would expand in the cylinder doing useful work (something that was known about from the days of James Watt). By this means the power output of the engine can be controlled[17][18] Figure 26. This arrangement was not new - the Gurney Drag (also currently on display in Riverside Museum) of 1831 also has expansion valves.

The slide valves are driven by vertical push/pull rods and horizontal weigh-shafts (rocking shafts), Figure 22, by the eccentrics which are driven from the crankshaft, Figure 19. The valves can be disengaged (thrown out of gear) from the eccentrics, by hand locking levers on the eccentric diagonal drive rods, Figure 21. The steam to the valves can be shut-off by a hand control, Figure 23a.

- **Reversing, Ahead or Astern**. This is done by moving the Main Slide Valves by hand with the engine stationary. (1) Shut off the steam supply to both cylinders. (2) Disengage the main slide eccentrics. (3) Engage the gear pinion to the gear quadrant by sliding the spoked wheel, and rotate the wheel for Ahead or Astern as called for. (4) Disengage the spoked wheels by sliding the wheel and pinion from the quadrant. (5) Re-engage the main slide eccentrics. (6) Open the steam supply.
- **Steam Expansion Cut-off**. Controlling the expansion can be done by moving the Expansion Valves by hand. This could be done with the engine running although some dexterity would be required as the hand levers are moving, driven by the eccentrics via diagonal drive rods. (1) Disengage the expansion eccentric. (2) Adjust the hand control lever to give whatever steam cut-off is desired. (3) Re-engage the expansion eccentric.

4.5 The Condenser, Hot Well, Air and Boiler Feed Pumps. It was known from the days of James Watt that employing a condenser, to condense the steam to water, and operate the engine at below atmospheric pressure, by lowering the back pressure, would enable more power to be obtained from the engine for the same amount of steam and hence improve the efficiency, Figure 27. The steam leaving the cylinder is exhausted into a condenser, which is working below atmospheric pressure i.e. in a vacuum maintained by pumps, known as air pumps due to the amount of trapped air in the condenser as a result of the introduction of cooling water to condense the steam(21). The condensate and air are pumped to a hot well where the condensate can be drawn off by boiler feed pumps or excess sent to waste overboard and the air vented.

The condenser used on SS *Simla* is a jet condenser(19), which consists of a large chamber where the exhaust steam enters and is condensed by cooling with a jet spray of cold water through valves adjusted by hand control. A diagrammatic of the jet condenser is shown in Figure 28.

The two air pumps, one each port and starboard, are driven from the crankshaft, Figure 14, and are large enough to maintain a vacuum by pumping the condensate (condensed steam and jet spray water) and air away to the hot wells, Figures 29 and 30. The purpose of the hot well(s) is to store the condensate prior to discharge overboard or to be drawn off by the boiler feed pumps to supply the boiler. The dome over the hot well is to provide extra storage should there be a built up of condensate. There is always an excess of condensate, with a jet condenser, due to the cold water spray requirements to condense the steam.

The condensate from the port hot well would be discharged overboard and air vented to atmosphere. The condensate pumped to the starboard hot well is drawn off by two boiler feed pumps(16) driven from a crosshead on the starboard side air pump trunk, Figure 30. The amount of boiler feed water pumped to the boiler is controlled by a spring-loaded valve on the side of the hot well, Figure 30. Excess condensate would be sent to waste overboard and air vented. Note that the dome cover on the starboard hot well and the boiler feed pump piping are missing on the model. An early photograph of the model, in reference 13, shows these items in situ.

There are also two valves on the starboard side of the condenser near the top of the condenser, Figure 30. It was the practice to provide bilge injection valves. In the event that the bilge pumps could not clear the bilge water (due to a serious leak in the ship) opening of these condenser bilge injector valves would allow the air pumps to be utilised for pumping out the ship, ref. 21.

4.7 The Condenser Drain/Blow-through Valves. There is a hand-operated drain/blow-through valve adjacent to the port forward side condenser/air pump housing, Figure 31. The valve on the opposite (aft) side is missing(22) but the drain hole can be seen, Figure 29. These valves would allow steam to expel any air and accumulated water during warm up the engine prior to starting, which could take up to 1 to 2 hours. It was also important that the condenser or hot well did not become full of water, if so the engine would not operate until drained of the water.

4.8 The Bilge Pumps. There are four bilge pumps on the starboard side; two each beside each cylinder, Figure 32. The bilge pumps are operated through vertical push/pull rods and horizontal weigh-shafts by engaging diagonal drive rods driven from the main slide valve eccentrics, Figures 19 and 20. Each drive rod can be engaged/disengaged by a hand lever so the bilge pumps only need to be pumping when required.

4.9 The Safety Valves. The cylinders are fitted with deadweight lever safety valves, Figures 33. These valves are essential to avoid overpressure of the cylinders. This could easily happen if the engine was started without clearing the cylinder of condensed water. Water is practically incompressible and has to be cleared before starting the engine. Deadweight lever safety valves are reliable provided they are maintained and have not been tampered with.

4.10 The Propeller Gearing. A significant feature of the *Simla* engine is the transmission gearing to the screw propeller(8), Figure 34. The early steamships were Paddle Steamers, many of which were powered by Napier steeple engines, and the engine turned the paddles at less than about half a revolution per second.

Screw propellers work better at several revolutions per second. Gearing was employed to increase the rotation of the propeller. However, gears were noisy and subject to rapid wear. It became normal practice to make the large wheel gear teeth from a hard tough wood, such as hornbeam (ref. 28), and the small pinion on the propeller shaft from iron, ref. 16.

It was also the practice to make the gears in several parts and stagger the teeth so they are not in a line. This made for smoother running, ref. 17. This arrangement is shown on the *Simla* model, which has four sets of teeth with a gear ratio of 2.75 to 1, ref. 25, i.e. for every revolution of the crankshaft the propeller would rotate 2.75 revolutions, Figure 34. The gearing of the SS *Simla* seems to have been of some interest as on Getty Images a 1/16 scale model of the *Simla* gears can be found.

4.11 The Thrust Bearing. With a screw propeller a thrust bearing is required(8)(9). As the propeller turns the axial thrust generated by the action of the water on the propeller blades is transmitted to the propeller shaft. This axial thrust has to be resisted (Newton's third law of motion) by a thrust bearing securely attached to the ships structure, and hence the ship is pushed through the water. The actual thrust bearing used on SS *Simla* is not known. However, two likely options are available:

(1) One early method was a thrust bearing on the free end of the gearing shaft (for ahead running) and a backing plate (for astern running) on the rudder post, ref. 18. It is possible that the pinion forward bearing support, Figure 34, could well house a thrust bearing for ahead running. The thrust transmitted by this method was very limited, too high a thrust and the bearing would run hot and seize.

(2) An alternative method was to use a Multi-Collar Thrust Bearing. This could be on the engine or on a separate block between the engine and the propeller. The multi-collars could take ahead or astern running. The best example in the museum is on the *King Edward* low pressure turbine, Figure 35. The thrust transmitted was still limited hence the need for multiple collars. The complete solution came, in 1905, with the invention of the Michell Thrust Bearing(8).

4.12 Some Details You Might Miss. The model has a lot of interesting details typical of engineering practice in the 1850's. We have already seen the method of attaching the connecting rod to the crankshaft by means of a wedge cotter, gib and strap arrangement, Figure 18; some other details are:

- **Steam Supply Pipes**. Figure 36 shows the supply pipes to be fabricated from two pieces of copper bent in a semi-circle and brazed with an irregular join to form a pipe then bent to form a tight 90 degree bend.
- **Cylinder Head Cover Bolting**. Figure 37 shows the cylinder head cover bolts are individually marked. Note the height of the nut. During the Second World War the size of nuts was reduced to save material and they never went back to the original.
- **Bearing Nuts and Locking Collar**. Figure 38 shows the means of locking the journal bearing nuts by means of a collar and screw.
- **Lock Nuts**. Figure 39 shows lock nuts (or jam nuts) used in several locations to give extra security.
- **Bearing Brasses**. Figure 40 shows the crankshaft bearing brasses are individually marked.
- **Frame Supports**. Figure 41 shows the frame supports are keyed in and secured by a wedge and bolting.
- **Support Brackets**. Figure 42 shows support brackets to be curved to fit the adjacent cylinder casting.

5.0 The Steeple Engine – the Decline In Its Use. With the increase in the size of ships, the engine power requirements also increased requiring larger more powerful engines. The steeple engine, because of its height, was at a disadvantage because the depth of a ship is limited (though horizontal steeple engines were built as mentioned above). There was also a difficulty in supporting the steeple guides to prevent them from vibrating, the taller the engine the worse this problem became. The use of the steeple engine gradually declined and was replaced by other types most notably the Diagonal Engine for Paddle Steamers (like *Waverley* and *Maid of the Loch*) and the Inverted Cylinder Direct Drive Vertical Engine for Screw Steamers (like *Shieldhall* and *Sir Walter Scott*).

6.0 Summary. In summary, the Steeple Engine invented by David Napier was just one of a number of types of marine steam engine developed during the 1800's when Britain and its expanding Empire were having a profound effect on World trade and the movement of people to all corners of the Empire. For many years it was a successful engine until replaced by more advanced types.

The marine engineers and shipbuilders of the day had the vision and energy to see that Glasgow and the Clyde would become, by the end of the 19th century, the most productive shipbuilding area in the world - alas, a time that has now long past.

Notes.

(1) The Napier Steeple Engine should not be confused with the "steeple" compound engine, a form of tandem steam engine of great height, which also became known as a "steeple" engine, refer: Wikipedia, Steeple compound engine.
(2) David Napier (1790 – 1869) the marine engineer should not be confused with his cousin David Napier (1785 – 1873) the founder of the precision engineering company D. Napier & Son Ltd. of London, notable for their luxury motor cars and later their aero and other engines. Their cousin Robert Napier (1791 – 1876) was the famous shipbuilder known as the "The father of Clyde shipbuilding".
(3) In the context of this note: SS stands for Single Screw Steamship, and PS stands for Paddle Steamer.
(4) The name: *Simla* (also known as *Shimla*) is the capital city of the Northern Indian State of Himachal Pradesh. A photograph of SS *Simla* near the outer dock at Southampton can be seen on the Royal Museums Greenwich website: https://prints.rmg.co.uk/products/ss-simla-near-the-outer-dock-at-southampton-p18063.
(5) David Tod and John McGregor both at one time worked for David Napier. The relationship between David Tod, John McGregor and David Napier is briefly discussed in references 5 and 6. The spelling of Tod & McGregor used in this note is that used on the decorative brasses on the model bearing frame, see the detail Figure 11. Other references sometimes use the spellings of Tod with two d's and McGregor as MacGregor.
(6) Reference 7 quotes the year built as 1853.
(7) The first draft of proposed Lloyd's Rules for Iron Ships appears to have been prepared at a conference held in Glasgow in February 1854; in the same year that SS *Simla* was built. By the mid 1850's Glasgow was the most important centre of iron shipbuilding. The first Lloyd's "Rules for Iron Ships" were issued in 1855, ref. 15. There were some initial reservations on the use of iron in particular its durability when subjected to continuous action of sea water and the chemical action of certain cargoes.
(8) The advantages of the screw over the paddle became apparent from the HMS *Rattler* (a screw steamship) versus HMS *Alecto* (a paddle steamship) trials in 1845. *Rattler* towed *Alecto* astern. The other advantage of the screw was that it was not so affected by the heeling of the ship in rough seas. However, there were disadvantages to be overcome: (a) in early steamships the crankshaft speed of rotation was low to suit paddle steamships (typically less than half a revolution per second). Screw propellers work better at several revolutions per second. Gearing was employed to increase the rotation of the propeller; these gears were noisy and subject to rapid wear. (b) The propeller trust, that drives the vessel through the water, has to be got from the rotating propeller shaft into the stationary hull. This requires a thrust bearing. On the early steamships the free end of the propeller shaft was used as a thrust bearing, ref. 18; but even with adequate cooling and lubrication (first with water, later with oil) the allowable thrust loading was limited. There was a high risk of metal-to-metal contact and eventual seizure of the bearing. The solution was eventually found in the multi-collar thrust bearing though the loading was still limiting. Later a complete solution was found (from 1905) by an Australian Anthony Michell (pronounced Mitchell). This bearing had a single large collar with several tilting pads on both sides of the collar for ahead and astern running. The tilting pads allowed film lubrication, which can transmit very large thrusts and is the thrust bearing still in use today, refer Wikipedia, Anthony Michell.
(9) Paddle steamers do not require a thrust bearing as the paddle thrust is transmitted to the vessel through the paddle shaft journal bearings, which are in housings attached to the vessel hull.
(10) Reference 7 gives the tonnage as 2430 tons. Reference 12 gives the tonnage as 2508 tons (by old measurement) and 2563 tons (by the new measurement). After the conversion to a 4-masted sailing ship the tonnage was reduced to 2288 gross tons, ref. 10 & 11.
(11) Reference 11 quotes the horsepower as 640. Reference 25 quotes the nominal horsepower as 640. Reference 7 quotes: 640 later 1,766 based on reference 14. Reference 12 mentions; "She has two steeple engines of the aggregate power of 642 horses" i.e. 642 horsepower. My interpretation of this is; by two steeple engines (ref. 7 & 10 also mentions two steeple engines) they mean two cylinders and the aggregate power is the average power of each cylinder, i.e. the total power of the engine is 1284 horsepower and hence the aggregate power per cylinder would be 1284/2 = 642 horsepower.
(12) Some references give the conversion to a 4-masted sailing ship as 1877 (ref. 10) or 1880 (ref. 11).
(13) Reference 11 gives the sinking as 1883.

(14) According to Williamson, ref. 22, the earliest recorded steeple engine was that fitted to the sea-going steamer “Clyde” in 1832. However, Walker in reference 23 states the first (i.e. a steeple engine) came out on PS *Clyde* about 1836.
(15) The name Mr. D. Desvignes would appear to be a miss spelling of the name G. F. G. Des Vignes of the West London Engineering Works, ref. 24. The name G. F. G. Des Vignes is also that used in the description of the model in the Science Museum Catalogue, ref. 25.
(16) The size of the boiler feed pumps is quite small compared to the air pumps, as the volume of steam condensed to water is about 1600 to 1 at atmospheric pressure.
(17) As an alternative to varying the cut-off, to control the power output, the power output of an engine could be controlled by varying the steam pressure by means of a throttling valve. During this throttling the cut-off would be constant. This was quite an effective way to govern an engine but was wasteful of steam, ref. 26. Note that on the model there is no apparatus or indication of how the *Simla* engine was governed.
(18) On many steam engines no expansion valves were fitted. The ordinary slide valve was arranged to provided the steam cut-off and no expansion valve was necessary. This worked well provided an early cut-off was not required. Expansion valves allowed early cut-off. The use of expansion valves gradually fell out of use when compounding and higher steam pressures were introduced. The ordinary side valves were then used to provide the cut-off, ref. 21, though on some compound engines an expansion valve was fitted to the high pressure cylinder, refer Wikipedia, Expansion valve (steam engine) and ref. 27.
(19) The jet condenser is a simple arrangement and was relatively inexpensive to manufacture but had some disadvantages such as a difficulty in maintaining a good vacuum, contamination of the condensate pumped back to the boiler and if the condenser flooded with condensate the engine would not operate. Later steamships used surface condensers to avoid the disadvantages of the jet condenser.
(20) Reference 25 quotes the nominal horsepower as 640 and the boiler pressure as 17 lb. per sq. in. The two cylinders (of the actual engine) as 90 inches diameter by 78 inches stroke.
(21) Water always contains a certain volume of air in solution. Increasing the temperature and/or decreasing the pressure will release the air from solution. This released air cannot be condensed at the temperature and pressure in an engine condenser.
(22) A close look at the aft drain hole shows that it appears to be misplaced. It would have to be positioned more in towards the base frame in order that a hand control rod would pass the bearing frame. In addition there are no screw holes for the bracket to support an aft hand control rod on the bearing frame. For these reasons it would appear that the aft drain valve might not have been fitted to the model?

9.0 References.

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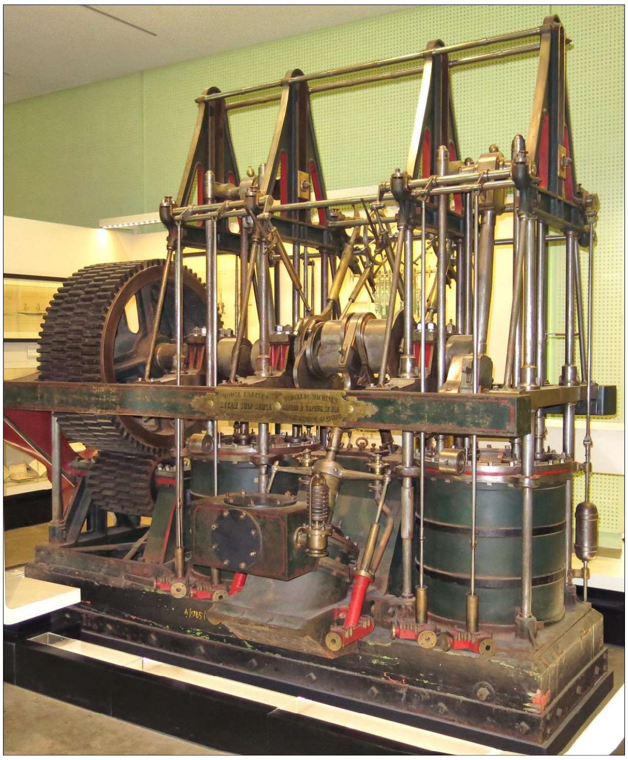


Figure 1, aft – port side. Figure 2, forward – starboard side.
Views of the quarter scale model of the SS *Simla* engine, Riverside Museum, 2019.

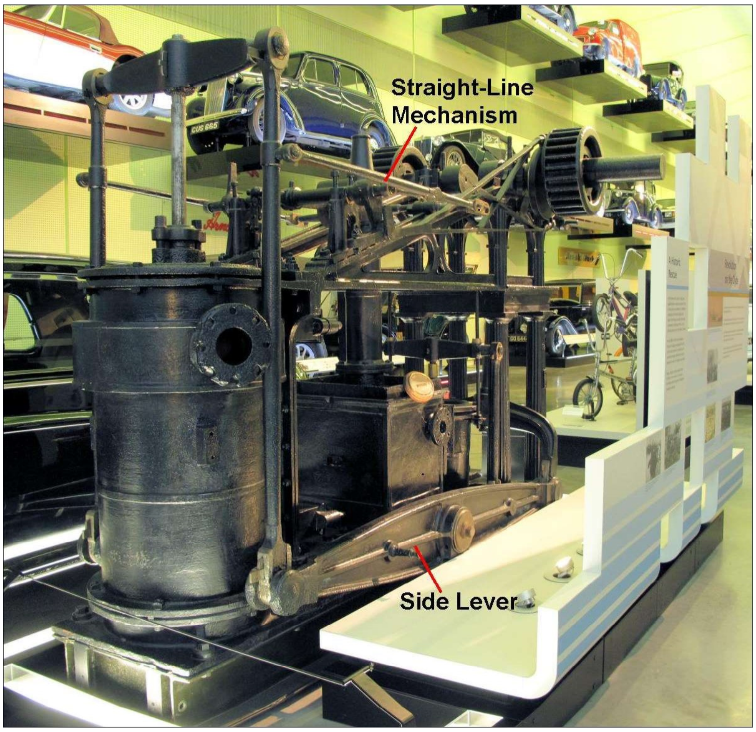
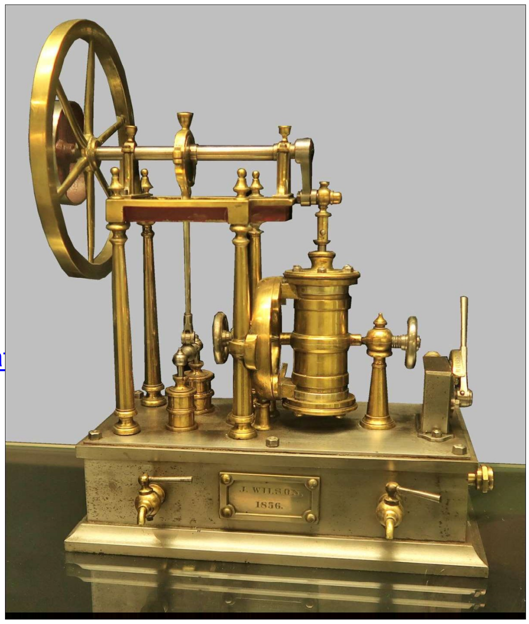


Figure 3, Side-Lever engine from the paddle steamer *Industry*, Riverside Museum, 2019.
This engine was built by Caird of Greenock and dates from 1828. An animation of a side-lever engine can be found at this link:
https://acwhyte.droppages.com/downloads/animations/side_lever_engine_animation_side_view.gif

Figure 4, A small model of an Oscillating Engine in Riverside Museum, 2019. Large engines of this type were used in marine applications. As the crankshaft turns the cylinder rocks, or oscillates. An animation of an oscillating engine is shown at the following link: https://acwhyte.droppages.com/downloads/anima



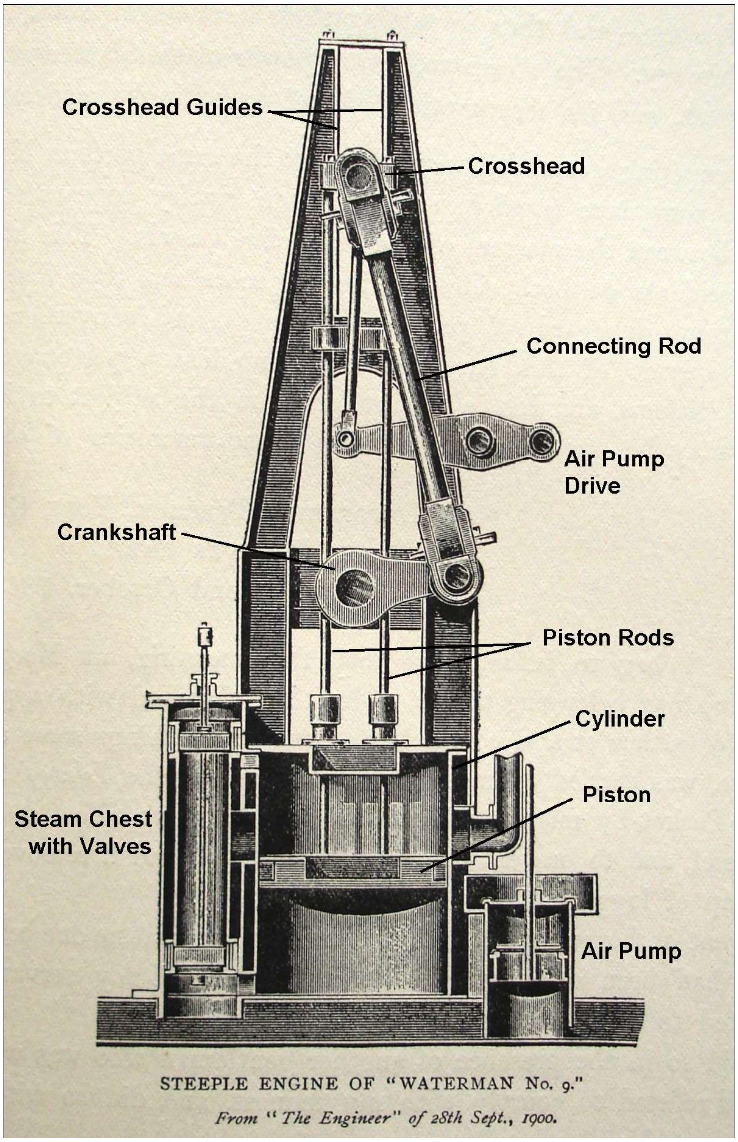


Figure 5, Section of a Napier Steeple Engine showing the main features of the engine, ref. 5 with added text. In this arrangement the engine sits on the vessel double bottom and the space between the double bottom is used as a condenser. This was a Napier patent, ref. patent No. 8044, 1839. *Improvements in Iron Steam-boats*.

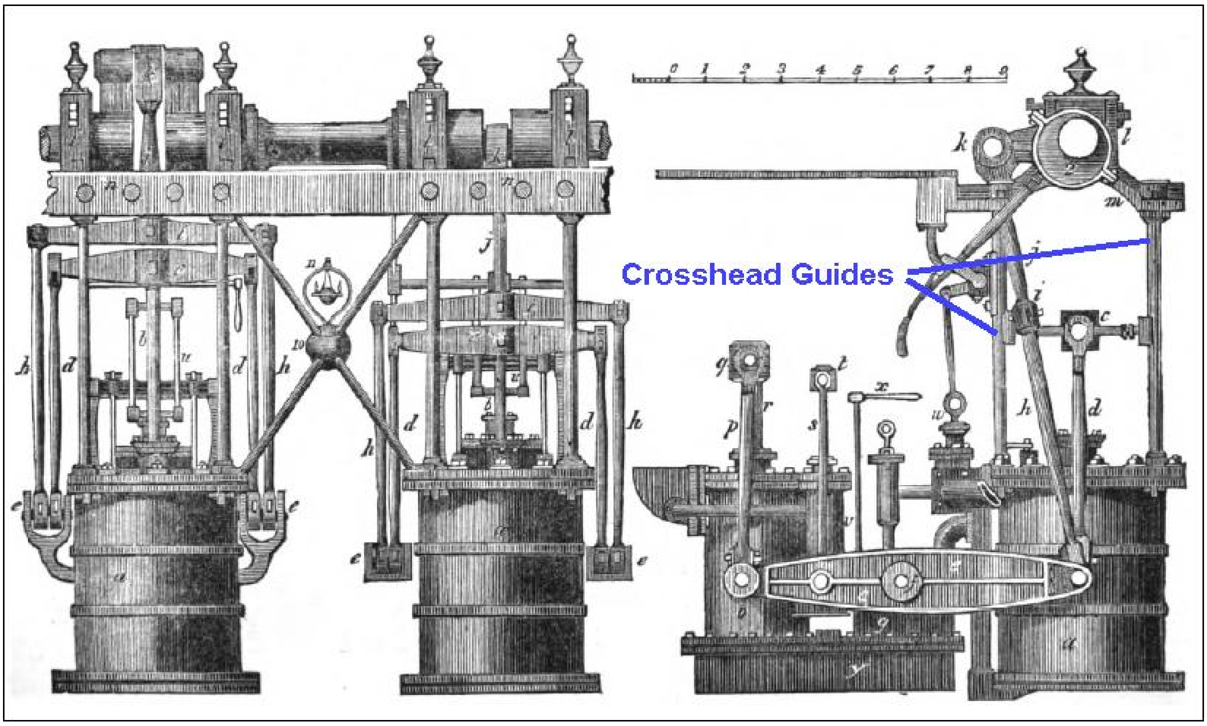


Figure 6, The side-lever engine of the PS *United Kingdom*, David Napier 1826, ref. 5 with added text. Note that Watt's equivalent straight-line mechanism has been replaced by vertical crosshead guides to guide the piston rod crosshead. In this arrangement the guides are <u>widely</u> spaced. This engine is also particularly interesting as the crankshaft is directly above the guides and driven, by side rods, yoke and connecting rod, at the same end of the beams as the cylinder. The other end of the beams drive the air pump.

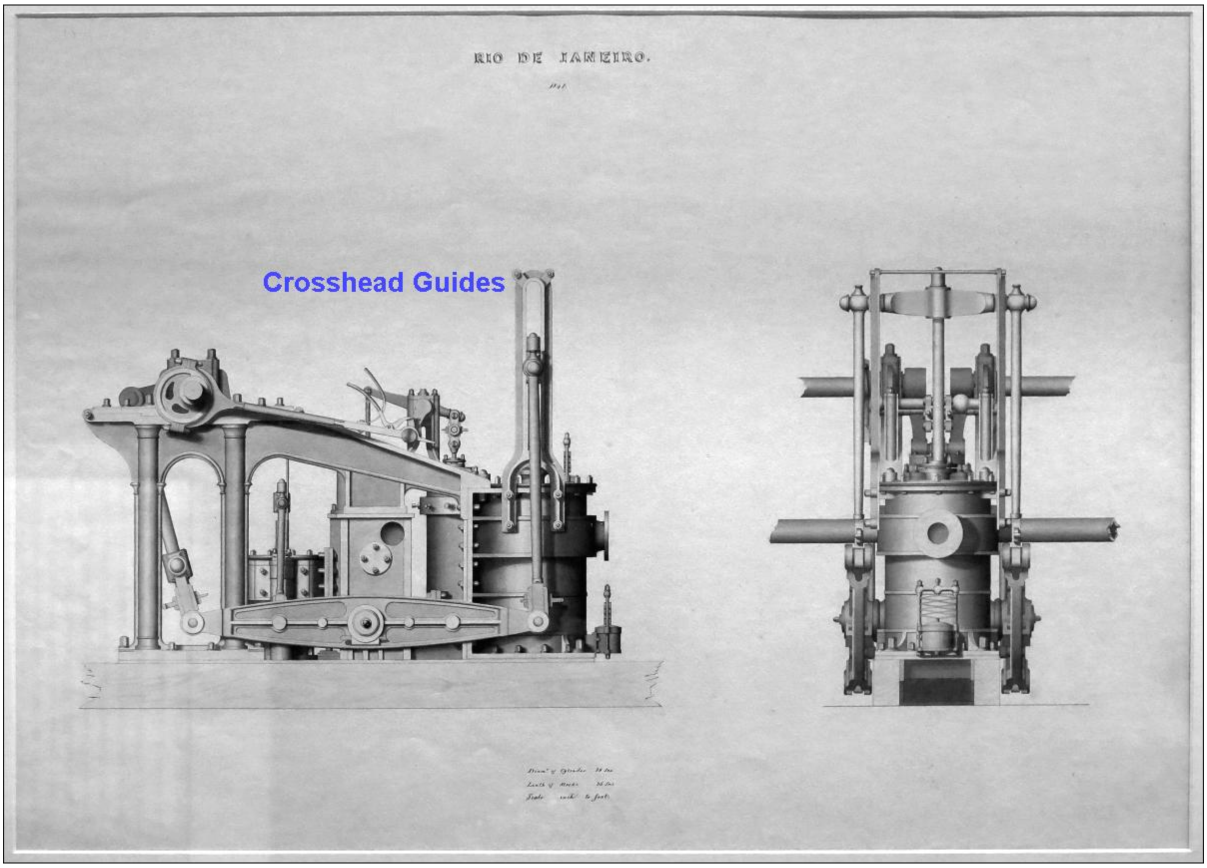


Figure 7, The side-lever engine of the PS *Rio de Janeiro*, Robert Napier 1841, Riverside Museum with added text. Note that Watt's equivalent straight-line mechanism has been replaced by vertical crosshead guides to guide the piston rod. In this arrangement the guides are <u>closely</u> spaced.

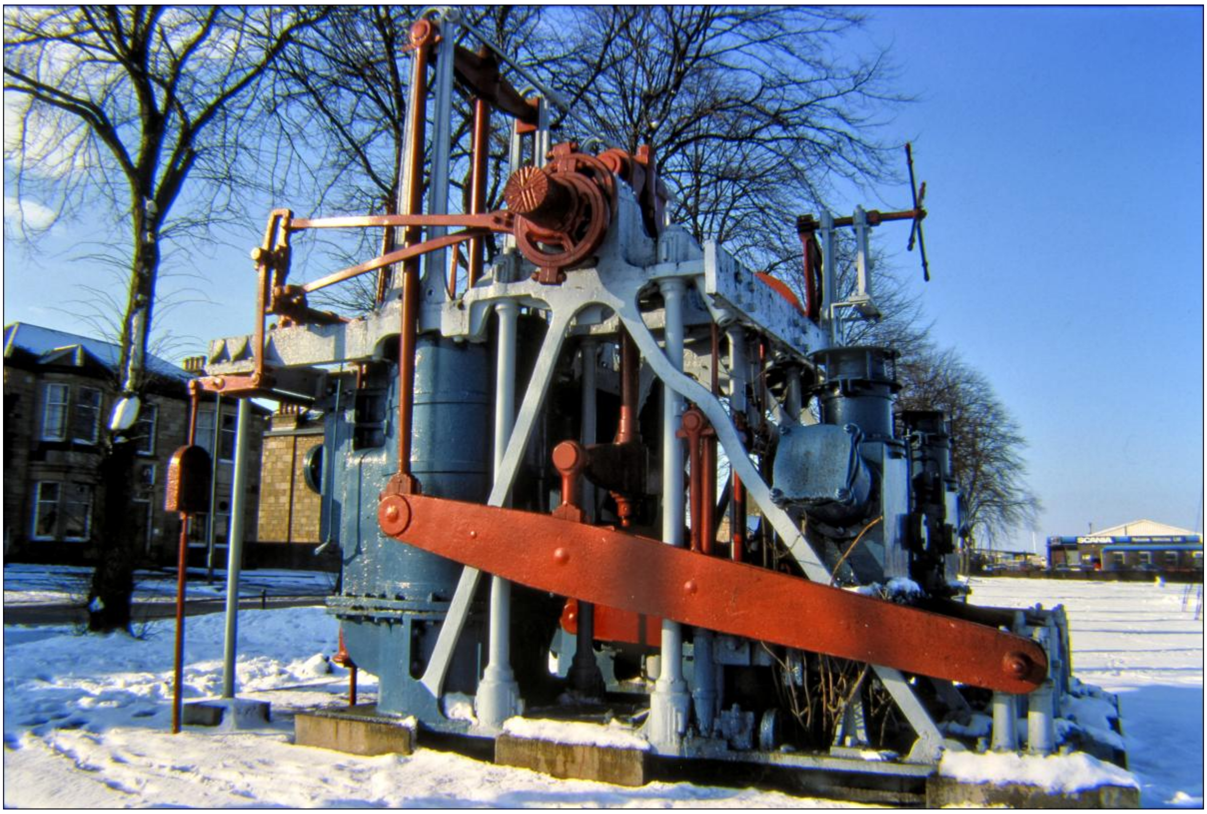


Figure 8, Renfrew Ferry Green: PS *Clyde* engines 1851. A side-lever engine of the grasshopper type this engine also has <u>closely</u> spaced crosshead guides to guide the piston rod.

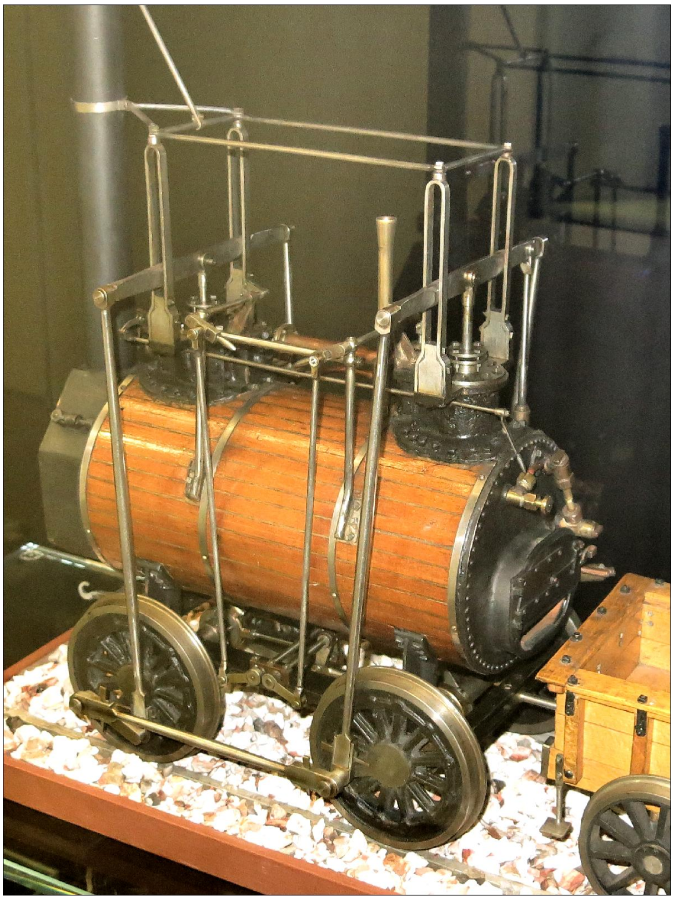


Figure 9, Riverside Museum; showing a small model of an early steam locomotive. This was Glasgow's first steam locomotive from 1831. It is a return connection rod engine. The piston rod crossheads are aligned between guides sticking up in the air. The connection rods return down to the cranks on the wheels.

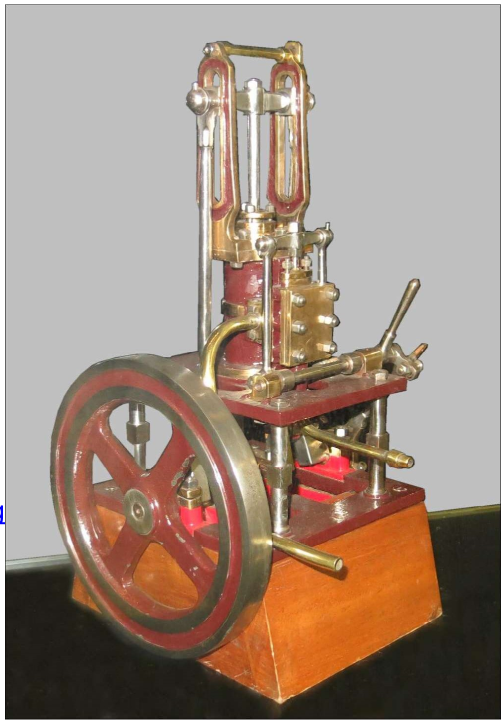


Figure 10, Riverside Museum; showing a small model of a return connecting rod engine known as a Table Engine. The cylinder sits on a table above the crankshaft (unlike the steeple engine, which has its cylinder below the crankshaft).

Table Engines were developed by James Sadler and Henry Maudslay, who used them as stationary engines in factories, refer: Wikipedia, Table engine.

An animation of a Table Engine can be found at this link:
https://acwhyte.droppages.com/downloads/animations/Table_eng

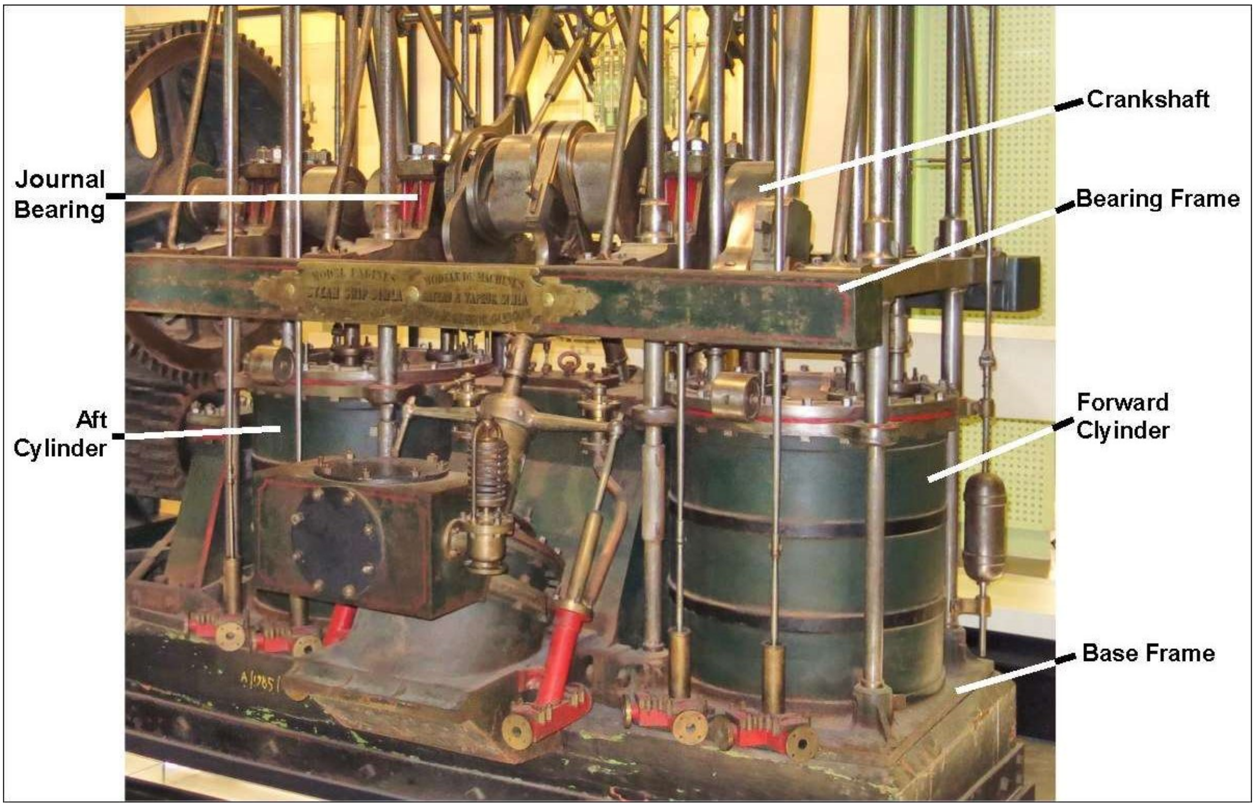


Figure 11, Starboard side view of the cylinders. Note the decorative brasses on the bearing frame:

Figure 12, The forward crank is a side crank.

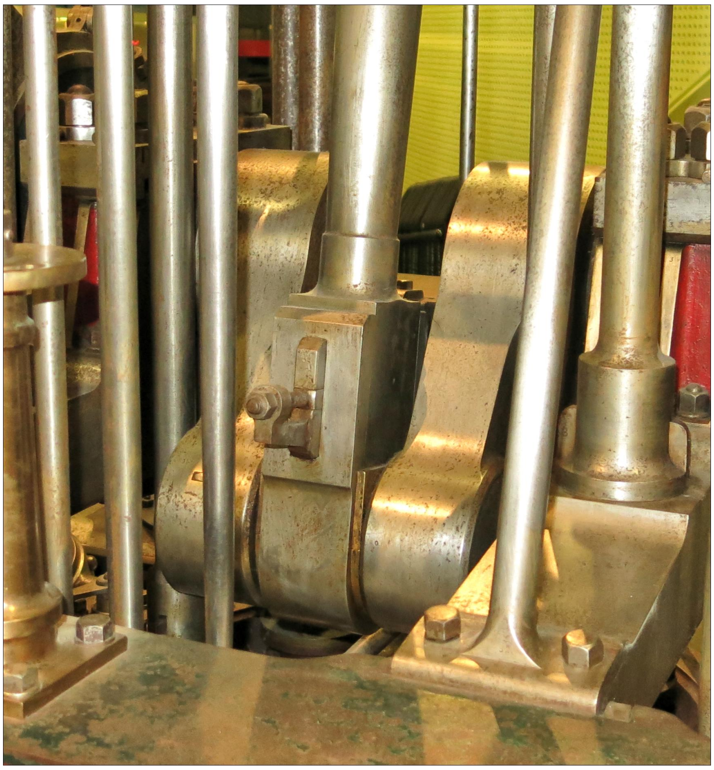


Figure 13, The aft crank is a centre crank.

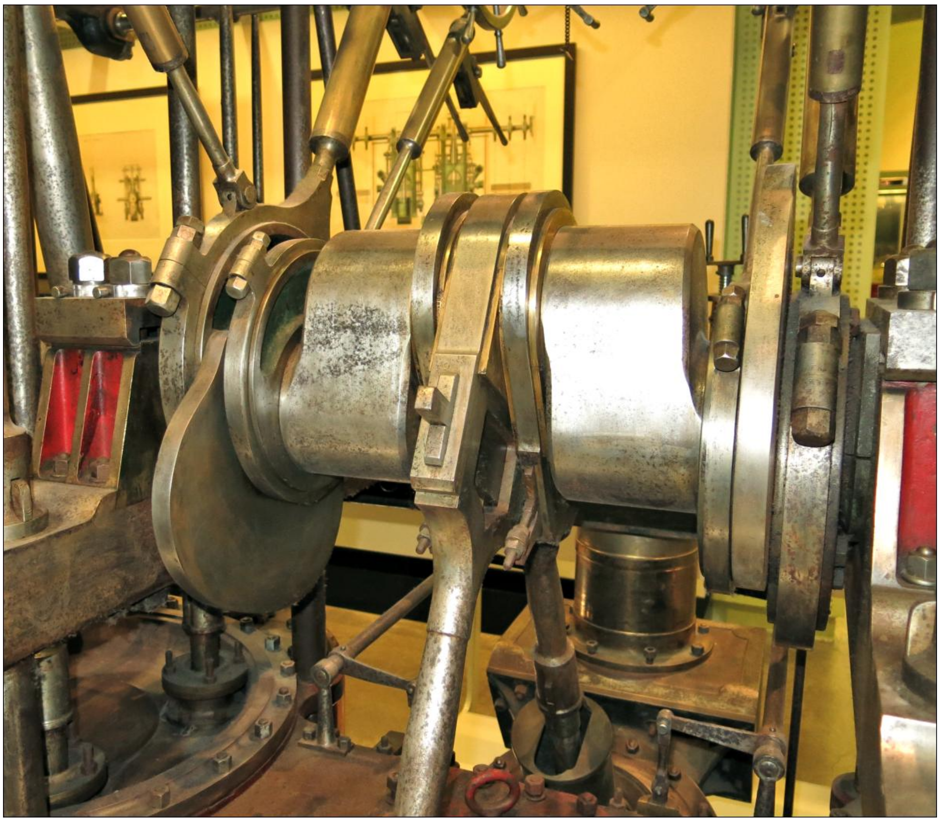


Figure 14, The third (central) crank drives two condenser air pumps, one each, port and starboard. Note also the two sets of eccentrics with balance weights adjacent to the crank. The eccentrics drive diagonal rods to the slide valves and bilge pumps.

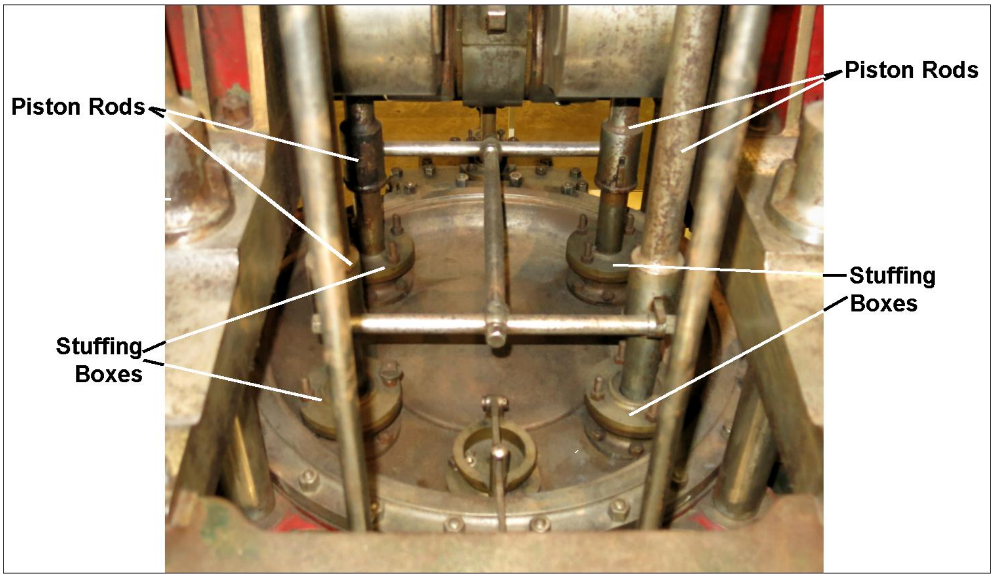


Figure 15, Cylinder cover showing the four piston rods and stuffing boxes.

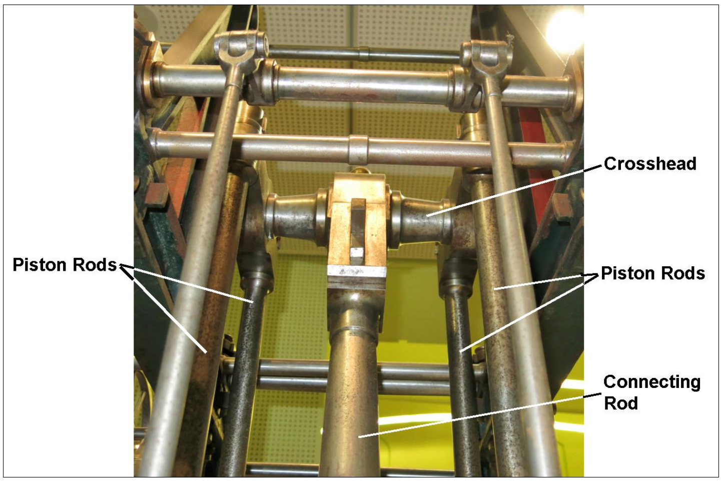


Figure 16, The four piston rods connecting with the guides crosshead and the connecting rod returning to the Crankshaft, refer Figures 12 and 13.

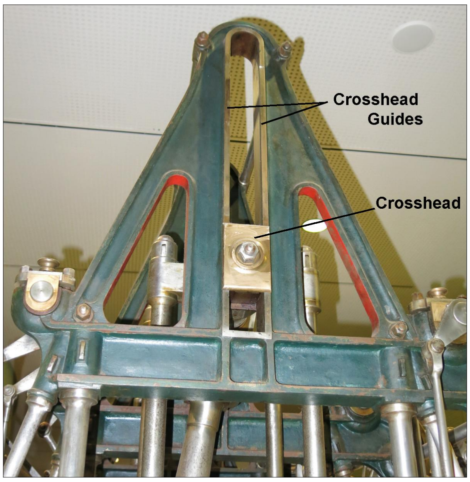
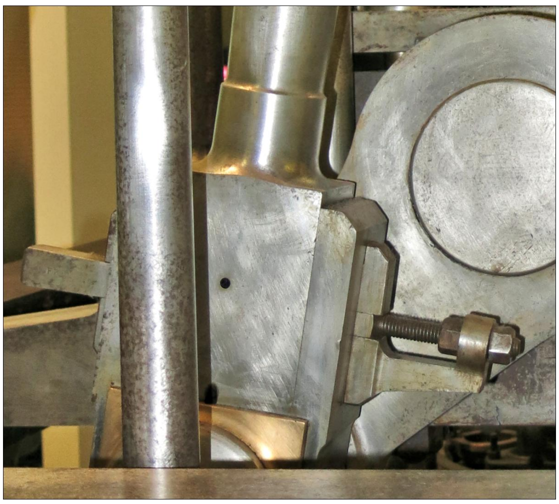


Figure 17, The crosshead and crosshead "steeple" guides.



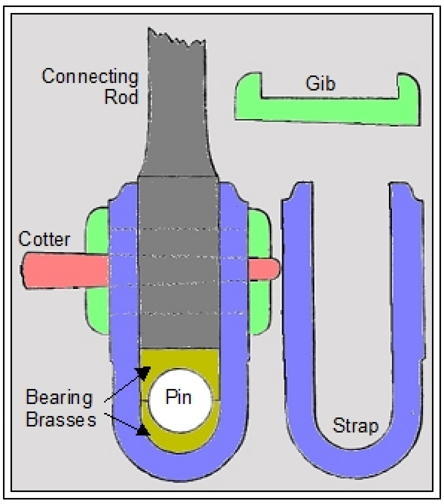


Figure 18, The connecting rod bearing ends are attached to the crank pins by a wedge cotter, gib and strap arrangement. Detail based on ref. https://commons.wikimedia.org/wiki/Category:Steam_engine_big_ends

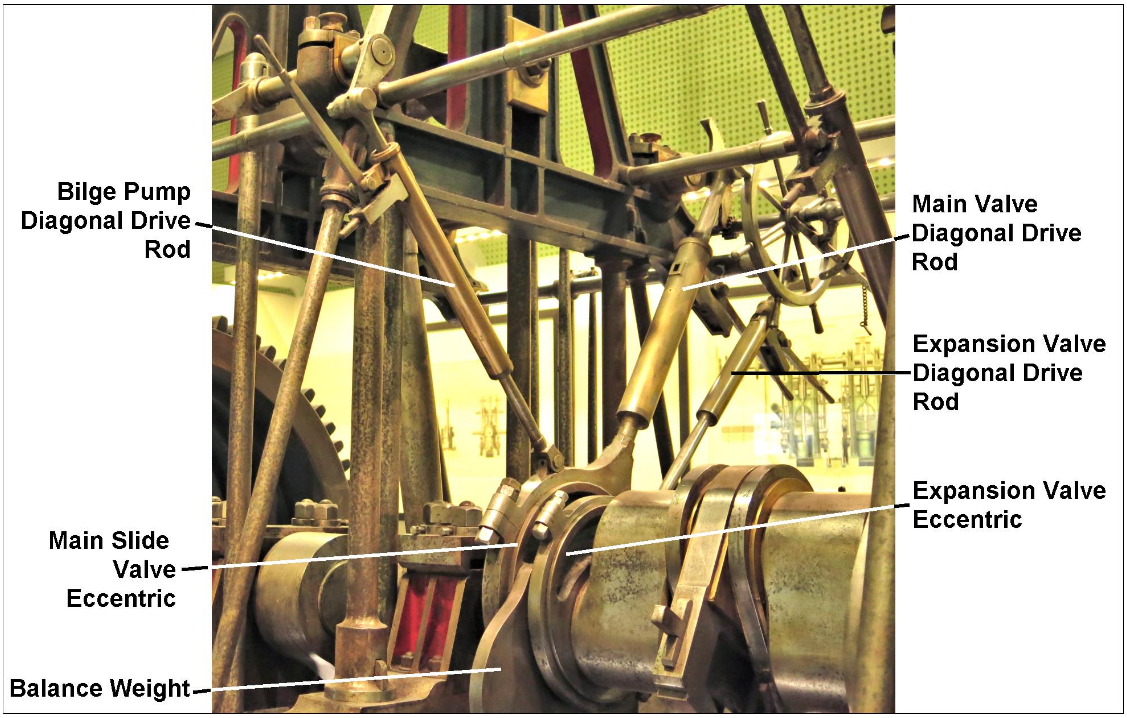


Figure 19, Showing the aft set of eccentrics and diagonal drive rods. The eccentrics are driven from the crankshaft. Note that the bilge pump diagonal rod is driven from the main slide valve eccentric.

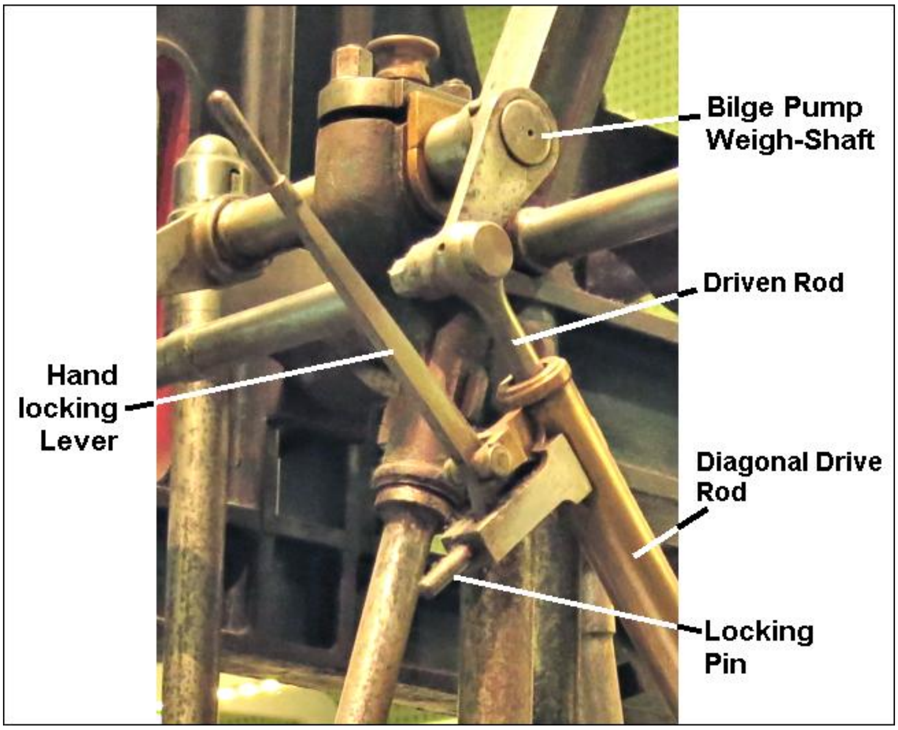


Figure 20, Detail of the aft bilge pump hand locking lever in the disengaged position. The locking pin is out hence the weigh-shaft would not be moving as the driven rod is not engaged by the pin (the driven rod would simply side freely inside the drive rod). Pulling the locking lever 90 degrees outward would push the pin in and allow the drive rod and driven rod to act in unison and rock the weigh-shaft. Figure 21 shows locking levers in the engaged position.

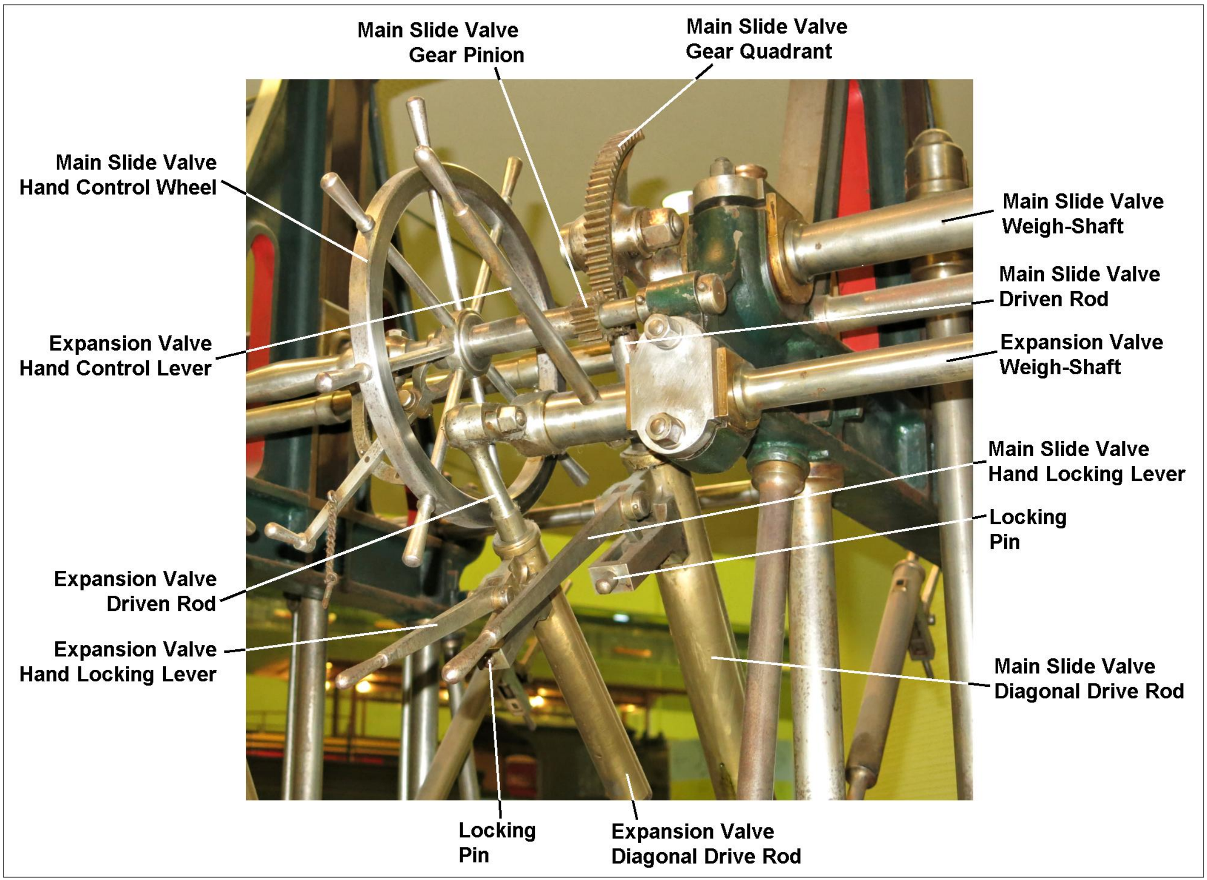


Figure 21, Detail of the aft slide valve hand locking levers in the engaged position. The locking pins are in when the hand lever is at right angles to the diagonal drive rods. The valve weigh-shafts would be moving (rocking) when the engine is running. Pushing the locking levers 90 degrees towards vertical would pull the locking pins out and disengage the valve weigh-shafts. Figure 20 shows a locking lever in the disengaged position.

Also seen in this photograph, Figure 21, are:

1. **The main slide valve hand control wheel**. With the engine stopped, this wheel can be moved (slid) to the right and the gear pinion can engage with the gear quadrant (as seen in the photograph). By rotating the control wheel by hand the main slide valve can be put Ahead or Astern as called for. The control wheel should be disengaged from the gear quadrant, by sliding the wheel and pinion to the left, prior to stating the engine.
2. **The expansion valve hand control lever**. When the expansion valve locking lever is disengaged the control lever can adjust the position of the expansion valve and hence amount of steam cut-off to the cylinder. Re-engaging the locking lever would then set the expansion valve position.

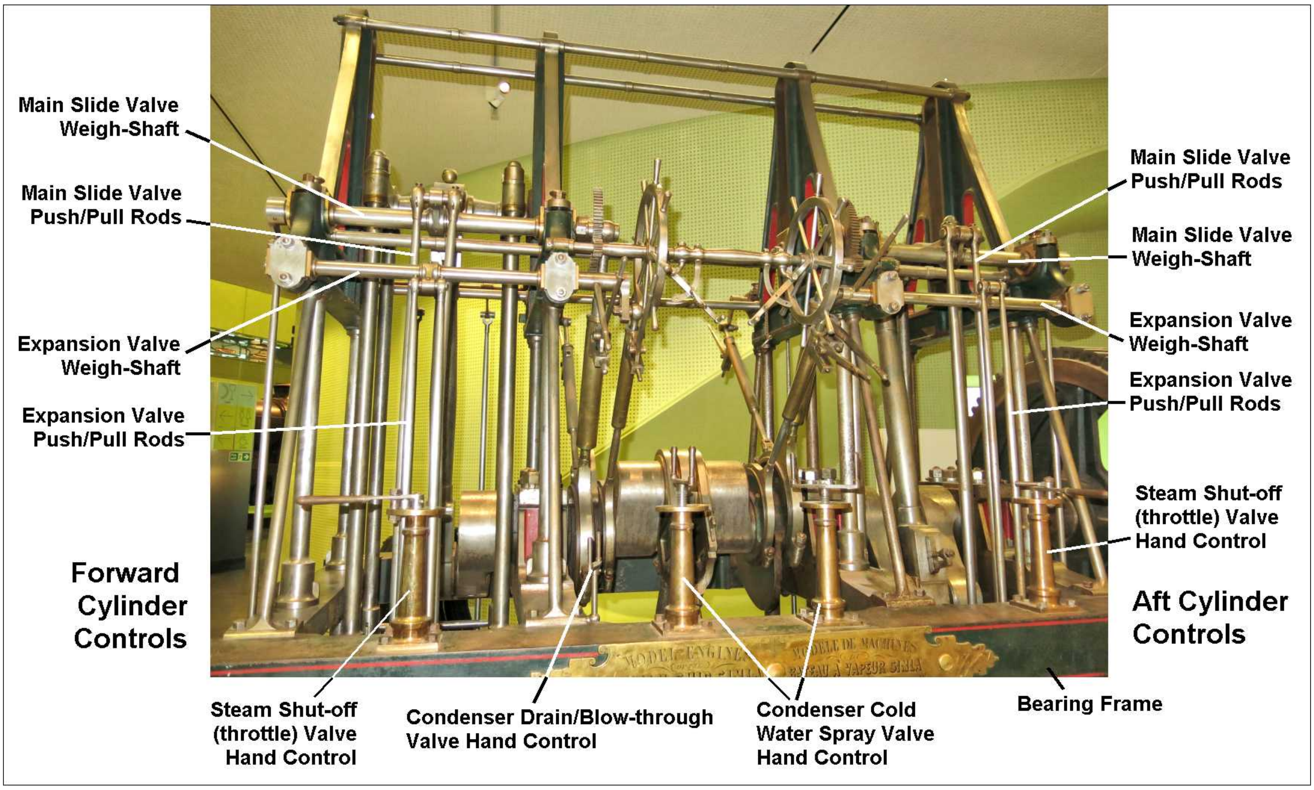


Figure 22, Detail of the engine controls for both cylinders. Each cylinder has its own valve and hand control gear on the port side of the engine. Note that the aft condenser drain valve and its hand control are missing.

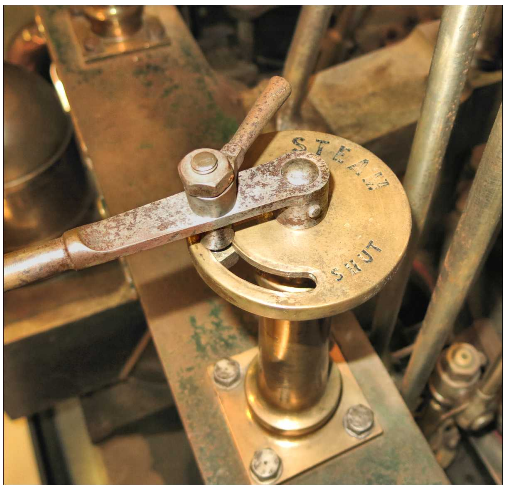


Figure 23a, Steam Shut-off (throttle) Valve Hand Control.

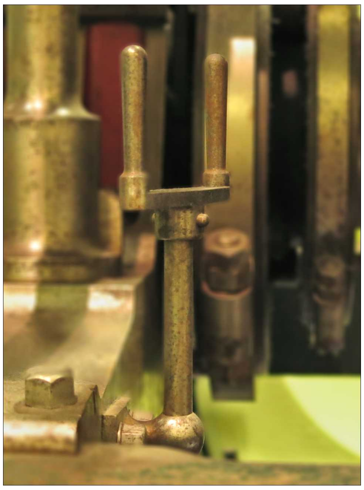


Figure 23b, Condenser Drain/Blow-through Valve Hand Control.

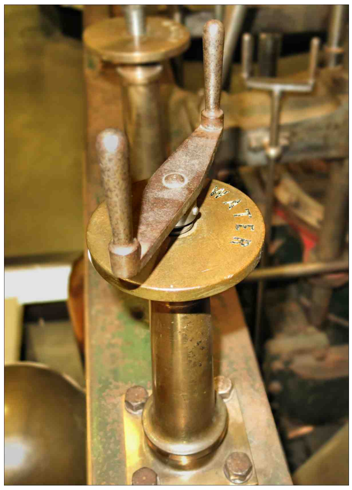


Figure 23c, Condenser Cold Water Spray Hand Control.

Figure 23, The hand controls on the bearing frame.

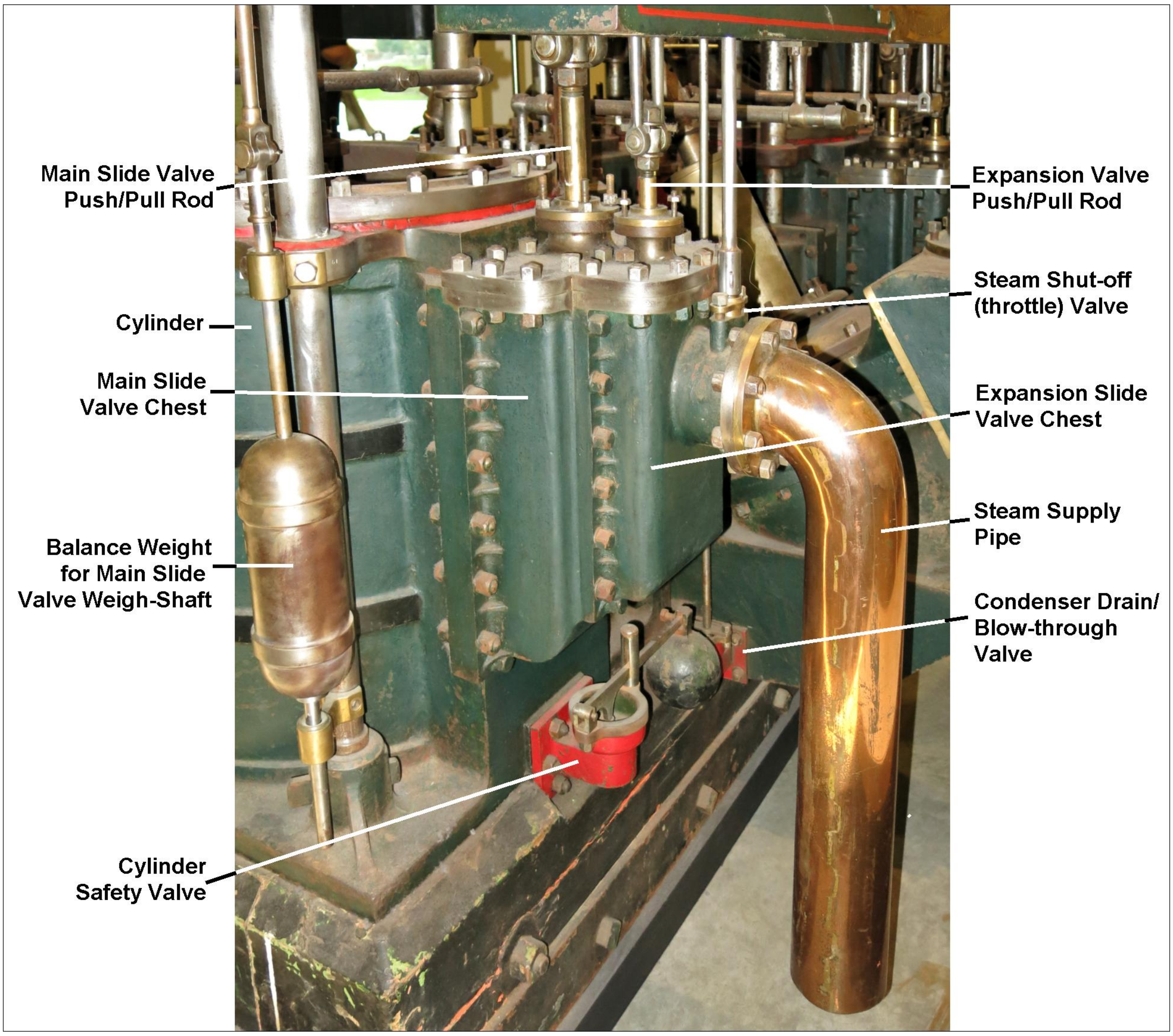


Figure 24, View of the steam supply and steam chests on the cylinder port side.

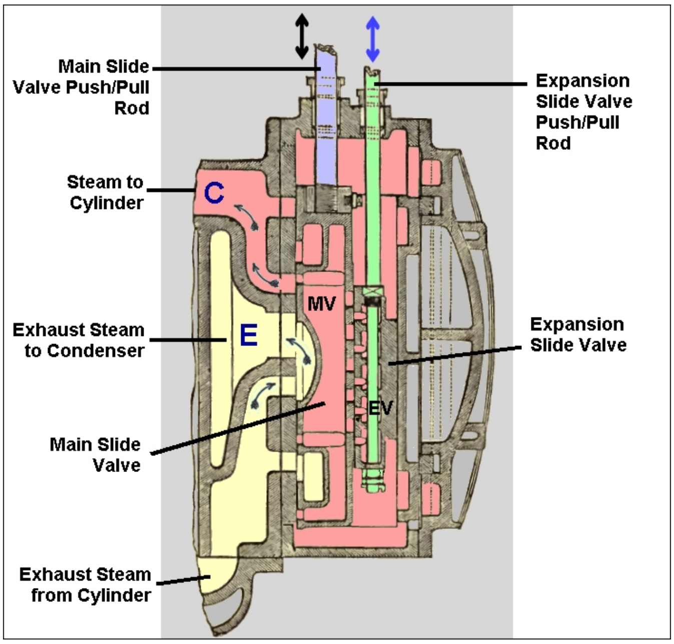


Figure 25, Section through a typical steam chest with main slide valve (D valve) and a gridiron type expansion slide valve, based on ref. 21 with added text.

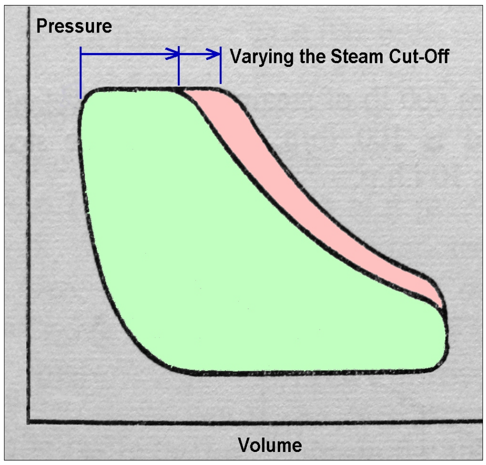


Figure 26, Indicator diagrams showing the effect on the power output of the engine by varying the steam early cut-off to the cylinder. The smaller the pressure – volume diagram the less the power output of the cylinder.

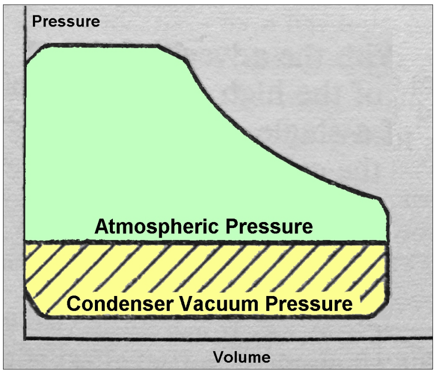


Figure 27, Indicator diagram showing the effect of working the engine below atmospheric pressure. The back pressure is lowered to condenser vacuum pressure. The result (the shaded area) is an increase in power output for the same amount of steam without a condenser.

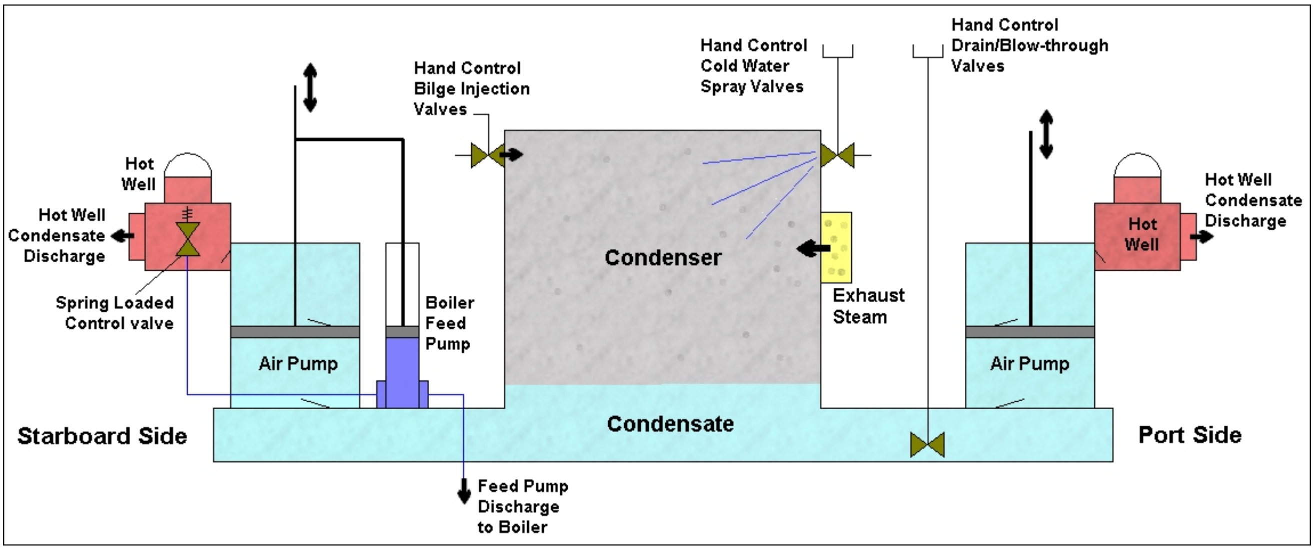


Figure 28, Diagrammatic of the main components of the *Simla* engine jet condenser, looking aft.

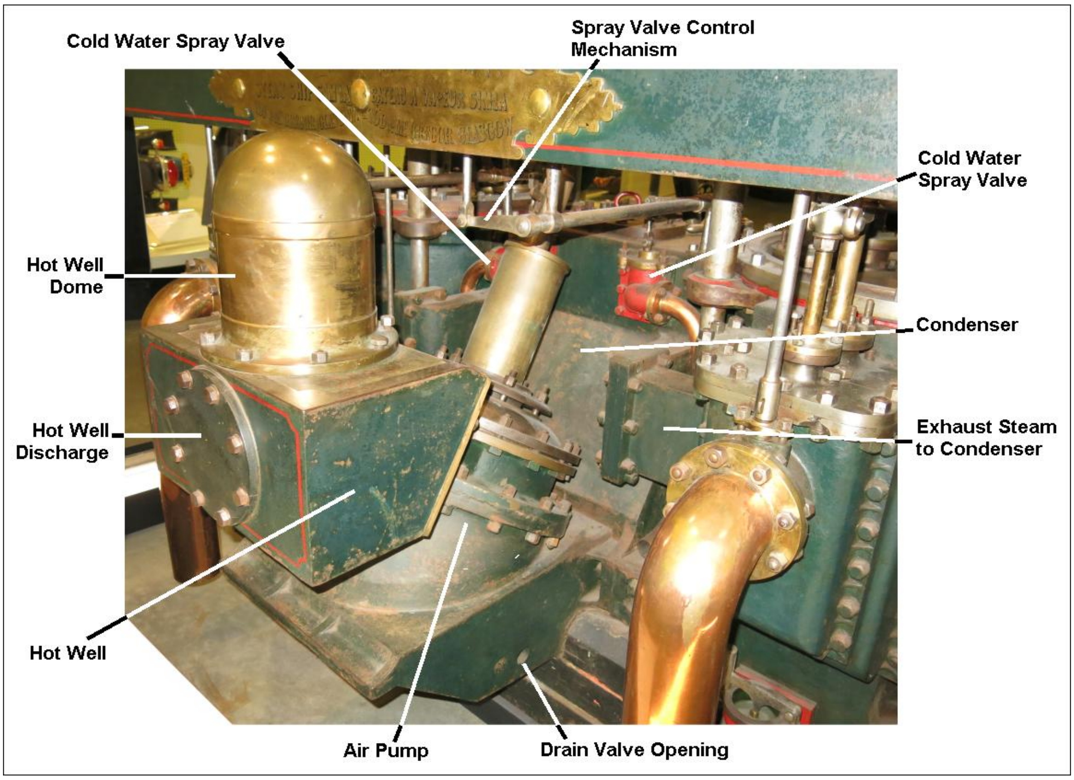


Figure 29, Port aft side view of the condenser.
Note that the drain/blow-through valve is missing on this aft side.

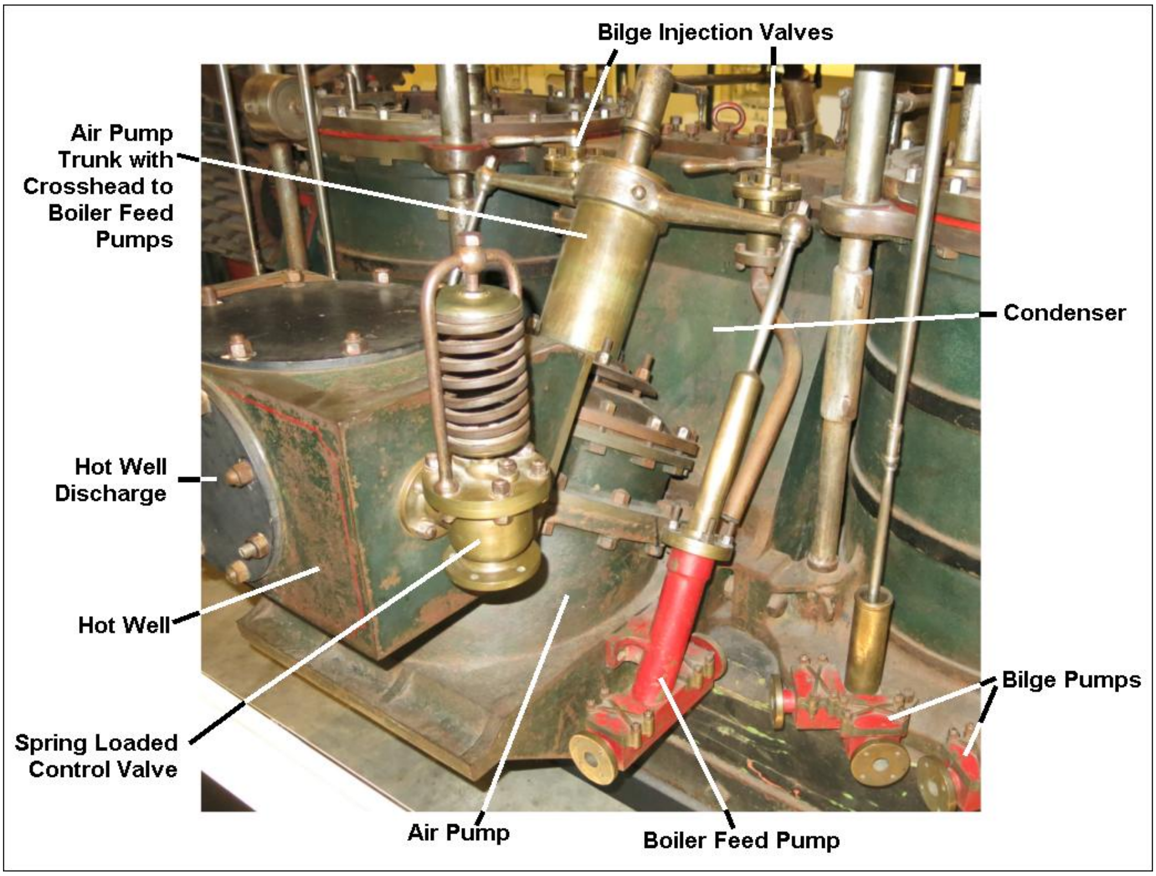


Figure 30, Starboard forward side view of the condenser.
Note that the hot well dome and boiler feed pump piping are missing.

Figure 31, Port forward side view of the condenser drain/blow-through valve and hand control, see also the detail in Figure 23b.

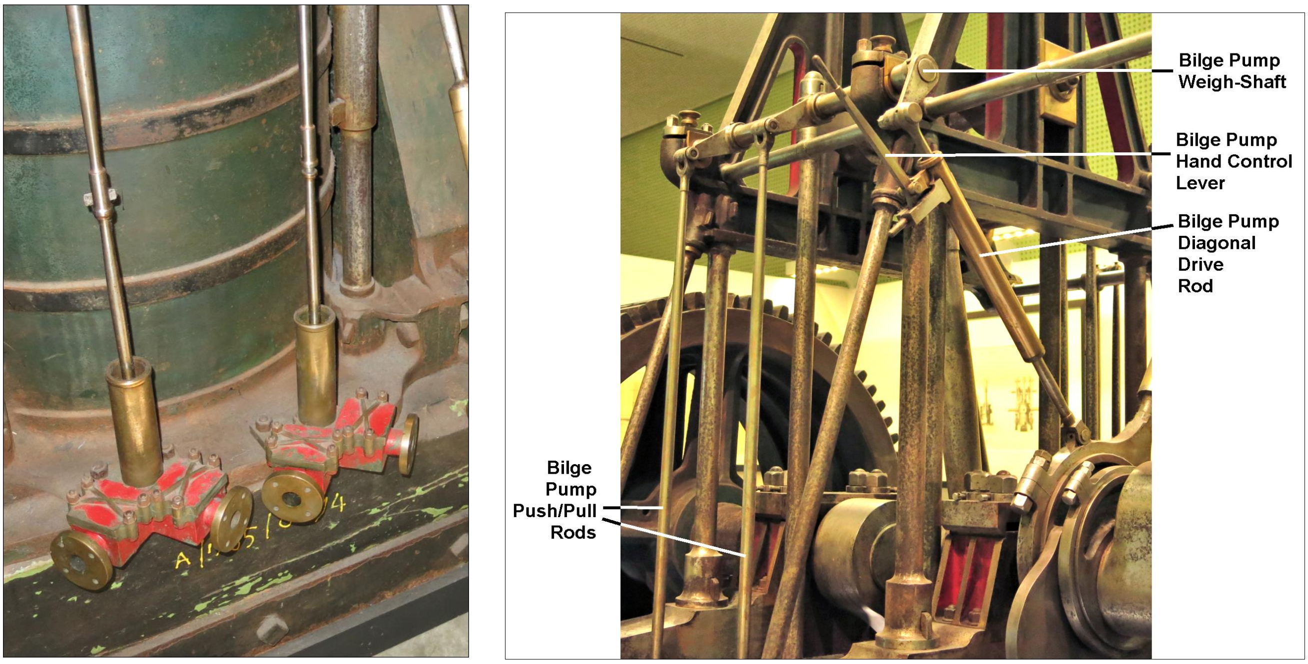


Figure 32, Two of the four bilge pumps on the starboard side, adjacent to the cylinders. The pumps are operated from a diagonal drive rod on the main valve eccentric. When engaged the pumps are driven through a weigh-shaft and push/pull rods. Each drive rod can be engaged/disengaged by the hand control lever so the bilge pumps only need to be pumping when required.

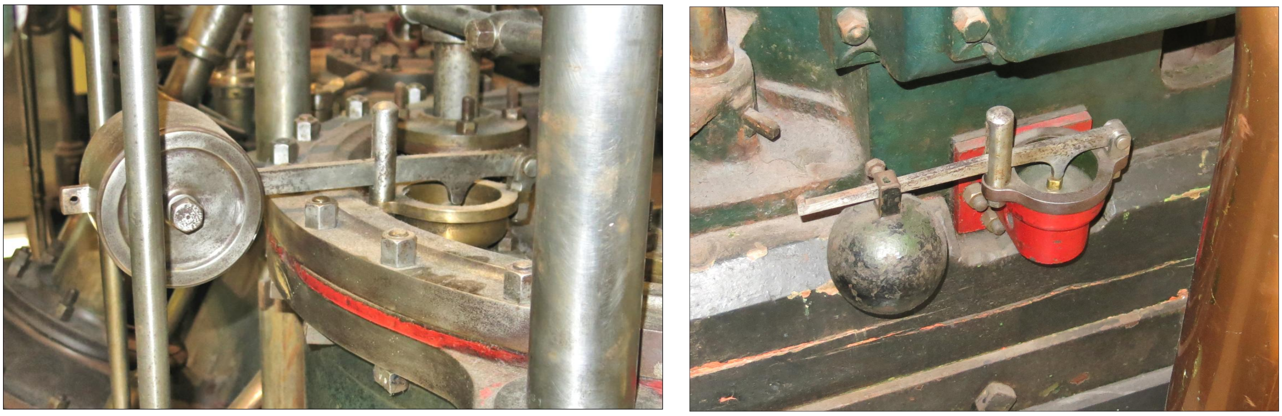


Figure 33, Deadweight lever safety valves are provided on the top and bottom of the cylinder.

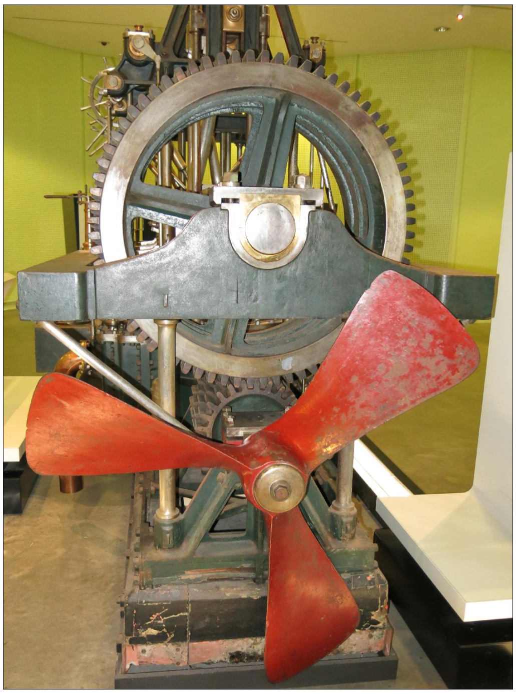


Figure 34, Gearing to drive the propeller on the *Simla* had a ratio of 2.75:1, ref. 25. The teeth on the large wheel are of wood. The pinion gear is of iron. The detail shows there are four sets of teeth and these are staggered to give smoother running. The detail also shows the pinion forward bearing support, which might house a thrust bearing.

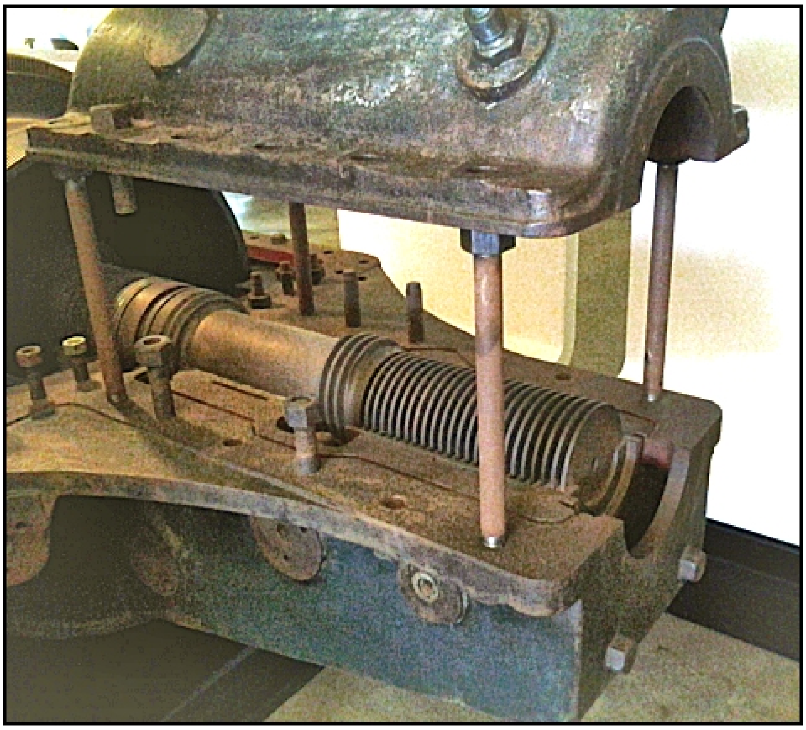


Figure 35, Riverside Museum, the multi-collar thrust bearing on the *King Edward* low pressure turbine.

Figure 36, Steam Supply Pipe.

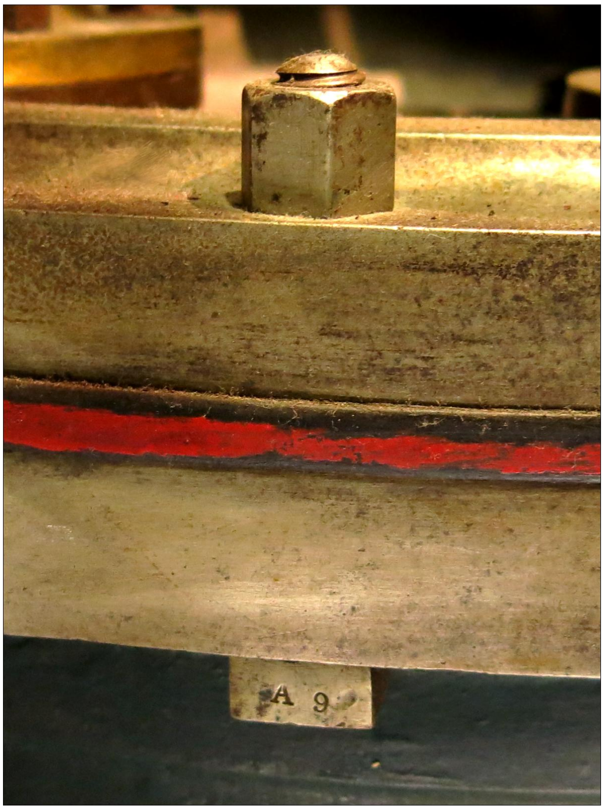


Figure 37, Cylinder Head Cover Bolting.

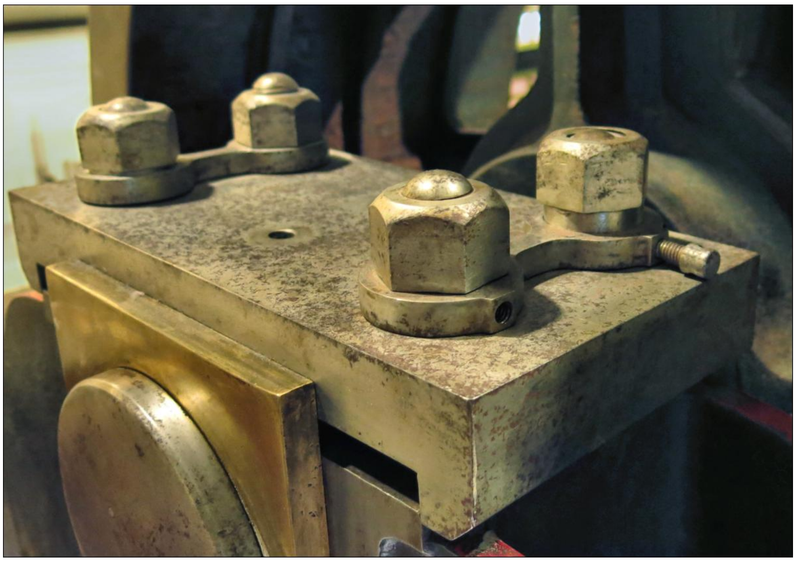


Figure 38, Journal Bearing Nuts and Locking Collar.

Figure 39, Lock (Jam) Nuts.

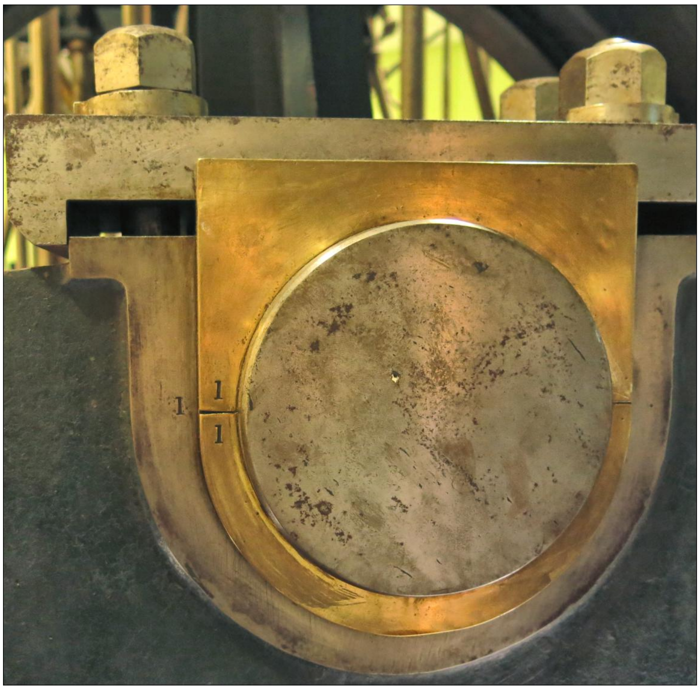


Figure 40, Journal Bearing Brasses.

Figure 41, Frame Supports

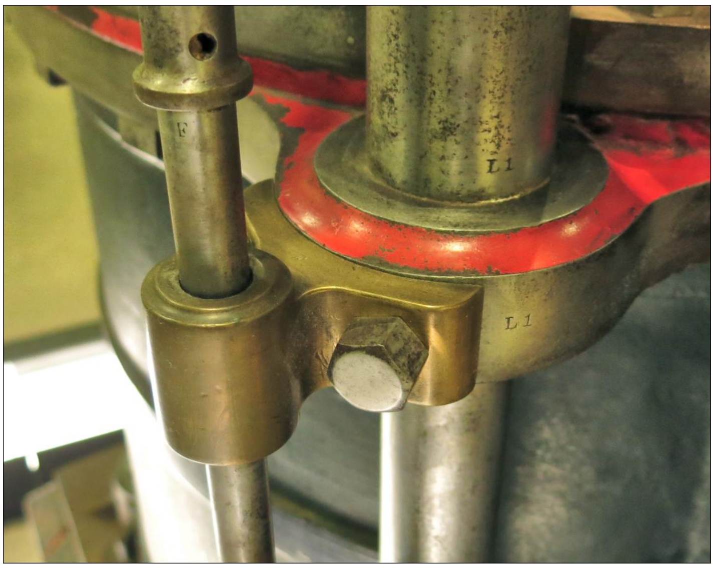


Figure 42, Support Brackets.
