

The Paddle Steamer *Industry* Engine at Riverside Museum

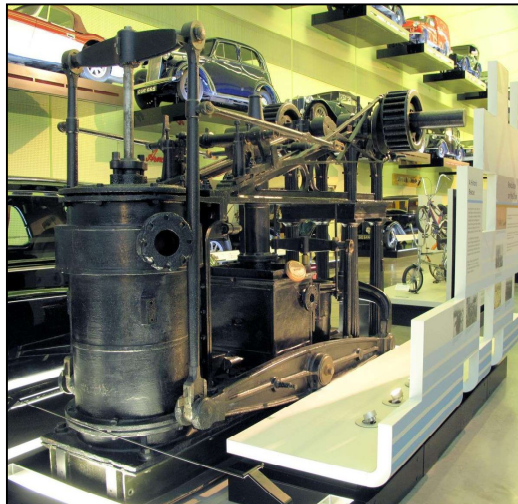
By Andrew C. Whyte, BSc, MSc, CEng, M.I.Mech.E.

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Web site: www.acwhyte.droppages.com

1.0 Introduction. Glasgow Museums have in their collection examples of early marine steam engines including the steam engine from the Paddle Steamer *Industry* (I.D. No. T.1958.1c), which is currently on display at Glasgow's Riverside Museum of Transport and Travel.

The *Industry* engine is technically important, it was one of the early types of reciprocating marine steam engine that was developed in Britain and in particular on Clydeside. The engine is of a type known as a Side-Lever Engine due to the side-levers or beams positioned low down on the engine to keep the centre of gravity of the engine as low as possible, which is an important stability requirement for a ship. Side-lever engines were robustly built, relatively simple to construct and operate, were well balanced as regards the moving parts and in general had a long service life. However, before going on to describe why this particular type of engine was built and how it operated in detail, a brief history of the PS *Industry* is necessary⁽¹⁾.



2.0 The PS *Industry*. Information on the *Industry* can be found in various references: Ransom ref. 1, Millar ref. 3 & 9, Williamson ref. 6, Cuthbert ref. 7, Walker ref. 10, Clark ref. 19. One word of warning, not all the data is consistent and the dates of some events and spellings are inconsistent.

The PS *Industry*, **Figure 1**, was a wooden hull paddle steamer known as a Tug Tender or 'Luggage' boat, Ransom ref. 1. *Industry* was built in 1814 by John & William Fife at Fairlie on the Firth of Clyde⁽²⁾⁽³⁾ for Cochrane & McTaggart of Glasgow, ref. 2, who appear to be leather merchants or tanners, ref. 1 and 10. This was just 2 years after Bell's *Comet*, the first viable steamboat service in Europe. *Industry* was a vessel of 69 gross registered tons, 68.1 feet in length, 17.2 feet in breadth and depth 8.1 feet⁽⁶⁾, ref. 2. The single double-acting steam engine provided power to drive port and starboard paddle wheels of 11 feet diameter with 10 paddle boards (floats) of 2 ft. 9 inches long, Miller, ref. 3. Between the crankshaft and the paddle wheels were a pair of spur gear wheels, **Figure 3**. The smaller gear wheels on the crankshaft were 1½ ft. diameter and the gears on the paddle shafts were 2 ft. diameter, Miller ref. 3. This gives a reduction in speed of the paddle wheels of $2/1.5 = 1.33$ reduction; i.e. the paddle wheels turn 0.75 times the speed of the crankshaft⁽⁷⁾⁽⁸⁾.

Her original steam engine, a side-lever engine of 10 nominal horsepower, was built by George Dobbie and Company of Glasgow⁽⁴⁾ this engine had a cylinder of 16 inches bore and a 32 inch stroke, Griffiths, ref. 5. The original engine was replaced in 1828 by one of 14 nominal horsepower built by Caird and Company of Greenock, ref. 1 and 2. This is the engine that is preserved in the Glasgow Museums collection⁽⁴⁾. It is a double-acting engine with a cylinder bore of 23 inches and a stroke⁽⁹⁾ of 32 inches (i.e. the same stroke as the original engine), Williamson ref. 6. The boiler pressure would be about 5 pounds per square inch and the exhaust steam from the cylinder would pass through a condenser where the steam would be condensed to water resulting in a vacuum. Hence, the power of the *Industry* engine derives from the expansion of steam and the vacuum resulting from the condensation of the exhaust steam.

In 1815 the Clyde Shipping Company was formed and *Industry* and another vessel become their first steamboats⁽¹⁰⁾. *Industry* remaining with this Company until 1856. Years later when this Company became Limited a replica of the old *Industry* was adopted for the Company seal, Cuthbert, ref. 7. In 1873 *Industry* was finally withdrawn from service⁽¹¹⁾, ref. 2, by then she was the oldest surviving steamship, ref. 1. She was laid up in Bowling Harbour, ref. 1 and 2, where the wooden hull was allowed to rot away, **Figures 2 and 3**, but the engine being recognised as historic was saved for preservation⁽³¹⁾. **Figure 4** shows the preserved engine as it was displayed outside Kelvingrove House in 1894. Today the engine is on display indoors in Riverside Museum, Glasgow; **Figures 7 to 11** show the general arrangement of the engine with a description of the parts where necessary.



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, Smith ref. 8.

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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 **Industry** engine of 1828.

3.1 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 (if it had one), pipework and valves, transmission shafting to the 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, boiler, and fuel bunkering hence the space for cargo and/or passengers on an early steamboat like **Industry** would be limited⁽⁶⁾.

3.2 Side-Lever Engines. There are many types of marine steam engines, refer: Wikipedia, Marine steam engine. There is not space here to discuss these in detail but many references including: Griffiths ref. 5 & 12, Smith ref. 8, Bourne ref. 11 & 21, Hebert ref. 13, Burn ref. 14, Sennett & Oram ref. 15, Jamieson ref. 16, Evers ref. 17, Scotts ref. 18, and Scott ref. 25 go into some description of the various engine types including side-lever engines.

The early pioneering steamships were Paddle Steamers. 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. 22 and 23. 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, Smith ref. 8.

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 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 well balanced engine that was very suited for driving side paddles and improved the stability of the ship by keeping the centre of gravity of the engine low and made sea-going service possible.

Just how important the side-lever engine was to the development of marine engineering can be judged from the depiction of a crown and side-lever engine on the coat buttons worn by Royal Navy Engineers from 1841 to 1856, Smith ref. 8. The side-lever engine was favoured by the Royal Navy for many years as the relatively low height made it less susceptible to battle damage, Wikipedia, Marine steam engine.



4.0 The Paddle Steamer *Industry* Engine – the Details - How It All Works. Figures 7 to 11 show the **Industry** engine as currently on display in Riverside Museum. In addition to the actual **Industry** engine, the museum also has a 1/10 scale model of the engine (I.D. LT.1992.2) shown in Figures 28a and 28b. This model was a working model in the old Museum of Transport, but now you can get an idea of the working of a side-lever engine from my gif animations⁽¹²⁾ in my website: <https://acwhyte.droppages.com/animations.htm>

Figures 29a to 29d show details of the gif animations based on the **Industry** engine. The general arrangement of the engine is that of a typical side-lever engine. All the major component parts are there except for some valves and other items, which has meant that some guess work and reference to other Caird & Co. and other typical side-lever engines has been necessary. The construction materials are largely: iron castings, wrought iron shafts, bars, rods and forgings, brasswork and copper for steam pipes. The key component parts are as follows:

4.1 The Sole-Plate. There is a sole-plate (or base plate or foundation plate or bedplate) upon which the components of the whole engine including the super structure framework sit, Figures 7, 9 and 11. Part of the underside of the sole-plate forms the bottom of the condenser and air pump. The sole-plate would be bolted to the ships hull in such a way that the engine was secured fore and aft and athwartships⁽¹³⁾.

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4.2 The Side-Lever Beams. There are side-lever beams on each side of the engine, port and starboard, and these are positioned as far low down as possible, **Figures 7** and **11**. In a typical side-lever engine, in plan, the beams are straight, but refer to section **5.2** below on the PS *United Kingdom* engine. Bosses and a tube or cylindrical passage is cast into the condenser through which a gudgeon is secured. The beams, which have a boss and brass bearings at about mid-length along the beam, can pivoted on the projecting ends of the gudgeon, **Figure 16**. Thus, the beams can rock about their pivot (or fulcrum).

4.3 The Steam Cylinder and Piston. At one end (the aft end) there is a single vertical steam cylinder, inside of which would be a reciprocating piston. The cylinder is securely bolted to the sole-plate, **Figure 7** and **11**. There is a connection flange conveniently positioned on the side of the cylinder to suit the boiler steam supply. On the top of the cylinder there is a bolted cover with a central stuffing box (gland), **Figure 17**, from which emerges a single piston rod that connects to a crosshead with a length longer than the cylinder diameter. The crosshead is guided by a Watt equivalent straight-line (or parallel motion) mechanism formed of short and long radius rods⁽¹⁴⁾, **Figure 18**; this arrangement being used on many side-lever type engines. The ends of the crosshead are connected to the aft ends of the side-lever beams by side rods (or links), **Figure 7** and **11**. Thus, as the piston reciprocates the side rods cause the side-lever to rock about its pivot.

4.4 The Framework, Crankshaft and Connecting Rod. At the opposite end from the cylinder (i.e. at the forward end) there is a structural framework of four columns which at the bottom connect with the sole-plate, while at the top the columns support a crankshaft on two journal bearings in plummer blocks, **Figure 9** and **10**. The framework directly supporting the crankshaft is sometimes referred to as the entablature, Scott, page 31. The crank is connected to the side-lever beams by a single long connecting rod⁽¹⁵⁾ with a cross-tail, at the bottom end, in the form of a fish tail which connects to the forward ends of the side-lever beams⁽¹⁶⁾, **Figure 9** and **10**. The connection rod attachment to the crank is by means of a wedge cotter, gib and strap⁽³²⁾, seen in detail in **Figure 19**. Thus, the rocking action of the side-lever beams bring about the rotation of the crankshaft.

4.5 The Slide Valve Control. Control of the piston is by means of a slide valve positioned within a valve chest on the forward side of the cylinder⁽¹⁷⁾, **Figure 20**. Operation of the slide valve is by an eccentric keyed to the crankshaft, **Figures 9, 19** and **21a**. As the crankshaft turns the eccentric, which has a strap around the eccentric, imparts a reciprocating motion to an eccentric rod with a gab (a hooked rod)⁽¹⁸⁾ on the end of the rod, refer Wikipedia, Gab valve gear. The gab hook engages a pin on the valve rocking lever, which is connected to a weigh-shaft or rocking shaft supported on bearings. Through the rocking shaft and links the slide valve spindle, **Figure 22**, and the valve itself is moved (reciprocated up and down) to enable the engine run ahead or astern and to be double-acting, i.e. steam would be applied alternatively to both sides the piston via ports in the cylinder controlled by the slide valve position; hence there will be two working strokes per revolution of crankshaft.

With the gab disconnected from the pin on the rocking lever (the end with the gab hook can be pulled up by a chain, **Figure 21a**), there is a balance weight (or counterweight), **Figure 22**, connected by an extension lever to the valve rocking shaft, which will move the slide valve so that the steam ports on the cylinder are closed and the engine stopped.

Getting the engine started was another matter. Several authors discuss this issue including Griffiths ref. 5, and Bourne ref. 21. The main points to note are:

- (1) With the main steam supply valve open. A small valve called the blow through valve is opened so as to allow steam from the boiler to enter the engine cylinder both above and below the piston, and enter the condenser and air pump. The steam expels the air and any water from the engine through a drain valve sometimes called a snifting valve.
- (2) The blow through valve is shut and a vacuum would form by the condensation of the steam within the engine.
- (3) The slide valve would now be moved, by hand, allowing steam to one side of the piston to move in the desired direction, ahead or astern. At the end of the stroke the slide valve is moved in the reverse direction. Working the slide valve by hand was done a few times until sufficient speed was attained to allow the hook end of the gab to engage the pin on the valve rocking lever, and keep it in position for steaming ahead or astern, Jamieson ref.16. Thus, allowing the engine to work the slide valve in the normal manner automatically via the eccentric.
- (4) The water injection spray valve on the jet condenser would be adjusted, by hand, to suit the running speed of the engine. Note that there is no apparatus or indication of how the *Industry* engine was governed or how the output was controlled⁽¹⁹⁾. The engine would have operated by simple expansion but the valves would be set to give cut-off of the steam supply as a percentage of the piston stroke⁽³³⁾, see Wikipedia, Cutoff (steam engine). After cut-off the

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steam would expand in the cylinder doing useful work (something that was known about from the days of James Watt).

4.6 The Condenser, Air Pump and Hot Well. Between the cylinder and the crankshaft support structure framework there is a condenser and an air pump, the latter being necessary to maintain the vacuum in the condenser. 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 thermal efficiency⁽²⁰⁾, **Figure 12a**. The steam leaving the cylinder valve chest is exhausted into a condenser via an eduction passage⁽²⁷⁾. The condenser is working below atmospheric pressure i.e. in a vacuum maintained by a pump, known as an air pump 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 a boiler feed pump or excess sent to waste overboard and the air vented.

The condenser used in *Industry* is of the jet type i.e. a jet of cold sea water is injected (sprayed) into the condenser chamber and condenses the exhaust steam to water to create a vacuum⁽²²⁾. On the *Industry* the jet spray valve and its control is missing but there is a bracket on the side of the condenser, **Figure 12a**, where a spray control lever would have been located. **Figure 12b** shows a detail from reference 20, plate XXIA, which shows a typical arrangement on Caird engines. A description of the condenser, air pump and hot well typical working arrangement is given by Burn ref. 14, page 180. The reciprocating air pump is driven from the side-levers by side (or link) rods to a crosshead and piston rod. The crosshead is guided by two vertical rods from the framework down to the top of the air pump, **Figure 12a**. The air pump maintains the vacuum in the condenser by removing condensate (condensed exhaust steam and jet spray water) and air away to the hot well. The hot well is cast within the condenser. Its purpose is to store the condensate prior to discharge overboard or to be drawn off by the boiler feed pump to supply the boiler as necessary. There is an air vessel⁽²³⁾ above the hot well and there is a side flange, which would connect to pipework leading the waste condensate overboard, **Figure 15**.

4.7 Boiler Feed and Bilge Pumps. There would be pumps for boiler feed water (necessary to maintain the water level in the boiler) and bilge water removal (necessary to remove water from the bottom of the boat). These pumps are missing on the engine but the spindles to operate such pumps can be seen on the side-levers⁽²⁴⁾, **Figure 16**. One such pump can be seen in position in **Figure 4**.

4.8 Blow-through Valve and Snifting Valve. If the condenser or hot well becoming full of water and trapped air this would prevent the engine from starting. There would be a blow-through valve (or cock) and a snifting valve fitted to enable the engine to be started. These valves are missing from the engine. **Figure 23** shows a housing with a cover on the port side of the slide valve steam chest. This is the usual position of the blow-through valve on Caird side-lever engines, ref. 20, Plate XXIA (see **Figure 24a** of this text).

Temporary opening the blow-through valve would allow steam from the valve chest to enter the condenser where it would condense and produce a vacuum once all the condensate and trapped air had been blown out through the snifting valve. The usual position of the snifting valve on Caird side-lever engines is at the crankshaft end, see **Figure 24a and 24b**, i.e. at the opposite end from where the steam enters, refer ref. 20, Plates XXIA and XXI and Scott, page 25. However, I cannot see any such valve or opening for a valve on the *Industry* engine. There is adjacent to the housing an opening with bolt holes into the eduction passage, see **Figure 23b**. It seems likely that this opening would mount a drain valve, but might also serve as a snifting valve.

4.9 Safety Valves. Safety valves (sometimes known as escape valves, refer Burn ref. 14 page 181, i.e. to allow water to escape from the engine) are essential to avoid overpressure of the cylinder. This could 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 otherwise damage to the cylinder and other components may result. These valves are missing from the engine, but there would normally be a lower valve at the bottom of the cylinder and an upper valve on the cylinder cover. These valves would usually be of the spring-loaded type or a deadweight lever type, typically as shown in **Figures 25 and 27**, and would be set with a pressure above that of the boiler but low enough to avoid overpressure with resulting damage to the engine.

4.10 Some Details You Might Miss. The model has a lot of interesting details typical of engineering practice in the 1820's.

- **The Side-Lever Fork Ends.** **Figure 30** shows the detail connection of the side rods to the fork ends of the side-lever beams. The connection makes use of the well tried

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wedge cotter, gib and strap arrangement used to connect the connecting rod to the crank, refer to **Figure 19**.

- **The Side-Lever Pivot.** **Figure 31** shows the boss and end detail of the side-lever beam pivot.
- **The Frame Connection to the Steam Cylinder.** **Figure 32** shows the detail connection of the framework to the top of the steam cylinder by means of bolting.
- **The Sliding Joint.** **Figure 33** shows the detail of the sliding joint, part of the Watt equivalent straight-line mechanism used to keep the steam cylinder crosshead and piston rod in alignment with the cylinder.
- **The Eccentric Rod Connection.** **Figure 34** shows the bolted connection to the strap around the eccentric.
- **The Gab and Pivot.** **Figure 35** shows the gab details and the pivot for the Watt equivalent straight-line mechanism.
- **Nuts and Bolting.** There is a mixture of nuts and bolt head types on the *Industry* engine. **Figure 36** shows just one example; the slide valve chest and the packing adjustment. A mixture of bolting types include: square bolt heads and nuts, old style hexagon nuts (during the Second World War the hexagon size of nuts and bolts was reduced to save material and they never went back to the original) and modern hexagon nuts.
- **The Safety Barrier Attachment Points.** **Figure 37** show where safety barriers (port and starboard) could be attached to the steam cylinder at one end and to the forward framework columns at the other end. There was also a central support to the barrier connected by two bolts to the top of the condenser. The barriers and support can be seen in position in **Figure 4** and in the detail **Figure 37c**.

5.0 Other Side-Lever Engines. **Figure 38** to **45** show some other side-lever engines that can be seen in the Glasgow, West of Scotland area or have some detail of interest.

5.1 The Paddle Steamer *Leven* Engine. This engine can be seen outside the Denny Tank Museum at Dumbarton, **Figures 38** and **39**. The engine was the first marine engine built by Robert Napier⁽¹⁴⁾ and dates from 1821⁽²⁵⁾. The design is a typical side-lever type and developed 33 horsepower, Clark ref. 19. Points to note are:

- (1) The general layout is very like the *Industry* engine. It has two side-levers with the pivot at the beam centre. In plan the two side-lever beams are straight. The steam cylinder is at the aft end. The crankshaft is at the forward end. The condenser and air pump are between the cylinder and crankshaft.
- (2) The engine drives the paddle shaft direct, i.e. there is no gearing.
- (3) The slide valve appears to be a Long D type⁽¹⁷⁾. Control of the slide valve is by eccentric, eccentric rod and gab. The eccentric has balance weights. The slide valve balance weights (counter weights) are concealed in a chest above the hot well. There is no air vessel above the hot well.
- (4) The guidance for the piston rod crosshead is like a Watt parallel motion, driven from the side-levers. Tredgold ref. 31, Plate X diagram Fig. 1, gives an explanation of this arrangement as does Hebert ref. 13, Section III, page 710. Later Robert Napier would use a much simpler arrangement with closely spaced vertical guides to insure parallelism of the piston rod crosshead. These guides stick up in the air like a David Napier steeple engine, Whyte ref. 34, see the PS *Rio de Janeiro* engine **Figure 25** of this text.
- (5) The cross tail to the crankshaft connection rod is a straight member, i.e. like an inverted T rather than a fish tail as on *Industry*.
- (6) The engine driven pumps (boiler feed and/or bilge pumps) are on the side of the air pump and are driven from the air pump crosshead.

5.2 The Paddle Steamer *United Kingdom* Engine. The PS *United Kingdom* was built in 1826 by Robert Steele of Greenock. She was built to sail between Leith and London and was regarded then as the finest steamship afloat, Napier ref. 30. Powered by two side-lever engines constructed by the marine engineer David Napier, the engines developed 200 horsepower, Napier ref. 30. The engines, shown in **Figure 41a**, are of a type described as Napier's direct-action engines by Luke Hebert ref. 13, Section III, pages 688 and 689, who provides a detailed description of the working of these engines⁽²⁶⁾ and the boiler, Hebert ref. 13, Section III, pages 721 to 723. The layout of the engines have some significant differences compared to *Industry*. The main features of the engines are:

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- (1) It has two side-levers with the pivot at the beam centre. The steam cylinder is placed at the forward end between the four columns supporting the crankshaft. The cylinder is immediately below and in alignment with the crankshaft hence the description: Napier's direct-action engines. The air pump is at the aft end where the steam cylinder would normally be. The condenser is between the steam cylinder and the air pump. There are two boiler feed pumps driven from the side-lever beams between the beam pivot and the air pump. By having the steam cylinder at the forward end with the crankshaft and the air pump at the aft end, the whole engine is made more compact in length compared to a typical side-lever engine.
- (2) In plan the two side-lever beams are not straight. There are two bends in the beam so that the forward end near the steam cylinder is further apart than the opposite end with the air pump, which has a smaller diameter than the steam cylinder. Hence the beams can take up as little room as possible, by lying close to the respected parts of the machinery, Hebert ref. 13, page 688. **Figure 41b** shows how the arrangement would work; the main mechanical difference between straight and bent beams is that the bent beams would be subjected to twisting moments (torque) as well as bending moments.
- (3) There is no gearing between the crankshaft and paddle shaft. The crankshaft bearings are supported on arches from the four columns rising from the top of the steam cylinder.
- (4) The cylinder piston rod connects to a crosshead whose alignment is by utilising the columns as widely spaced vertical guides to insure parallelism, see **Figure 41a**. Thus, a Watt equivalent straight-line mechanism is avoided. The crosshead is wide enough to allow the side rods from the crosshead to the side-lever beams to pass outside of the steam cylinder.
- (5) The cross tail to the crankshaft connecting rod is a straight member, i.e. like an inverted T. The cross tail has to be wider in length than normal in order to allow the side rods (which are longer than normal) to pass outside the side rods of the steam cylinder crosshead.
- (6) The slide valve details are not known but the valve is driven from an eccentric on the paddle shaft via eccentric rod, gib and levers.

5.3 The Paddle Steamer *Clyde* Engine. This engine can be seen on the banks of the River Clyde, at the Low Green, Renfrew, **Figures 43 to 45**. These engines (there are two engines side by side) were built in 1851 for the paddle tug *Clyde*, Walker ref. 10, and memorial plaque **Figure 44**. The designer of the engines was Andrew Brown the so-called 'father of the steam dredger', Riddell ref. 28. The design is that of a side-lever engine of the grasshopper type (sometimes called a lever or half-lever type), i.e. the pivot of the side-lever beams is at the end opposite from the cylinder end, while the drive to the crankshaft is taken from the beams at about the three-quarter position from the pivot end. The engine driven pumps (for condenser cold water and boiler feed) are driven from the beams at about mid-length. Other features of this engine are:

- (1) The piston rod is guided by vertical closely spaced crosshead guides sticking up in the air.
- (2) The slide valve is controlled by Stephenson's link motion valve gear, i.e. for each engine there are two eccentrics driving eccentric rods to a curved expansion link guiding a link block connected to a rocker arm moving the slide valve. The link block can be moved into forward or reverse gear via rocker arms and rods.
- (3) Condensers are of the surface type.
- (4) There is a hand control mechanism, shown in **Figure 45**, to allow disengaging of the crankshaft, between engines, so that each engine can drive (or free wheel) its own paddle wheel independently of the other. Thus, the tug would be capable of great manoeuvrability⁽³⁴⁾.

5.4 The Compound Side-lever Engine. The typical side-lever engine was designed for single (or simple) expansion working. It was not really suited to compound expansion, i.e. two (double) stages of expansion. However, it was possible to configure an arrangement for compound working and obtain more power output and improved thermal efficiency provided a high pressure steam supply of above say 50 pounds per square inch was available (with too low a pressure there is a limit to how far the steam could expand). There were two possibilities available for side-lever engines:

- (1) **McNaught type compounding**⁽²⁸⁾. This was a method mainly used for upgrading existing engines. Burn ref. 14, pages 68 to 77 gives a very detailed description with figures of an arrangement of a marine side-lever engine adapted for a factory. Figures show that a small diameter high pressure cylinder is placed between the four columns supporting the crankshaft and is immediately below and in alignment with the paddle shaft. The connections for the crank being similar to that by David Napier i.e. like the Napier Direct-action engine discussed in section 5.2 above. The large diameter low pressure cylinder, at the end opposite the

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crankshaft, is worked by the exhaust steam from the high pressure cylinder, via a long pipe. The long pipe acted as an expansive receiver or reservoir. The high pressure steam acting on one end of the side-levers is always balanced by the low pressure steam and vacuum at the other end. This reduced the stresses in the side-lever beams.

- (2) **Woolf type compounding with receiver**⁽²⁹⁾. In this case two side-lever engines could be placed side by side, their cranks driving a single paddle shaft. One side-lever engine was worked by a high pressure cylinder and the other engine worked by a low pressure cylinder with air pump and condenser. A large diameter pipe connected the valve chests of the two engines to provide the steam receiver (or reservoir). Griffiths ref. 5 page 44 figure 4.1 shows an arrangement of Roentgen compound engine design of 1834, based upon a patent granted to Ernst Wolff. In this arrangement there is the added benefit of the cranks at 90 degrees to each other and this would avoid any difficulties of starting if a piston came to rest at top or bottom dead centre and hence become liable to stick on centre⁽³⁰⁾.

6.0 The Side-Lever Engine – the Decline in its Use. The side-lever engine was for several decades from the 1820's the marine steam engine of choice; mainly due to its robustness, relatively simplicity to construct and to operate. However, with the increase in the size of ships, the engine power requirements also increased requiring larger more powerful engines. The side-lever engine with its low pressure, low thermal efficiency, and limited capacity for compounding was at disadvantage, being large and heavy, compared to other types of steam engine being introduced such as David Napier's steeple engine and the oscillating engine perfected by John Penn. Also the side-lever engine was best suited as a paddlewheel engine and was not really suitable for driving screw propellers, which were becoming the favoured method of propulsion for ocean going vessels⁽³⁵⁾.

The use of these early types of marine steam engine gradually declined and were replaced by other more advanced types, most notably the near horizontal 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*). By this time the introduction of compounding and triple expansion working had brought the thermal efficiency of the reciprocating steam engine to around 12%.

7.0 Summary. In summary, the side-lever engine 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.

8.0 Notes.

- (1) In the context of this note: PS stands for Paddle Steamer and SS stands for Single Screw Steamship. I use the word steamship or steamboat interchangeably.
- (2) Fife is sometimes spelt Fyfe. **Industry** was the only steamship built by the firm, ref. 1. The family firm became famous for designing and building high quality yachts. Including Two America's Cup yachts for grocery and tea magnate Sir Thomas Lipton.
- (3) In 1814 **Industry** was one of at least seven steam vessels working on the Clyde, ref. 1 and 3.
- (4) Miller reference 3 states the original engine was by Thomson of Tradeston, but this was corrected in the discussion in Millar reference 9, most references accept that George Dobbie and Company built the original engine. Reference 3 puts the date of the replacement engine as around 1826. However, most references seem to accept the later date of 1828. Little is known of the boiler, which would not have survived. Millar reference 3 states that **Industry** first had a copper boiler, in these early days pressures were low, but afterwards this was replaced by an iron one. The type of boiler its position and orientation in the boat are unknown.
- (5) There is some questions on the date and location of this photograph, **Figure 1**. Apparently, *Industry* was laid up around 1872 (Glasgow Museum Mimsy quotes 1869. Ransom reference 1 quotes 1862, Clydeships database reference 2, and Clark ref. 19 quote 1873) following a collision, which removed her starboard paddle box. However, Millar, in the discussion reference 9, reports the collision as being in the summer of 1862. The starboard paddle box is missing in the photograph and so it is believed that the photograph shows the vessel being unloaded in Greenock after the collision. However, the photograph, reference 4, in the Scottish Maritime Museum collection states the location to be the Broomielaw, i.e. in Glasgow. Reference 4 and Clark ref. 19 also report that *Industry* was fitted with a folding funnel to allow her to pass under bridges. Reference 4 also reports that *Industry* was the first steamboat to be fitted with paddle boxes.
- (6) The tonnage and dimensions of **Industry** vary depending on which reference you are looking at. For example, Miller ref. 3 quotes: Length 68 ft., Breadth 17 ft., Depth 8ft., Gross Tonnage 69, Register

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Tonnage 42; again Millar in the discussion ref. 9, dimensions 65 ft. by 16 ft. is quoted. Cuthbert ref. 7 quotes: Length (Between Perpendiculars) 67 ft., Beam 14 ft. 6 in., Depth 8 ft. and Tonnage 53. Williamson ref. 6 gives dimensions and tonnage in fractions: Length B.P. $66\frac{9}{10}$ ft., Beam $14\frac{7}{10}$ ft., Depth moulded $8\frac{1}{10}$ ft., Tonnage $52\frac{98}{100}$. Regardless, both the **Comet** (43ft 6 inches in length) and **Industry** (at around say 68 ft in length) were small vessels. A good comparison of some leading steam vessel sizes, from the **Comet** of 1812 to the **City of New York** of 1888, is provided by Millar ref. 3 and shown in **Figure 6**. I have added an indication of the tonnage capacity, in brackets () for additional comparison. It is clear that the increase in size or tonnage was not a linear relationship. Another comparison is that of the paddle steamer common on the River Clyde, Hebert ref. 13, Section I, page 661, shown in **Figure 40a**. By rough scaling the engine room (engines and boilers) take up around one third of the volume of the vessel.

- (7) With paddle steamships the crankshaft speed of rotation has to be low (typically less than half a revolution per second) otherwise the slamming of the floats against water (a relatively dense fluid) would be detrimental to the construction of the paddle wheels. The crankshaft could be connected direct to the paddle wheel shaft in many cases. Particularly common with the early (older) steamboats, spur gearing was fitted between the engine and paddles to reduce the speed of the paddle wheel, Millar ref. 3 and 9.

By gearing we are not talking about precision spur gears, well lubricated and manufactured from alloy steel, like we have today. The gears (cogs) would be iron castings and subject to wear and tear with only rudimentary lubrication. In the discussion on Millar's paper reference 9, it was confirmed that spare gear wheels were always kept in readiness. From the grinding sound the gears made the **Industry** was known as the 'Coffee mill', Miller ref. 3 and 9.

A key requirement for gears that are to be free of noise and vibration, and wear and tear is that they should have Constant Velocity Ratio. Only certain gear profiles have this characteristic such as Involute gears, Cycloidal gears and Novikov gears. These types of gear have reduced noise and vibration, smooth power transmission and reduced energy losses from friction. Ideally the velocity ratio should be constant, although a small variation is usually acceptable, any more and there is increased risk of wear and tear, increased noise and vibration and even jamming of the gears. Involute gears are by far the most common type of gear profile but 'once when I was young' I did have to produce a finite element mesh for a Novikov gear; see my MSc Thesis at:

https://acwhyte.droppages.com/downloads2/my_MSc_thesis_Nov_1970_for_web.pdf.

It is worth mentioning that it is perfectly possible to design and manufacture Variable Velocity (non-circular) gears for specialised applications. When I last visited Summerlee Museum, many years ago, I did see machines in operation that utilised elliptical gears to give a variable speed to the driven shaft.

- (8) Paddle steamers do not require a thrust bearing (like screw propeller driven ships do) as the paddle thrust is transmitted to the vessel through paddle shaft journal bearings, which are in housings attached to the vessel hull. The hull would be reinforced in the way of these bearings. The action of the torque on the paddle shaft from the engine crankshaft results in the paddle wheel floats pushing against the water (the pivot) and this provides the forward thrust to move the vessel. In essence the principle is the same as an observer looking at a rowing boat where the oar blade is the pivot (or fulcrum), the rower provides the effort and the rowlock is the load (the boat) to be moved. There will of course be losses as water slips past the edges of the floats, and especially on fixed paddle wheels, as the floats enter and exit the water at a steep angle, lifting and churning the water wastes energy. The introduction of feathering paddle wheels allows the floats to enter the water vertically, minimising drag reducing churning and gives a horizontal thrust to the floats. This leads to an increase in the propulsive efficiency (hydrodynamic efficiency) compared to a fixed paddle design.
- (9) The stroke of the engine appears to vary depending on which reference you are looking at. Millar ref. 3 quotes 2 ft stroke which is too short, while the Clyde Built Ships database ref. 2, quotes a stroke of 45 inches which seems too long. The 32 inches quoted by Williamson ref. 6 looks about right by viewing the engine.
- (10) Cuthbert in ref. 7 frontispiece, shows a copy of a painting of **Industry**. This detail from the painting shows the vessel skipper standing on a platform, i.e. a bridge, between the paddle boxes. This must be the one of the first images of what would become known as the 'bridge'. According to Clark ref. 19 the painting is by William Clark and dates from 1857.



- (11) The date of withdrawal from service varies depending on which reference you are looking at. The Glasgow Museum Mimsy quotes 1869. Ransom reference 1, quotes 1862 the same year as the collision, Millar discussion ref. 9. Clyde Built Ships database ref. 2 and Clark ref. 19, quotes 1873.

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- (12) The animations are based on the model with 8 paddles; when I tried 10 paddles I got a stroboscopic effect on my computer screen causing the paddle wheel to keep turning in the same direction as the crankshaft.
- (13) As regards how the engine was mounted in the hull the details are not known. The photograph **Figure 3** showing the engine in position, low down in the hull, is not all that clear. It appears to show the sole-plate attached to two side plates and possibly a bottom plate to form a box section so as to make a bedplate to support the engine. However, section drawings of typical side-lever engines mounted in the hull of a wooden vessel show the sole-plate is bolted to deep wooden reinforcing beams running longitudinally along the bottom of the hull in the way of where the engine is positioned, **Figures 25 and 26**. The distance between these wooden reinforcing beams would be a close fit with the sole-plate underside where it forms the bottom of the condenser and air pump so that the engine is located athwartships. Some references, ref. 20 and Bourne ref. 21, call these reinforcing beams engine keelsons (or kelsons) probably because they perform a similar function to a structural beam or member on a ship that lies on top of the keel, running along the length of the vessel's bottom to provide additional strength and stiffness to the hull, refer Wikipedia, Keelson, and see **Figure 26**.
- (14) The piston rod crosshead had to be guided in order that the piston and its rod moved parallel to the axis of the cylinder. Failure to do this would result in excessive wear on the cylinder, piston, piston rod and the piston rod sealing packing on the cylinder cover, something that was known about from the days of James Watt. On some engines the crosshead guide was much like a Watt parallel motion, see Robert Napier's first marine engine for the PS **Leven**, **Figure 38**. In other cases vertical guides were provided, see David Napier's side-lever engine for the PS **United Kingdom**, **Figure 41a**, Robert Napier's side-lever engine for the PS **Rio de Janeiro**, **Figure 25**, and Andrew Brown's side-lever engine of the grasshopper type for the PS **Clyde**, **Figure 43**. Note that 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' but who also designed and built marine engines.
- (15) A long connecting rod was an advantage as it avoided excessive fluctuating fore and aft forces at the crankshaft bearings.
- (16) On some engines this cross tail is simply a straight cross member, so we have an arrangement of a crank connecting rod and cross tail like an inverted T, thus $\perp$.
- (17) From the shape of the steam chest, the type of slide valve is certain to be the long D slide valve, which is generally credited to be the invention, in 1799, of William Murdoch (or Murdock) who worked for and was later a partner in the firm of Boulton and Watt, refer Wikipedia, Slide valve. He is notable for his many inventions including the oscillating steam engine and his introduction of gas lighting, refer Wikipedia, William Murdoch. The valve was 'long' as the steam passages (ports) leading to the valve chest were at the top and bottom of the cylinder and hence separated by a relatively 'long' distance. A section through the valve chest and valve is, in plan view, in the shape of a letter 'D', **Figure 20b**. Hebert ref. 13, page 713 also Burn ref. 14 pages 107 and 108 and Jamieson ref. 33 all give a description of the working of the valve. A key aspect to the performance of the valve was the adjustment of the hemp packing with tallow lubrication at the back of the slide valve so that the valve faces on the front of the valve pressed against the facings on the cylinder. The facings would be planed, and ground upon each other, to achieve steam tightness, ref. 13. In some cases brass faces were fitted to the cylinder, ref. 20, in other cases the slide valve (which was usually of cast iron, ref. 25) was gun-metal faced or even the whole valve made of gun-metal, ref. 13. The adjustment was by means of screws, **Figure 20a**; too tight and friction becomes excessive, too slack and there will be a loss of steam tightness and loss of power. It was for this reason that the long D type valve fell out of use in favour of the locomotive or short D slide valve (sometimes called a three-ported valve), Jamieson ref. 33.
- (18) An eccentric is used as it takes up less space and does not weaken the crankshaft (which a crank would do). The throw (or stroke) of the eccentric is twice the eccentricity, i.e. twice the distance between the shaft centre and the offset distance of the eccentric. An eccentric rod attaches the gab to the eccentric. In many engines this rod is just that, a solid rod of wrought iron with the gab on the end; also some engines have balance weights on the eccentric e.g. see the engine for the PS **Leven**, **Figure 39**. In the case of **Industry** the rod is fabricated from iron bars forming a 'Light' lattice structure and no balance weights are fitted to the eccentric. The gab used on these marine engines was a single (or simple or plain) gab often fitted as on **Industry** with a guard to maintain alignment, **Figure 21a**. A double gab (or 'X' type) to ease reversing, refer Wikipedia, Gab valve gear, had been introduced as far back as 1818 by Carmichael's of Dundee, ref. 27, but it does not seem to have been favoured by marine engineers. The later marine engines like Andrew Brown's grasshopper engine of 1852 for the paddle tug **Clyde** used a Stephenson type valve gear, **Figure 43**. The best example of the double gab, in Riverside Museum, is that fitted to the Gurney steam drag of 1831, **Figure 46**.

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- (19) For power output and speed control of steam engines, there are two possibilities: (a) *Throttling Governing*, by varying the pressure of the steam to the engine cylinder or (b) *Cut-Off Governing*, by varying the cut-off of the amount of steam to the engine cylinder. The latter method of control would require a means of varying the cut-off, like an expansion valve. However, there is no indication on the **Industry** engine of such a device, but see also **Note (33)** below. Hence, it is likely that the power output of the **Industry** engine was controlled by varying the steam pressure by means of a throttling valve, but how the valve was governed is not known. The throttle valve typically used on marine steam engines was of the butterfly type, i.e. a disc, inside a pipe, turning on an axis. The amount of disc turning (quarter turn on/off, and partial disc closure) being set by hand to control the speed of the engine, refer Wikipedia, Butterfly valve. Jamieson ref. 33, page 211 explains the construction and action of a throttle valve for marine applications where it was usual to employ two throttle valves between the engine stop valve and the slide valve casing (chest). One valve was under hand control of the operator who could throttle or wire-draw the steam by partially closing the valve or shutting off the steam completely in an emergency. The other valve was connected to the governor and was used for controlling the flow of steam and not for cutting it off completely. Throttle governing was quite an effective way to govern an engine but was wasteful of steam as the steam cut-off was constant at all loads, Joel ref. 29, see **Figure 48**. Note that in the Riverside Museum collection the Gurney steam drag and the SS **Simla** model engine, Whyte ref. 34, have examples of expansion valves.
- (20) At this early date (the 1820's) the steam pressures would be low (only a few pounds per square inch). The engine relied on a condenser to condense the exhaust steam and hence obtain a greater work output for the same amount of steam resulting in an improved thermal efficiency, Joel ref. 29, see **Figure 47**.
- (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) The jet condenser is a simple arrangement and was relatively inexpensive to manufacture but had some disadvantages such as: (a) the cooling spray water was taken from the body of water the vessel is floating in, which in a sea going vessel would be sea water, (b) a difficulty in maintaining a good vacuum, (c) contamination (impurities) of the condensate pumped back to the boiler and (d) if the condenser flooded with condensate the engine would not operate. There is always an excess of condensate, with a jet condenser, due to the cold water spray requirements to condense the steam. Later steamships used surface condensers to avoid the disadvantages of the jet condenser, although early designs of surface condensers did have some operational issues that were eventually resolved.
- (23) The air vessel is frequently dispensed with, Burn page 180 ref. 14.
- (24) The size of the boiler feed pump is quite small compared to the air pump, as the volume of steam condensed to water is about 1600 to 1 at atmospheric pressure.
- (25) The PS **Leven** was a wooden vessel built by James Lang of Dumbarton (Williamson ref. 6 quotes W. Denny as the builder). Some references also quote different build dates; a descriptive plaque beside the engine quotes the build as 1821, Williamson ref. 6 and Smith ref. 8 quote a date of 1823, Clark in his Fleet List ref. 19 quotes 1824. Later the engine was transferred to a new vessel **Queen of Beauty**. The preserved engine was at one time mounted on a plinth at the base of Dumbarton Rock on ground just outside of Dumbarton Castle as a monument to Robert Napier.
- (26) The sections of the steamboat **Figure 40a**, is also given in Napier ref. 30 with a caption: "United Kingdom," Section. However, this caption cannot be correct as the detail close up of the engine room, **Figure 40b**, clearly shows typical side-lever engines and not Napier's direct-action engines shown in **Figure 41a**. Nor are the boiler details correct when compared with the **United Kingdom** boiler shown in **Figure 42**. There is a description of the **United Kingdom** engines and boiler given by Hebert in reference 13, Section III, pages 688 and 689, and pages 721 to 723. However, there are some anomalies, in Hebert ref. 13, page 688, that are worth pointing out: (a) Makes reference to; *j* as the apparatus for blowing through, previous to starting the engine. However, *j* is shown in **Figure 41a** as the crankshaft connecting rod! (b) Makes reference to; a rod and lever *x* for the purpose of regulating the quantity of injection water which enters into the condenser, i.e. this suggests a requirement for a jet condenser. However, Napier in ref. 30 pages 56 and 61 makes clear that the **United Kingdom** engines used an arrangement for surface condensation and would seem not need to inject water?
- (27) The details of the eduction passage between the cylinder valve chest and the condenser does vary depending on the engine builder. Sometimes a division was fitted between the eduction passage and the condenser to prevent injection water and condensate passing into the lower part of the cylinder, refer Burn ref. 14, page 180, and Caird engines reference 25, Plates LX and LXL. In other cases the eduction passage was at the top of the valve chest, refer Caird engines reference 24, but there could be eduction passages top and bottom of the valve chest, again refer Caird engines reference 25.
- (28) William McNaught (1813-1881) of Paisley, introduced an improvement to the power output and thermal efficiency of the steam engine by a patent in 1845, which acquired the name 'McNaughting', by adding a

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high pressure cylinder to existing Watt type beam engines, but could also be applied to the marine side-lever engine, ref. 26. Note that William McNaught should not be confused with his father John McNaught (1771 – 1844) who made improvements to the engine indicator by introducing the rotating drum (Glasgow Museums have examples of McNaught indicators in the collection).

- (29) The question of compounding appears to go back as far as the days of James Watt and Jonathan Hornblower (1753 – 1815) of Cornwall, see Wikipedia, Jonathan Hornblower. In 1804 (or 1805) another Cornishman Arthur Woolf (1766 – 1837), see Wikipedia, Arthur Woolf, obtained a patent for a compound steam engine based on a high pressure cylinder in parallel with a low pressure cylinder. Various arrangements were possible, see Wikipedia, Compound steam engine, including Cross compound and Tandem compound. In the 1820's a Dutch Naval officer Gerhard Moritz Roentgen (1795 – 1852) introduced the idea of a steam receiver between the high and low pressure cylinders, see Wikipedia, Gerhard Moritz Roentgen. In 1834 Roentgen's United Kingdom representative, another Woolf, an Ernst Wolff of Magdeburg, Germany obtained a British patent for a compound steam engine based on Roentgen's invention, see Wikipedia, Gerhard Moritz Roentgen. The steam receiver or reservoir in most cases was the steam pipe connecting the valve chests of the high and low pressure cylinders, Griffiths ref. 5. On later engines the receiver was often steam jacketed and lagged, and in some cases constructed with tubes, refer Haeder ref. 32.
- (30) Bourne ref. 21 Question 641, explains that although a single engine is more liable to stick on centre, than two engines with their cranks at right angles, numerous paddle vessels were plying successfully propelled by a single engine.
- (31) A plaque on the engine condenser, **Figure 13**, shows that the engine was rebuilt by Dorothea Restorations Limited, and sponsored by the Clyde Shipping Company.
- (32) The attachment of the connecting rod bearing ends by means of a wedge cotter, gib and strap was a common method of attachment. For example, the SS *Simla* engine model, from 1853, uses this form of attachment, refer Whyte ref. 34.
- (33) Although there appears to be no means of adjusting the steam cut-off on the *Industry* engine, it was perfectly possible to arrange a means of adjusting the cut-off on side-lever engines. Griffiths ref. 5, page 11, explains the method used in the PS *Great Western*. Some Caird engines were fitted with expansion valves the operation is explained by Scott in reference 25, page 22. Basically, how the arrangement works is that a cam is attached to and rotates with the crankshaft of the engine. A small roller is kept pressed against the cam, which has several profile steps to adjust the amount of expansion cut-off, with the aid of a counter balance. Through a series of levers, links and pivot the lift of an expansion valve fitted to the steam inlet to the engine can be adjusted to the desired degree of cut-off. The steam inlet in this case is on the same side of the engine as the cam and connects direct to the slide valve steam chest, refer Scott ref. 25, Vol. 2, Plates LVI and LVII.
- (34) For stability reasons, disengaging the paddle wheels was not usually employed on passenger steamers. Hence paddle steamers like *Waverley* do not have disengaging paddle wheels, but have solid drive shafts which does limit their manoeuvrability and results in a wide turning radius. Paddle tug boats are a different matter, they do not carry passengers and the advantages of good manoeuvrability is clearly important, refer Wikipedia, Paddle steamer.
- (35) The last Cunard paddle steamer with a side-lever engine for Atlantic service was the *Scotia*, Napier ref. 30, launched in 1861.

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Figure 1. The Paddle Steamer *Industry* transported cargo between Glasgow's docks and the deep-water port at Greenock. Seen here berthed alongside the East India Harbour, Greenock around the 1850's⁽⁵⁾. The angle between paddles (floats) is 36 degrees confirming that the wheel has 10 paddles. ©CSG CIC Glasgow Museums and Libraries Collection.



Figure 2. The Paddle Steamer *Industry* seen here as a hulk in Bowling harbour about 1870. ©CSG CIC Glasgow Museums and Libraries Collection.

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Figure 3a. The Paddle Steamer *Industry* seen here as a hulk in Bowling harbour about 1870. This view (looking forward) shows the inside of the vessel with the 1828 engine in position shortly before it was removed for preservation. ©CSG CIC Glasgow Museums and Libraries Collection.

This photograph and the detail **Figure 3b** below is of great historical interest as it confirms the following:

- (1) It shows the engine is positioned low down and on the centre line of the hull.
- (2) The engine sole plate appears to be part of a box section forming a bedplate to support the engine.
- (3) The crankshaft with a single centre crank is towards the forward end of the vessel.
- (4) There is a single cylinder towards the after end
- (5) One of the side-levers and a feed (or bilge) pump, driven by the side-lever, can be seen, low down, just to the left of the cylinder.
- (6) The paddle wheels, port and starboard, are driven via their own set of spur gears supported at the hull sides. The smaller gears are on the end of the crankshaft.
- (7) The larger spur gears are aft of the crankshaft and drive the paddle wheels. Hence the paddle wheels will be turning at a slower speed (reduction in speed) than the crankshaft.

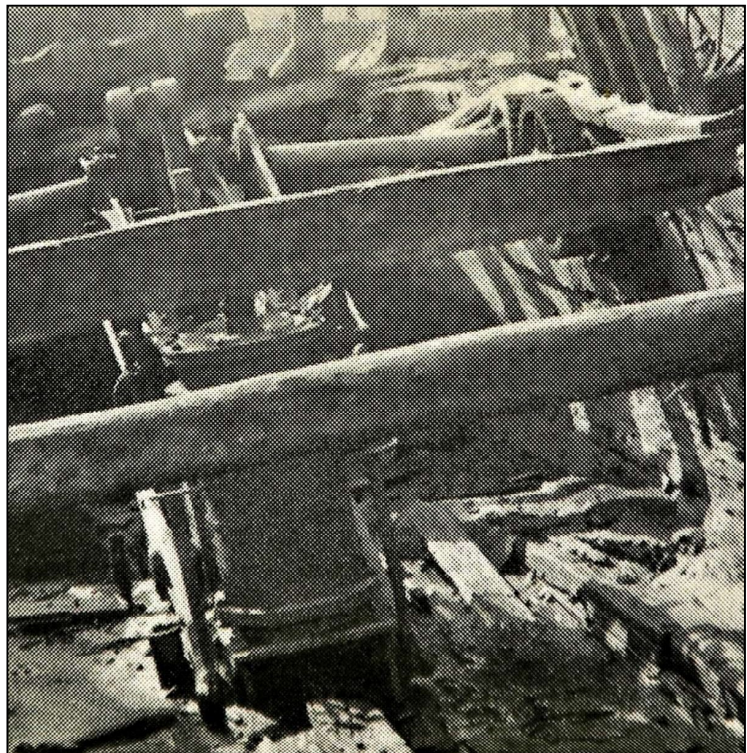


Figure 3b. Detail of *Industry* engine of 1828.
©CSG CIC Glasgow Museums and Libraries Collection.

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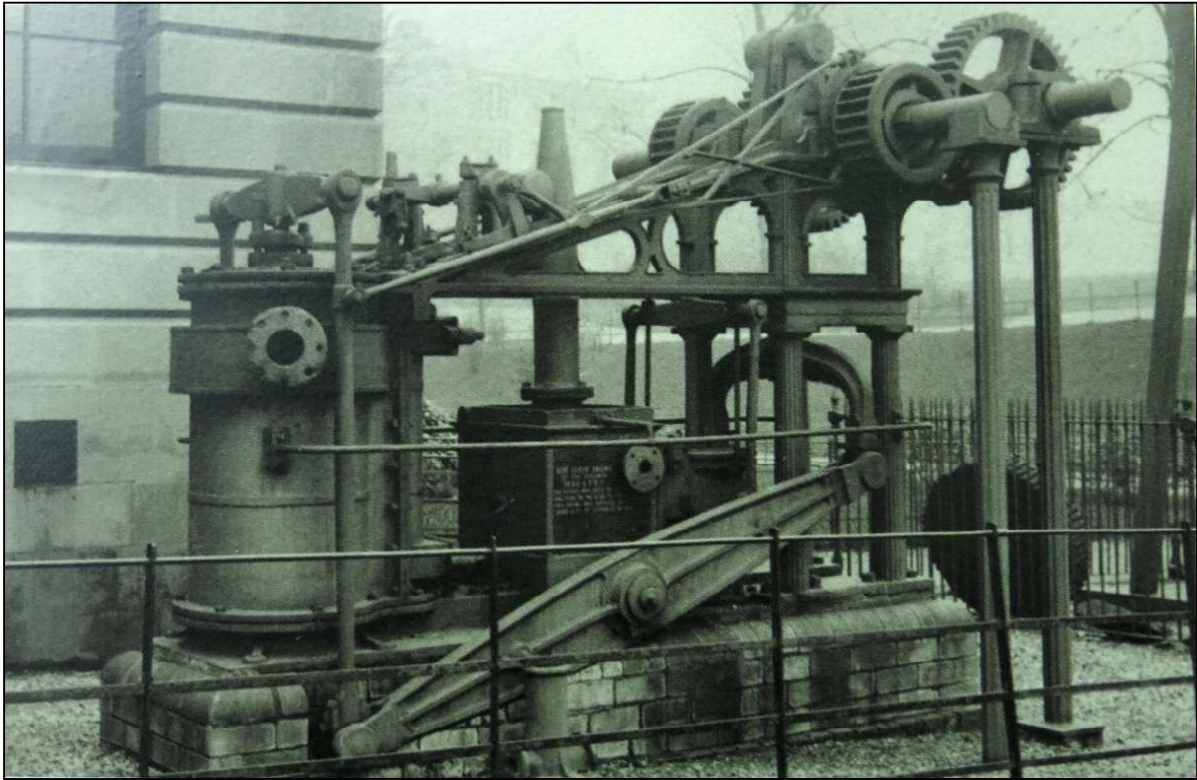


Figure 4. The Paddle Steamer *Industry* engine of 1828 seen outside Kelvingrove House in 1894. To remove the engine from the hull the crankshaft (5½ inches diameter) was cut through and the drive gears were repositioned near to the crank. The large gears with shaft, top right representing the paddle wheel drive gear and shaft, are not in the correct position and not on the display at Riverside Museum. We know from **Figure 3** and **Figure 5** below the paddle wheel gear drive should be on the opposite side (i.e. aft) of the crankshaft drive. Note also that there is a boiler feed water (or bilge water) pump actuated by the starboard side-lever beam. This pump is not on the display at Riverside Museum. Note also the rather rudimentary safety barrier connecting from the steam cylinder to the forward column with a midway support taken from the top of the condenser. These barriers and supports are not on the display at Riverside Museum.

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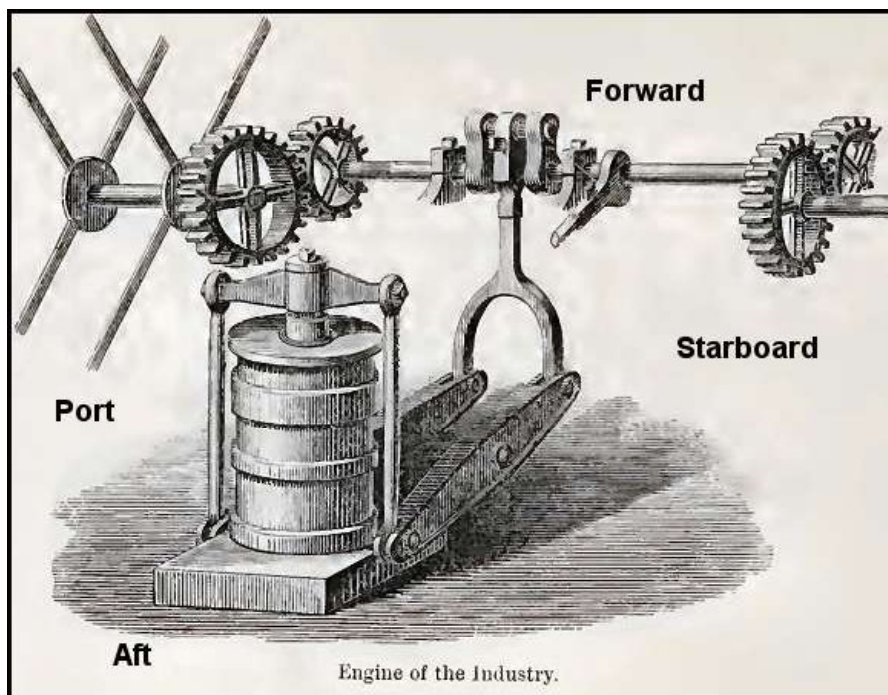


Figure 5. The Paddle Steamer *Industry* engine of 1828 showing the layout of the engine and gear transmission to the paddle wheels. The eccentric to drive the slide valve can be seen just outside of the starboard crankshaft bearing (plummer block) , Millar ref. 3 with added text.

The PS *Industry* Engine at Riverside Museum

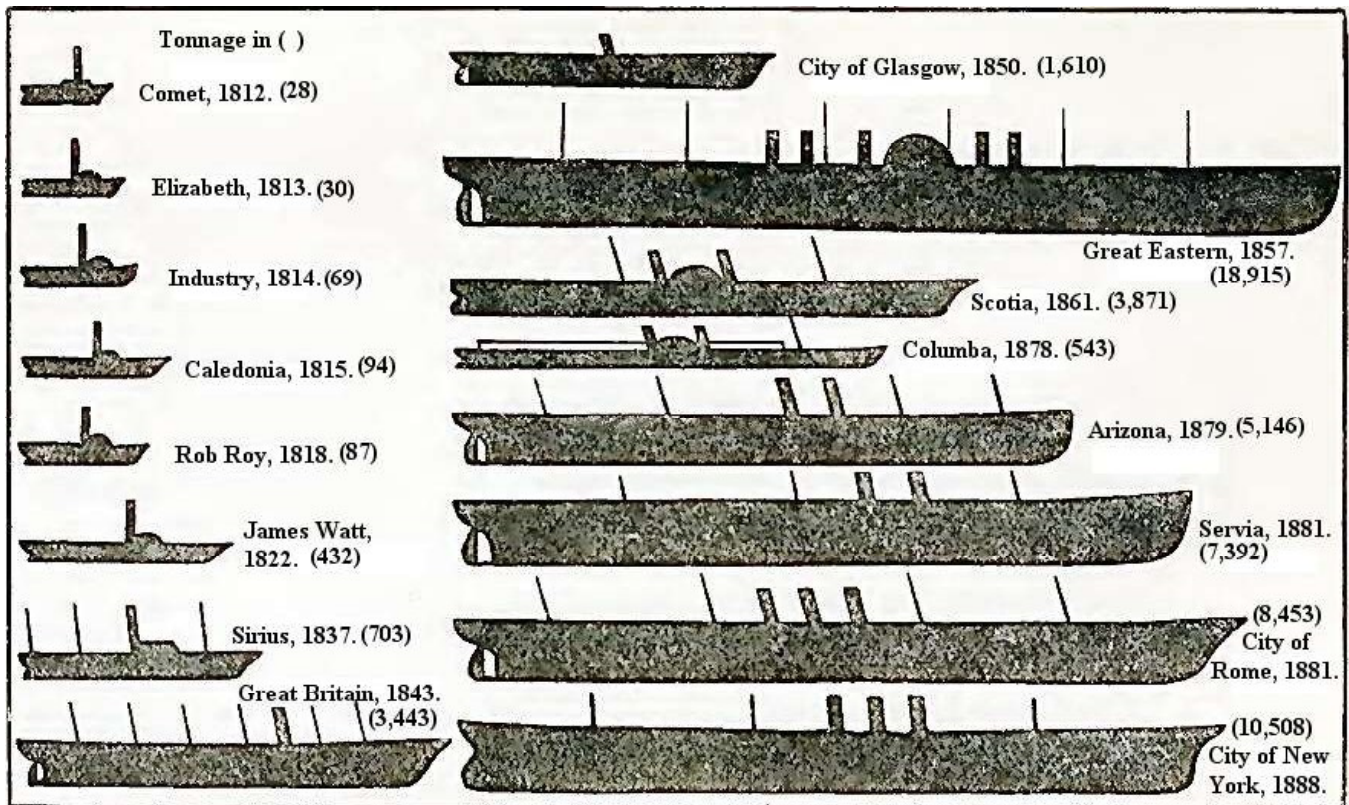


Figure 6. Comparative Sizes of some early and later steamships from the *Comet* of 1812 to the *City of New York* of 1888, Millar ref.3, with information on the approximate capacity tonnage in brackets () added. The capacity of the *Great Eastern* was not surpassed until 1901 by RMS *Celtic* with a gross tonnage of 20,904 tons, ref. Wikipedia SS *Great Eastern*. The last Cunard paddle steamer with a side-lever engine for Atlantic service was the *Scotia*, Napier ref. 30, launched in 1861.

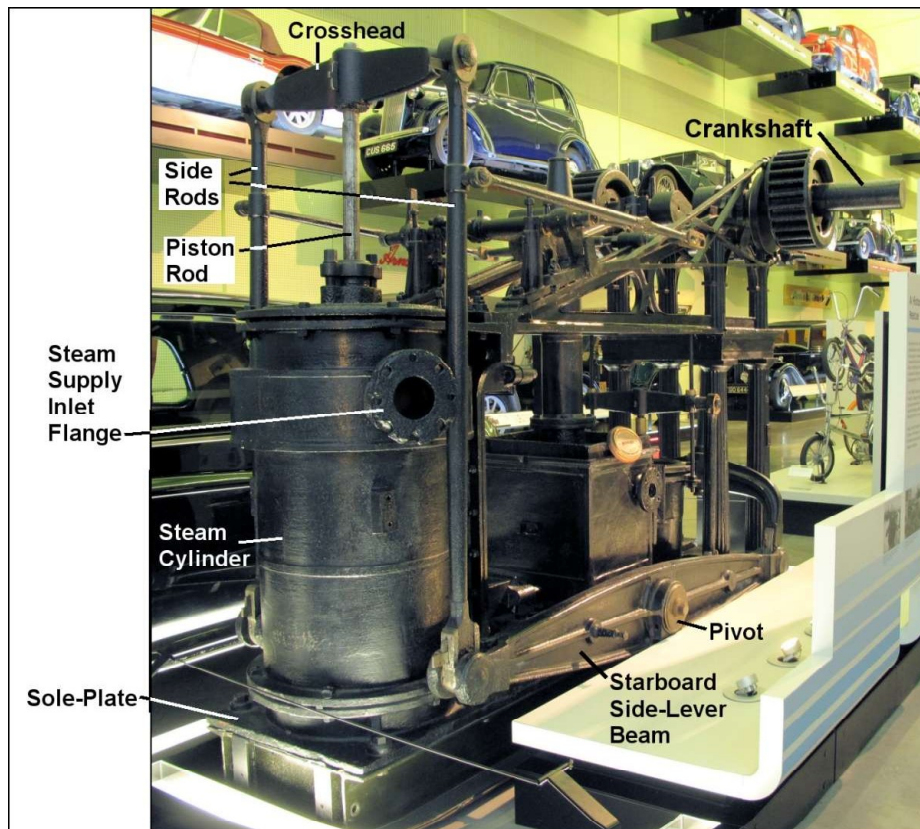


Figure 7. Paddle Steamer *Industry* engine at Riverside Museum. View showing the steam cylinder, bolted onto the sole-plate at the aft end, and the starboard side side-lever beam. The boiler steam supply inlet flange to the cylinder, the piston rod and crosshead and side rods to the side-levers are also seen.

The PS *Industry* Engine at Riverside Museum

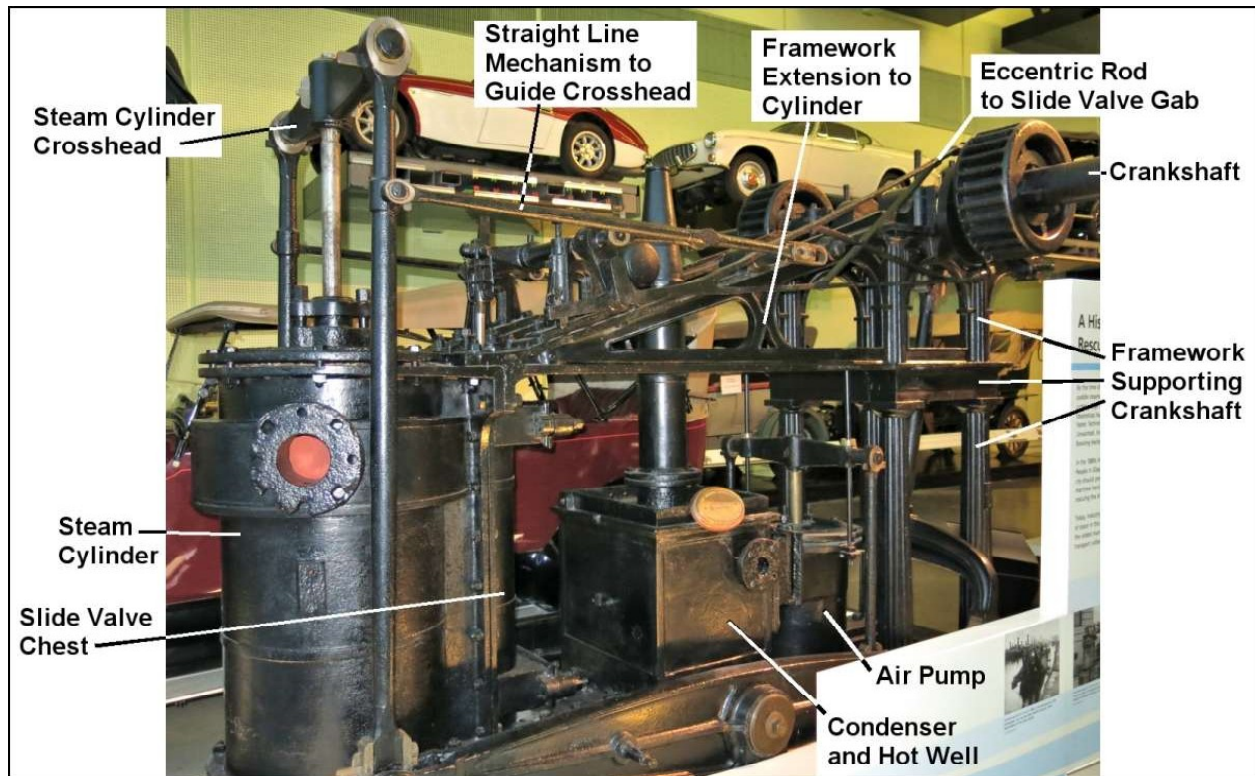
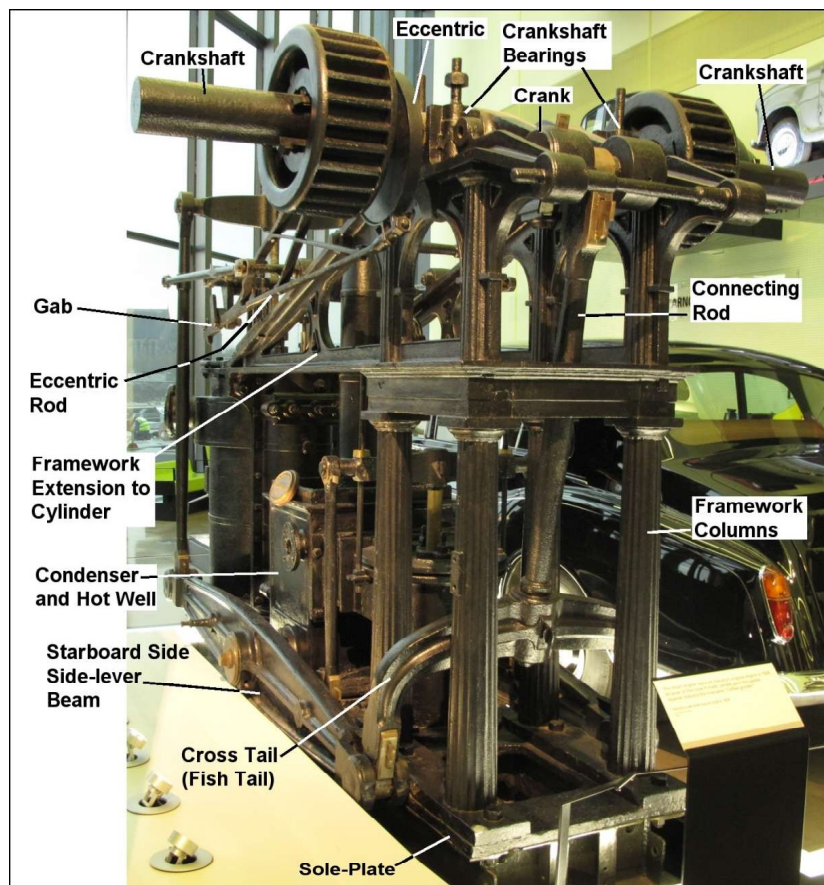


Figure 8. Paddle Steamer *Industry* engine at Riverside Museum. Starboard side view showing the cylinder with steam supply inlet flange, the D type slide valve chest on the forward side of the cylinder, the condenser casing and hot well, the air pump and its crosshead are positioned between the cylinder and the super structure framework which supports the bearings for the crankshaft. The framework is typically in a gothic style decoration. A tapered (triangular) extension of the framework projects aft to connect with the steam cylinder to aid in tying (diagonal staying) the whole framework together. The equivalent Watt straight-line mechanism to guide the steam cylinder crosshead and the eccentric rod driving the slide valve gab is also seen on this starboard view. More details are shown in **Figures 18, 19 and 21**.

Figure 9. Paddle Steamer *Industry* engine at Riverside Museum. View showing the crank end (forward end) and the starboard side side-lever. The gothic style framework is secured to the sole-plate. The upper part of the framework (sometimes called the entablature) supports the crankshaft. There is a single connecting rod and cross tail in the form of a fish tail that connects to the forward end of each of the side-levers. The top end of the connecting rod connects with the crank. The crankshaft is supported on journal bearings in plummer blocks (the top half of the blocks are missing, but the bolting and a nut can be seen). The eccentric to drive the slide valve gab can be seen just outside of the starboard bearing.

The crankshaft would extend to journal bearings at the side of the hull, and the two cast iron gear wheels would be positioned close to the hull sides, see **Figures 3 and 5**.



The PS *Industry* Engine at Riverside Museum

Figure 10. Paddle Steamer *Industry* engine at Riverside Museum. View showing the crank end (forward end) and the port side side-lever beam. Note that the spur gear pinions are iron castings so we are not talking about precision gears here, refer to **Note (7)**.

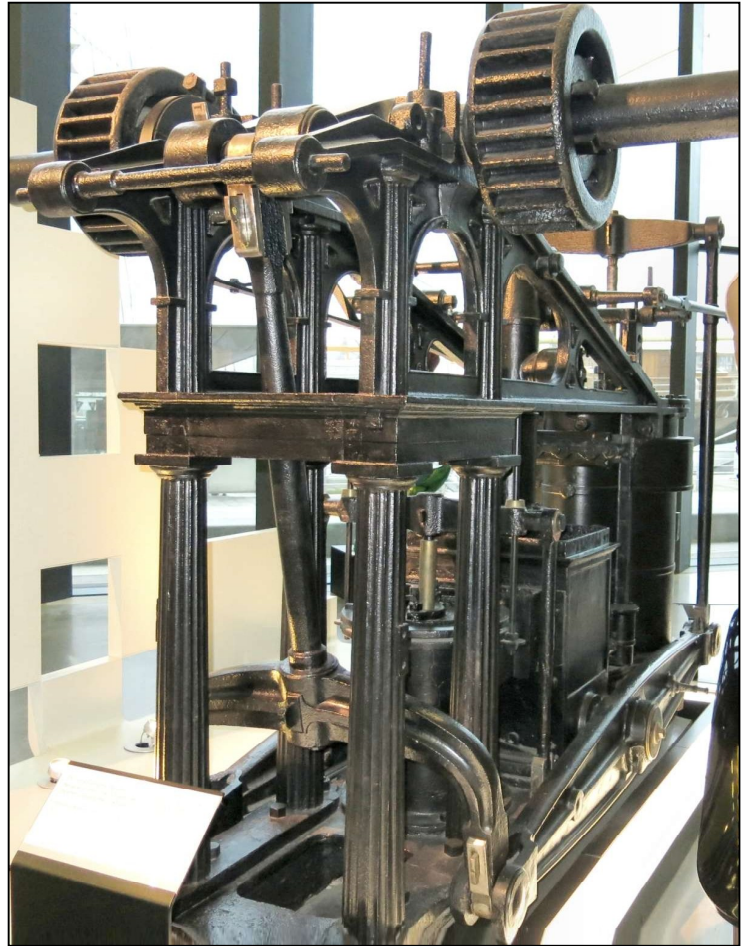


Figure 11. Paddle Steamer *Industry* engine at Riverside Museum. View showing the steam cylinder bolted onto the aft end of the sole-plate, and the port side side-lever beam. Note that the crosshead has to be long (wide) enough so that the side rods can clear the cylinder diameter.

The PS *Industry* Engine at Riverside Museum

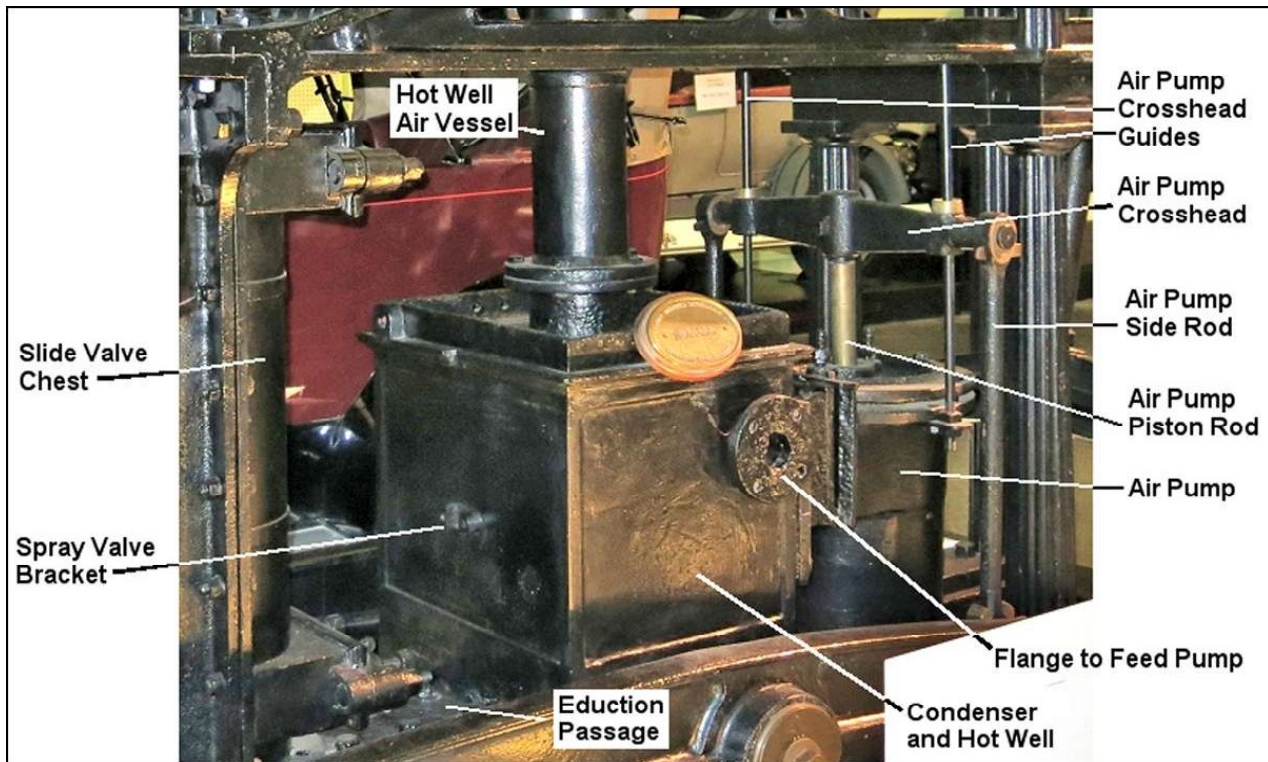


Figure 12a. Paddle Steamer *Industry* engine at Riverside Museum.

Details of the condenser and air pump from the starboard side.

On the left is the D type slide valve steam chest, to the centre is the condenser with the hot well air vessel above (the hot well is cast within the condenser). Between the bottom of the slide valve chest and the condenser is the eduction passage where exhaust steam exits the cylinder to the condenser. The condenser is a jet condenser. This maintains a vacuum by a spray of water to condense the exhaust steam from the cylinder. However, I cannot see an opening for the water spray valve though there is a bracket about half way up the condenser, on the steam cylinder side, that would have allowed the fitting of a spray control lever (Cairn engines ref. 20, 24 and Scott ref. 25 show a bracket with the spray opening near the top of the condenser, see **Figure 12b** below). The flange on the condenser would connect with the boiler feed pump which would take water from the hot well and pump it to the boiler as necessary; excess water building up in the hot well air vessel would be discharge to waste overboard, see **Figure 15**.

To the right of the condenser is the air pump with piston rod and crosshead, which is driven from the side-lever beams by side rods. The crosshead is guided by two vertical rods from the framework down to the top of the air pump. There will be a non-return foot valve between the condenser and air pump suction to prevent condensate being pumped back to the condenser (sometimes a division was fitted to prevent condensate passing into the steam cylinder. The Caird engine, Scott ref. 25, shows such a division). Between the air pump discharge and condenser there will be a non-return discharge valve to the hot well. This is to retain condensate in the hot well and frees the air pump from an unnecessary weight of condensate.

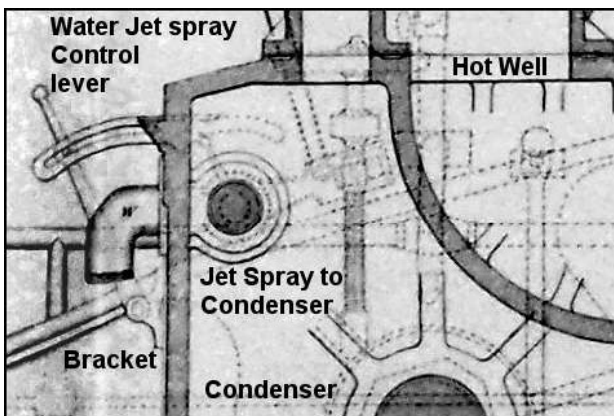


Figure 12b. Detail from reference 20, Plate XXIA, showing a typical water spray injection to the condenser on Caird built side-lever engines.

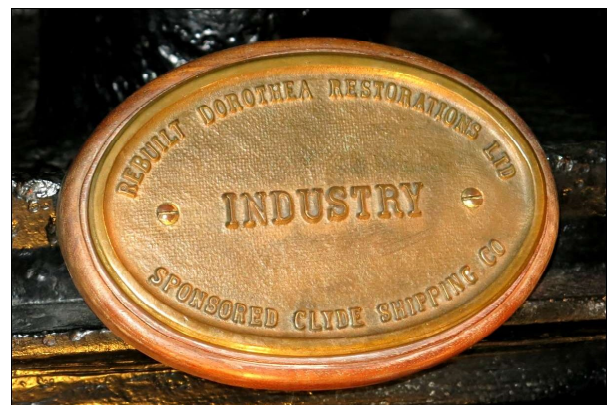


Figure 13. Plaque on the condenser recording that the *Industry* was rebuilt by Dorothea Restorations Limited, and sponsored by the Clyde Shipping Co.

The PS *Industry* Engine at Riverside Museum

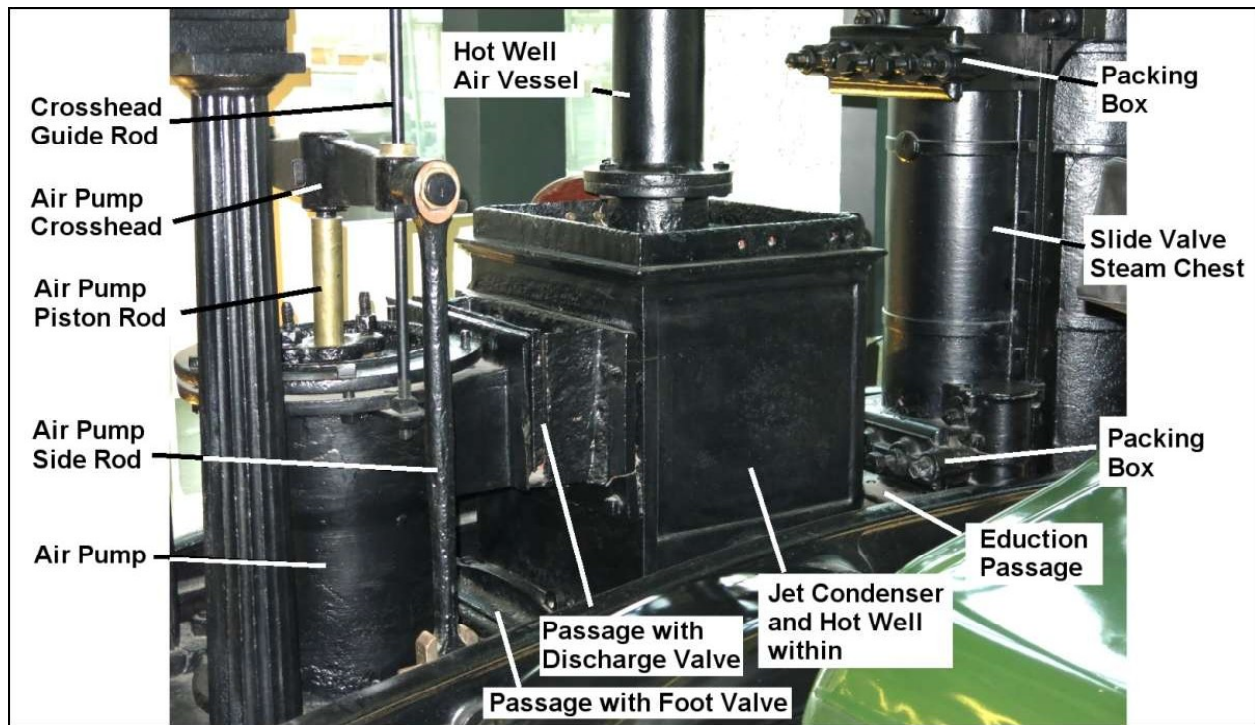


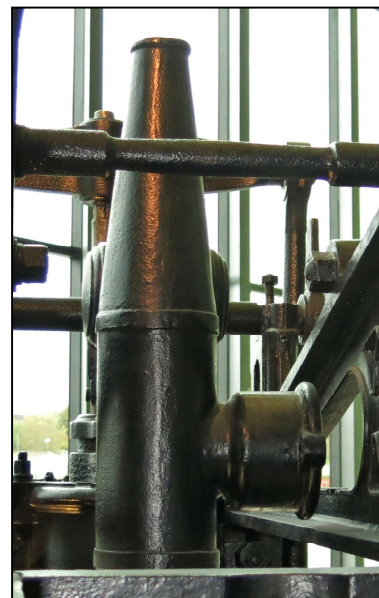
Figure 14. Paddle Steamer *Industry* engine at Riverside Museum.

Details of the air pump, condenser and D type slide valve chest from the port side.

On the left is the air pump with piston rod and crosshead, which is driven from the side-lever beams by side (or link) rods. The crosshead is guided by two vertical rods from the framework down to the top of the air pump. The jet condenser is the square box like structure in the centre. Between the air pump suction (at the bottom of the air pump) and the condenser there is a passage with a non-return foot valve to prevent condensate being pumped back to the condenser (sometimes a division was fitted to prevent condensate passing into the steam cylinder. The Caird engine ref. 25 shows such a division). Between the air pump discharge (at the top of the air pump) and condenser is another passage which would house a non-return discharge valve to the hot well within the condenser. Above the condenser is the hot well air vessel, see **Figure 15** below. Note the two holes on the condenser top centre, these are for connecting a support for the safety barriers, seen in **Figure 4** and **37**, and discussed in the main text section 4.10.

To the right is the slide valve steam chest, which in section is in the form of a D. At top and bottom of the steam chest are the packing boxes with screws for adjusting the slide valve packing, necessary to keep the valves to the face of the steam cylinder, see **Figure 20** for further details. Between the bottom of the slide valve chest and the condenser is the eduction passage where exhaust steam exits the cylinder to the condenser.

Figure 15. Paddle Steamer *Industry* engine at Riverside Museum. This view shows the top of the hot well air vessel in the form of a cylinder and cone. There is a side flange on the cylinder, which would connect to pipework leading waste condensate overboard.



The PS *Industry* Engine at Riverside Museum

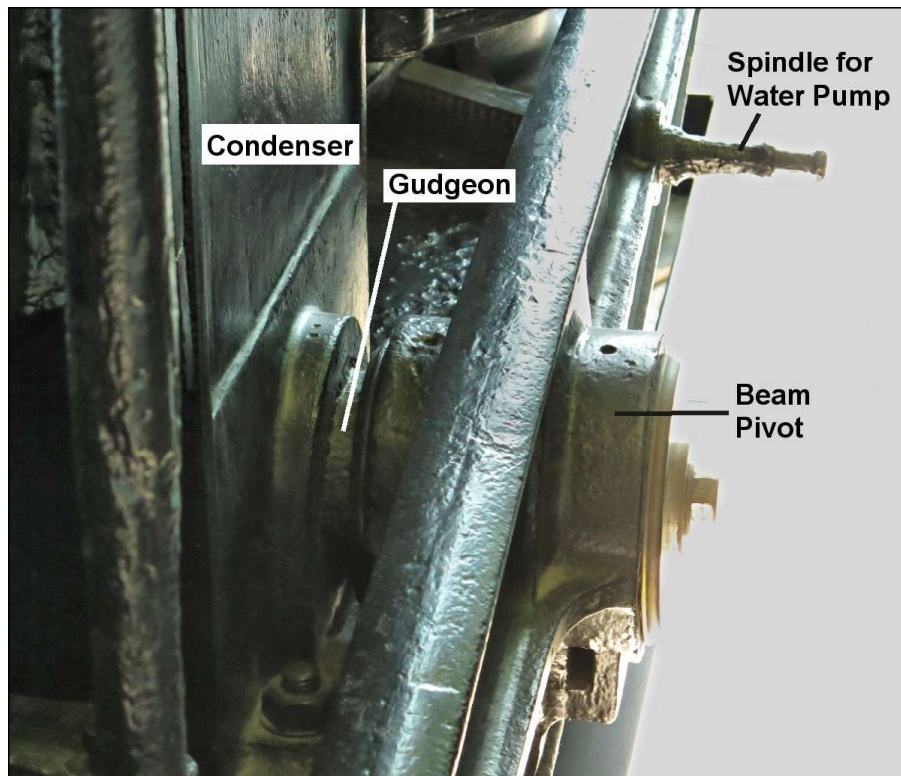


Figure 16. Paddle Steamer *Industry* engine at Riverside Museum.

Details of the port side side-lever beam showing the beam pivot (fulcrum) with brass bearing and bosses each side of the beam. A gudgeon passes through the condenser (on the left) to the starboard side side-lever beam. The gudgeon is securely wedged into bosses cast into the condenser. The gudgeon projection ends support the side-lever beams forming a pivot around which the beam rocks. Note the spindle top right for actuating a boiler feed water pump (or a bilge water pump). A similar arrangement is on the starboard side beam, refer to **Figure 4** to see a pump in position.

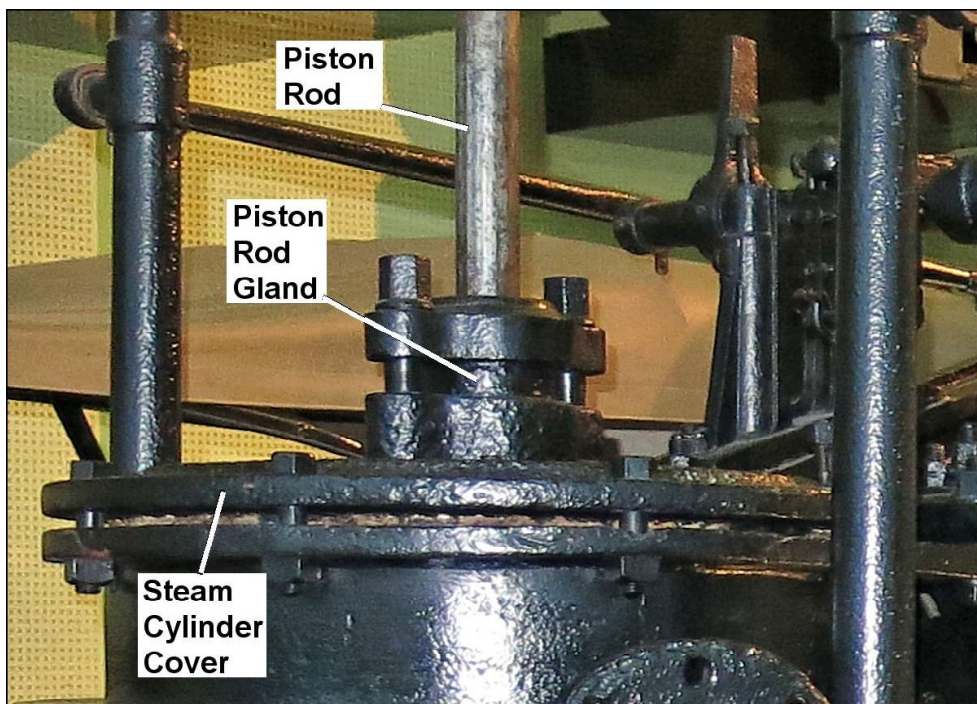


Figure 17. Paddle Steamer *Industry* engine at Riverside Museum.

Details of the steam cylinder cover with a stuffing box (gland with packing) to seal the piston rod where it penetrates the cover, refer Wikipedia, Stuffing box. A similar arrangement would apply to the air pump.

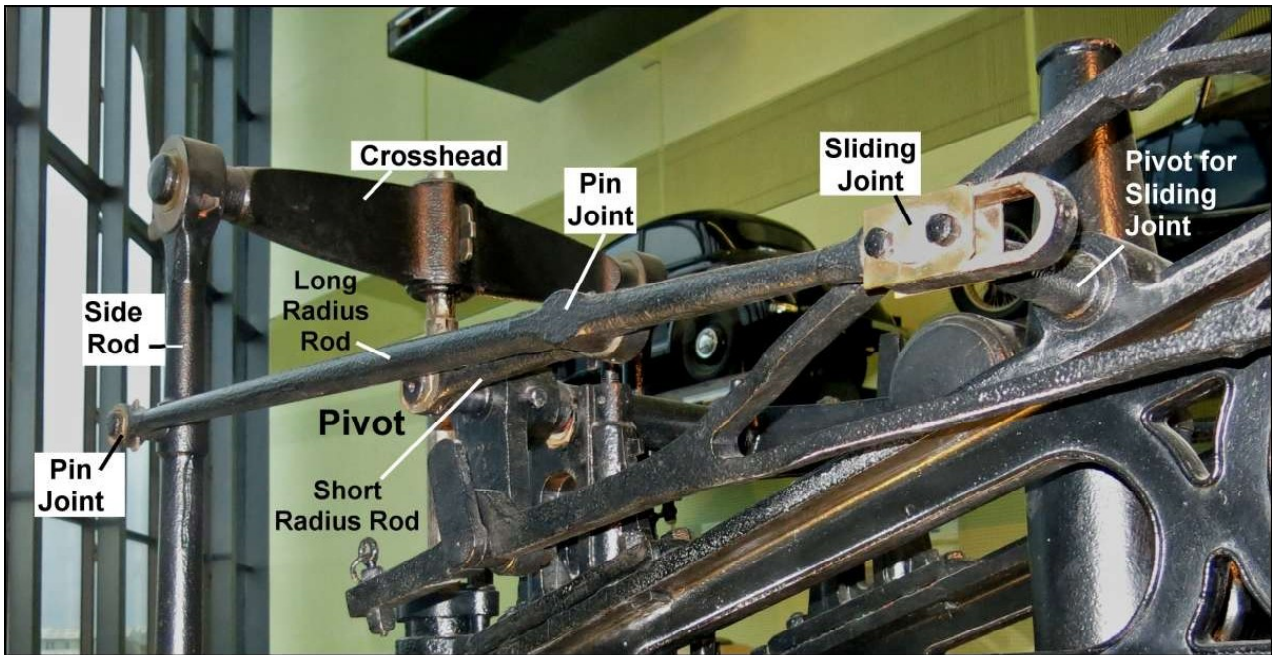


Figure 18a. Paddle Steamer *Industry* engine at Riverside Museum.

The steam cylinder crosshead is guided by a Watt equivalent straight-line (or parallel motion) mechanism formed of short and long radius rods on both port and starboard sides of the engine. The short radius rod is Pivoted at one end and pin jointed to the long radius rod at the other end. The pivot for the short rod being coaxial with the slide valve drive shaft (weigh-shaft or rocking shaft). The long radius rod is pin jointed to the crosshead side rod at one end and extended to be pivoted to a sliding joint at the other end. The pivot for the sliding joint being fixed to the engine framework. Other arrangements of long and short radius rods were used on many side-lever type engines, see for example **Figure 18b** below for a typical arrangement.

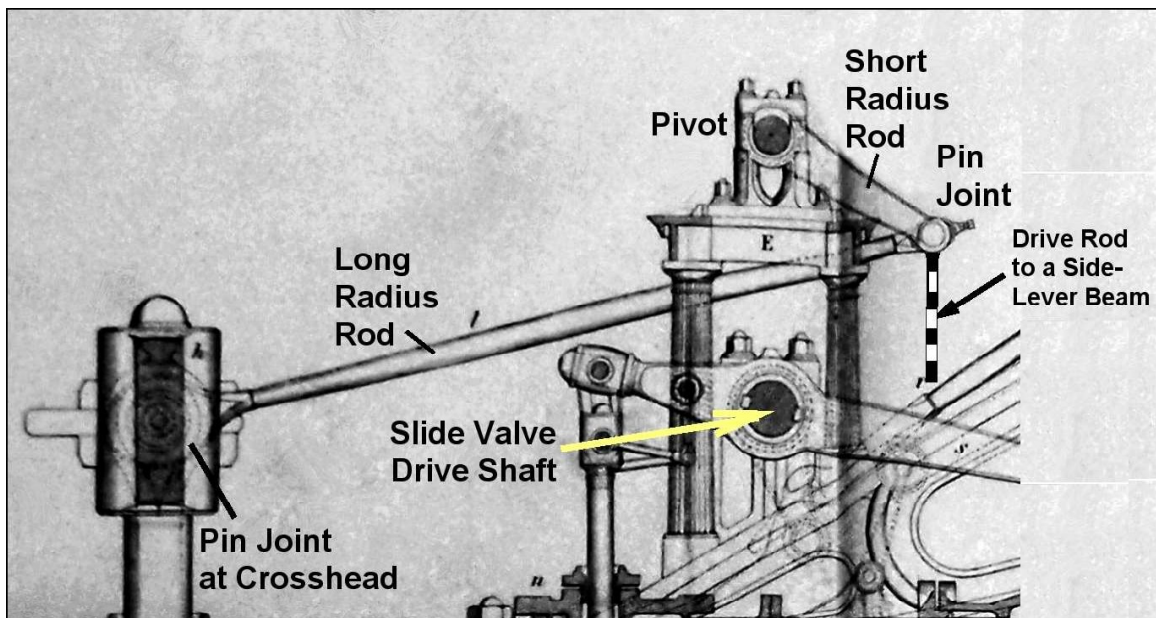


Figure 18b. This shows another typical arrangement of long and short radius rods to guide the steam cylinder crosshead on side-lever engines.

This example of a Caird engine from 1841, reference 24 part view with added text and drive rod, shows a typical arrangement used on many side-lever engines. The long radius rod is pin jointed direct to the crosshead (or pin jointed to the side rod just below the crosshead, like that shown in **Figure 18a** above), and the long rod terminates at the pin joint to the short rod, i.e. the long rod extension to the sliding joint and its pivot, shown in **Figure 18a** above, is dispensed with. A drive rod (shown dotted) to the pin joint would connect to one of the side-lever beams so as to impart motion to the pin joint so that the short radius rod swings about its pivot. Note also in this example, the pivot for the short radius rod is not coaxial with the slide valve drive shaft (weigh-shaft or rocking shaft).

The PS *Industry* Engine at Riverside Museum

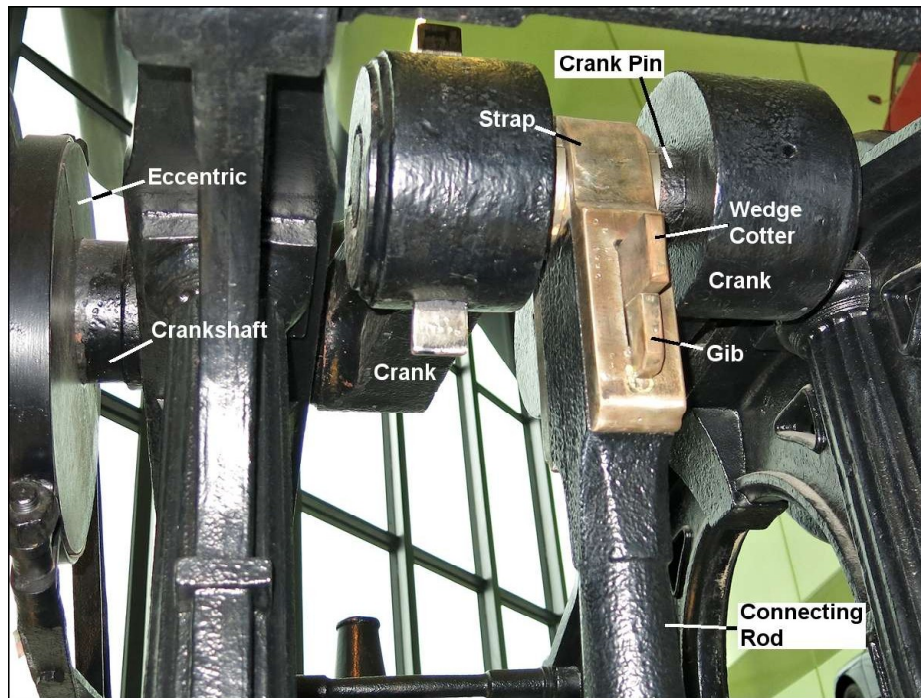
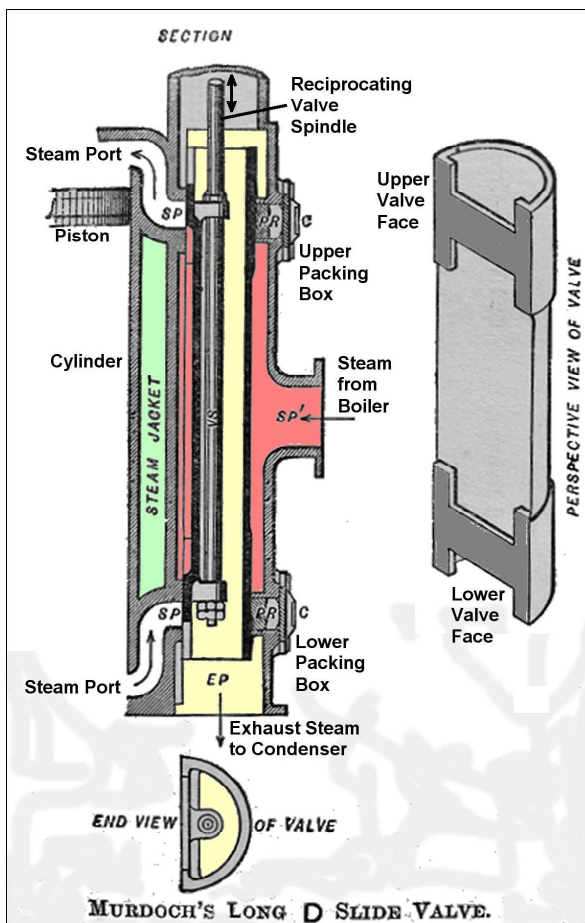


Figure 19. Paddle Steamer *Industry* engine at Riverside Museum. The connecting rod bearing end is connected to the crank pin with a wedge cotter, gib and strap arrangement, refer Wikipedia, Cotter (pin).

Figure 20a. PS *Industry* engine at Riverside Museum →.

The slide valve chest is bolted to the forward side of the steam cylinder. The valve would be the long D type seen in the detail below. The two packing boxes, upper and lower, have screws for adjusting the hemp packing so that the valve is pressed to the valve face on the cylinder.



← **Figure 20b.** Section details of Murdoch's Long D Slide Valve, refer Jamieson ref. 33 (also Wikipedia, Slide valve) with added text.

The PS *Industry* Engine at Riverside Museum

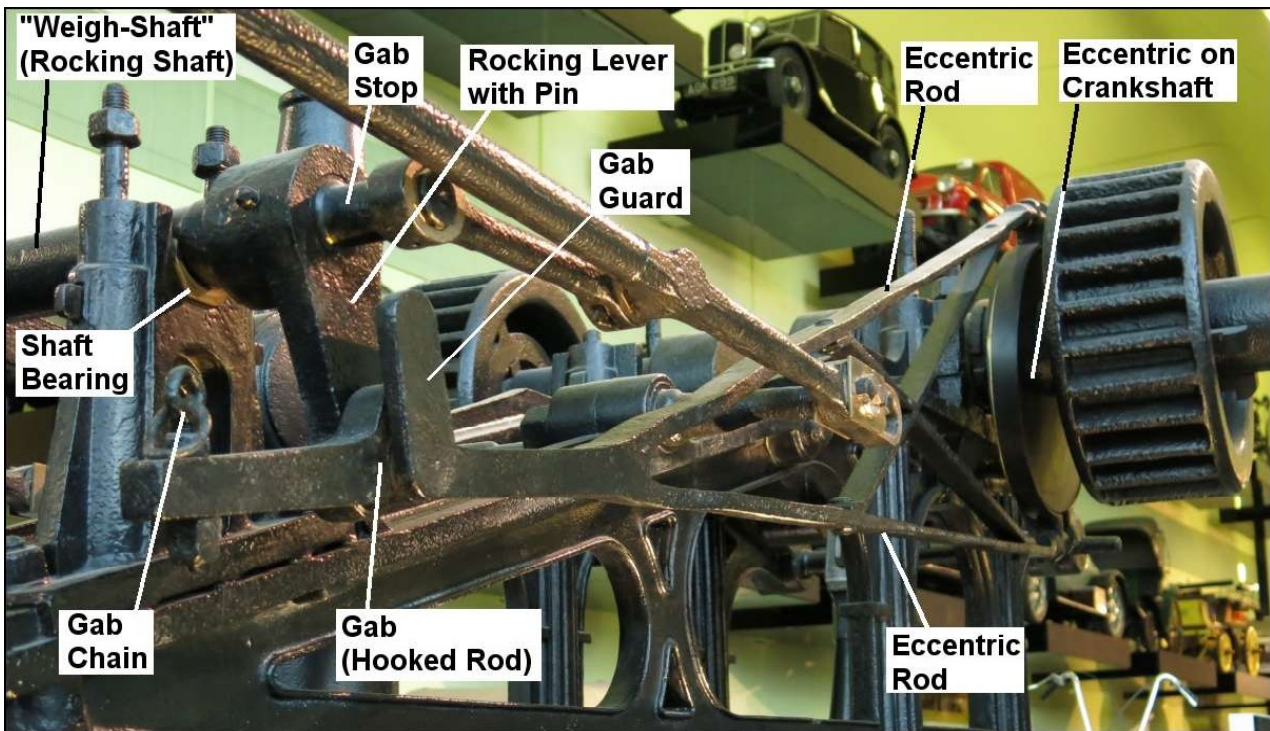


Figure 21a. Paddle Steamer *Industry* engine at Riverside Museum.

This starboard side view shows the components required to work the long D slide valve shown in **Figure 20b**. An eccentric is keyed to, and hence turns with, the crankshaft. This imparts a reciprocating motion to an eccentric rod, which in the case of *Industry* the rod is fabricated from iron bars forming a 'Light' lattice structure and no balance weights are fitted to the eccentric. At the end of the rod is a hooked rod known as a gab, which engages a pin on a lever that rocks to and fro and actuates a weigh-shaft or rocking shaft (or drive shaft) supported on bearings. Through the rocking shaft and links, shown in **Figure 22**, the slide valve spindle and the valve itself is driven (reciprocated up and down) to enable the engine to be manoeuvred ahead or astern and to be double-acting. The gab can be disengaged, to stop the engine and when manoeuvring, by the operator pulling up on a chain so the gab disengages from the rocking lever pin like that shown in **Figure 21b** below. In the case of *Industry* there is a stop and guard to prevent the gab completely disengaging and getting out of alignment; so the gab can be readily re-engaged by the operator at any time.

Figure 21b. This photograph shows an example of a disengaged gab (hooked rod). Reference: Calvert's beam Engine from Wikipedia, Gab valve gear.



The PS *Industry* Engine at Riverside Museum

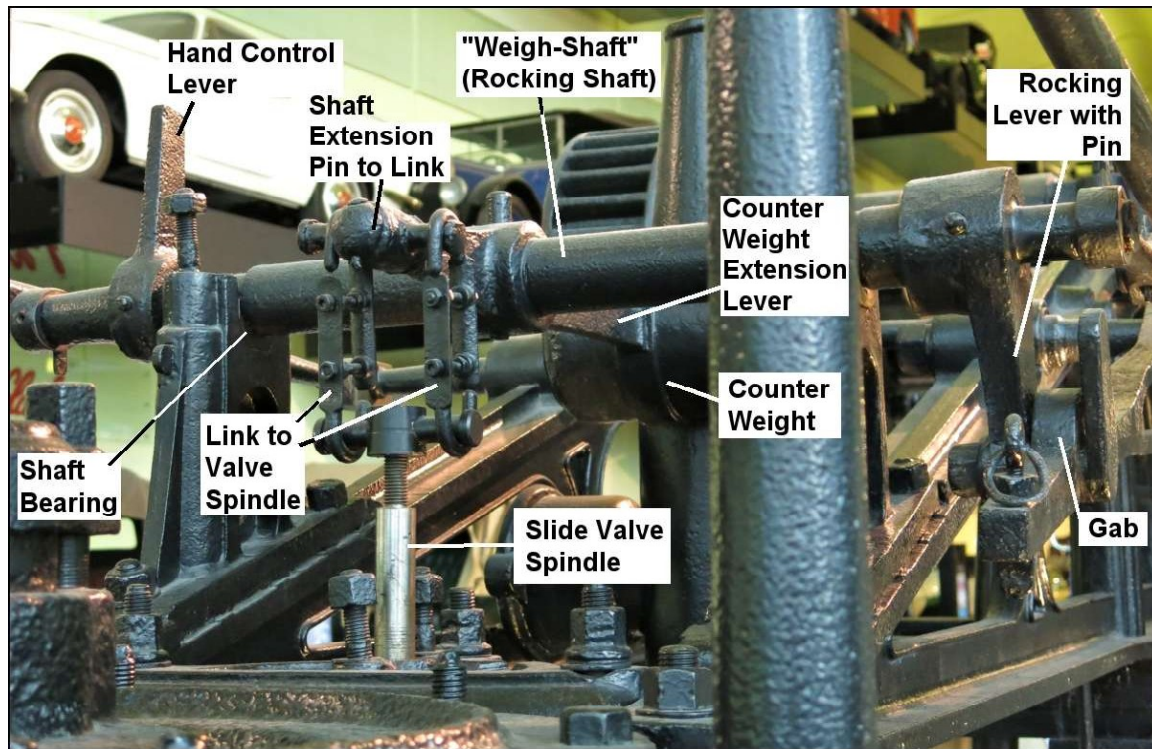


Figure 22. Paddle Steamer *Industry* engine at Riverside Museum.

This view shows the main components making up the controls for the long D slide valve. On the right is the gab and rocking lever that drives the weigh-shaft or rocking shaft, which is supported on bearings. An extension pin to the shaft connects with a link, which connects to the slide valve spindle (this link provides some flexibility and avoids undue side thrust onto the valve spindle). Rocking of the weigh-shaft reciprocates the link and slide valve spindle and the valve up and down. There is also a counter weight connected to, and rocks with, the weigh-shaft by a extension lever. The purpose of the counter weight is to move the slide valve to close off the steam ports, and hence bring the engine to a stop, when the gab is disengaged. To the left there is a hand control lever (top part is missing) connected to the weigh-shaft. With the gab disengaged, the slide valve can be moved by the operator actuating this hand lever so that the engine can be started, running ahead or astern as required. With the engine running the gab can be engaged and the engine will run automatically.

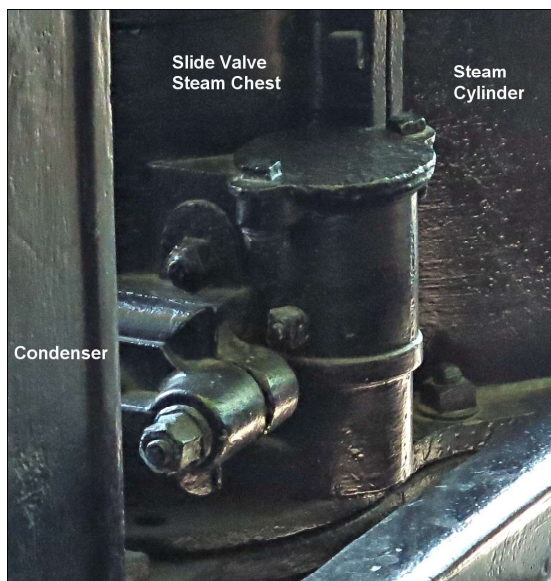


Fig. 23a Looking Aft

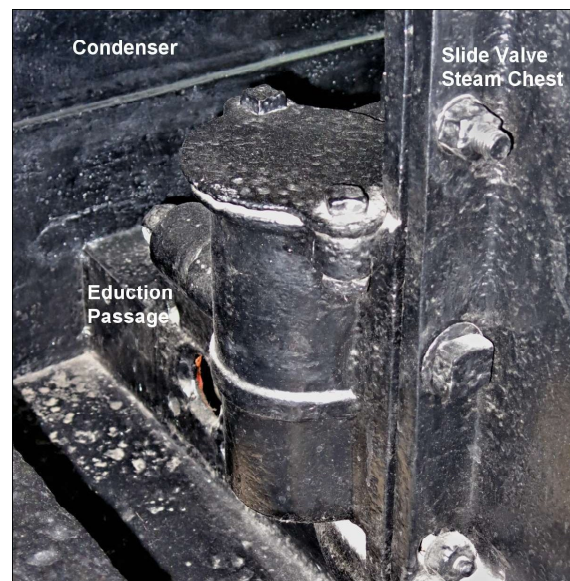


Fig. 23b Looking Forward

Figure 23. Paddle Steamer *Industry* engine at Riverside Museum. Port side views of a housing with a cover attached to the slide valve steam chest. The position of this housing is typical of that for the blow-through valve (or cock) on Caird side-lever engines, see **Figure 24** overleaf. There is also an opening with bolt holes, seen in **Fig. 23b**, to the eduction passage adjacent to the housing. This could have mounted a drain or a snifting valve, see the main text section 4.8.

The PS *Industry* Engine at Riverside Museum

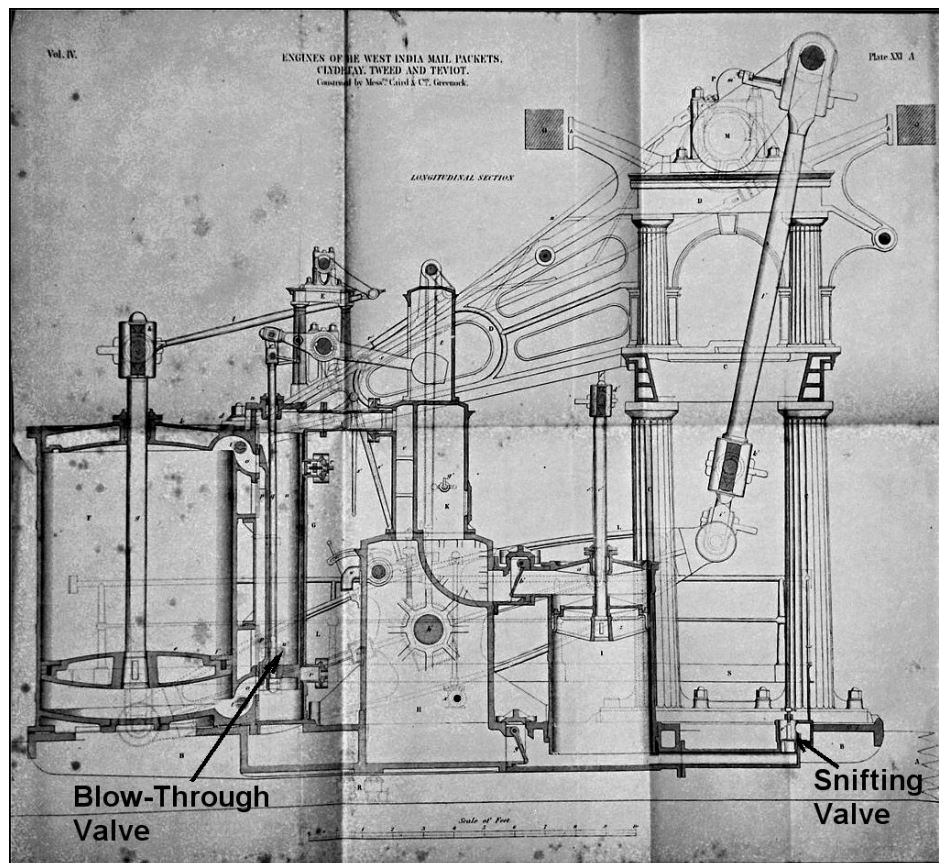


Figure 24a. This view shows a section of a Caird side-lever engine for the West India Mail Packet vessels, ref. 20, Plate XXIA with added text, from the starboard side. The blow-through valve is on the port side of the slide valve steam chest as shown. The snifting valve (it is called a shifting-valve in ref. 20) is on the centre line of the engine at the crankshaft end as shown, see **Figure 24b** below.

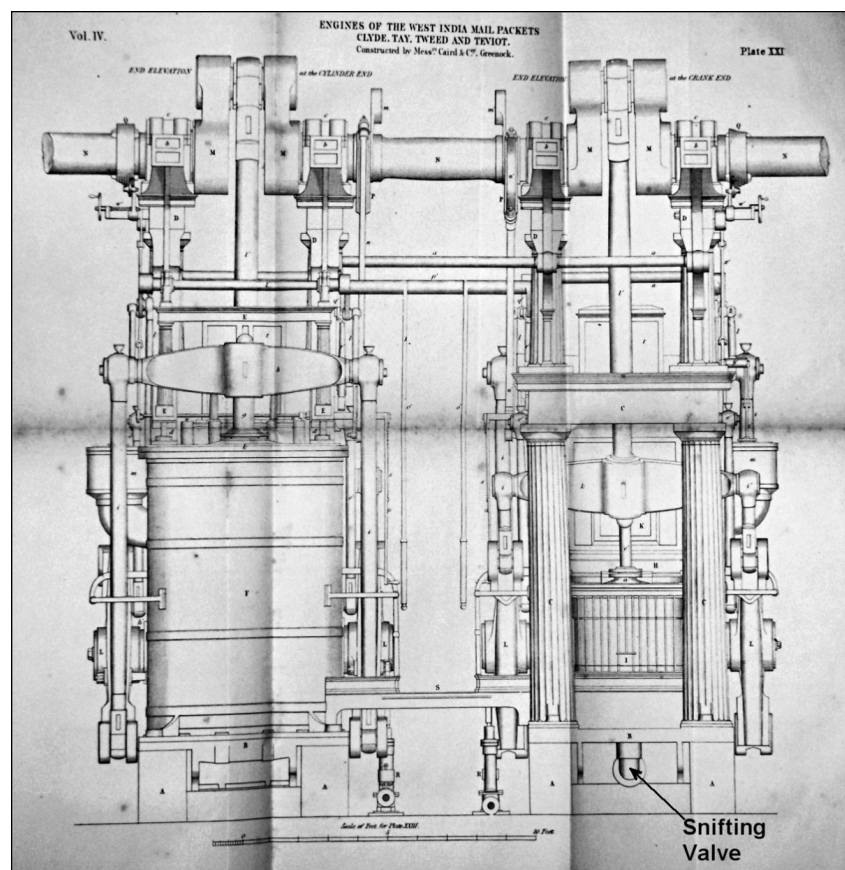


Figure 24b. End views of Caird engines showing the position of the snifting valve on the centre line of the engine at the crankshaft end. Ref. 20, Plate XXI with added text.

The PS *Industry* Engine at Riverside Museum

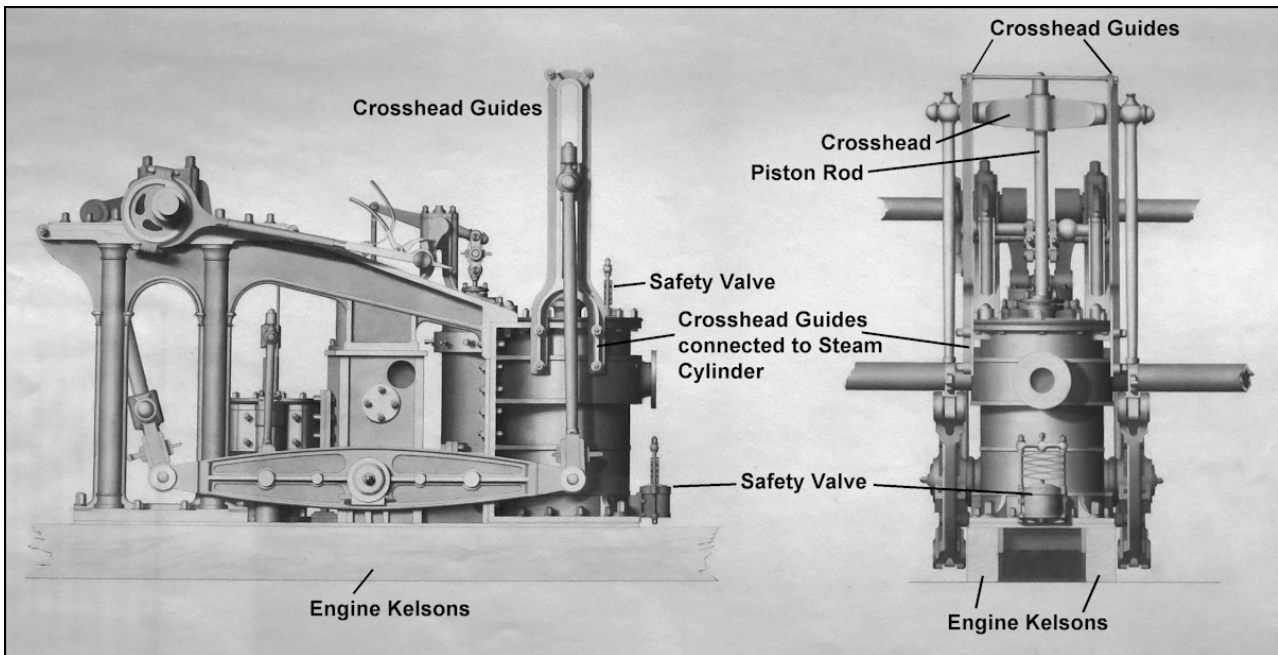


Figure 25. The side-lever engine of the PS *Rio de Janeiro*, built by Robert Napier & Son of Glasgow in 1841. Riverside Museum with added text. ©CSG CIC Glasgow Museums and Libraries Collection.

The engine is bolted to wooden beams running longitudinally along the vessel hull; hence they are sometimes called engine kelsons. The steam cylinder is protected from overpressure by spring type safety valves on the cylinder cover and on the bottom of the cylinder. Note also the Watt's equivalent straight-line mechanism has been replaced by closely spaced (narrow) vertical crosshead guides to guide the cylinder piston rod; the guides being securely bolted to the steam cylinder.

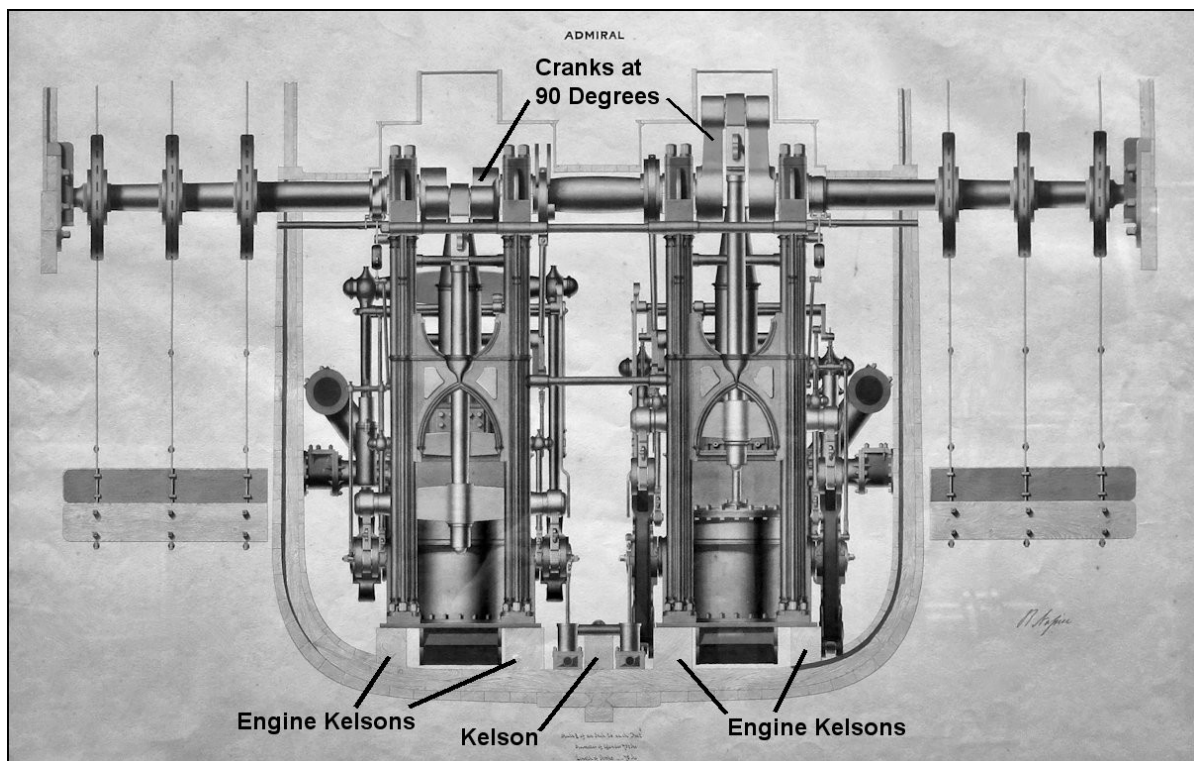


Figure 26. The side-lever engine of the PS *Admiral*, built by Robert Napier & Son of Glasgow in 1840s. Riverside Museum with added text. ©CSG CIC Glasgow Museums and Libraries Collection.

As vessel size increased so did the need for increased engine power. It became normal practice to fit two side-lever engines side by side. This had the benefit of arranging the engine cranks at 90 degrees to each other and so could avoid start up issues of a single engine stuck on top or bottom dead centre. Both engines are securely bolted to their engine kelsons and the vessel hull can be readily fitted with a kelson proper between the engines.

The PS *Industry* Engine at Riverside Museum



Fig. 27a. Safety valve on cylinder cover.



Fig. 27b. Safety valve on bottom of cylinder.

Figure 27. Deadweight lever safety valves on the SS *Simla* engine model, refer Whyte ref. 34.

Figure 28a. Starboard side view of 1/10 scale model of the paddle steamer *Industry*. Riverside Museum, Glasgow.

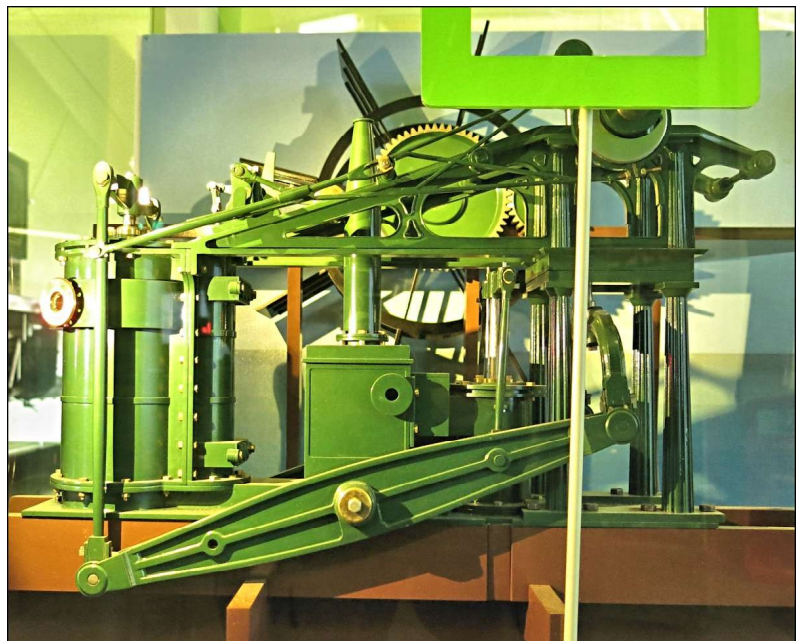


Figure 28b. Plan view of 1/10 scale model of the paddle steamer *Industry*. Riverside Museum, Glasgow.

The PS *Industry* Engine at Riverside Museum

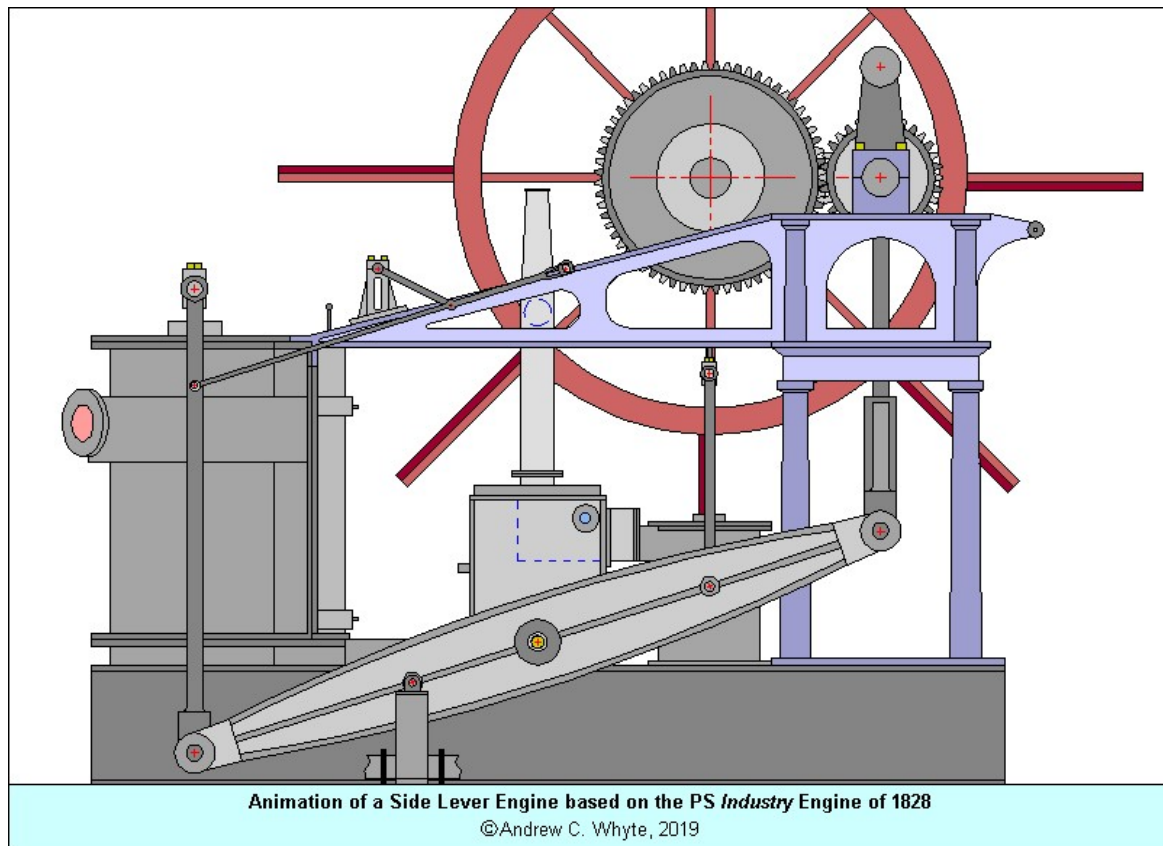


Figure 29a. Starboard side view of a side-lever engine based on the PS *Industry* of 1828.
https://acwhyte.droppages.com/downloads/animations/side_lever_engine_animation_side_view.gif

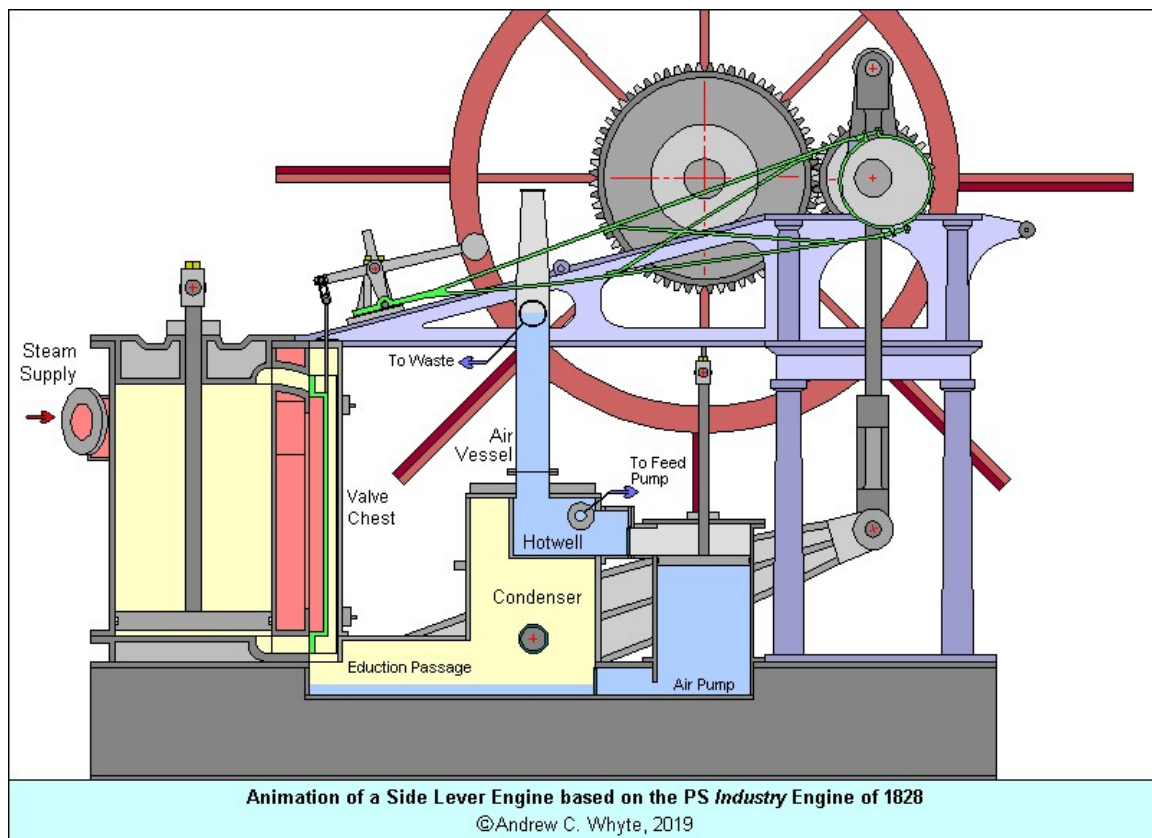


Figure 29b. Section view of a side-lever engine based on the PS *Industry* of 1828.
https://acwhyte.droppages.com/downloads/animations/side_lever_engine_animation_section_with_text.gif

The PS *Industry* Engine at Riverside Museum

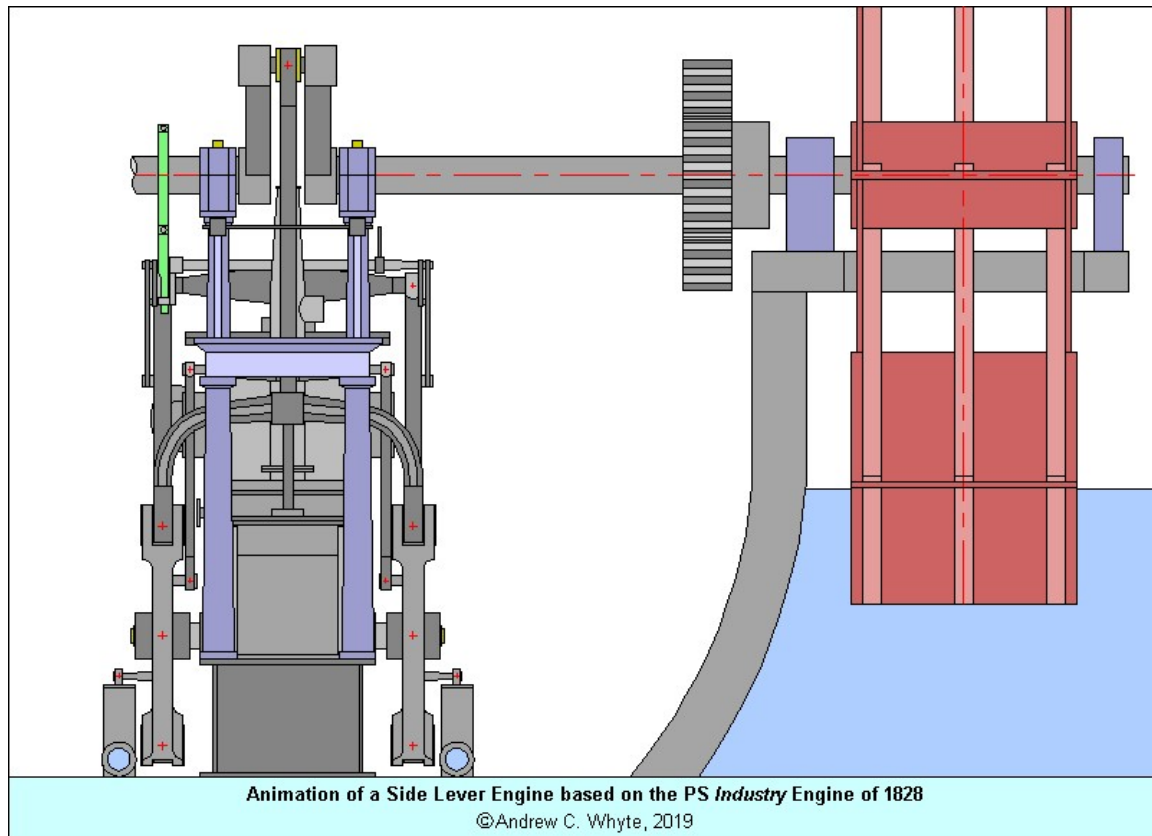


Figure 29c. Crankshaft end view of a side-lever engine based on the PS *Industry* of 1828.
https://acwhyte.droppages.com/downloads/animations/side_lever_engine_animation_crank_end.gif

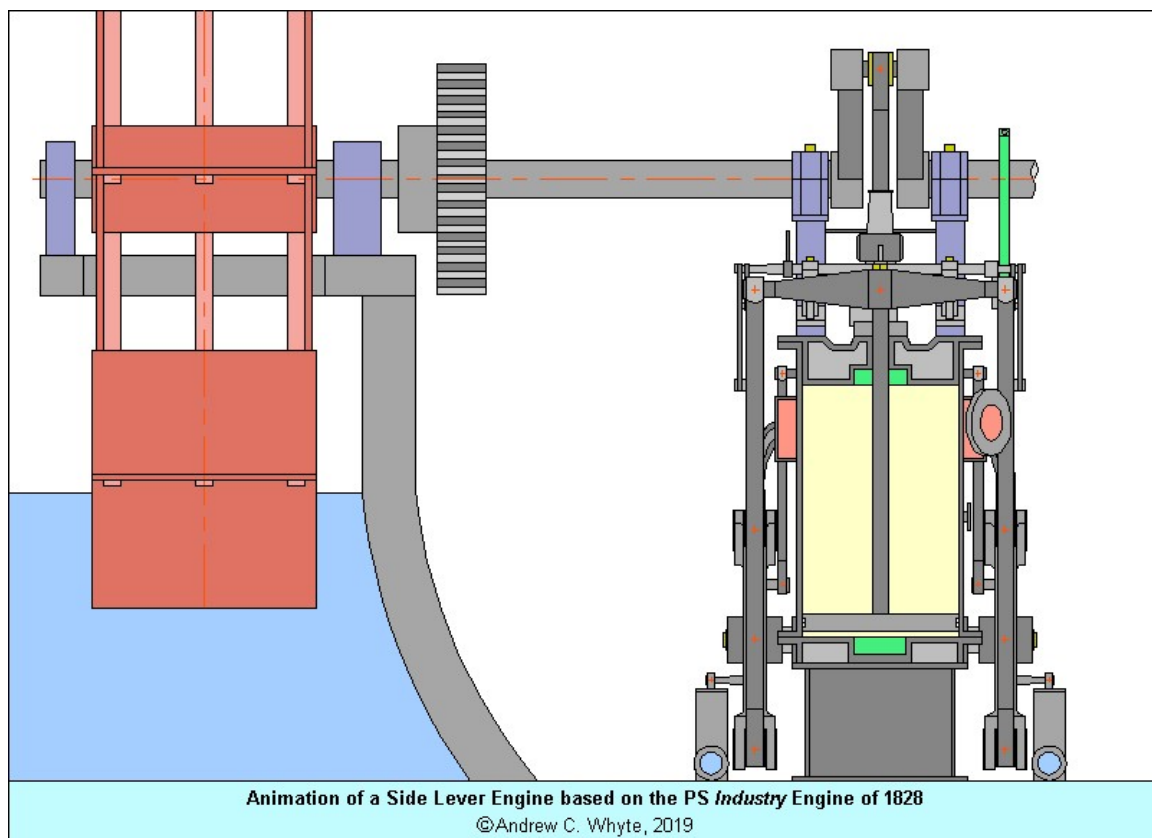


Figure 29d. Cylinder end section view of a side-lever engine based on the PS *Industry* of 1828.
https://acwhyte.droppages.com/downloads/animations/side_lever_engine_animation_cylinder_end.gif

The PS *Industry* Engine at Riverside Museum

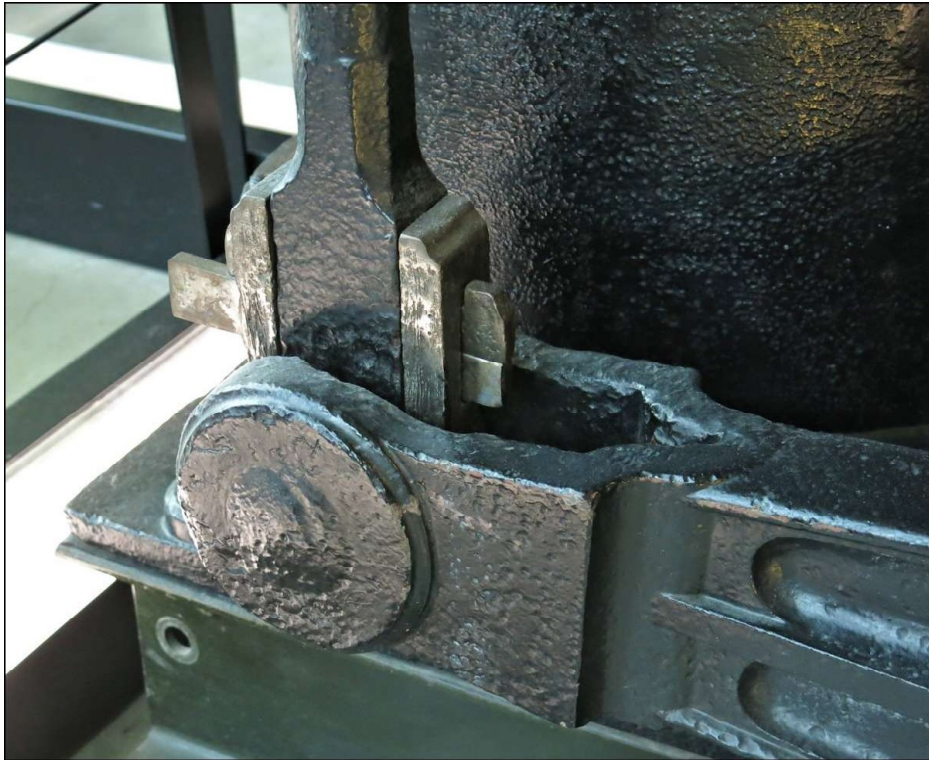


Figure 30. PS *Industry* Riverside Museum, Glasgow. The side rod connection detail to the side-Lever fork end. This connection makes use of the well tried wedge cotter, gib and strap arrangement used to connect the connecting rod to the crank, refer to **Figure 19**.



Figure 31. PS *Industry* Riverside Museum, Glasgow. The side-lever beam pivot detail.

The PS *Industry* Engine at Riverside Museum

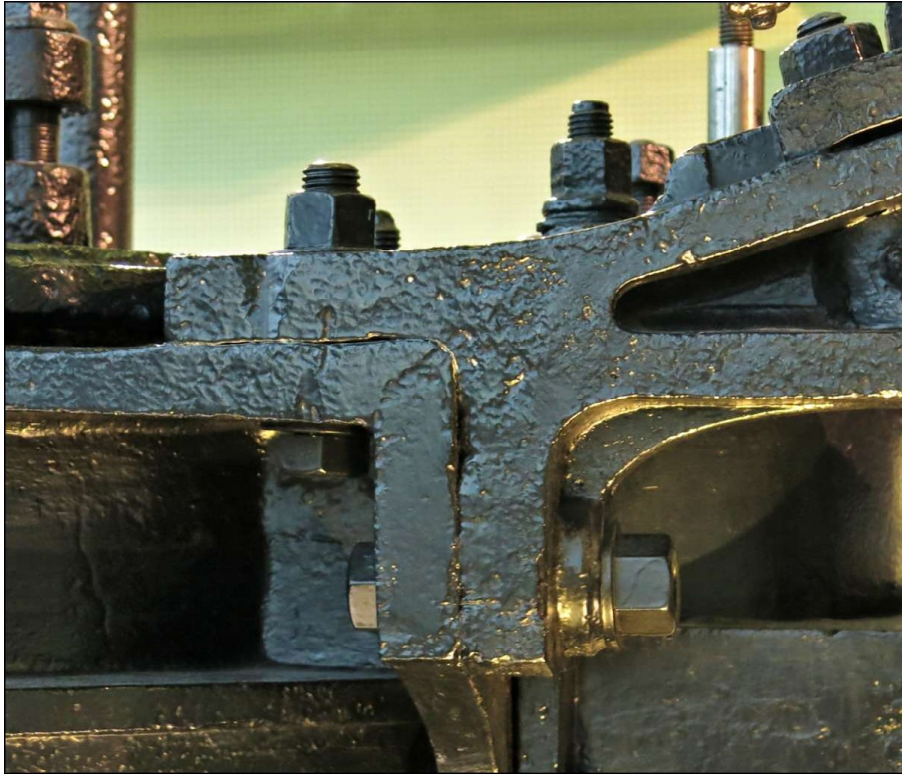


Figure 32. PS *Industry* Riverside Museum, Glasgow. This detail shows the frame connection to the top of the steam cylinder by means of bolting.



Figure 33. PS *Industry* Riverside Museum, Glasgow. This detail shows the sliding joint, part of the Watt equivalent straight-line mechanism used to keep the steam cylinder crosshead and piston rod in alignment with the cylinder.

The PS *Industry* Engine at Riverside Museum

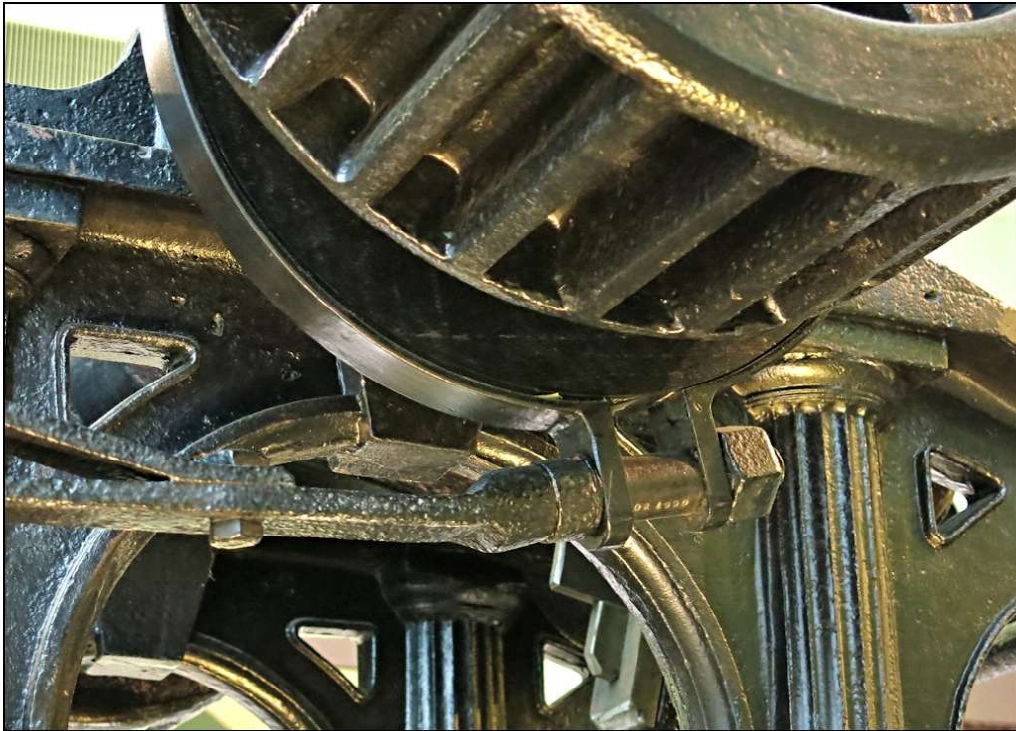


Figure 34. PS *Industry* Riverside Museum, Glasgow. This detail shows the eccentric rod connection to and adjusted by bolting to the strap around the eccentric.



Figure 35. PS *Industry* Riverside Museum, Glasgow. This detail shows the gab at the end of the eccentric rod. Also seen is the pivot point for the Watt equivalent straight-line mechanism.

The PS *Industry* Engine at Riverside Museum

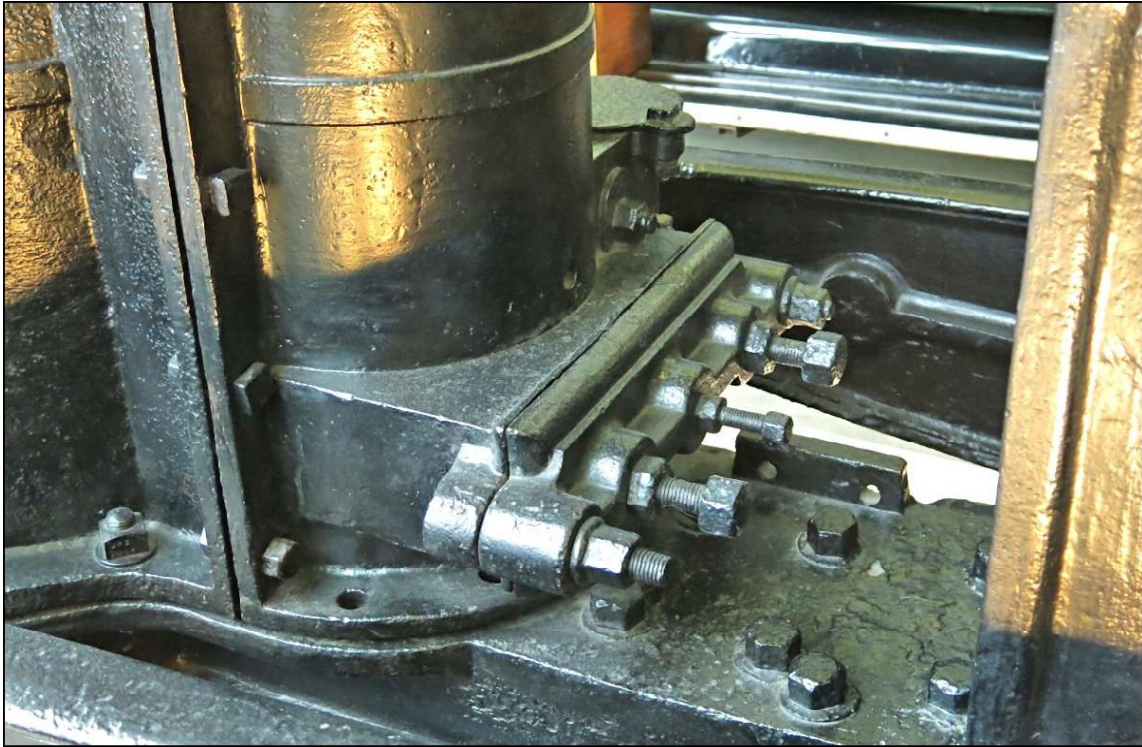


Figure 36. PS *Industry* Riverside Museum, Glasgow.

This detail shows the slide valve chest and the lower slide valve packing box and adjustment screws. A mixture of bolting types can be seen including: square bolt heads and nuts, old style hexagon nuts (during the Second World War the hexagon size of nuts and bolts was reduced to save material and they never went back to the original) and modern hexagon nuts and bolt heads.



Figure 37a. Attachment point on Steam Cylinder.

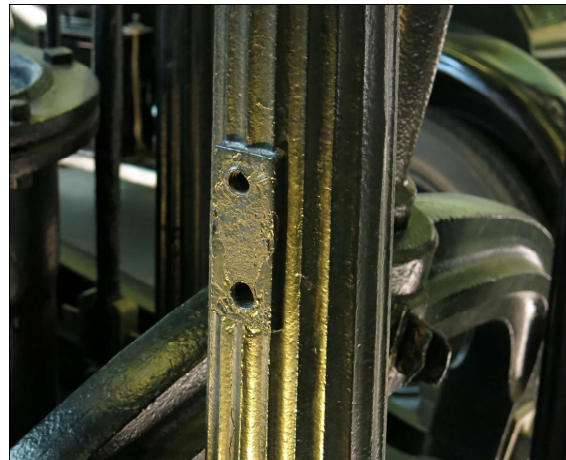


Figure 37b. Attachment point on forward column.

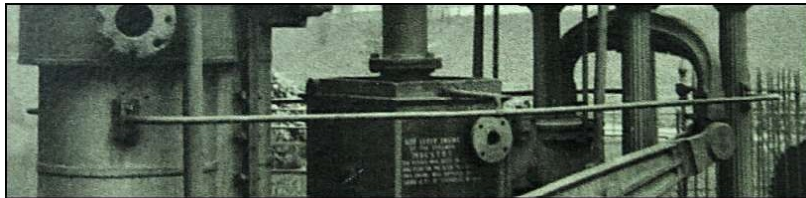


Figure 37c. Detail from **Figure 4** showing the starboard side safety barrier.

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Figure 37. PS *Industry* Riverside Museum, Glasgow. These details show safety barrier attachment points cast into the steam cylinder, **Figure 37a**, and at the forward framework columns, **Figure 37b**. The barriers can be seen in position in **Figure 4**, as seen in the detail **Figure 37c** above. There was also a central support to the barrier connected by two bolts to the top of the condenser. On the starboard side these now connect the commemorative plaque as shown in **Figure 13**, but the two holes for the bolts can be seen in the port side view **Figure 14**.

The PS *Industry* Engine at Riverside Museum



Figure 38. Port side view of the side-lever engine for the PS *Leven* at the Denny Ship Model Experiment Tank Museum, Dumbarton.

This engine built by Robert Napier was his first marine engine. The engine arrangement is that of a typical side-lever engine of the early 1820s⁽²⁵⁾, i.e. crankshaft forward, steam cylinder aft, with condenser and air pump between. Notable on this engine is the Watt parallel motion, driven from the side-levers, to keep the crosshead and piston rod in alignment with the steam cylinder.



Figure 39. Starboard side view of the side-lever engine for the PS *Leven* at the Denny Ship Model Experiment Tank Museum, Dumbarton.

This view shows the crankshaft driven eccentric, eccentric rod and the single (simple) gab and the rocking lever to reciprocate the slide valve. Note that the eccentric has balance weights and the slide valve has two balance weights concealed in a chest above the hot well.

The PS *Industry* Engine at Riverside Museum

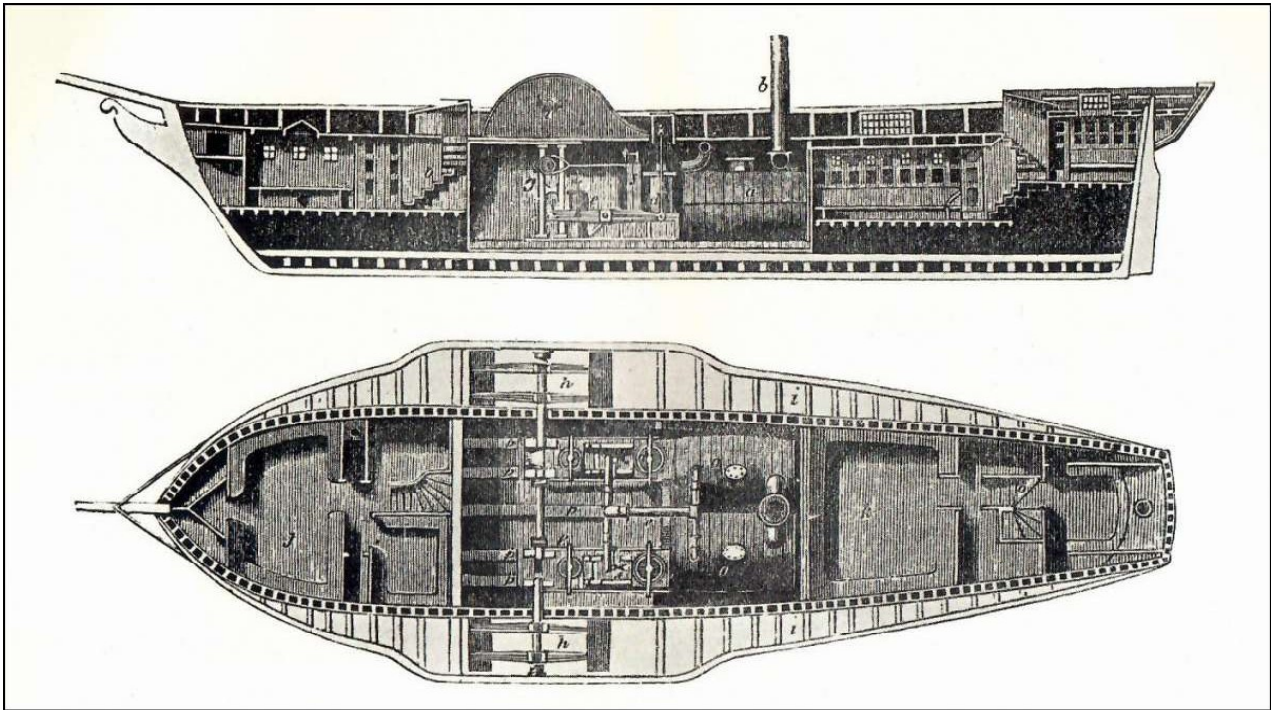
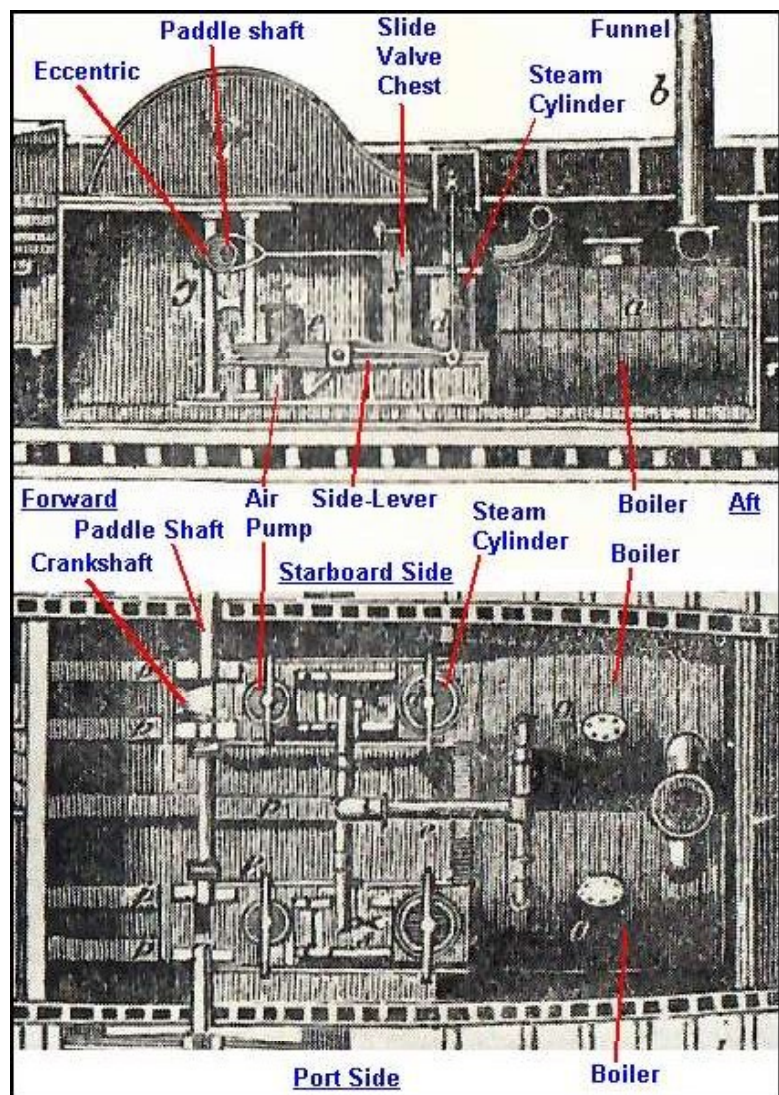


Figure 40a. Plan and Port Side Sections of a paddle steamer common on the River Clyde, Hebert ref. 13, Section I, page 661.

These sections show clearly how the engine room (engines and boilers) take up a significant amount of space, around a third of the volume of the vessel. The detail, **Figure 40b**, below shows a close up view of the engine room.

Figure 40b. Sections of a paddle steamer common on the River Clyde, close up of the engine room, Hebert ref. 13, Section I, page 661 with added text. The description by Hebert ref. 13, Section I, page 660 makes it clear that the engine room has two typical side-lever engines supplied by steam from two boilers, but refer also to **Note (26)**. The paddles are driven from the crankshaft without the use of gears.

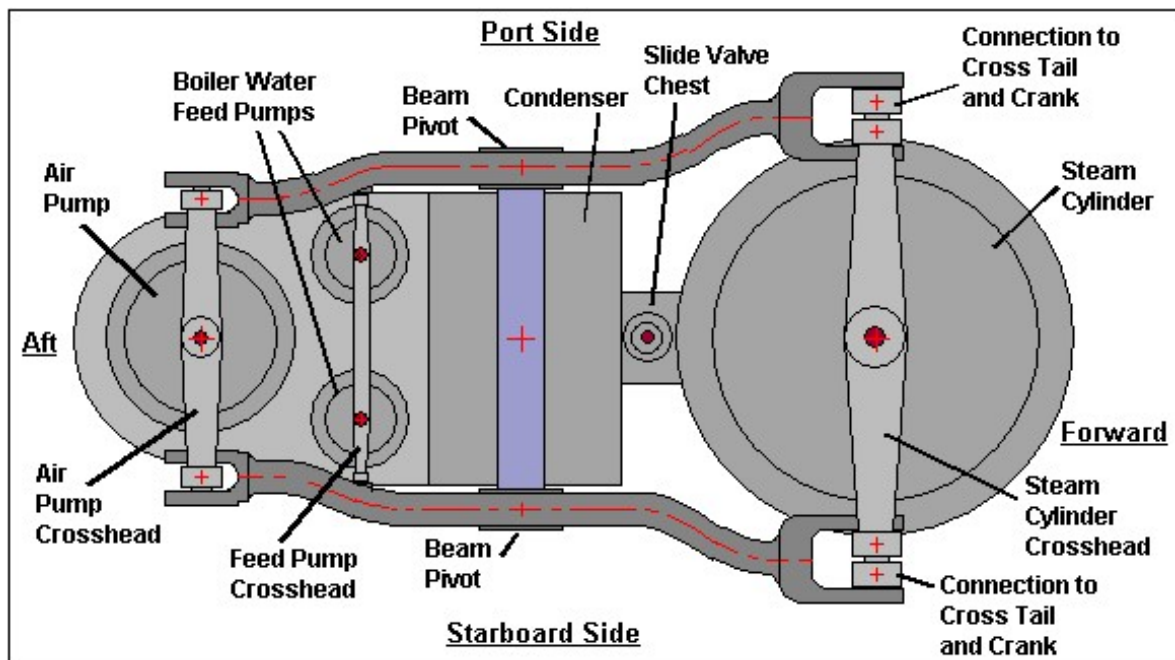


Technical drawing of a steam engine mechanism, showing the steam cylinder, crosshead, columns, and guides. The drawing includes a scale bar at the top and labels for various components.

Labels and components shown:

- Steam Cylinder
- Crosshead
- Columns as Crosshead Guides
- Scale bar (0 to 8)
- Labels: a, b, c, d, e, f, g, h, i, j, k, l, m, n, o, p, q, r, s, t, u, v, w, x, y, z

The engines are of a type described as Napier's direct-action engines by Hebert ref. 13, Section III, pages 688 and 689, who provides a detailed description of the working of these engines, but refer to **Note (26)**. Note also the steam cylinder piston rod connects to a crosshead whose alignment is by utilising the columns as widely spaced vertical guides to insure parallelism. Thus, a Watt equivalent straight-line mechanism is avoided. The crosshead is wide enough to allow the side rods from the crosshead to the side-lever beams to pass outside of the steam cylinder. The cross tail to the crankshaft connecting rod is a straight member, i.e. like an inverted T. The cross tail has to be wider in length than normal in order to allow the side rods (which are longer than normal) to pass outside the side rods of the steam cylinder crosshead, see **Figure 41b** below. Animations of this engine is given in my website: <https://acwhyte.droppages.com/animations.htm>



Hebert ref. 13, Section III, pages 688 and 689 describes the working of the **United Kingdom** engines. Unlike typical side-lever engines (with straight beams) the two side-lever beams on the **United Kingdom** are not straight. There are two bends in each beam so that the beams can take up as little room as possible, by lying close to the respected parts of the machinery. The plan view above shows how the arrangement would work. An animation is given in my website: <https://acwhyte.droppages.com/animations.htm>

The PS *Industry* Engine at Riverside Museum

Figure 42. The boiler of the PS *United Kingdom*, Napier ref. 30. A detailed description of this boiler is given by Hebert ref. 13, Section III, pages 721 to 723. The boiler is of wrought iron with a length of 25 feet 6 inches and breadth of 19 feet. The height is 8 feet 6 inches. There are 8 rectangular furnaces.

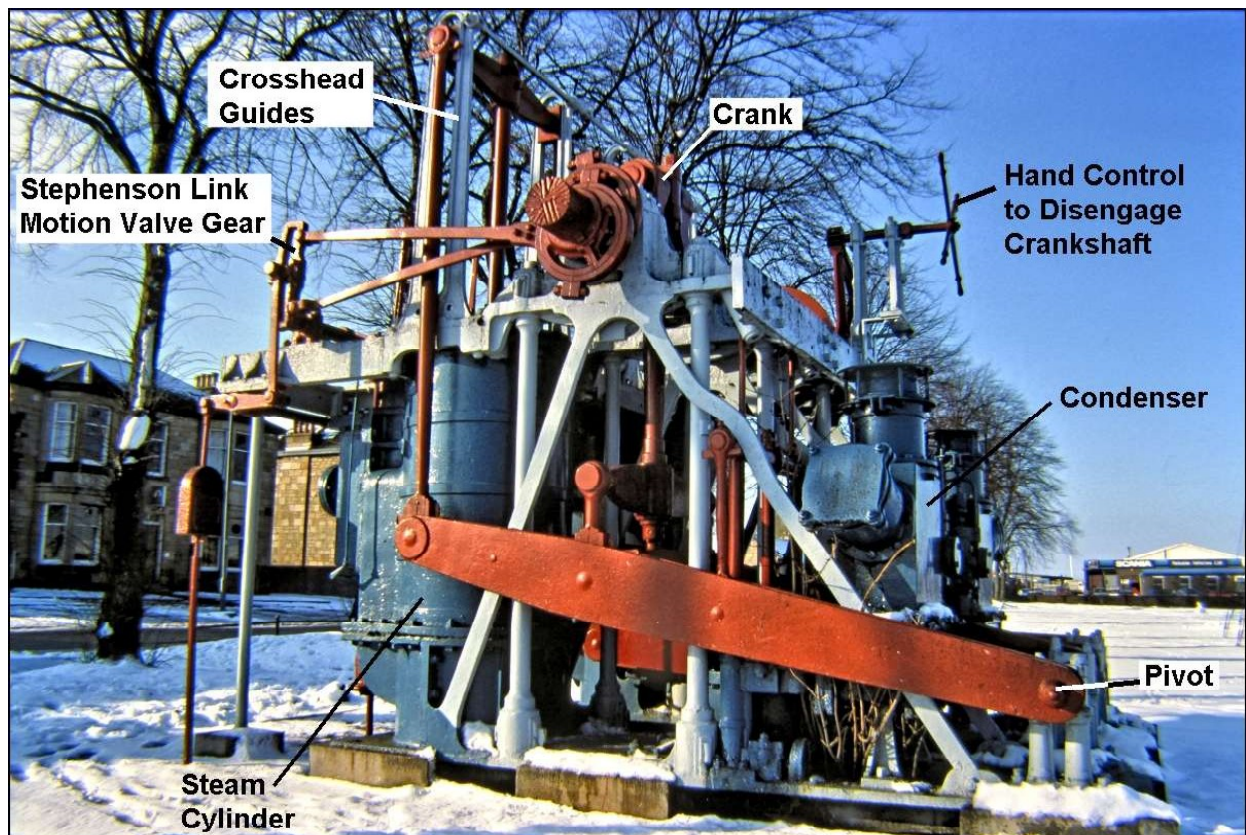
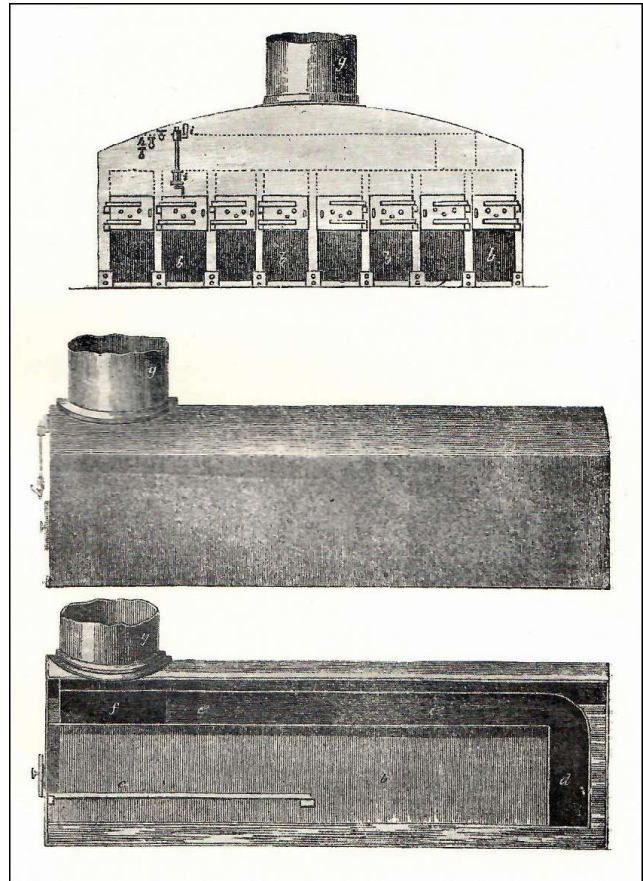


Figure 43. Renfrew Ferry Green: PS *Clyde* engines 1851.

These engines are side-lever engines of the grasshopper type. The pivot is at one end of the side-lever. The engines have closely spaced crosshead guides to guide the piston rod. The slide valve is controlled by a Stephenson's link motion valve gear. There is a hand control mechanism to allow disengaging of the crankshaft, between engines, so that each engine can drive (or free wheel) its own paddle wheel independently of the other.

The PS *Industry* Engine at Riverside Museum

Figure 44. Renfrew Ferry Green: PS *Clyde* engines 1851. The memorial plaque to Andrew Brown 'the father of the steam dredger'.

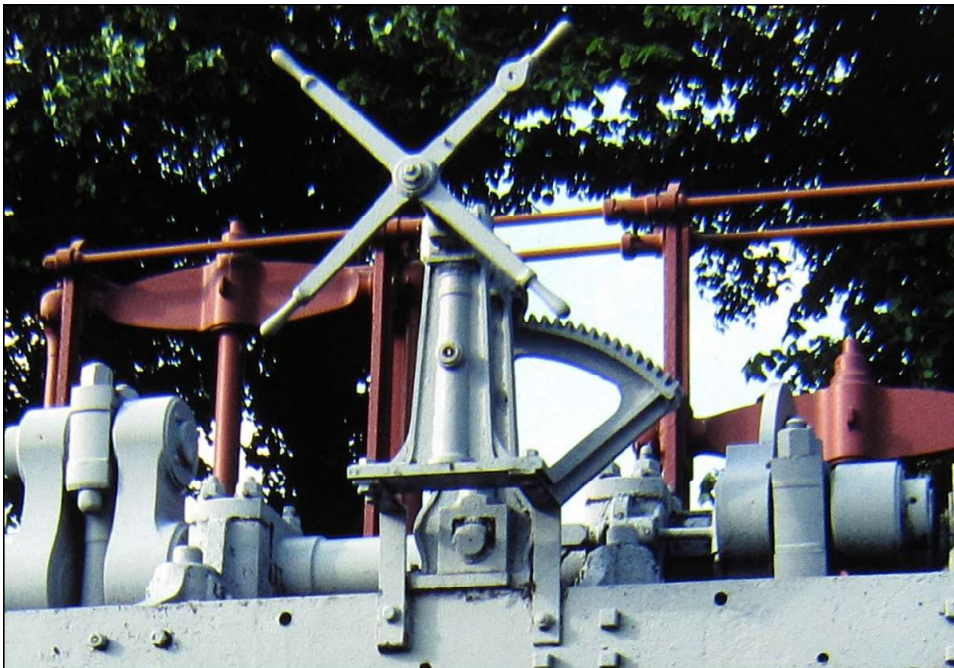
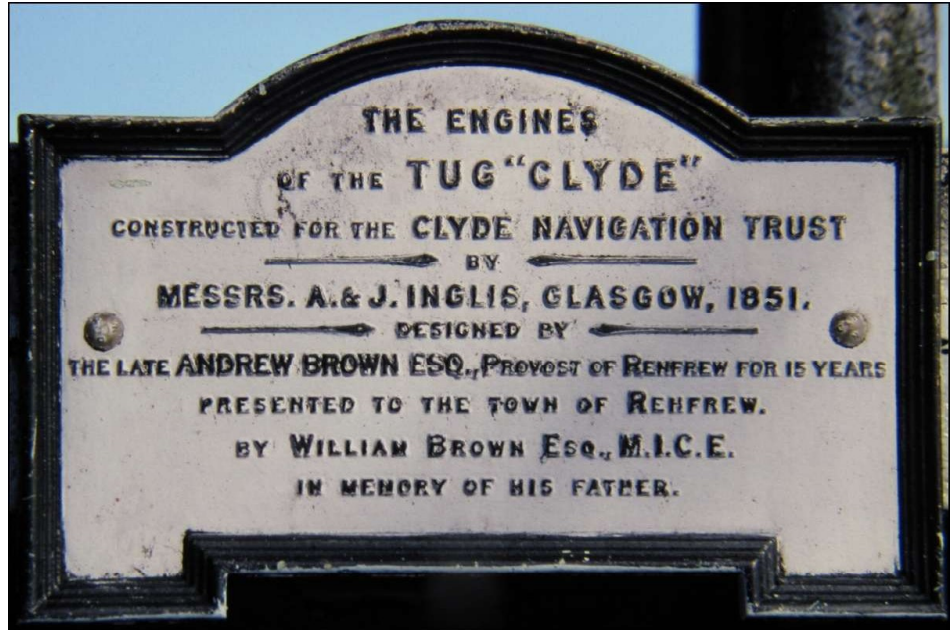
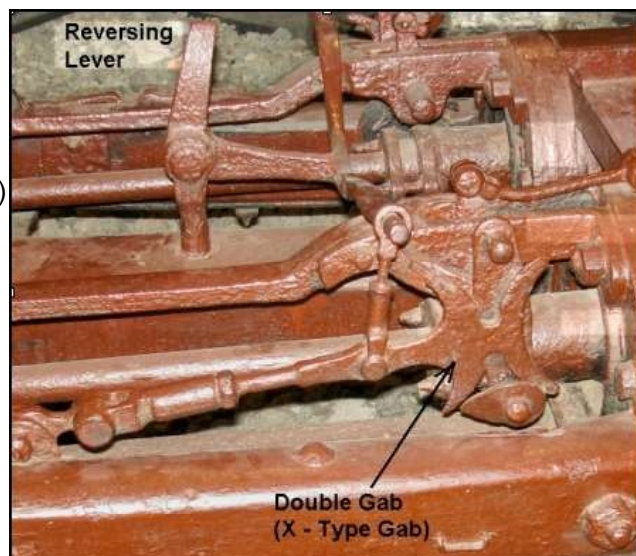


Figure 45. Renfrew Ferry Green: PS *Clyde* engines 1851. The four-arm hand wheel turns a gear pinion, which turns a gear quadrant that operates a mechanical clutch to disengage the crankshaft between engines, so that each engine can drive (or free wheel) its own paddle wheel independently of the other.

Figure 46. The double gab (or 'X' type) to ease reversing dates from 1818. This example is that fitted to the Gurney steam drag of 1831. Riverside Museum, Glasgow.



Animations of this gab can be found in my website: <https://acwhyte.droppages.com/animations.htm>

Figure 47. Typical indicator diagram (pressure – volume diagram) showing the effect of working the engine below atmospheric pressure by creating a vacuum in the condenser. In the early steam engines (the 1820's). Steam pressure (boiler pressure) would only be a few pounds per square inch. The engine relied on working below atmospheric pressure by lowering the back pressure to condenser pressure (the hatched area). The result being an increase in power output for the same amount of steam without a condenser.

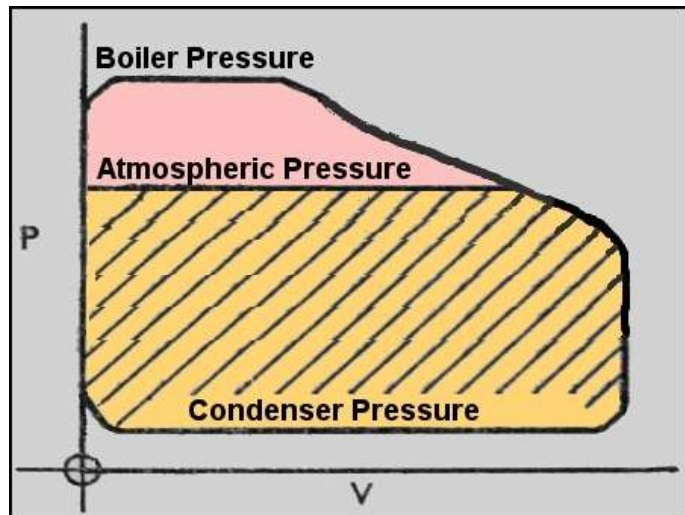


Figure 48. Typical indicator diagrams (pressure – volume diagrams) showing the effect of power output of the engine by varying the steam pressure from the boiler by throttling. During throttling the steam cut-off would be constant.

