The hydraulic system in Bristol City Docks

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The word hydraulic can be traced back to the Greek word 'hydor' meaning. water and 'aulos' meaning pipe, and early hydraulic machinery was indeed machinery which derived power from water. Such machinery can be divided into two broad categories. Firstly, there is hydro-kinetic machinery which uses the energy of moving liquid to drive machine parts, early examples being undershot waterwheels and Norse mills, and more modern applications being such things as the fluid torque converters of the type found in automatic transmission in motor vehicles. Secondly, there is hydrostatic machinery, which uses the pressure of a liquid to provide a driving force. The liquid usually moves very slowly, as in a hydraulic jack, or hardly at all, as in a hydraulic braking system. Since liquids generally are virtually incompressible, it is possible to develop very high pressures with almost no reduction in their volume (2000 lbs per square inch is common nowadays). These high pressures allow very large forces to be generated, and therein lies the usefulness of the hydraulic principle. Modern hydraulic machinery usually uses a mineral or vegetable oil based liquid, but 19th century machinery frequently used water as the operating medium. and this is the case in Bristol City Docks.

Description of the system

The water used is taken from the Docks, is pumped around the various supply pipes to the operating points, and is finally discharged back into the Docks. Water is drawn in via a duct and filter and is pumped to a header tank situated above the hydraulic engine house at Underfall Yard. This also serves as a settling tank, since water remains still for long enough to allow suspended solids to settle out, the muddy sediment being washed out about every three years. The clean water is drawn off from this tank, and is raised to a pressure of 750 lbs per square inch in the pumps. The discharge from the pumps passes to a hydraulic accumulator situated just outside the west wall of the engine house. This consists of a 20 ins diameter piston, sliding in a vertical cast-iron cylinder. Attached to the end is a weight of 90 tons: the weight is, in fact, a steel drum filled with scrap iron, the drum forming a sleeve which surrounds the cylinder. The complete piston assembly with the drum has a mass of 105 tons, and the purpose of the device is to store hydraulic energy, and then to deliver it in the form of pressurised water whenever it is needed. If there were no accumulator, the pumps would have to be capable of producing enough power to operate all the hydraulic installations likely to be used at the same instant, and this would mean extremely large and powerful pumps. The accumulator enables pumps of a more economical size to be used, and stores energy by rising through a vertical distance of 20 ft maximum. It is controlled automatically by electric trip switches which switch on the pumps when the weight descends to a certain point, then switch them off again when a certain height has been reached. Should the switches fail to operate for any reason, audible alarms have been fitted: an electric bell would ring if the weight descended too far, and a siren would sound if it went too high. A further safety device exists in the form of pressure relief valve which would discharge water rapidly should the mass continue to rise: this is a lever type safety valve which is lifted off its seat by a chain pulled upwards by the accumulator weight. The chain is suspended at its upper end from the accumulator framework, and is lifted upwards by a latch which in turn is moved by a bracket on the accumulator weight. Another accumulator which is no longer in use is situated inside a tower forming part of the west end of the engine house: use of this accumulator (dating from 1887 : see historical notes below) was discontinued in 1956 after becoming dangerous

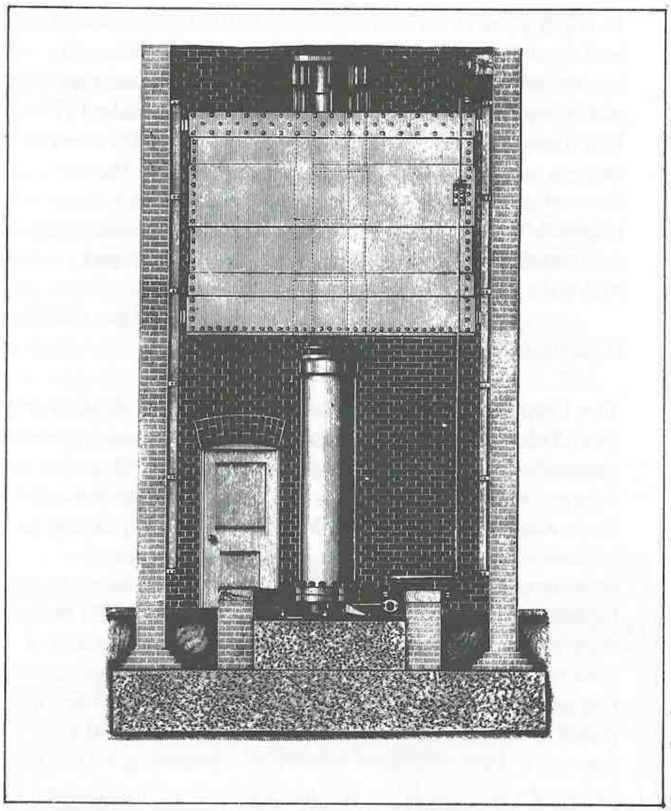
The pumps are by Fullerton, Hodgart and Barclay Ltd of Paisley, are dated 1907, and are driven by 3-phase slip ring electric motors of 125 horse power via a pair of double helical reduction gears. The motors were made by J H Holmes & Co Ltd of Hebburn on Tyne. There are three pump sets, and each set has a central drive with two disc cranks each driving pump pistons. Each pump cylinder has two rams entering the cylinder from opposite ends, one being of 5 ins diameter and one of 3⅝ ins diameter. The pressure is therefore raised in two stages, the highest pressure being obtained from the smaller diameter pump. Electrically driven pumps were first installed in 1907-8, replacing earlier steam driven units (see below).

Initially water is sucked into pumps, known locally as jack pumps, near the Underfall slipway, and is forced upwards into the header tank already mentioned. From here it is fed by gravity to the main pressure pumps. These then pump water to the accumulator, and from there it passes into the system. The jack pumps are below engine house floor level and are driven from the same crank as the pressure pumps.

In its heyday, the hydraulic system in the City Docks was extensive, operating the entrance gates at the junction with the River Avon at one end, and machinery on The Grove in the vicinity of the 'Hole in the Wall' public house at the other end, a distance of about 1¼ miles. The diameter of the pipes conveying the water round the system varies, but is mostly 7 inches. Where the water is required to travel only short distances, the diameter is smaller, 3 inch and 4 inch diameter pipes being used to supply the lock gates at the entrance from the River Avon and the capstan nearby. Most of the piping is of cast iron. The map shows the location of the various items of hydraulic equipment in the dock area and the layout of the piping, and the list below includes both these and other items which were hydraulically operated but have now disappeared:-

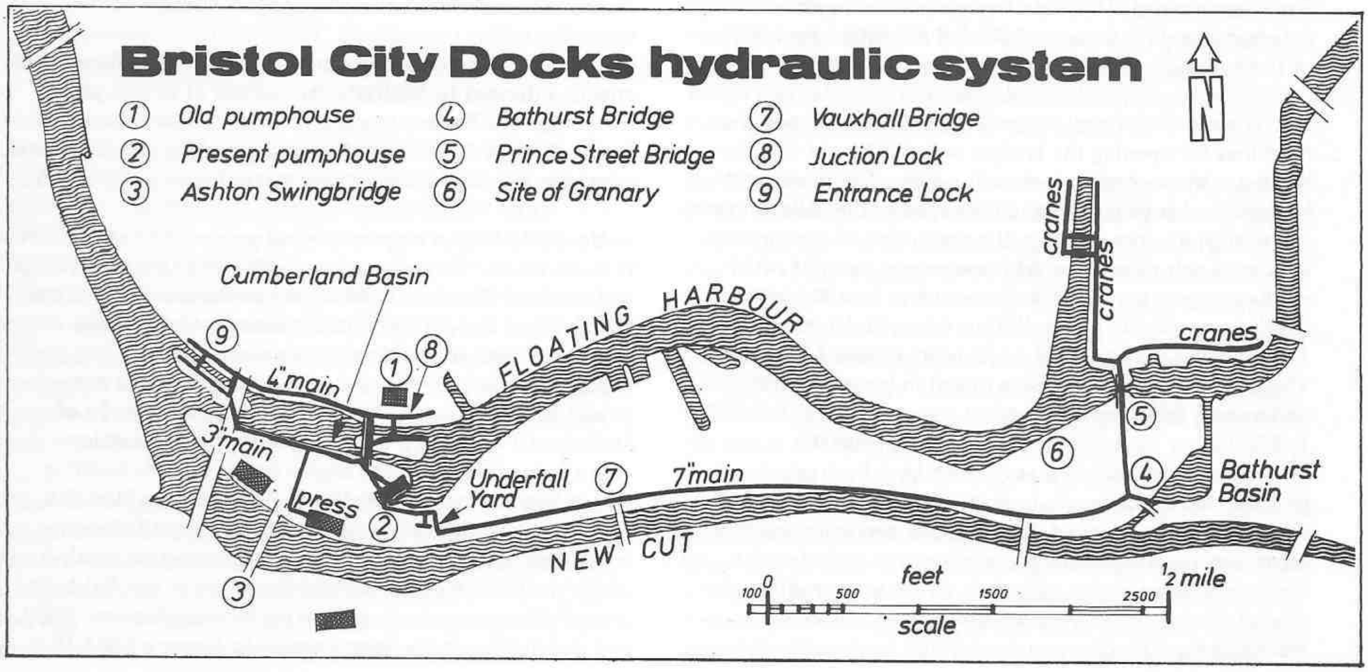
Lock gates of New Entrance Lock
Capstan used for opening these gates in emergency (this has recently been overhauled)
Lock gates of New Junction Lock

Tidal stop gate of New Junction Lock (this prevents flooding of the centre of Bristol during high spring tides)
Cumberland Basin Swing Bridge (of the 'centre press' type: see description of Prince Street Bridge in 'Historical Notes' below)
Ashton Swing Bridge (no longer swung due to demise of shipping on New Cut).
Hydraulic press inside tobacco bond 'B' (formerly used to press tobacco into special transport drums called tierces)
(Railway) swing bridge across New Junction Lock
Underfall Sluices (see BIAS Journal 10) installed by Brunel in order to allow-water to be discharged from the Floating Harbour into the New Cut, either for swilling out purposes or to lower the water level in the harbour.
Vauxhall footbridge, which carries pedestrians from Cumberland Road to Coronation Road/Greenway Bush Lane: connected to hydraulic system some time after completion
Corporation Granary (destroyed in Blitz: see below)
Prince Street Bridge
Swing bridge across entrance lock at Bathurst Basin
Two cranes outside 'E' shed on St Augustine's Reach
Two cranes outside 'W' shed on St Augustine's Reach
Two cranes on Broad Quay
Three cranes on Narrow Quay
Three cranes on The Grove (near the 'Hole in the Wall' public house)


A typical arrangement of a hydraulic accumulator in the late 19th century

In addition to the above, there were many hydraulically powered sluices: there were 8 sluice gates at each of the locks at Cumberland Basin. There are also two sluices in the immediate neighbourhood of the 'Nova Scotia' public house which allow the Cumberland Basin to be filled from the Floating Harbour. Four more sluice gates are used to lower the level of the Cumberland Basin by discharging water into the River Avon when required, though they are seldom used now. Their principal purpose was to enable more shipping to pass through the Basin by extending the period during which vessels could enter or leave it. They are also used when the Basin level has to be reduced for work on gulleys, gate sluices and guideways to be carried out (as happened on several occasions during 1979).

The former railway bridge (of the bascule type) across the lock between the Floating Harbour and Bathurst Basin was independently powered by steam, the engine surviving in Bristol Industrial Museum. Redcliffe Bridge (also a bascule bridge) dates from the early 1940s, and was electrically powered. The modern Plimsoll Bridge across Cumberland Basin has no connection with the hydraulic system. It uses its own system, and is electrically powered.



Details of routes to Ashton Swing Bridge, Vauxhall Footbridge and the Granary are uncertain and have, therefore, been omitted.

In conclusion, it is worth noting that the hydraulic system in Bristol City Docks is one of a dying breed. The well-known London Hydraulic Power Company closed down its public hydraulic power distribution system in July 1977 (see '*New Scientist*' for 28th July, 1977) after 96 years of service, and extensive systems are now few and far between. Despite electricity's major disadvantage (the impossibility of storage) its ease of distribution has made it preferable and brought about the decline of piped hydraulic power systems.

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Historical Notes

The Floating Harbour, as completed by Jessop in 1809 and modified by Brunel, relied solely on muscle power for the operation of sluices, lock-gates, etc. Not until Thomas Howard's improvements were started in the Cumberland Basin area from the mid 1860s onwards was it possible to contemplate hydraulic power, which had developed considerably during the intervening years. In a letter to the Docks Committee dated 7th March, 1870,[1] Howard stated that 'it has been proposed from the beginning that with a view to facilitate the entrance of vessels into the harbour and extend the available time of working on each tide, that power of some kind should be provided in lieu of the necessary slow process of opening the gates & c. by hand.' He sought permission to contact the leading firm in the field at that time, namely Sir William Armstrong & Co of Newcastle-upon-Tyne. Permission was duly granted and hydraulic machinery, together with steam engines to provide the power, was obtained from Armstrongs and installed and tested by August 1871.[2] This enabled the New Junction Lock to be opened without ceremony on 16th October, 1871, but local press reports made no mention of hydraulic power . The steam engines and accumulator were housed in an attractive stone building which fortunately survives alongside the lock. (*see cover drawing*)

Almost two years later, on 19th July, 1873 (a date which had been chosen deliberately, since 19th July was the day on which both the Great Western and the Great Britain had been launched) the New Entrance Lock at Cumberland Basin was opened. This time there was considerable ceremony, and local papers included a detailed description of the hydraulic system.[3]:-

'. . . These gates, as well as the large sluice valves, and the machines for opening the bridges and capstans at the pier heads are all worked by hydraulic power. The power, may be described as generated and conveyed in the following way: in the engine house, built on the north side of the junction lock are a pair of engines, 44 horse-power, each of which works a ram or pump which forces water into the bottom of a large vertical cylinder. Within this cylinder works a ram 17" diameter, having fixed on its head a load of 80 tons. The water, therefore, which is forced in by the pumps underneath this ram, is all subject to a pressure of from 700 to 800 lbs per square inch, and is carried from the accumulator cylinder in pipes, which have been proved up to 2,000 lbs to the square inch, to all parts of the works where it may be required. In use at any particular work this water acts upon small gun metal pistons in cylinders (as steam in a steam engine cylinder), which set in motion the gear of the particular machine acted upon. All these machines are placed in chambers neatly sunk below the surface of the ground, the waste pressure water running away into the lock. In this way the hydraulic capstans, which readily haul the heaviest vessels, are actuated, a small two-cylinder engine being placed beneath them. In the same way the sluicing valves are raised or lowered.'

A bridge spanning the New Junction Lock is also described as being ' . . . easily and quietly opened by machinery. . .' This refers not to the present Cumberland Basin Swing Bridge, which dates from the 1920s, but to its predecessor - an iron swing bridge manufactured by the Avonside Engine Co of Bristol.

On 27th January, 1879, a new hydraulic swing bridge was opened in Prince Street in place of the old toll-bridge, the work again being under the supervision of Thomas Howard. Though ultimately connected to the hydraulic main, auxiliary power originally existed in the form of an Otto gas engine[4] housed in the small building which survives alongside this bridge. Again, local press reports gave a detailed description of the bridge and how it worked[5]:-

' . . . The total weight of the structure is 170 tons. The bridge rests on sets of blocks, fixed in the coping of the masonry. When required to be opened the whole structure is lifted bodily about three inches by the pressure of water admitted to the under side of a ram or hydraulic press immediately under the centre of the bridge, which being lifted by the pressure water, is swung open by a horizontal cylinder, lying under the bridge, which works a chain passing round a concentric drum, and turning the bridge smoothly open. The diameter of the central ram is 29 inches, and the pressure water is compressed as it were to between 600 and 700 lbs to the square inch. The operation of closing the bridge is just the reverse of this. The motive power of raising the water to the high pressure mentioned is obtained from one of Otto's gas engines. This works two hydraulic rams, which pump the water into the bottom of a cylinder in which works a piston carrying between 30 and 40 tons weight, so that all the water between this piston, contained in the cylinder, is raised to the pressure referred to. From the bottom of this cylinder there are pipes leading to the central ram and the two side cylinders, which raise and swing the bridge respectively. There are two capstans in connection with the bridge, and worked directly from the engine, intended to facilitate the passage of vessels past the bridge . . . The contractors for the work are the well-known firm of Sir William Armstrong and Co., of Newcastle, who have supplied the whole of the hydraulic machinery...'

In the mid-1880s,a large municipal granary was erected on Prince's Wharf. This was an imposing building 9 storeys high and made of Cattybrook brick, the contractor being Storrs Son & C0 of Stalybridge.[6] It contained a considerable amount of hydraulic machinery (elevators, conveyors, etc), though this time the tender put in by Armstrongs was passed over in favour of that of Messrs Spencer & Co of Melksham.[7] Originally there had been some discussion about a separate hydraulic engine house for this building also, a location between Bathurst Basin and the New Cut being one of the sites considered[8] but eventually it was connected to the hydraulic main, the connection passing under the GWR harbour railway line close to the Fairbairn crane.[9] The granary was opened on 18th September, 1888, and was destroyed by enemy action in January 1941.[10]

Whilst construction of the granary was proceeding, the Docks Engineer - John Ward Girdlestone, who had succeeded Thomas Howard in 1882, recommended that the original steam engines installed by Armstrongs at New Junction Lock be replaced by more powerful units in view of the increasing loads being put on them by additional installations. He favoured direct-acting Worthington-Simpson engines, and this is the type that was acquired. The tenders received make interesting reading, and are reproduced in full in the table below.[11] The long letter which Girdlestone wrote to the Docks Committee to support his case[12] comments on the tenders as follows:-

' . . . Of these tenders the first two, having no special points in their favour, may, chiefly on account of their amounts, be at once dismissed. Of the remaining four that of Messrs Simpson amounting to £3,297 is the one I now recommend for acceptance.

The type of engine Messrs Simpson propose to supply, namely the Worthington or horizontal direct acting crankless engine, is the one which has in practice proved to be specially adapted for dealing with high pressures. It is a pumping engine pure and simple and is remarkably stead in discharge being more so in fact than is or can be any engine which is fitted with a crank. This point of great steadiness will in the present instance, the main being of considerable length, prove of much value owing to the freedom from broken pipes and started joints which will on account of such steadiness, of necessity ensue . . .

. . . So reliable are these engines that even if the pressure valve be suddenly and repeatedly shut and opened the engines will start and stop promptly and safely: this test being one to which I believe that no other engines could with safety be submitted.

Then too the type of engine recommended occupies less space by far than does any form of crank engine whatsoever: this point being one of considerable importance when, as in the case in question, the amount of available space is somewhat limited . . .

. . . Suffice it then to say that the engines proposed to be supplied by Messrs Simpson are in all respects adapted for the purpose to which they are to be applied; are at least as promising as any of the others offered; and, as compared with the lowest in price on the list, they are certain to prove more satisfactory in work; more durable, and consequently less costly to maintain; less trying to the mains and connections, and that, owing to the low piston speed specified (90 feet per minute), and consequently to the comparatively great size and strength of the engines proposed a large margin of power will be available for use in an emergency.'

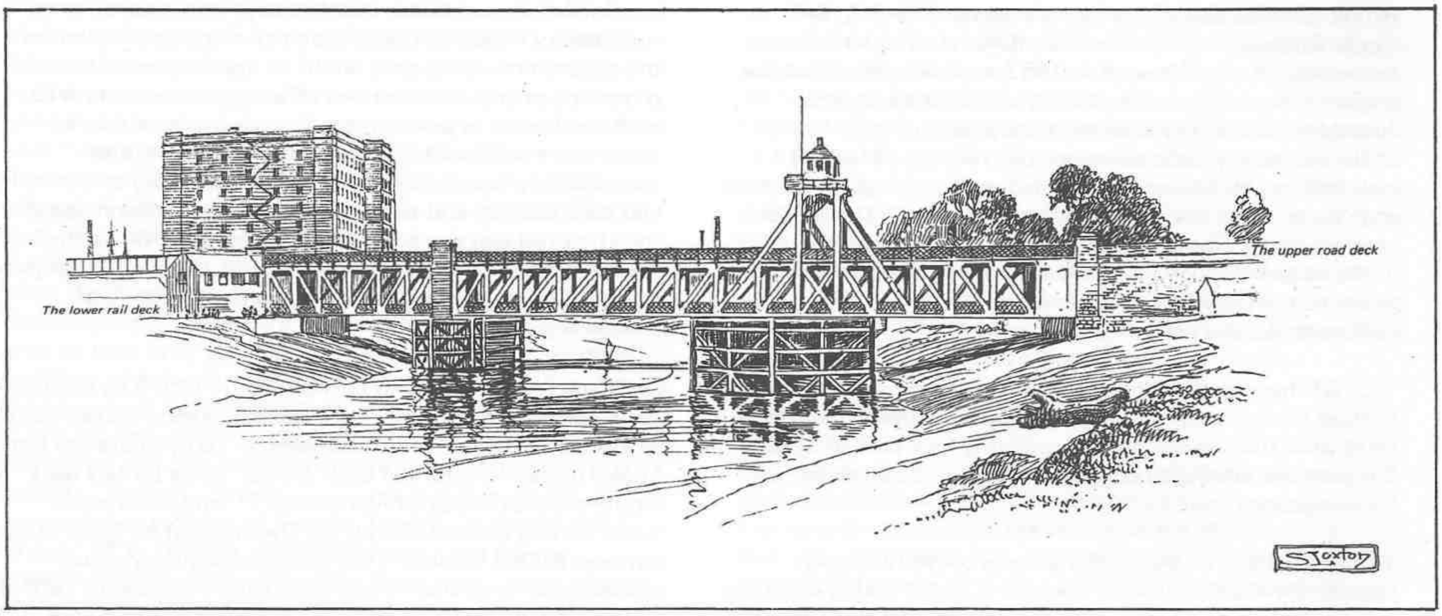
Girdleston's optimism was ill-founded, in fact. The engines were indeed installed in a new red brick engine house, built by a Mr C A Hayes[13], at the Underfall Yard, where the Port Authority workshops had been set up. Three boilers were supplied by Galloway of Manchester[14], an unsuccessful tender having been put in (as for the engines) by local firm Stothert & Pitt. However, the Simpson engines proved troublesome in service[15], and were to be replaced in 1907-8 by the existing electric pumps, though the engine house was retained and survives with these pumps in it.

Shortly afterwards Girdlestone approached the Docks Committee again, writing 'I beg therefore to recommend that in place of-the two sets of horizontal crank engines now at Avonmouth, two sets of direct acting engines of the Worthington type similar to those now under construction for use in the New Hydraulic Engine House, Cumberland Basin, be procured.' These also were acquired, replacing an Armstrong engine, which probably dated from the opening of the dock, and a similar one by Oliver of Chesterfield.[16]

The Vauxhall (pedestrian) swing bridge spanning the New Cut was opened on 1st June 1900. Originally electrically powered, this was later connected to the hydraulic main.

Ashton Swing Bridge, which carried a main road on its upper deck, and the new GWR harbour railway lines on its lower deck, was officially opened on 4th October, 1906. Pressure water was carried under the New Cut in 2½ ins

Name of Tendering	Price per Two Sets	Cylinders	Engine per Set Piston Speed	Type	Pump
East Ferry Road Engineering Coy	£5,380	14, 14, 28, 28 30	200	Horizontal Two Crank	Two 6⅞" Differential Rams
Chester Hydraulic Engineering Coy	£4,900	20, 26¼ , 26¼ 24	200	Vertical Three Crank	Three 5⅝" Rams
Stothert and Pitt	£3,390	12, 12, 21, 21 24	200	Horizontal or Vertical Direct Acting Crankless	Two 7" Differential Rams
Simpson & Co - Original Tender	£2,986	22, 22, 38, 38 30	55	Horizontal Direct Acting Crankless	Four 9" Rams
Simpson & Co - Revised Tender	£3,297	17, 17, 30, 30 30	90	Horizontal Direct Acting Crankless	Four 7" Rams
Tannett & Walker	£2,250	15, 15, 24, 24 24	200	Horizontal Four Crank	Four 4¾ " Rams
Sir W G Armstrong, Mitchell & Co Hick Hargreaves & Co	Not in position to Tender				



Ashton Swing Bridge, courtesy of Avon County Library

copper pipes (with steel cables laid 50 yards upstream and downstream to protect them from vessels dragging their anchors) to the cabin on top of the bridge where the hydraulic machinery was located:-

'The turning engines are three-throw reversible hydraulic engines with rams 4 inches in diameter and 14 inches stroke. Two engines are provided, the second being used only in case of a breakdown. These engines, by means of spur-pinions and wheels, drive two horizontal shafts, at the ends of which bevel-gearing drives vertical shafts placed at diagonally opposite corners of the tower. These shafts pass through bracket bearings attached to the legs of the tower . . . and at their lower ends carry pinions 1 ft 2 ins in diameter on the pitch-circle, which engage with the circular rack on the bottom roller-path and thus turn the bridge'[17]

Each opening and closing of the bridge used 182 gallons of water, and the complete operation of opening or closing took 2 minutes 15 seconds. Despite being opened on average 270 times per month during the first ten months of operation, the bridge was swung less frequently as traffic along the New Cut diminished. It was not swung at all after 1936, and the Bristol Corporation Act of 1951 rescinded the obligation to open it.[18] Top deck and cabin have now been removed; the lower deck remains in a fixed-position and the railway track has been singled.

Bathurst Basin Swing Bridge was completed sometime between 1905 and 1909,[19] but like Ashton Swing Bridge (and Vauxhall Bridge) has not been operated since the 1930's.

John Powell

References

1 Docks Engineers' Report 7th March 1870

2 Docks Committee Minutes 24th July 1871

3 An extract from what appears to have been an official press release as it appeared in more than one paper - eg *Western Daily Press and Bristol Times & Mirror* 21st July 1873. A shorter version also appeared in the *Engineer* of 1st August 1873.

4 A type of engine developed during the 1860's by the German Nikolaus August Otto in collaboration with Eugen Langen which worked on a mixture of coal gas and air. A detailed description and drawings of an Otto engine and the later development 'Silent Otto' appears in the recently published *Machines : an Illustrated History* by Sigvard Strandh (Mitchell Beazley 1979). The engine in question was later replaced by electric power.

5 *Western Daily Press* 28th January 1879.

6 *Builder* 28th April 1888.

7 Docks Engineers' Report 6th September 1886.

8 Ibid. 24th June 1887.

9 Docks Works Committee Minute Book 23rd January 1888.

10 Winstone, R *Bristol Blitzed* 2nd ed 1976 plates 108-110. Machinery was electrically powered from the early years of the present century.

11 Docks Engineers' Report 10th October 1887 (appendix).

12 Ditto

13 Docks Works Committee Minute Book 7th October 1887.

14 Ibid. 28th October 1887.

15 Buchanan 8i Cossons *Industrial Archaeology of the Bristol Region* (David & Charles 1969) p.46.

16 Docks Engineers' Report 28th October 1887.

17 A full description of this bridge and its construction (with drawings) appears in the *Proceedings of the lnstition of Civil Engineers* Vol CLXX 1906-7 Pt IV p.159 onwards.

18 Railway Development at Bristol - 3, by C R Clinker in *Railway Magazine November* 1956 p.736.

19 Wells, C A *Short History of the Port of Bristol* (Arrowsmith 1909) p.360.