The Sentinel Steam Waggon at Riverside Museum

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1.0 Introduction. Glasgow Museums have an significant collection of motor vehicles many of which are on display at Glasgow's Riverside Museum of Transport and Travel. This Research Technical Note describes some of the features of just one of these vehicles; the Standard 6 ton Sentinel Steam Waggon (Works No. 1286), that was built in Shrewsbury 100 years ago, in 1916, during the First World War. At one time these waggons (road going lorries) were built in Glasgow by Alley & MacLellan Limited who used the spelling of Waggon with two g's.

The waggon in the museum collection (I.D. No. T.1973.32) was one of nine owned by the Sheffield steel maker Brown Bayley Steels Ltd. (ref. 6) who restored the waggon in 1966 after 50 years of service. There is a road tax disc on the cab franked in Sheffield on 24 May 1971. The waggon was last steamed in the 1970's and was purchased in 1973 with the assistance of government funding.

2.0 Alley & MacLellan Ltd. and the Steam Waggon. I do not intend to detail the history of Alley & MacLellan Ltd., that has been done by others (refs. 1-5, 8-10, & 19). Here is a very brief history of what you need to know in connection with the steam waggon. In the latter half of the 19th century Stephen Alley and John MacLellan established an engineering business in London Road, Glasgow. In the 1870's they moved to a larger site at Jessie Street, Polmadie in the South side of Glasgow. This new premises being named "The Sentinel Works" (the building still survives but in a derelict state). The company produced valves, air compressors, high-speed steam engines and pre-fabricated ships.

In 1903, Alley & MacLellan took over the Shropshire Company Simpson & Bibby of Horsehay, who made steam lorries and moved the works to Polmadie. They had the assistance of the lorry designer Daniel Simpson (ref. 4). The Heavy Motor Car Order introduced in 1904 gave encouragement for the development of steam waggons. The original waggon design featured a small high-speed steam engine with reduction gear and two speeds. It was heavier than expected and it was decided to fit a larger slow-speed engine, with a single chain driving a differential gear on the rear axle. This became the "Standard Sentinel Waggon" dating from 1906. This waggon was specifically designed for road work and became very successful. The last "Standard Waggon" (Works No. 4426) was built in 1923 by which time 3746 had been built (ref. 4).

> [According to reference 1, full records of the numbers of Alley & MacLellan steam waggons and tractors made have not survived.]

Around 1915, due to lack of space at Glasgow and to be nearer the main English market, Alley & MacLellan moved the steam waggon production to a new factory in England at Shrewsbury. They continued to promote the Sentinel trademark; a standing knight with a sword surrounded with the slogan "Ever Watchful & on the Alert" (Fig. 1). The Sentinel Waggon Works Ltd. of Shrewsbury produced a range of successful tractors, buses and waggons. Development of steam waggons, from 1923, included the "Super Sentinel", the Double Geared "DG" and Shaft drive "S" type waggons.

With the outbreak of the Second World War production of steam waggons ceased and the factory went over war production work. After the war the company entered the diesel powered lorry market but there was an order, in 1950, for 100 "S" type steam tipper waggons for a customer in Argentina. Production of steam waggons finally ceased in 1951 with the delivery of a Dumper waggon for the UK (ref. 4).

3.0 Where Motor Waggons Pay. The older methods of haulage were by horses or railway. Alley & MacLellan Ltd. considered that motor waggons, like the Sentinel, would pay in a haulage business whose costs (in 1912) were £300 or more per annum (ref. 1). For comparison they compared the cost of haulage by horses against the haulage by steam waggon. In summary the figures are (ref. 1):

Horse Haulage. Based on 3 – Two-horse lorries, 7 horses (one as spare), 6 set of harness.
Total Capital Outlay £555.
Annual running cost, based on 4% interest on capital, depreciation at 15%, fodder, bedding, shoeing, repairs to lorries and harness, stableman and 3 drivers, veterinary surgeon, insurance, rent of stables, taxes and sundries.
Total per Annum £755.

Steam Waggon. Based on one 6 ton Standard Sentinel Waggon complete with flat platform and canopy and usual accessories, ready for running.
Total Capital Outlay £610.
Annual running cost, based on 4% interest on capital, depreciation at 12½%, maintenance and repairs, fuel (80 tons gas coke at 12 shillings/ton), oil, waste, stores, rent of shed, taxes, wages of driver and loader, license. Insurance and sundries.
Total per Annum £385.

Although the capital cost is higher for the steam waggon, the running cost show a potential saving of £370 per annum in favour of the steam waggon. Note, however, the capital cost of the waggon is for steel tyres. The cost of rubber tyres was an expensive extra at about £210 (ref. 1).

The steam waggon paid best on long journeys of say 20 miles out and 20 miles back home with loads both ways. The waggon could work a 40 or 50 mile day and be ready for a repeat journey the next day. Horses could not stand this. In rush hours waggons could cope with the extra work whereas horses would be working near their limit and could not do more. In terms of ton-miles, the waggon working rate was reckoned to be 1¼ old pence per ton-mile as against 2¾ old pence per ton-mile for horses. This latter figure is considered to be very low, horse costs were often 4 to 6 old pence per ton-mile (ref. 1). However, reference 14 (a Brewer's working with three to four Sentinel waggons) quotes a figure of 2.6 old pence per ton-mile and average annual running cost of a waggon at £400 to £430.

Compared to railways Alley & MacLellan Ltd did claim it was cheaper to use your own steam waggon instead of the railways and did quote a couple of examples where the steam waggon did pay. They were also keen to point out that money saved was not the only advantage. The use of steam waggons meant that despatch and delivery could be arranged to the best advantage and so avoid the uncertainties of railway traffic. Reference 14 also makes comparison with railway rates and quotes a net profit of £335 in favour of the Sentinel waggons.

4.0 General Configuration of the "Standard Sentinel Waggon". The general configuration of the "Standard Sentinel Waggon" is that of an ***undertype*** waggon where the engine is suspended horizontally under the waggon (Fig.2) and the boiler is at the front (Fig.4). There is a large water tank attached to the chassis under the waggon at the rear (Fig. 3).

The waggon has an oak plain flat-platform, with heavy cross bearers, fixed to the chassis frame by steel angles and bolting (Fig. 5) [there was an alternative end-tipping waggon, see **section 15.0** below]. The chassis frame is constructed of two straight steel channels, cross braced by channels of similar section joined up by gussets and plates top and bottom. According to reference 1 riveted construction was used and care was taken not drill holes where they would weaken the frame members. However, inspection of the museum waggon shows there is very little riveting. The frame is mainly fabricated by welding with some riveting and bolting. It could be that the demands of war time production dictated what sizes of material were available and this influenced the type of construction carried out. Some of the welding looks very rough and might be weld repairs (Fig. 6)?

The frame is supported by well sprung semi-elliptical leaf springs, two on the front axle and two on the rear axle. The whole layout allowed a short wheel base and a good distribution of weight on the axles. Maximum load could be carried without exceeding the axle weights limited by the Heavy Motor Car Order.

The driver and stoker (loader) sat comfortably in a front cab with a roof canopy. The fuel bunker was near at hand between driver and stoker. Apart from the chimney there was a clear view of the road ahead. The cab is narrowed from the drivers seat towards the front. This allowed a clearer view of the road and aided the entry into narrow gateways (ref. 1).

> [In 1911 an ***overtype*** "Sentinel" waggon was produced. On this type of waggon the boiler is horizontal with the engine on top, i.e. a similar configuration to that of a steam road roller or traction engine. Waggons of this type were typically used for furniture removals where the load carried never exceeded 4 to 5 tons (ref. 1). This design was not successful only seventeen ***overtype*** Sentinel waggons were built, ref. 4 and 10.]

5.0 Load Capacity and Speed Limits. The museum waggon has a load capacity of 6 tons and on good macadam or paved roads could carry this load up a gradient of 1 in 8. An additional 4 tons could be drawn with a trailer up a gradient of 1 in 10 (ref. 1). The total weight of waggon plus load was limited to 12 tons by the Heavy Motor Car Order.

> [It appears that Standard Sentinel Waggons were produced with load capacity from 3½ tons up to 8 tons, ref. 7. Some references (ref. 4 and 10) mention 3 ton waggons.]

Size was important. The waggon had to be large enough to carry the pay load but small enough so that it took up no more room than an ordinary horse-lorry. The platform was 13 ft. 6 in. long by 7 ft. wide, or a clear floor area of 86 square feet inside the edge rails (ref. 1). The platform was long compared to the overall length of 19 ft. 3 inches. For extra light and bulky loads the platform could be lengthened by a foot or so. The standard platform was lined with steel coping with a portable rail at the back. The height of the platform was 3 ft. 9 in. above ground level, this was about the same as an ordinary horse lorry, and was important where much loading was done by hand. The museum waggon has hinged sides and back (Fig. 3). Other arrangements with fixed sides, loose sides and other special bodies could be supplied to order e.g. 1000 Gallon Watering Waggon or 1000 Gallon Waggon with Tar-spraying apparatus (ref. 1).

One of the objections to steam waggons was that they could not work in awkward places where the horse-lorries went. Hence, Alley & MacLellan Ltd. did emphasise the manoeuvring qualities of their steam waggon claiming that it could be handled like a motor car and could be turned or moved forwards or backwards a few inches at the will of the driver (ref. 1).

The speed was restricted to 5 miles per hour (or 8 miles per hour on tyres of soft material when not drawing a trailer) by the Heavy Motor Car Order. Although these speeds are very low by modern standards it must be remembered that the main competition was horse haulage. The aim was to be competitive enough so that hauliers would replace their horses with steam waggons.

> [Marked, on the museum waggon chassis left side framework, is U.W. 6 - 13 - 0. i.e. an Unladen Weight of 6 tons 13 hundredweight. These weights would be the Long or Imperial measure i.e. ton = 2240 lb. and hundredweight = 112 lb. Also marked on the chassis frame is a maximum speed of 12 mph.]

6.0 How does it all Work. A great deal of information on the working of the steam waggon can be obtained from reference 1 although some components e.g. the feed water heater are not mentioned. In technology and operation the waggon was very like a steam railway locomotive. It had several controls that would be found on a steam locomotive with the added complication that it was not running on smooth rails and gradients but had to run up and down hills and over rough roads. The driver had, of course, to be alert at all times for other road users and pedestrians. Operation of the waggon was a two person job, especially with the museum waggon, as some of the controls were not in easy reach or sight of the driver. Three main components made the waggon work: (1) the boiler and controls, (2) the engine and transmission, and (3) the water tank.

6.1 Boiler and Controls. The boiler is a key feature of the design it had to be strongly built for safety reasons, easy to fuel and maintain, be efficient and economic to run. The boiler, at the front of the waggon (Fig. 4), is a vertical design constructed of a steel outer shell and an inner steel firebox (ref. 1 and 12). Each being manufactured from a single plate and flanged top and bottom.

Within the firebox are fixed short water-tubes; twenty of these are screwed into the plate to form stays. The centre section of the firebox, with the water-tubes, is of square-section. A superheater of solid-drawn steel tubing is fitted, in the flue gas stream, at the top of the smoke-box. The boiler was hydraulically tested to 350 lbs. per square inch and certified for a working steam pressure of 230 lbs. per square inch (ref. 1). At this working pressure the superheater would raise the steam temperature from about 400°F (204°C) to about 650°F (343°C). To conserve heat and protect the driver and stoker the boiler is cleaded and exposed steam piping is lagged.

Two safety devices were provided: (1) a safety valve with a discharge pipe by the side of the chimney (Fig. 7) and (2) a fusible plug. The latter was set into the inner firebox just above the water-tubes. With a high water level a gradient of 1 in 6 could be accommodated without uncovering the water tubes.

On the road the aim was to keep a water level at about 3 inches from the bottom of the water level gauge and a steady steam pressure of around 200 lbs. per square inch. The safety valve was set to blow off at the certified working pressure of 230 lbs. per square inch and should be tested daily (ref. 1).

The boiler design is suitable for burning either coke or Welsh coal (ref. 1). The fuel is fed to the bottom of the firebox from the top of the boiler through a central stoking shoot and onto a set of firegrates (two halves). Stoking was therefore much more comfortable with this waggon as there was no need to stoop to stoke or light the fire through a door at floor level. Although it was more difficult to observe the state of the fire (ref. 25).

The firegrates are supported by trunnions and the design allowed the firegrates to be rocked by means of a crank (firegrate trunnion lever). Beneath the firegrates is an ashpan (Fig. 8), half filled with water, to avoid hot ashes falling onto the road. The ashpan could be lowered for cleaning and the height adjusted to allow the draught through the boiler to be varied.

The waggon ran best on good gas coke or Welsh steam coal. Coke was preferable as coal caused a deposit of soot on the tubes and hence required more frequent cleaning (ref. 1). For thorough cleaning of the inside of the boiler the firebox could be lowered. If pure water was used this need only be done once or twice a year but if hard or dirty water was used then the firebox should be lowered and cleaned every second month (ref. 1).

The following lists the controls and instruments found on the steam waggon. Many of these controls and instruments are similar to that found on a steam locomotive. **Appendix 1** shows the connected pipework, in diagrammatic form, between the various controls.

(1) **Steering Wheel**. This is positioned for a right hand drive.
(2) **Hand Brake**. This hand brake is to the left of the driver, within easy reach (Fig. 4 & 12). It operated a band brake on the rear axle (Fig. 9 & 10).
(3) **Reversing lever**. This is to the right of the driver, within easy reach (Fig. 4 & 12). It operated directly, through levers, links and pins, on the control lever on the sliding camshaft of the engine valve gear (Fig. 2 & 11). The reversing lever has a quadrant with positions for forward, stop and reverse. When starting the lever would be pushed to the Start position and when under way pulled to the Fast position.
(4) **Steam regulator (throttle) stop valve**. This valve is attached to the boiler within easy reach of the drivers left hand (Fig. 4). The valve is combined with the injector steam valve, the blower valve, and the foot release valve. There is also a cylinder lubrication oil connection from the mechanical lubricator attached to the left side of the valve (hidden in Fig. 4). The speed of the waggon was adjusted by use (throttling) of this regulator valve which also acted as a steam stop valve. Superheated steam passing through this valve went direct to the engine inlet manifold.
(5) **Foot Pedal (foot release valve)**. This is in front of the driver at footplate level (Fig. 13). When operated, a mechanical linkage to the underside of the steam regulator (throttle) stop valve (Fig. 4) would shut-off steam to the engine. The steam in the piping would be released to the feed water heater Fig. 14) where it would be vented up the chimney with the engine exhaust steam (Fig. 15). Any condensate in the feed heater would be drained into the ashpan (Fig. 8). By depressing the foot pedal steam is quickly shut-off from the engine and is of great value when manoeuvring or using the engine as a brake. The foot pedal must always be depressed when moving the reversing lever from forward to reverse and vice versa.
(6) **Steam Injector valve**. This valve is attached to the left side of the regulator (throttle) stop valve (Fig. 4). The steam injector was required when the waggon was stationary or if the mechanical feed pump failed or to prevent the safety valve blowing off in towns (ref. 1). When opened superheated steam was directed to the injector.
(7) **Injector**. The injector is in front of the driver at footplate level and separate from the boiler (Fig. 16). Opening the water cock allowed water, at atmospheric pressure, from the tank to enter the injector and exit any overflow to the drain. Opening the steam injector valve drives the water and condensed steam, at pressure, to the left side of the check valve (Fig. 14) and into the boiler.
(8) **Boiler Check valve**. This valve is half way up the left side of the boiler (Fig. 14). It is not in easy reach, and is probably out of sight, of the driver. It would therefore appear that the stoker was to be relied on for the operation of this valve. The valve has to be open when pumping water to the boiler. The valve discharge is directly attached to the boiler. There are two inlet connections. The left side inlet is from the Injector as discussed above. The right side inlet is from the feed water heater which in turn comes from the mechanical feed pump which draws water direct from the water tank.
(9) **Boiler feed water pump bypass valve**. This valve is on the feed pump (Fig. 17), and is continually working when the waggon is in motion. As water is practically incompressible an air receiver (accumulator) is fitted to smooth out pressure fluctuations. The valve opening and closing is controlled by a wire rope (cable) and a control lever in front of the stoker seat. With sufficient water level in the boiler this bypass valve would be open to allow feed water to circulate back to the tank. When water to the boiler was required, the boiler check valve would be opened and the control lever (in front of the stokers seat) operated to release the cable and allow the bypass valve to close. This will allow the feed pump to pump water from the tank to the feed heater and into to the boiler by way of the check valve.
(10) **Blower valve**. This valve is attached to the right side of the regulator (throttle) stop valve (Fig. 4). Opening this valve allowed superheated steam to be directed, via a pipe, into the chimney. This created a slight vacuum and encouraged a draught through the firegrate. The normal use of the blower valve would be when the waggon was stationary or when coasting with the regulator valve shut and hence no exhaust steam going up the chimney via the blast pipe. The use of the blower valve was not recommended when raising steam as this often spoiled the fire for the whole day (ref. 1).
(11) **Auxiliary valve**. This valve is directly attached to the top left side of the boiler (Fig. 18). It is used to assist the filling of the water tank. When opened superheated steam is directed to the water tank lifter nozzle (Fig. 6). The tank could be filled, from a suitable water source, through the suction hose with strainer, in about 6 minutes (ref. 1).

(12) **Ashpan lifter**. This lever is located to the front left of the cab (Fig. 14). It allowed the ashpan to be lowered allowing access to the firegrate for cleaning. The lifter operated on a quadrant and so the lowering or raising the ashpan allowed the draught through the firegrate to be adjusted (Fig. 8).

(13) **Engine warming and draining valve**. This valve is on the engine exhaust manifold (Fig.11). The valve was operated by wire rope and a control lever, to the left of the driver, in front of the fuel bunker (Fig. 12).

(14) **Pressure gauge**. This was attached to the left side of the cab. A pressure pipe connected to the lower left side of the boiler and a shut-off valve was provided. The gauge is marked (in red) for the certified working steam pressure of 230 lbs. per square inch, i.e. the safety valve setting.

(15) **Water level gauge glass**. This was on the left side of the boiler within view of the driver (Fig. 12). At the bottom of the gauge is a stop valve to allow the gauge to be drained to ground (Fig. 8 & 14). The working level was 3 inches from the bottom of the glass when on the level. When going uphill the water level would rise in the glass and vice versa.

(16) **Boiler filling and washout plug**. This is positioned at the top left of the boiler (Fig. 18).

(17) **Boiler blow-off valve**. This is positioned at the bottom front of the boiler (Fig. 8).

(18) **Boiler cleaning valve**. This is positioned on the top right of the boiler (Fig. 15).

6.2 Engine and Transmission. The engine design is a “Sentinel” patent reciprocating steam engine, which operates by simple expansion. The whole assembly, cylinders, crankcase and valve gear is suspended from the chassis frame by lugs and brackets (Fig. 2). There are two double-acting cylinders 6.75 inches diameter by 10 inch stroke. The cranks are at 90 degrees so there is no dead centre. Power up to 70 horse power can be obtained for a short time (ref. 1). According to reference 20 the power of the Sentinel 6 ton waggon was in the range 30 to 50 hp. The crank speed is 150 revolutions per minute at a waggon speed of 5 miles per hour. The whole engine is enclosed in an oil bath and fully protected from dust and grit. The engine cylinders are cleaded to conserve heat.

The engine valve gear is located beneath the cylinders (Fig. 11). Each double-acting cylinder had separate steam inlet and exhaust poppet valves at each end (i.e. a total of four pairs of valves) operated by a single sliding camshaft. The use of cam-operated poppet valves was considered to give less wear and tear and less leakage compared to other types of valve gear (ref. 17). The camshaft drive is taken from the engine crankshaft and rotated in phase with crankshaft through bevel gears. The camshaft could be slid lengthways, by means of the reversing lever in the cab, to give the correct steam distribution to go forward (ahead), stop or reverse. As well as inlet and exhaust cams the camshaft also had a set of intermediate cams to give the “stop” position. When in the “stop” position all the valves are open for warming and draining the engine cylinders. This arrangement avoided cylinder drains as required on steam locomotives. The warming and draining of the cylinders was achieved by the driver operating a control lever in front of the fuel bunker this opened a valve on the engine exhaust manifold (Fig. 11), allowing water to drain from the cylinders and valve gear and steam to circulate warming the cylinders and valve gear.

The exhaust steam from each cylinder was collected, in the exhaust manifold, to a single exhaust pipe that was routed to the feed water heater (see **section 6.3.1** below) and then to the base of chimney to form a blast nozzle in the chimney (Fig. 15).

The Standard Sentinel Waggon used a very simple transmission drive comprising of just three components: (1) A chain sprocket pinion on the end of the engine crankshaft (Fig. 2), (2) a “Renold” type roller chain (ref. 11), (3) a chain sprocket wheel on the rear axle (Fig. 9 & 10).

This arrangement was able to work due to the power and slow speed of the engine and required no complicated change-speed gears. Apart from the simplicity, it had the safety feature that the drive was always coupled to the rear axle, there was no chance of “missing a gear” when going up or down hills. The pinion, wheel and chain were all manufactured from steel and the chain was tested to three times its normal load (ref. 1).

As the chain was not enclosed it had to be kept well oiled and clean. It was advised to take it off monthly and clean in paraffin to get rid of the grit, followed by a bath of hot oil. It was considered good practice to keep a spare chain, swapping them added to their life (ref. 1).

> [The chain for the museum waggon is not fitted but does exist, it is on the waggon platform. The “Renold” type of roller chain significantly reduced wear and noise compared to previous types of chain.]

6.2.1 Rear Axle and Differential Gear. The axle is connected to the chassis frame by semi-elliptical leaf (plate) springs which are bolted to the axle bearing housing. The longitudinal (fore and aft) position of the axle is maintained by radius bars (Fig. 10). These are attached to the chassis frame at one end and to the axle bearing housing at the other end.

Like any motor vehicle the Sentinel Waggon required a differential gear to allow the rear road wheels to be free to turn one faster than the other when turning corners. Without this arrangement slipping would occur and may start a dangerous side slip as well as strain the waggon.

In the Standard Sentinel Waggon the chain sprocket wheel on the rear axle carries three small bevel gear pinions. These gear pinions engage with two larger bevel gear wheels. One of these large gear wheels is fixed to the rear axle shaft and drives the near (left) side road wheel which is also fixed to the axle. The other large gear wheel drives the off (right) side road wheel through a sleeve surrounding the other end of the axle. On turning a corner, when one road wheel has to travel a greater distance than the other road wheel, the small gear pinions revolve to allow the road wheels to turn one faster than the other. The whole arrangement is strongly manufactured in steel and the differential gears are totally enclosed in an oil bath, and thus protected from dust and grit.

6.2.2 Differential Gear Locking. It was sometimes necessary to lock the differential gear so that both rear road wheels turned in unison. This was recommended when, ref. 1: (1) ascending or descending steep hills, (2) when on soft ground, greasy roads or slimy setts, (3) when on frost-bound roads. The differential gear was locked by putting a locking pin into a hole in the boss of the right hand rear road wheel, between two projections on a locking disc. When in use corners had to be turned with as large a radius as possible.

The museum waggon has no locking disk fitted so the differential cannot be locked on the museum waggon (Fig. 20). It could be that since the waggon was only used in a steel works, with no steep hills to climb or descend, there was never any need to lock the differential.

6.3 Water Tank. A large water tank, which can hold 180 gallons (ref. 14), is located at the rear of the waggon under the platform (Fig. 3). A large tank was necessary since the engine was non-condensing, the steam exhaust went up the chimney (like a puffer) (Fig. 15). It was essential, when out on the road, that a source of water was available to top up the tank. Like a steam locomotive the waggon was more likely to run out of water than fuel. Pure and clean water such as that from town or drinking water from the mains was preferred, but water from a pond or burn would do provided it was clean and care was taken to ensure the hose strainer did not clog up.

Two boiler feed water systems were provided: (1) a reciprocating mechanical pump driven off the engine crankshaft (Fig. 17), and (2) a steam injector (Fig. 16). The injector operated in a similar way to that on a steam locomotive. The reciprocating pump is used when the waggon is running. The steam injector was required when the waggon was stationary or if the pump failed or to prevent the safety valve blowing off in towns.

6.3.1 Feed Water Heater. Steam boilers do not like sudden changes in temperature. It was not good practice to heat or cool a steam boiler too quickly as this can lead to leaking joints. When feeding the boiler, by the mechanical pump, cold water would be pumped to the boiler. To avoid this situation the museum waggon is fitted with a feed water heater (Fig. 14). This device, used to pre-heat the water delivered to a boiler, is a worthwhile addition to a steam system as it increases the thermodynamic efficiency of the system, resulting in lower fuel consumption, and reduces the thermal shock to the boiler (ref. 18).

The feed water heater consists of a sealed box connected to the exhaust steam from the engine. Inside the box is a pipe coil connected at one side to the feed pump (which is mechanically driven from the left end of the engine crankshaft) and at the other side to the boiler check valve. When required to feed the boiler with water: (1) the check valve would be opened. (2) the feed pump bypass would be closed by operating the lever on the front of the stokers seat. The water in passing through the coil would be heated, by the exhaust steam surrounding the coil, before entering the boiler. The exhaust steam on exiting the feed heater is piped to the base of the chimney and finally exits via a blast pipe and nozzle in the centre of the chimney. This creates a draught through the boiler in a similar manner as on a non-condensing steam locomotive.

7.0 Road Wheels. The museum waggon has road wheels with solid rubber tyres manufactured by Dunlop, a single tread on the front wheels and a double tread on the rear wheels. These solid rubber tyres were an optional extra introduced from 1911 and became standard on the waggons and trailers from 1914 (ref. 4).

Prior to 1911 and whenever there was a requirement for heavy haulage work, the waggons used the patent “Sentinel” composite road wheels. These were of steel and wood construction, designed for strength and durability, necessary for heavy haulage work. There were four main parts: (1) a steel centre, (2) a steel sliding felloe ring, (3) an oak felloe and (4) a steel tyre. The rear wheels could have straked tyres to provide a better road grip.

The strength of this construction was considered to be twice as great as that of wooden artillery pattern wheels. There were no wooden spokes to become loose and the oak felloe provided cushioning to absorb shocks and help to deaden the noise of the steel tyre on the road. The sliding felloe ring formed a double cone that allowed easy adjustment to expand the felloe onto the tyre.

The arrangement also allowed the steel tyre to be replaced without the need to remove the wheel centre. The felloe with tyre was easily removed by undoing twelve bolts and the spare could be fitted in an hour. The arrangement was interchangeable with the rubber tyre (ref. 1).

8.0 Front Axle and Steering Gear. This axle is connected to the chassis frame by semi-elliptical leaf springs which are attached directly to the axle by bolting (Fig. 19).

Steering of the Sentinel Steam Waggon was by means of a teak hand-wheel on the right side of the cab. Steering was achieved as follows: (1) the steering column has a quick tread and nut running in a totally enclosed oil bath. (2) the pull from the steering column acted directly on a bell-crank lever, drag link and steering lever. (3) the front wheels are dished outwards to allow the short front axle to be fixed to the wheel centre and the axle journal bearing to be in the middle of the tyre. (4) there is a pivot above the axle journal bearing allowing the wheel to be turned and a coupling rod connects the wheels so they act in unison in a similar way to an Ackermann type steering gear (ref. 13) designed to solve the problem of wheels on the inside and outside of a turn needing to trace out circles of different radii and thus avoid sideways slip of the tyres when cornering. (5) the pivot locates in the heavy main front axle. (6) the main axle is connected to the chassis frame by semi-elliptical leaf springs.

The whole arrangement allowed the waggon to be quickly steered with one hand like a light motor car. The waggon could be turned completely within a 25 foot radius without backing up (ref. 1). All shocks were taken by the heavy main axle and not transmitted to the steering gear. Journal bearings were of Admiralty bronze and the journals of case-hardened steel. The steering column screw is steel with a bronze nut.

9.0 Brakes. The waggon was considered to be under “Town Control” if it can be stopped in about 30 ft., and under “Close Control” when it can be stopped in about 10 ft. Two effective braking systems, a hand brake and an engine brake, were provided each being independent of one another (ref. 1).

9.1 Hand Brake. The rear axle has a friction band brake, with a wide and large diameter drum, bolted to the adjacent transmission chain sprocket wheel (Fig. 10). Applying the hand brake therefore locks the transmission. The brake was applied by hand, from the drivers position in the cab, through a screw, bevel gears, links, pins and wire rope (Fig. 12). The hand brake was used for all normal conditions. It should always be put on when the waggon was standing and should be screwed up ready for immediate use when approaching hills (ref. 1).

9.2 The Engine Brake. The engine could be used as a compressed air brake. With the steam shut-off and the reversing lever in reverse position the engine will act as an effective pneumatic brake operated by the foot pedal in front of the driver (ref. 1). The engine as a brake would be used under the following conditions:

1. **To stop slowly on the level**. The driver would shut-off the steam (using the regulator valve) and put the reversing lever in the stop notch. When the waggon rolls to a stop apply the hand brake.
2. **To stop more quickly**. The driver would press the foot pedal, put the reversing lever into reverse notch and shut-off the steam (using the regulator valve). When the waggon stops put the reverse lever into the stop notch and apply the hand brake.
3. **To stop nearly instantaneously at the risk of smashing the engine**. The driver would press the foot pedal, put the engine in reverse then gently take the foot off the pedal, keeping the steam still on. This stop should only be used to avoid a collision or to prevent anyone being run over.

10.0 Lights. The museum waggon has two oil lamps to the front attached to the canopy supports and two electric lights attached to the rear of the platform. There are also two reflectors on the hinged back and there are wires in the cab indicating that at one time there was electric lighting in the cab. The use of electric lighting would normally require a battery charged by a dynamo. These items appear to be missing from the museum waggon.

> [The spare parts list for a Super-Sentinel Waggon does make reference to the use of C.A.V. Lighting Sets with a battery and belt driven dynamo. However, there appears to be no obvious attachment point or drive for a dynamo on the museum waggon.]

11.0 Whistle/Klaxon Horn. The museum waggon has a steam whistle on the top of the cab canopy (Fig. 21). However, there is no connection pipe to the steam supply or pull chain to the valve lever so this whistle was not in use. There is a mechanical hand activated Klaxon horn, attached to the right hand cab pillar, within reach of the driver (Fig. 22).

12.0 Lubrication. The lubrication was essential to the smooth running of the waggon. At key parts there were lubrication points and sight glasses were provided where necessary. The engine is enclosed in an oil bath as is the differential gear and the steering column thread and nut.

A mechanical lubricator is provided for the lubrication of the engine cylinders and valves by pumping (by drips) steam cylinder oil into the steam inlet flow. Steam cylinder oil is a very viscous oil that barely flows at room temperature but when mechanically injected by drips into a steam supply, it will atomise and be carried along in the steam flow to provide adequate lubrication of the engine valves and cylinders. Note that normal bearing or crankcase oils are unsuitable for use at steam temperatures.

The lubricator is driven from a crank on the right end of the engine crankshaft (Fig. 2 & 9). It could be operated manually for priming and during warming the cylinders at start up. On the museum waggon the oil is pumped, via a copper pipe, to the left side of the steam regulator valve where it would enter the superheated steam flow to the engine.

13.0 Shed Day. It was recommended that at least once a week the waggon be “stabled” and maintenance carried out. Instructions are given in reference 1. The steam waggon required care and attention similar to that required by a steam locomotive. Some disadvantages of the undertype waggon become apparent when maintenance is carried out. The boiler was awkward to repair. The dropping of the firebox required the removal of a large number of nuts and breaking of the steam-tight joints. Getting full access to the engine required the platform to be removed. These aspects are discussed in more detail in references 15 to 17.

14.0 Getting Up and Running. Instructions are given in reference 1, the following briefly summarises what is required to get a steam waggon ready for running.

14.1 Raising steam. Steam could be raised from cold water in 50 minutes without using the blower. The use of the blower was not recommended when raising steam as this often spoiled the fire by blowing holes in the fire, although the time to raise steam was reduced. When the waggon was to be used the next day the fire could be kept warm overnight, with about 10 lbs. per square inch pressure, by following the correct procedure as outlined in reference 1. Full steam pressure could then be raised in about 30 minutes.

(1) With the waggon on the level, the boiler should be filled with clean water up to the working level of 3 inches from the bottom of the gauge glass.
(2) Fill the fuel bunker, coke is best but steam coal will also do.
(3) Clean the ashpan and firegrate and half fill the ashpan with water.
(4) Light the fire by the stoking shoot by dropping wood shavings or waste soaked in paraffin onto the firegrate. Add firewood until there is a good blaze and thick fire. Spread a layer of fuel on top. When red hot add more fuel slowly, spreading it from time to time.
(5) Check that the steam valves are working freely. Try the reversing lever and put it in the Stop notch. Test the hand brake and steering gear.
(6) Fill the water tank with clean water. If steam is up the tank can be filled, by means of the auxiliary steam valve and water lifter nozzle, through the suction hose and strainer. Otherwise fill the tank from a tap by a hose inserted into the tank filling hole. The parts list (ref. 7) for the water tank on a Standard waggon shows a tank filling hole. However, there appears to be no filling hole on the museum waggon other than that for the lifter nozzle.

14.2 Getting ready to start.

(1) Test the steam injector.
(2) Lubrication; ensure that all parts are well oiled and oil gauges full to within 1 inch from the top of the glass. All grease nipples should be well charged.
(3) Check the lighting.
(4) Warm and oil the cylinders. With the reversing lever in the Stop notch. Open the engine drain valve using the control lever in front of the fuel bunker. Open the steam regulator valve slightly and allow steam to blow through the cylinders for two minutes. While the steam is blowing work the lubricator by hand for about twenty strokes.
(5) After warming and oiling the cylinders close the regulator and the engine drain valve.
(6) Starting; check that the fire is bright and there is 200 lbs. per square inch showing on the pressure gauge.
(7) Check the road is clear. Push the reversing level to the Start position. When underway pull the reversing level back to the Fast position and go ahead, keeping within the legal speed limit.

15.0 "Standard Sentinel Waggon with End-Tipping body". This waggon could carry 5 tons and was very useful for delivery of loose material as no time is wasted in discharging such material i.e. the material could be dumped by simply tipping the platform. It was considered to be vastly more profitable than horses (ref. 1).

The platform body of this waggon was extra strong and the extra weight had to be counted as part of the total load, hence the need to limit the load carried to 5 tons. The waggon could carry a trailer loaded with 4 tons (giving 9 tons total) up a gradient of 1 in 10 on good roads. The water tank was repositioned behind the cab and resulted in a shorter platform (11 ft. 6 in.). The platform could tip-up (to about 40 degrees) by means of a hydraulic tipping cylinder located beneath the platform. From start to finish, discharge and return to level, tipping could be completed in three minutes (ref.1). Apart from the addition of the tipping gear the waggon had the same boiler, engine, chain transmission and operated in a similar manner to the "Standard Waggon with plain flat-platform".

16.0 Summary.

In summary, the Sentinel Steam Waggon built by Alley & MacLellan Limited was a successful heavy motor car. It was designed at a time when steam power was still a conventional means of propelling road vehicles and railway locomotives. Owners, drivers and the general public were used to using and seeing steam powered vehicles, locomotives and ships.

However, as the 20th century progressed, steam powered vehicles came under increased competition from the more efficient, cheaper to run and cleaner running internal combustion engined vehicles powered by a petrol or diesel engine. The Salter report (ref. 21) of 1933 had important implications for the users of heavy goods vehicles. The government introduced legislation, including new speed limits, licensing, and increased road tax, that restricted the use of heavy goods vehicles in favour of lighter internal combustion engine lorries – the result was the demise of the steam waggon.

17.0 References.

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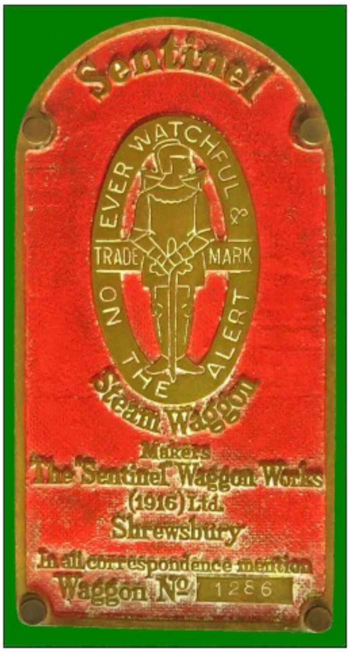

Figure 1

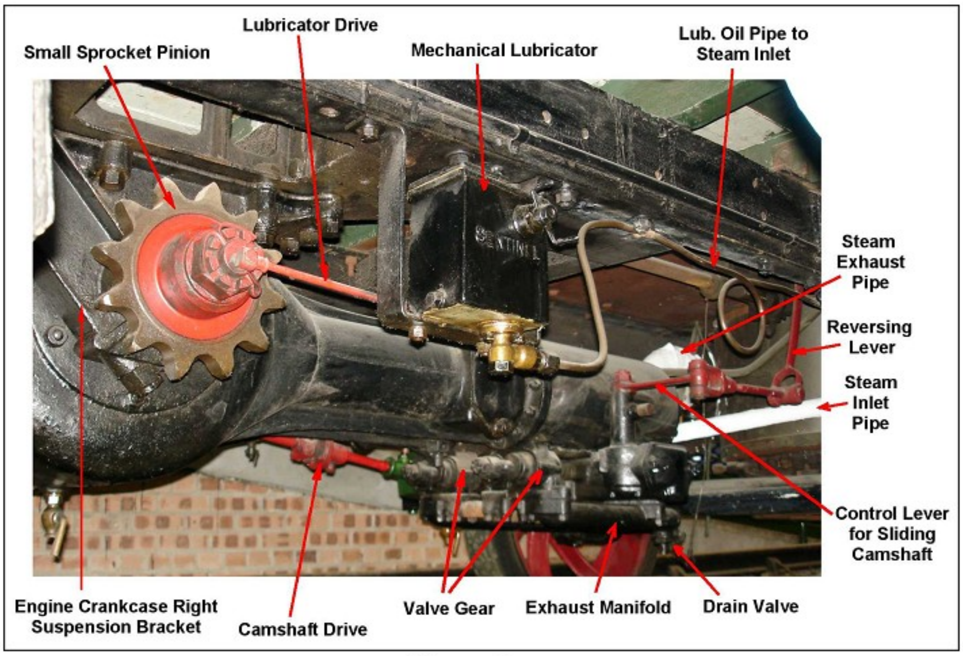

Figure 2

Figure 3

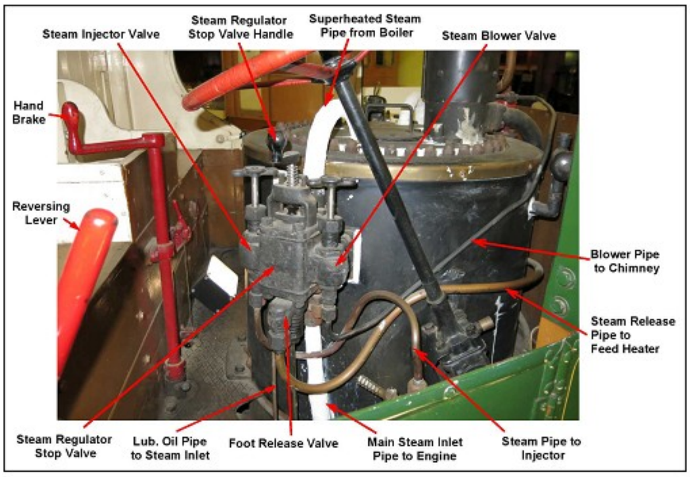

Figure 4

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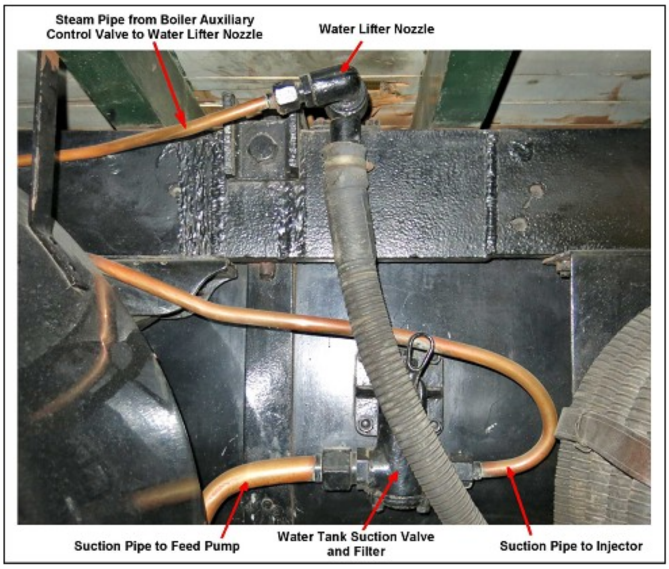

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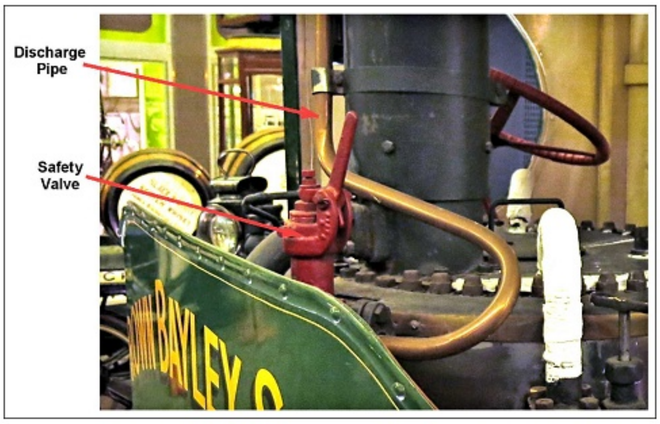

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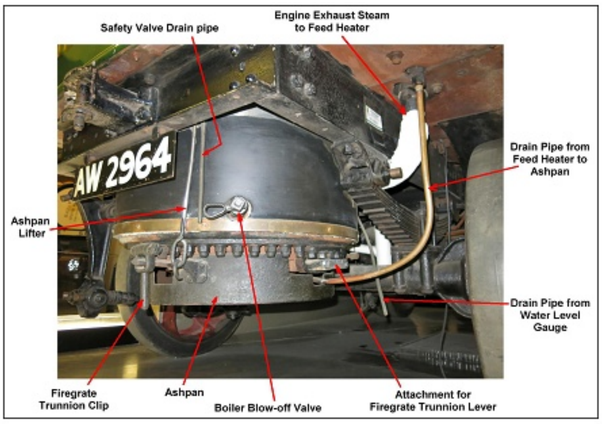

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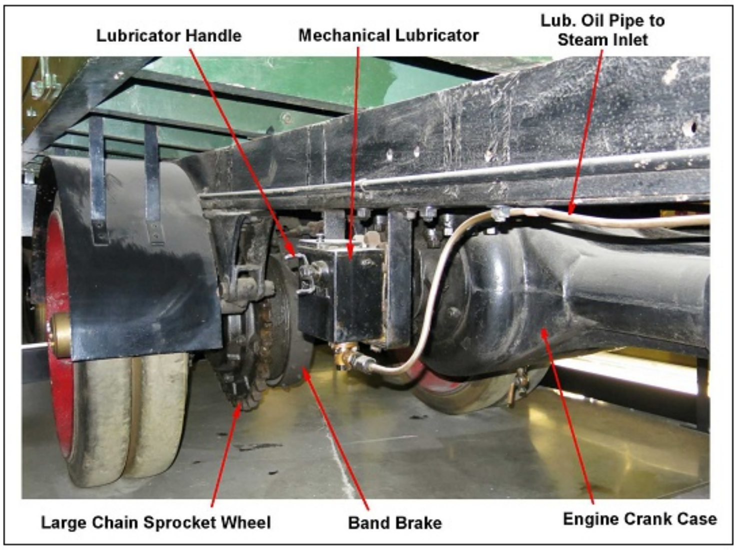

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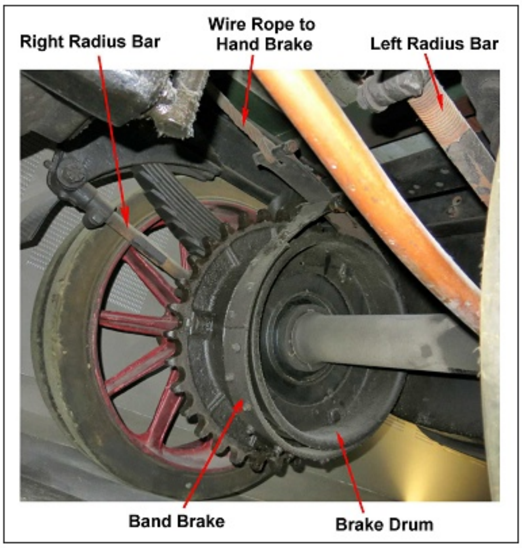

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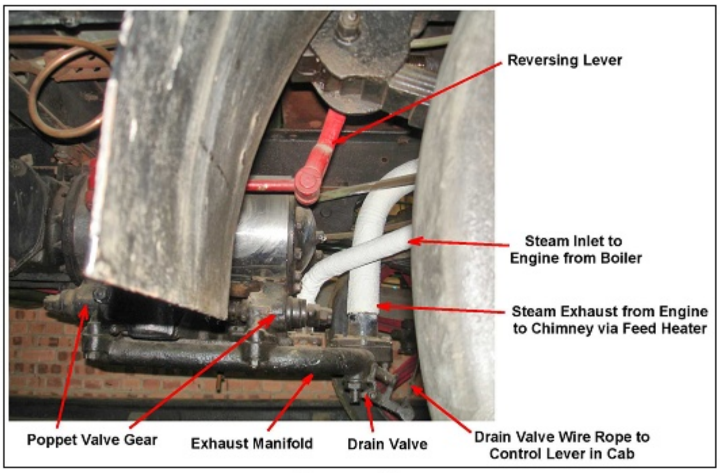

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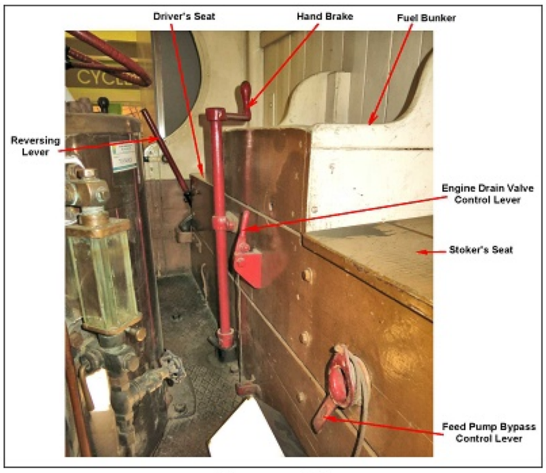

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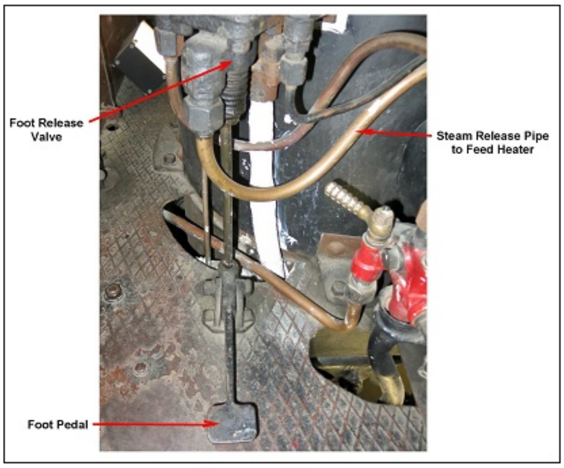

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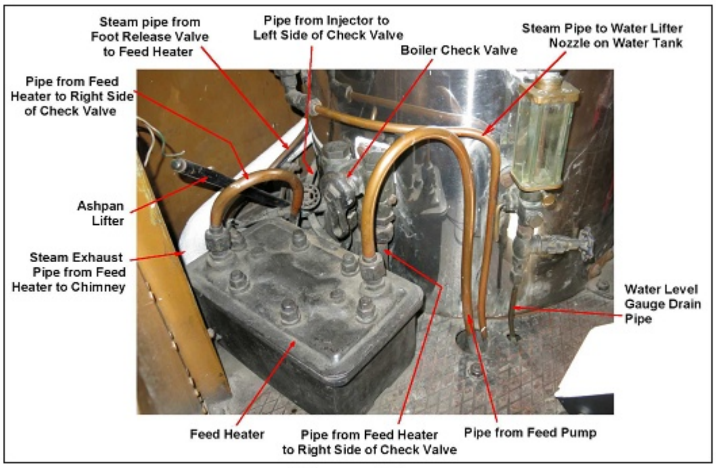

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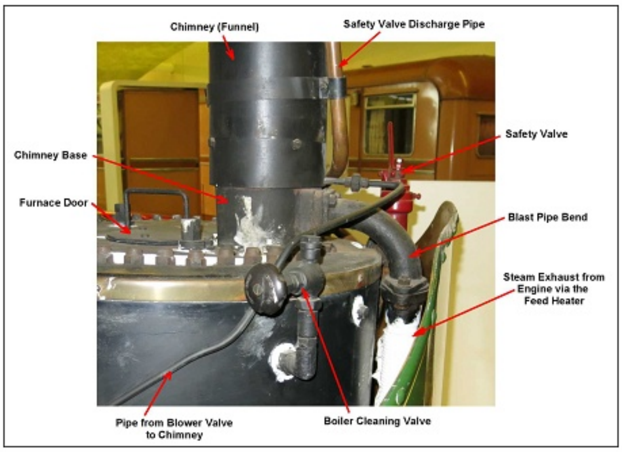

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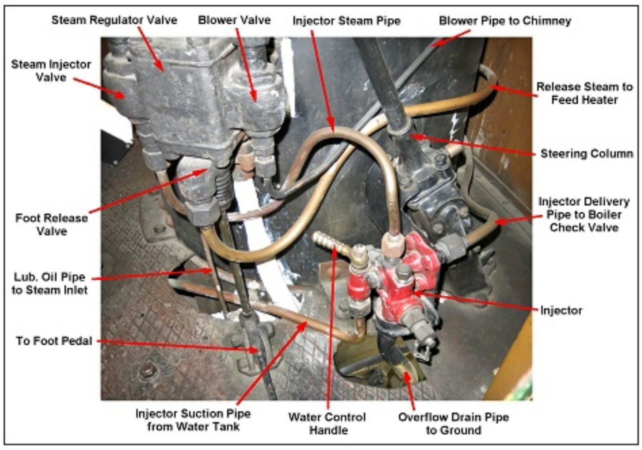

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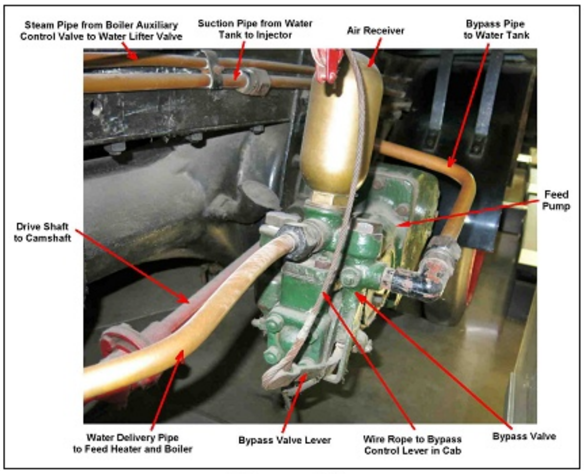

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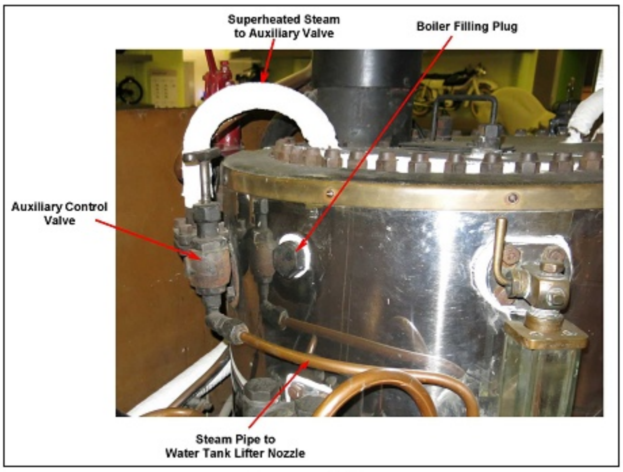

Figure 18

Figure 19

Figure 20

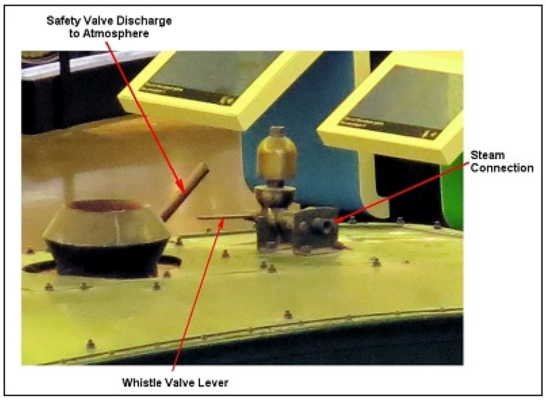

Figure 21

Figure 22

The Sentinel Steam Waggon at Riverside Museum

Appendix 1, Pipework Diagrammatics

By
Andrew C. Whyte, volunteer guide

As an aid to the understanding of the way the Standard Sentinel Waggon operated the following pipework diagrammatics have been drawn. For convenience the pipework can be grouped into four systems as follows:

(1) Boiler Feed Water System
(2) Engine Steam Supply System
(3) Water Lifter System
(4) Boiler Safety System

The diagrammatics of these piping systems are shown attached.

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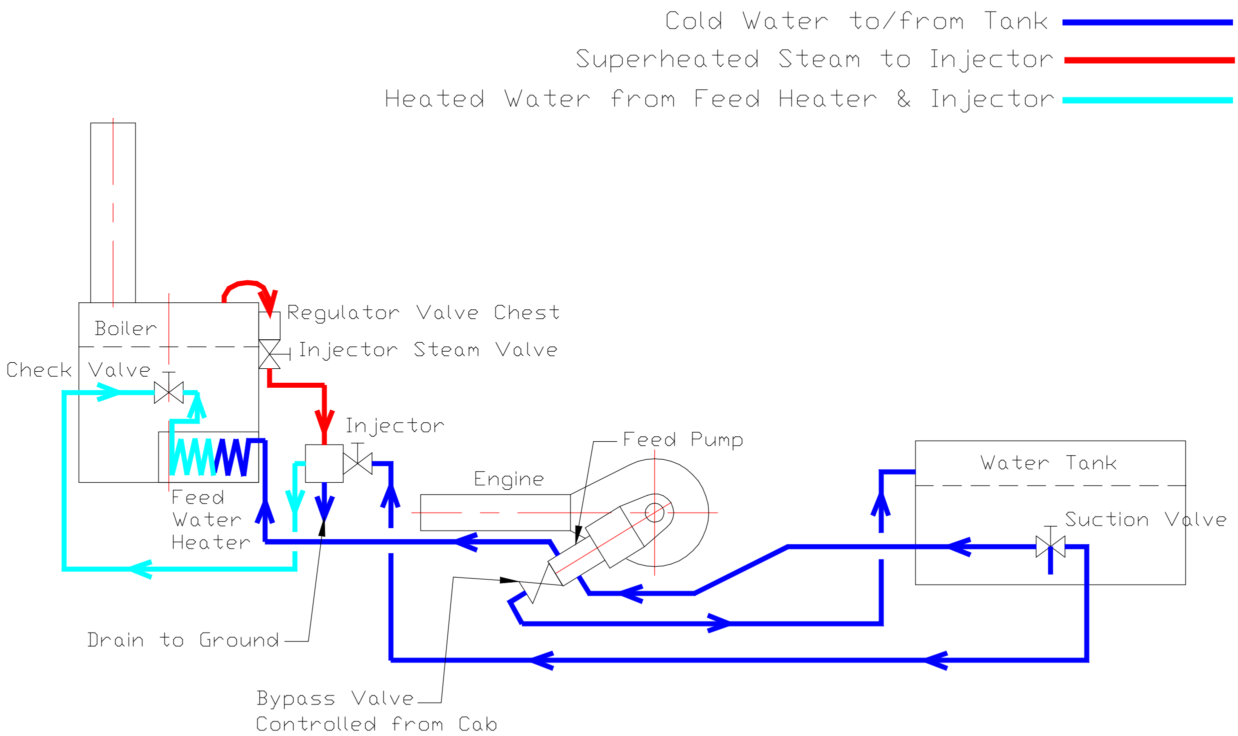
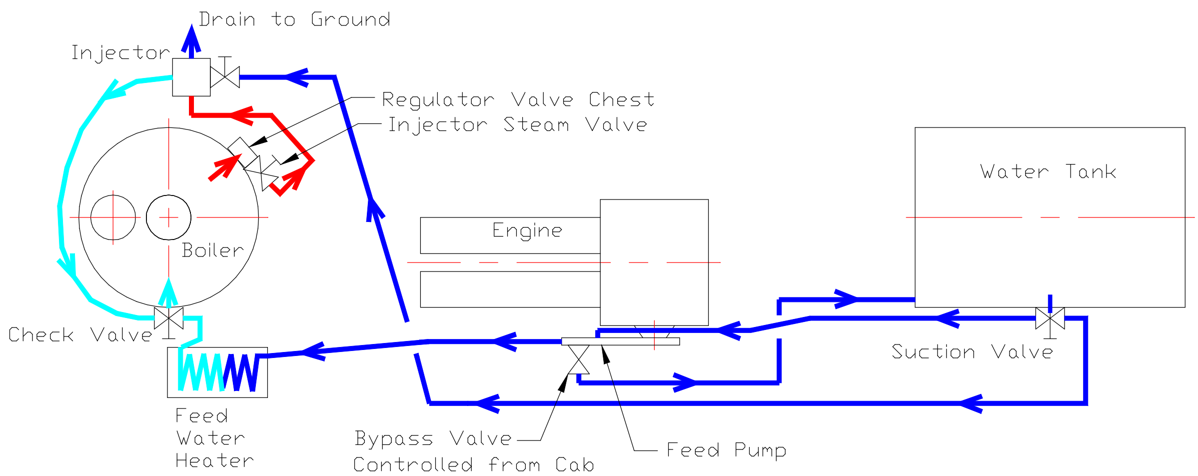
April 2016



ELEVATION VIEW

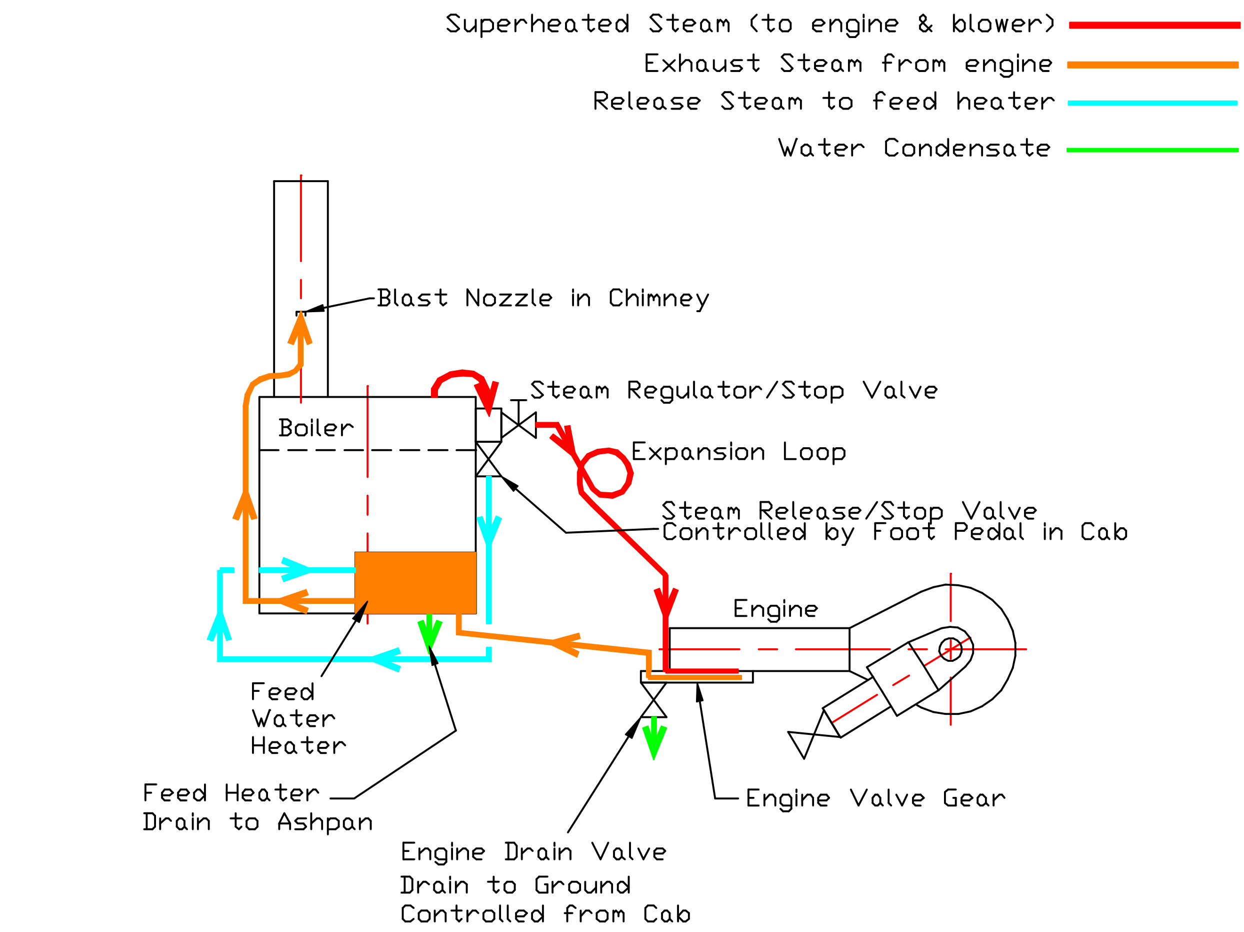


PLAN VIEW

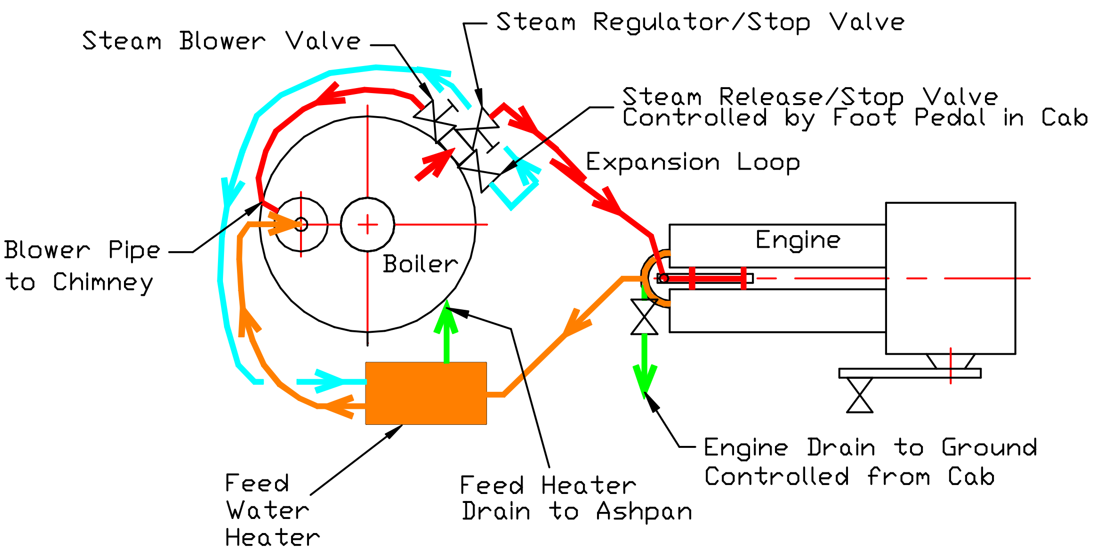
Riverside Museum "Sentinel Steam Waggon"
Piping Diagrammatic (Not to Scale)

BOILER FEED WATER SYSTEM

A. C. Whyte, February 2016



ELEVATION VIEW



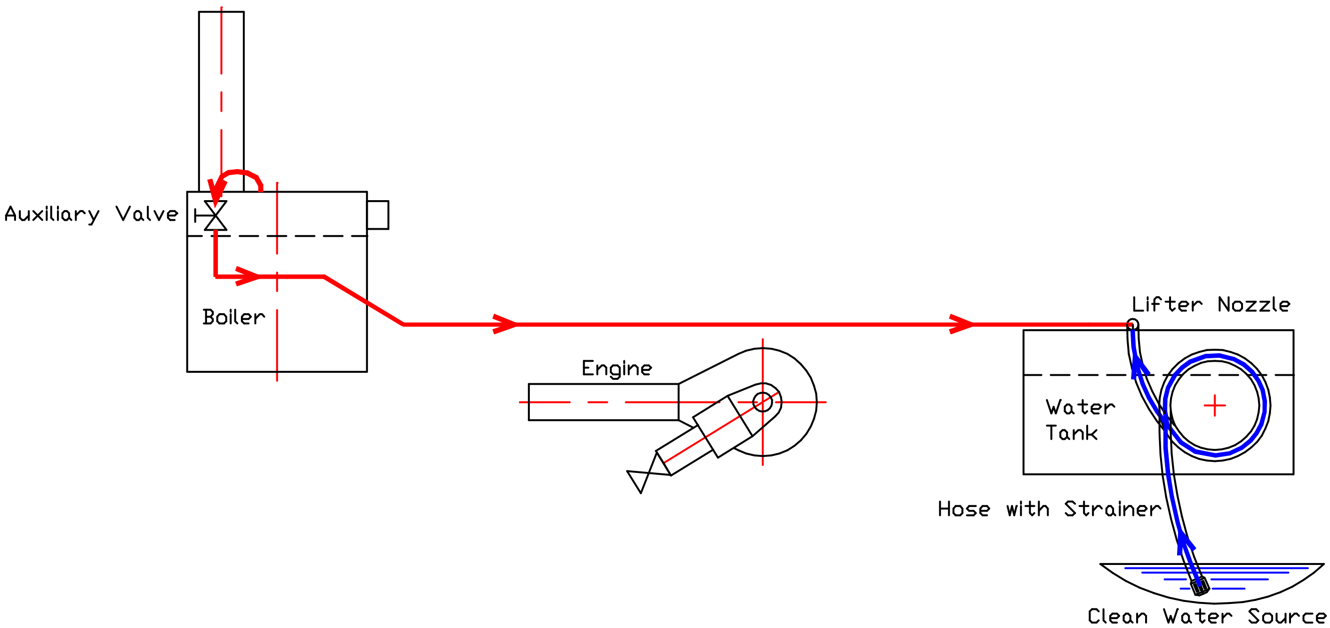
PLAN VIEW

Riverside Museum "Sentinel Steam Waggon"
Piping Diagrammatic (Not to Scale)

ENGINE STEAM SUPPLY SYSTEM

A. C. Whyte, April 2016

Cold Water to Tank
Superheated Steam to Water Tank Lifter Nozzle



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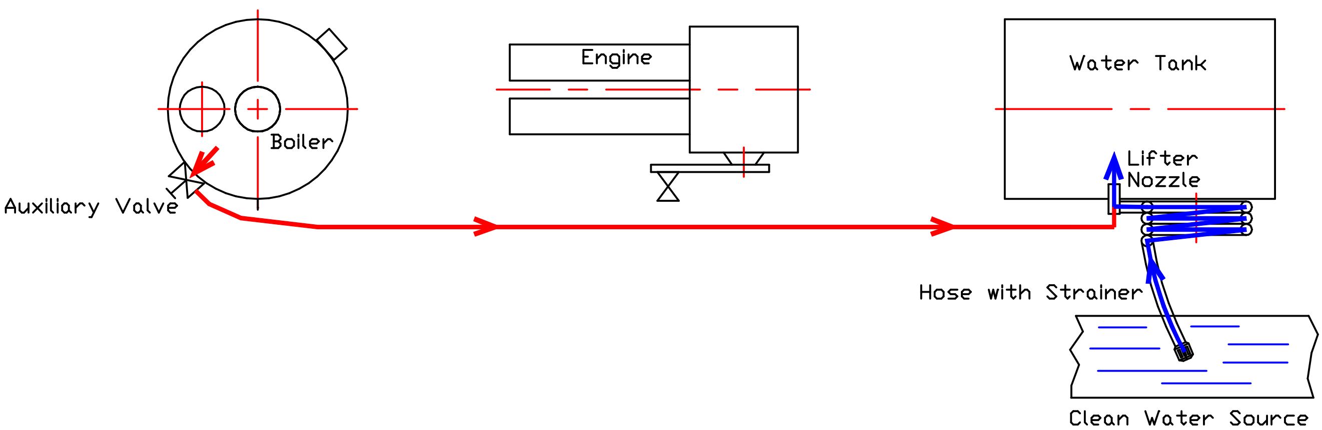
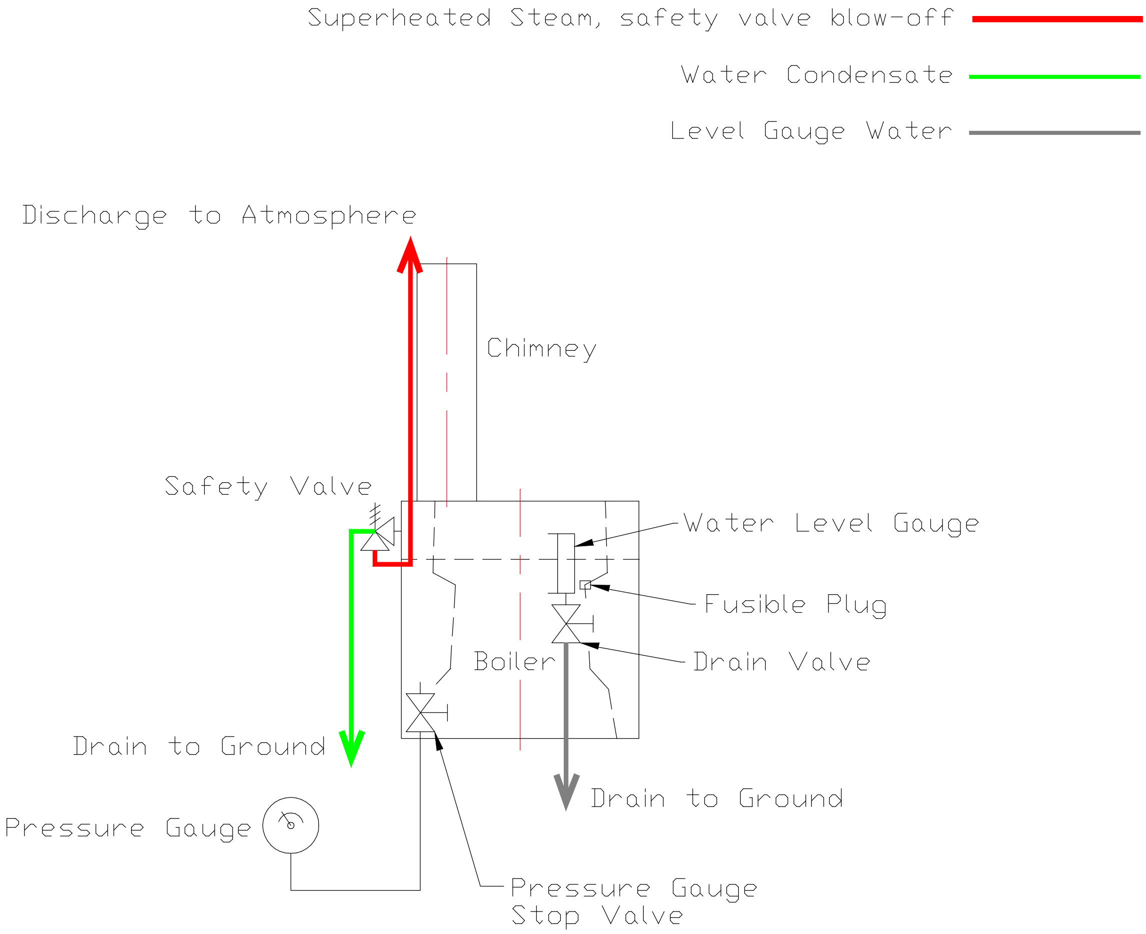


PLAN VIEW

Riverside Museum "Sentinel Steam Waggon"
Piping Diagrammatic (Not to Scale)

WATER LIFTER SYSTEM

A. C. Whyte, February 2016



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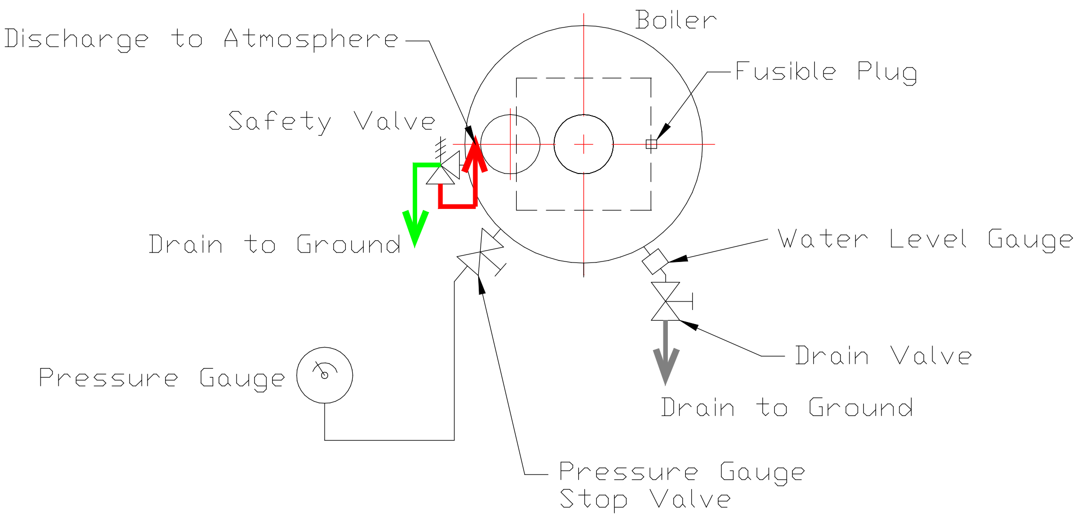

PLAN VIEW

Riverside Museum "Sentinel Steam Waggon"
Piping Diagrammatic (Not to Scale)

BOILER SAFETY SYSTEM

A. C. Whyte, April 2016