Drawbars

The locomotive is fitted with sturdy drawbars at both front and back, confirming that it was used to haul loads in both directions.

The front drawbar is a heavy-duty iron forging, with two 'wings' and a 'tail' riveted to the boiler barrel.

Fig. 13.5. Front drawbar with wings and tail.

These are all dog-legged to leave the top face around the eye of the drawbar some 3½ in below the boiler barrel.

The drawbar is 39 ½ in long overall, the rectangular tail being 20 in long and 5 in wide. It is fixed to the boiler plate by eight 1 in rivets. Its dog-leg curve is 4½ in wide and 2 in thick. The wings, which measure 23½ in from tip to tip, are 3 in wide and 1 in thick, each fixed to the boiler by three 1 in rivets over a 10 in length. The material round the drawbar eye is 2 in thick and the eye has worn to an oval 1½ in wide and 1¾ in long.

The rear drawbar seems to be a replacement for an earlier version, a line of redundant 1 in rivets alongside the surviving drawbar tail being evidence of this. The surviving drawbar is similar to the front one. Its total end to end length is 34 in. The tail is 19 in long, 4 in wide and 1 in thick, fixed to the underside of the boiler barrel with a single line of five 1 in rivets. Its dog-leg curve is 4 in wide and 1¼ in thick and leaves the top face around the eye of the drawbar 4½ in below the boiler barrel. The wings have a tip-to-tip measurement of 44½ in, and are 4 in wide x 1 in thick, each fixed to the barrel by four 1 in rivets over a 14 in length. The material round the drawbar eye is 1½ in thick, the eye being 1½ in diameter.

Fig. 13.6. Rear drawbar with tail and wings, together with drawbar pin and coupling.

The rear drawbar is fitted with a wrought iron coupling to the tender. This coupling is bent into a shallow 'S' shape and has a clevis at each end to fit with the drawbars on the locomotive and tender. The leading clevis is 6 in long and 3 in wide, increasing to 3½ in around the pin eye. The clevis gap is 1½ in and clevis arms are 1 in thick. The rear clevis is 5½ in long and 3 in wide. The clevis gap is 1¾ in and the clevis arms are 1 in thick. The coupling is 21 in long, 2½ in wide and 1½ in thick, with the eye centres 17½ in apart. The coupling pins are 1⅜ in diameter.

Fig. 13.7. Coupling between locomotive and tender

Mud-holes

A mud-hole opening is fitted into the bottom of the boiler at approximately mid-length but some 5½ in to the right of the centreline. It is oval with a maximum length of 5½ in and a maximum width of 3½ in. The closure measures about 5 in by 7 in at its internal rim and is retained in place by a bridge of some 5½ in span, secured with a ½ in nut.

Fig. 13.8. Mid-boiler mud hole closure. Front of boiler to the right in this view. Significant corrosion has taken place in the surrounding area.

A second mud-hole and closure of similar design is fitted at the trailing end of the boiler, partly covered by the rear drawbar. Corrosion reveals its form in more detail.

Fig. 13.9. Rear mud-hole overshadowed by rear drawbar. Closure rim revealed by corrosion.

Boiler barrel repairs

A repair at the bottom of the boiler consists of a plate tailored to avoid the central mud-hole, and rivetted on one side along the boiler plate seam. This patch is 1 ft wide and 2 ft long at its maximum.

Fig. 13.10. Patch repair and holes in region of central mud-hole, looking towards rear of boiler.

Two further patches are in the areas of the bottom flanges of the right-hand boiler support brackets. The patch at the front bracket is oddly shaped (Figs. 13.2 and 13.11). At its bottom edge it is overlapped by the bottom flange of the bracket and is secured generally by the bracket flange rivets. At its rear corner it underlaps the patch near the central mud-hole, where a single rivet fastens both patches.

Fig. 13.11. Patch under front right boiler support bracket bottom flange (right side of view) extending rearwards to, and, under the corner of the patch near the central mud-hole.

Fig. 13.12. Patch under rear right boiler support bracket bottom flange (right side of view), extending beyond the bracket to both front and rear. Note line of three unused rivets associated with an earlier drawbar.

The patch at the bottom flange of the rear boiler support bracket is rectangular. Its bottom edge is generally secured by the bracket bottom flange rivets, as before. The flange then extends forward of, and rearward of, the bracket flange and also above it (Figs. 13.2 and 13.12).

The rivets securing the boiler support brackets carried the weight of the boiler and the reciprocating reaction forces from the cylinders, which would have been generally about half a ton. On Killingworth *Billy* this led to fatigue crack growth around the rivets.[322] The inside of the barrel was inspected for signs of fatigue cracking around the rivets securing the bottom flange of the rear bracket, but none was seen. It is therefore likely that these patches were required because rainwater was trapped in the folds for the flanges and caused corrosion.

The boiler was only seven years old when fitted in 1834, and only thirteen or fourteen years old when *LOCOMOTION* was taken out of service. As the boiler was steamed both in 1846 and between 1850 and 1856, it seems likely that the repairs were undertaken during or after the lengthy period when the locomotive was displayed in the open air (Section 8). Despite these patch repairs, there are now holes around the mud-holes through which rust on the flue is visible (Figs. 13.8 and 13.9).

14. Boiler Endplates and Fire-Hole Door

COMPONENT HISTORY

Boiler endplates on early locomotives were usually dished (so called 'egg-ended'), except where they provided the fixtures for return-flues, when they were flat. In 1827 Thomas Tredgold suggested that 'flat segments are more convenient in construction' for the dished ends; such 'petal' construction survives on *Puffing Billy* (c1814) and *Sans Pareil* (1829). Tredgold also recorded a rule of thumb that the radius of curvature of the dished endplates should equal the diameter of the barrel.[323] The portrayal of a Killingworth-type locomotive with a 4 ft diameter barrel (Fig. 14.1) shows such dishing which scales at 5 in, whereas according to the rule it should have been 6½ in. The difference may have been 'draughtsman's licence' or alternatively may show that the rule was still being developed in 1818. It is nevertheless likely that *Active*, with its 4 ft diameter barrel (Section 13) had endplates dished to 6½ in, giving an overall boiler length of 11 ft 6 in. This was confirmed by the visiting Prussian engineers in 1827.[324]

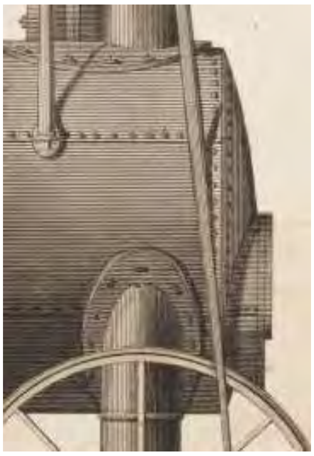


Fig. 14.1. Killingworth-type boiler back-plate.

[Nicholas Wood, 1825, Plate V - detail]

During the 1828 re-build a 4 ft 6 in diameter boiler was fitted (Section 13). Since it contained a double-return flue (Section 15), one of the endplates would have been flat at about ⅜ in to ½ in thick, and, in line with the above rule, the other end would have been dished to 7¼ in, giving an overall boiler length of around 11 ft.

The surviving boiler barrel from *DILIGENCE*, fitted during the 1834 re-build, is 10 ft 2 in long and 4 ft diameter. This re-build provided a single return flue so, with one flat end plate and one end dished at 6½ in, the overall length would have been around 10 ft 9 in.

Finally, the restoration team at Shildon in 1857 were faced with replacing the single return flue with a central straight flue, in keeping with the original design of *Active* (Section 15). Section 17 points out that the pre-existing cylinders, designed for insertion into a 4 ft 6 in diameter boiler would have fouled a central flue at its usual height in the 4 ft diameter boiler. The team's response was to set the flue exceptionally low. This brought about another problem. Straight flues were usually secured and sealed with external angle-irons rivetted to both the flue and the endplates. However, some of the latter sets of rivets would have been located at or very close to the ends of the boiler barrel, which ruled out the use of angle-irons. The solution was to swage flanges on a new pair of endplates. The swaging process would probably have been too difficult if applied to dished endplates, which themselves would have been expensive to construct, and so flat ones were made, giving an overall boiler length of 10 ft 3¼ in.

A disadvantage of using swaged flanges is that they had to form close-fitting sleeves around the flue, so that the rivets along the length of the flue would have prevented the insertion/withdrawal of the flue after the endplates had been rivetted in position (unlike with the use of angle-irons).

In all the above boiler configurations the sizes and shapes of the fire-hole doors would have been determined by the sizes and shapes of the parts of the (main) flues above the fire-bars (Section 15). The doors would have been hinged to plates themselves secured to the ends of these flues. These plates would have been cut away at their bottoms to allow air and other access beneath the grates and cut away centrally to give access to the fires.

ARCHAEOLOGY

The existing boiler endplates are made from ⅜ in wrought iron plate and are 4 ft 5½ in diameter (front) and 4 ft 6½ in diameter (rear). The difference in diameters reflects the way in which the boiler plates were 'telescopically' joined longitudinally in 1827 (Section 13). It is possible that these endplates, fitted in 1857, were originally both of the same larger diameter, since there is evidence to suggest that excess material has been flame-cut away from parts of the front endplate to improve the appearance. This may have been undertaken during the 1924 restoration before the British Empire Exhibition (Section 8).

The endplates are made from two pieces of wrought iron plate rivetted together. The bottom piece at the front has an overall height of 35½ in and overlaps the top piece by 3 in, whereas at the rear the bottom piece has an overall height of 36¾ in and overlaps the top piece by 2½ in. The joins are made with ¾ in rivets at a nominal 1⅞ in pitch. The endplates are joined to the angle-iron 'hoops' at the ends of the boiler barrel with ¾ in rivets at the same nominal pitch.

Fig. 14.2. Front endplate.

Fig. 14.3. Rear endplate (Backplate).

Both endplates have 3 in wide flanges formed by swaging the plate. The smooth curve left by the swaging process can be seen to the left of the cover plate (Fig. 14.3). The outside diameter of the flanges so formed is 24¾ in, with a nominal bore of 24 in. The flanges provide fixings for the flue projecting from each end of the boiler (Section 15). At the front the centreline of this flange is 16½ in above the bottom of the endplate whereas at the rear this dimension is 17½ in.

The backplate carried two try-cocks, one of which is now missing (Section 22). The centres of these try-cocks are 1½ in above and 3 in below the backplate join line, and 10½ in and 16¼ in to the left of the backplate vertical centreline. The lower try-cock is a nominal 4 in above the top of the flue.

The fire-hole door is hinged to a ¼ in thick cover plate which is attached to the circumference of the flue-tube by three short angle-irons, each bolted through the flue and flange in place of a ¾ in rivet.

Fig. 14.4. Bolts on angle-iron securing fire-hole plate to backplate flange on the left side.

The nuts on the three bolts securing the fire-hole cover plate to the angle-irons are above the fire-door, to the top left of it, and below the top hinge-strap on the right of it (Figs 14.3 & 14.5). The wrought iron cover plate itself is 26½ in diameter, set so that its top edge just overlaps the flange with larger overlaps at its sides and bottom. A round-topped rectangular cut-out gives an opening 14¼ in wide and leaves a 5½ in wide annulus at the top. The area of this annulus that would have been exposed to the fire is shielded by a ½ in thick curved wrought iron plate rivetted to it with ¾ in spacers.

Fig. 14.5. Fire-hole door, hinge-straps, latch and heads of rivets securing baffle-plate.

The round-topped fire-hole door is ⅛ in thick, 13 in high at its highest and 16⅛ in wide. It is held by two hinge-straps, each about 1¼ in wide and 15 in long with a ¾ in diameter hinge-pin, which is in turn fastened to the cover plate by a]- shaped strap. The door carries a conventional latch.

A baffle-plate is rivetted to the back of the fire-hole door. This plate is ⅜ in thick, 13 in wide and 8 ¼ in high. It is rivetted to the door at each corner with ⅝ in thick spacers.

15. Flue and Fire-grate

COMPONENT HISTORY

The straight wrought iron flue first fitted in *Active* would have been circular in section, around 24 in to 25 in external diameter; the latter size was reported by Von Oeynhausen and Von Dechen following their examination of the S & D R locomotive fleet in 1827.[325] This represents a significant increase from the flue diameter of 22 in in the 1818 Killingworth locomotives.[326] *Active*'s flue would have been perhaps 11 ft 8 in to 12 ft long, to protrude beyond the dished boiler endplates, where it was secured by angle-irons (Section 14), for the attachment of the chimney base and fire-hole cover plate and door (Fig. 2.1).

During the 1828 re-build with a 4 ft 6 in diameter boiler, a double return-flue was fitted. The data in Section 3 specifies that this weighed 1 ton 13 cwt and 13 lb. It is likely that the main flue was slightly oval to give an increased fire-grate width. Nicholas Wood in 1825 stated that he had 'lately put an oval tube into one of the engines on the Killingworth Rail-road but …. cannot at present give the result',[327] a precedent that may have been followed on *Active*. A ranging weight calculation indicates that the main flue may have been 27 in wide by 23 in high externally, with twin return flues of 16 in external diameter, which would have been a suitable proportion of the main flue size. An indicative arrangement is shown in Fig. 4.1.

During the second rebuild in 1834, when the original boiler from *DILIGENCE* was fitted, a single return-flue was installed (Section 5). An exploratory drawing (Fig. 5.1) showed that an oval main flue 24 in wide by 20 in high externally, with a suitably sized return-flue of 15½ in external diameter, would have fitted comfortably in the 4 ft diameter boiler. While the return-flue provided an increased steaming rate and efficiency (Section 27), another benefit of this arrangement is that it reduced the height of the main flue and placed the return-flue to the side of the boiler, thus avoiding a potential clash with the cylinders (Section 14).

During the restoration in 1857 the return-flue was removed, and a replacement straight flue was fitted. This flue is circular with an outside diameter of only 24 in, with a measured plate thickness of ⅜ in (see below).

The standard length of the fire-bars in the Killingworth-type locomotives was 4 ft.[328] The bars would have been supported by a pair of transverse cast iron joists near each end. These joists would have simply rested on the inside of the flue at the appropriate height, taking advantage of any flue plate edges in the vicinity. The height of the fire-grate relative to the flue would have been selected as a compromise between allowing sufficient space beneath the grate for ash and air flow for the fire, and sufficient space above the fire to allow firing to the front of the grate, with a shallow fire. A firebrick wall would have been built at the end of the fire to block the further flow of air into the flue and to contain the fire.

Evidence from later applications of firebrick walls is that they were supported by cast iron pieces, shaped to fit in the bottom of the flue, and with rectangular openings fitted with damper doors.[329] These doors could have been used to allow excessive air flow to bypass the fire. Such a capability would have been useful in allowing a 'black' fire to heat up without being cooled by a blast sized to give sufficient air flow to a 'white-hot' fire.[330] The date of introduction of these doors is not known, but one might have been installed during the operational period 1834 to 1840/41.

Maintenance records show a significant effort was required in re-caulking, repairing and even replacing the flues. Typical entries include: June 1837: "Men's time caulking main tube … repairing the tube … putting a new plate on the tube…",[331] November 1837: "Men's time putting in a new tube …",[332] February 1839: "Men's time taking out old tube, taking a plate out of bottom of boiler and a new one put in its place, putting in a repaired tube and riveting it in".[333] Over a twenty-five month period around these dates, during which the locomotive would have been fitted with a return flue, there are seven entries on re-caulking a tube, nine entries on repairing a tube and two entries on replacing a tube.

ARCHAEOLOGY

The surviving wrought iron flue has a nominal outer diameter of 24 in. It is an estimated 11 ft long and is constructed of plates ⅜ in thick, with four plates making up the circumference. These are arranged so that the top and bottom runs of plates are inside the plates at the sides, to which they are joined by ¾ in rivets at a nominal 2 in pitch. The top plates are 15½ in wide, the bottom plates 20½ in wide and the side plates both 22½ in wide, all with 2½ in overlaps. There are four plates in each run at top and bottom, of which the longest is around 4 ft 4 in, and three plates in each run at the sides, of which the longest is around 4 ft 11 in., all with 2 in to 2 ½ in overlaps. These longer plates are all towards the front end of the flue, implying that the rear plates had been cut so that sections of them could be replaced. The area of the flue directly above the fire with the original component would have been liable to damage from the high surface temperature since most of the heat transfer to the water in the boiler occurred there (Section 27). These flue plates may also have been subjected to chemical attack from the products of coal combustion.

Fig. 15.1. Inside of flue, with fire-grate and brick wall.

The flue is secured to the boiler endplate flanges (Section 14) by ¾ in rivets at a nominal 2 in pitch. The flue protrudes through the front flange by a few inches for attaching the chimney base.

There is no evidence that a fusible plug was fitted to this flue. Such plugs were introduced in 1829, but seem to have had a limited take-up, noting that neither Killingworth *Billy* nor Hetton *Lyon* have fusible plugs either.[334]

An unexpected feature of the flue is the absence of corrosion damage. Rainwater would have entered the chimney and thence the flue during the many years when *LOCOMOTION* was on display in the open air (Section 8). The condition of the flue in *INVICTA* shows the damage that can occur in such circumstances.[335]

Fig. 15.2. Corrosion damage due to rainwater ingress on *INVICTA*'s flue.

A cast iron threshold bar spans the flue immediately inside the fire-hole opening. This bar is 23 in long, 4 in wide and 1¼ in deep. The top of the bar is 9 in above the bottom of the flue. A hook is fastened to the bottom of this bar. This may have been to hold a damper plate to control the air flow beneath the grate. This would have served a similar purpose to a damper door in the fire-brick wall, as described above.

Fig. 15.3. Fire-hole, with door hinges and latch, and threshold bar and fire-bars.

Thirteen wrought iron fire-bars (an excessive number), 4 ft long and 1¼ in square in section, are supported by transverse cast iron joists, 3 in square in section. These joists are moveable but are placed 11 in and 3 ft 2 in from the back ends of the fire-bars. The ends of these joists are crudely shaped but are supported by the edges of the bottom flue plates. There is an air gap of only 3 in between the bottoms of the joists and the bottom of the flue.

Fig. 15.4. Joist supporting fire-bars.

The fire-brick wall (which appears to be constructed of house bricks) at the far end of the grate is 9 in from front to back and extends upwards from the bottom of the flue to 6 in above the grate (Fig. 15.1).

16. Chimney and Smokebox

COMPONENT HISTORY

The three contemporary representations of *Active*'s chimney as it was first made in 1825 are varied according to the perception of the artists, but all bear enough similarity to form a likely understanding of its form.

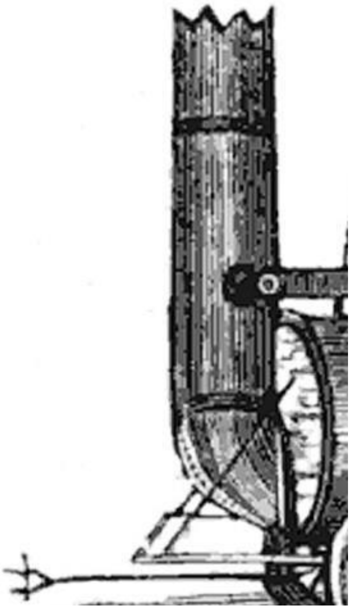


Fig. 16.1 Contemporary views:
View 'A' [Fig. 2.3 – detail] **View 'B' [Fig. 1.6 - detail]** **View 'C' [Fig. 1.4 – detail]**

The chimney, formed of wrought iron plates, formed an extension of the single flue which, for all the early Stephenson-built S & D R. locomotives, the diameter of which, almost certainly the outside diameter, was stated to have been 25 in.[336] The transition curve at the base of the chimney would have been riveted to the forward end of the flue, beyond the boiler's convex end-plate. The transition curve would have had a forward-facing opening and cover of about 8 to 10 in square, to allow the removal of ash and sweeping out the flue.

A lower vertical chimney, about four feet tall, with an external diameter of c23 in, would have been inserted within the upper perimeter of the transition curve to which it would have been riveted. The locomotive's exhaust pipe, with an internal diameter of 3 to 3¼ in (Section 21), would have been fitted to the side of this upright. The Brewster sketch (Fig. 16.1 View A) suggests that this was on the left side of the chimney, although the other two views fail to show this feature. Within the chimney the exhaust was directed through a pipe curved to point upwards for about 6 in while reducing in diameter to about 2½ in. Robert Stephenson later wrote of this feature on his father's earliest locomotives that "the orifice of the blast-pipe was, I believe, in no instance contracted so as to give a less area than that of the steam-ports."[337]

The upper chimney, of the same diameter as the lower vertical one, was possibly fitted with a 'fluted' crown. This is shown in the Brewster sketch, but not in the other sketches. The fluted finish appears to have been acknowledged (perhaps by memory) in 1857 when the locomotive was re-assembled, as this feature was then re-created on the preserved vehicle. It was noted in 1827 that the Stephenson locomotive chimneys projected about 8 ft above the boiler.[338] This would have made the top of the chimney some 14 ft 10 in above rail level.

To counter the swaying of the chimney whilst in motion, two stays appear to have been fitted. The lower one appears to have been a ring fitted around the junction between the transition curve and the lower vertical chimney stem and was fitted to the front of the boiler end-plate. It was approximately 6 ft 3 in above rail level. The upper one was also a ring fitted around the upper chimney, approximately 12 ft above rail level, and fitted back to, and thus in line with, the slide-bar braces, although this is omitted in the Brewster sketch.

It is assumed that this chimney remained in use from September 1825 until the 1st July 1828 when the locomotive was disabled by the boiler failure which killed the driver. When the new boiler was fitted, it had two return flues, with two chimneys at the rear of the boiler. The weight of both the new chimneys was recorded by Robert Stephenson & Co.:[339]

2 Chimneys & Roots 7 (cwt) 0 (qrs) 2 (lb)
1 stay in 3 pieces 0 (cwt) 3 (qrs) 6½ (lb)

These were charged out at £15 18s 4d.

The arrangement of the return-flue boiler (Section 13) determines that the two chimneys would both have been of 16 in diameter, with their tops again at 14 ft 10 in above rail level, the estimated weight of which accords with the Stephenson Company's account entry. The stay would have been formed of two rings around the chimneys fitted to a stay between them and two stays back to the boiler.

The locomotive's replacement cylinders were cast with two exhaust outlets, to provide a draught from each cylinder to each chimney. It is likely that the route of the two exhaust pipes along the top of the boiler would have passed through the rear faces of the chimneys before turning up inside them to provide the draft.

In August 1832, a serious line-side fire (Section 4) led to trials of different forms of spark arresters on all the locomotive fleet.[340] From that time *LOCOMOTION* would have been fitted with a form of wire gauze cap on each chimney, similar to that shown in the contemporary view of No. 2 *HOPE*.[341]

Fig. 16.2 Chimney crown and spark arrester cap, as fitted to No.2 *HOPE*.
[Kitching/Whessoe Papers, Durham County Record Office]

LOCOMOTION retained the two chimneys until 1834, when it was again rebuilt at Shildon Works by Timothy Hackworth, but with a single return-flue boiler, apparently formerly fitted to No.4 *DILIGENCE* (Section 5).

According to the list of locomotives on the S & D R in November 1840, possibly prepared by John Graham, the railway's Operating Superintendent, *LOCOMOTION*'s flue was 24 in in diameter with a return-flue of 16 in diameter.[342] The chimney diameter would therefore have also been 16 in, the same diameter as both its previous chimneys. This dimension was in marked contrast to the description given by Francis Wishaw who states that the return-flue boiler had a 24 in diameter flue which returned to the fire-grate end, with no mention of a reduction of the diameter.[343] As other comments written by Wishaw appear to show misunderstanding, it is probable that the reduced diameter of 16 in was correct.

At some stage in 1834, probably coincident with the re-fitting of No. 4's boiler, *LOCOMOTION* was fitted with a 'smokebox'.[344] It is unlikely that this took the form of a vacuum chamber, as an extension to the boiler barrel, as then adopted in mainline locomotive practice. Rather, it would have been similar to the return flue exterior extension and exterior housing as fitted to *SAMSON* in 1838 by Hackworth & Downing for the Albion Mines Railway in Nova Scotia. This made possible the centralised position of the chimney, on the top platform of the 'smokebox'. A hatch was provided, at the base of the exterior extension, for the removal of ash.

Fig. 16.3 *SAMSON*'s front end showing its 'smokebox' fitted to the front of the boiler, housing the exterior extension of the return flue and the access to the fire-grate. A single exhaust pipe enters the rear of the chimney. [Michael R. Bailey]

Fig. 16.4 *SAMSON*'s front end with smokebox housing removed to show the return flue exterior diversion, and the fire-grate. [Michael R. Bailey]

As the locomotive retained its cylinders fitted in 1828, the twin exhaust pipes were also retained. These remained in their boiler top alignment, the leading ends being diverted into the side faces of the chimney, made possible by its central location. It is also most likely that, on the interior of the chimney, there was an arched pipe linking the two exhaust pipes. The centre of this pipe was opened up at its top to allow the exit of the exhaust steam in the form of a ‘blast-pipe’, an arrangement that remains present on the locomotive (See Archaeology section below).

The chimney required occasional maintenance, the details of which were shown on Hackworth’s detailed records which survive for the 1837 to 1840 period. In April 1837 a “ring” for the chimney was replaced, weighing 5 lb, quite possibly that for the stay, together with 3 pounds of “bolts”.[345] In June that year a plate on the chimney, weighing 36 lb, had to be replaced. The chimney and the smokebox were removed and re-fitted to enable the repairs to be carried out.[346] In August that year a new chimney section, weighing 66 lb, was fitted.[347]

In June 1838, a 12 lb plate had to be replaced, together with a 4 lb ‘hoop’, presumably for the stay.[348] Just two months later a further 78 lb section of the chimney had to be replaced, together with a ‘hoop’, suggesting that fatigue cracking was incurred by the swaying motion of the chimney.[349] Yet a further 24 lb plate had to be renewed on the chimney in the following month.[350] Repairs to the chimney ‘root’ had to be undertaken in October, together with the replacement of a 32 lb plate.[351] Repairs again had to be made to the chimney root in December.[352]

Only one entry is made regarding the chimney between 1839 and 1840. A 42 lb plate for the chimney had to be replaced in March 1839.[353]

It is most likely, in the absence of any further evidence, that *LOCOMOTION* retained its smokebox and centralised chimney when it undertook its work for the Merchandise department during 1846. It is further probable that it retained them when it was re-used as a steam boiler supplying steam for a pumping engine at Pease’s west Colliery between 1850 and 1856.

ARCHAEOLOGY

When the locomotive was brought back to Shildon in 1856 to be returned to an 1825 ‘look-alike’, Shildon Works would have removed the chimney, smokebox, boiler end-plates and return flue, and in their place would have fitted a single flue, replacement boiler end-plates, and the lower part of the chimney. This lower chimney was formed of a transition curve riveted to the flue, and a lower vertical chimney length as far as the exhaust pipe flanges. An upper chimney was added that slid over the upper ring of the lower chimney, to which it was bolted, for occasional removal to allow for ease of transport.

The chimney is 10 ft 3 in tall, and its top is 13 ft 1 in above rail level. The external diameter of the lower chimney is 18½ in. As the plates are ¼ in thick, the internal diameter is 18 in, 2 in more than it had been when last in service, and 7 in less than it had been when first built in 1825. The upper chimney (5 ft 7½ in high) is formed of three rings, each riveted to the outside of the ring beneath it. The lower ring slides over the lower chimney by 3 in. The external diameter of the uppermost ring is thus 20 in. It is retained in place by four bolts. The centre-line of the exhaust pipe flanges is 7 ft 1½ in above rail level.

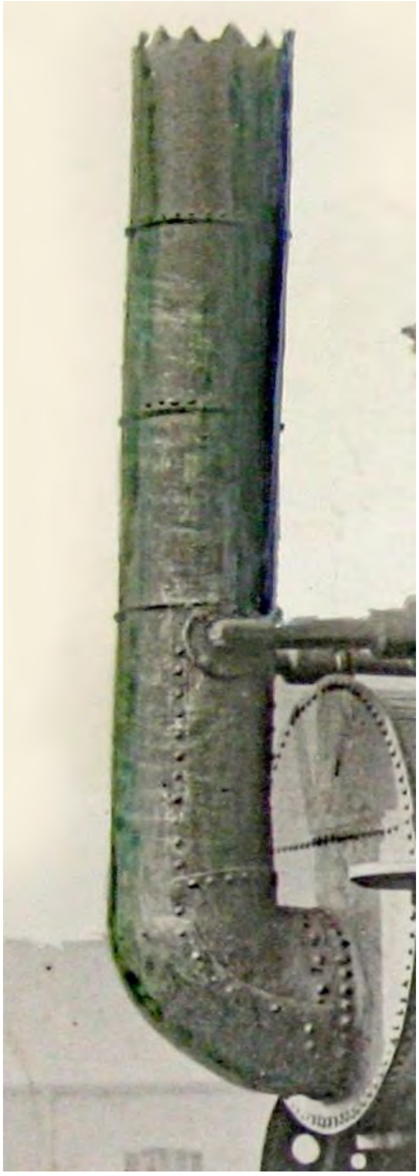


Fig. 16.5 1857 view of the chimney as first installed on to *LOCOMOTION* on the plinth at Darlington North Road Station [NRM, York HQ Photos, Box 9, 1065 & x35789]

Fig. 16.6 2022 view of the chimney

The lower chimney is formed of small pieces of previously used wrought iron plates, forged into shape and riveted together, rather than being formed from new in a pre-determined layout. Some plates are 3/16 in thick, and appear to have been part of a previous chimney, whilst others are ¼ in thick.

Fig. 16.7 Downward view of the rear vertical plate of lower chimney which has a circular patch covering a previous opening, possibly for an exhaust pipe flange.

The final plate to have been riveted in place in 1856 was a forward cover plate for the transition curve. This had a small opening, just below its upper edge, for access to the flue. In photographs taken in later years, this opening was covered with a patch which remained on the chimney until the restoration programme of 1961. After this restoration the patch and the hole it covered were no longer present.

In 1924 a bracket was riveted on to the front vertical plate in readiness for the centenary parade in the following year when it was used to carry the number '54' on a circular disc. The bracket remained in place through to 1961. It survived the initial restoration (Fig. 16.10), but a last minute change of mind belatedly saw it removed. Both the hole on the lower cover plate and the holes left from the leading bracket fixture were filled with an unknown substance and sanded smooth before repainting at Darlington North Road.

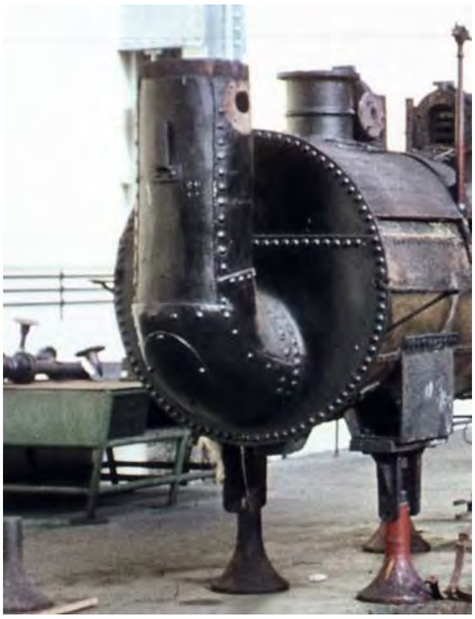


Fig. 16.8 Front view of lower chimney taken before restoration in 1961. [J.W. Armstrong Trust – 015]

Fig. 16.9 Front view taken during the recent survey.

The upper chimney was probably made new by Shildon Works in 1856/7. Its top ring has been decorated with fluting to aid its resemblance to how the locomotive probably looked when first made in 1825.

The chimney was in the open air during the locomotive's 35 years on the plinth at North Road station and would have deteriorated in the weather during that time. It is therefore probable that one or more of the plates have been replaced during one of the locomotive's periods of restoration in North Road Works. The most vulnerable plates were in the transition curve where rainwater tended to collect, leading to rusting. A small hole has been inserted into the underside of the transition underplate, no doubt to allow surplus water to escape and to provide a circulation of air to reduce moisture as far as possible.

In spite of this, it is noteworthy that the transition curve upper plate has been replaced at some stage, the surviving plate being slightly larger than the previous plate, through photographic comparison (Figs. 16.8 & 16.9). It is also likely that the upper chimney plates have been replicated at some stage, the surviving fluting being better defined than the 1857 example (Figs. 16.5 & 16.6).

On the inside of the upper part of the lower chimney, between the flanges of the two exhaust pipe inlets, an arched pipe has been fitted. This was probably recovered from the locomotive's pre-1856 chimney, where it would have received the exhaust steam which was then ejected out of the arch crown through a narrow orifice; a simple form of 'blast pipe'. The arched pipe is about 2 in too small in diameter for the surviving chimney and has been accordingly fitted with wide flanges.

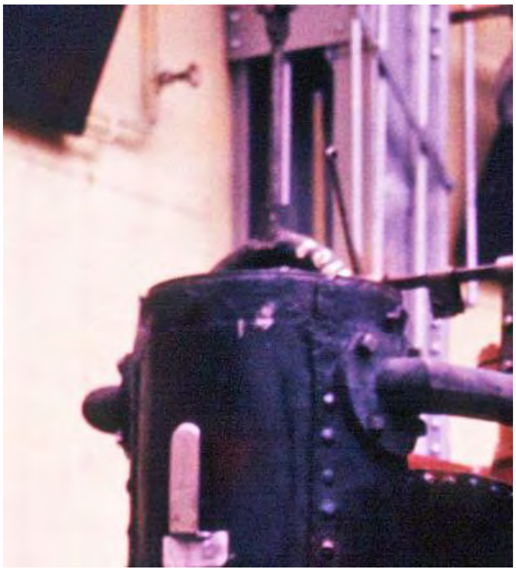


Fig. 16.10 Blast pipe seen during the 1961 refurbishment. [Fig. 8.30 – detail]

Fig. 16.11 Blast pipe seen looking down from the top of the chimney.

17. Cylinders and Valve-Chests

COMPONENT HISTORY

By 1825 the design of the cylinders and valve-chests on Stephenson locomotives had become standardised, building on the work of others. Firstly, Richard Trevithick (1771-1833) initially designed single-cylinder stationary steam engines, using cylinders fixed to, and partially immersed in, the boilers, as a natural solution to his aim to provide engines that were portable and compact. He then applied this monolithic construction to his locomotive engine designs. This approach was taken up by Matthew Murray (1765-1826) in his designs for two-cylindered (and therefore self-starting) locomotives for John Blenkinsop at the Middleton Colliery, Leeds.

Fig. 17.1. Notional drawing of Trevithick's *Catch Me Who Can*, 1808.

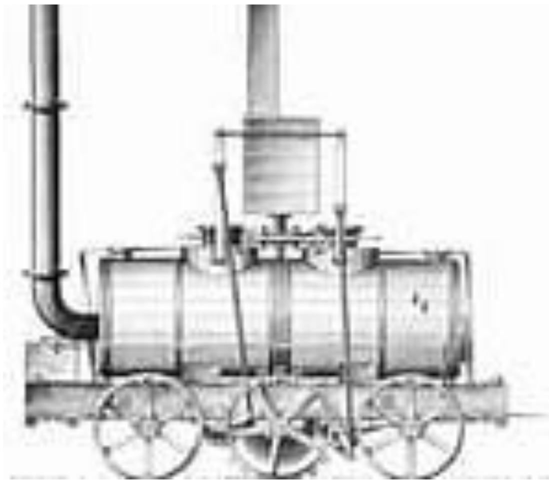


Fig. 17.2. Drawing of Murray's *Salamanca*, 1812.

George Stephenson followed this proven approach, which economically used the boiler, inevitably a strong structure, to carry the weight of, and the reaction forces from, the cylinders, rather than adding strong frames for this purpose. The resulting cylinder design was applied to the Killingworth-type locomotives from about 1814 to beyond 1825.[354]

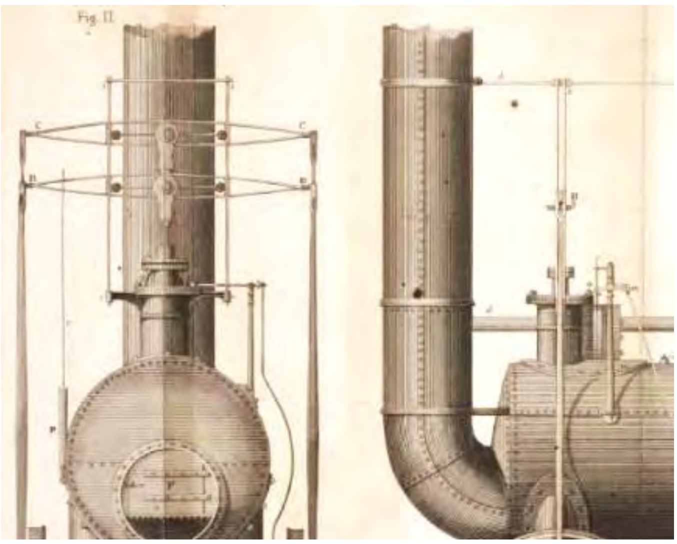


Fig. 17.3. Killingworth-type locomotive cylinder alignment.

[Nicholas Wood, 1825, Plate V – detail]

This standard design provided a cylinder bore of 9 in and a stroke of 2 ft.[355] The cylinder casting was provided with a flange for bolting it to the boiler. A single exhaust pipe connected to each cylinder casting ran along the side of the locomotive to an exhaust outlet in the chimney. The valve-chest was bolted, via flanges, to the side of the cylinder at its top to allow most of the cylinder to be immersed in the boiler. There would however have been minor variations, of which the most significant would have been in the length of the cylinder casting itself. This length would have been determined by the 2 ft stroke, the thickness of the piston, probably 4½ in, and the required piston end clearances.

If, as argued in Section 20, *Active* was originally fitted with fixed axle bearings at the front and a pivoting axle at the rear, then the end clearances need not have included an allowance of perhaps 2 in for vertical movements of the axles. A nominal end clearance of ¾ in at each end, would have given a required free bore length of 30 in. This would have been some 2 in shorter than required on the Killingworth-type locomotives. Another example is the immersion length of the cylinder inside the boiler, which would have depended on the space available within the boiler, between the top of the flue and the top of the boiler, which in turn depended on the diameters of these components. Similarly, it would be expected that the curvature of the flanges for bolting the cylinder and valve-chest to the boiler would have matched the diameter of the latter.

Sections 1 and 18 argue that *Active* was originally fitted with slide-bars, rather than parallel motion, to guide the piston rods. Such slide-bars are shown in Fig. 17.3, and their use required the addition of 'ears' either side of the cylinder top flange to locate them. These 'ears' can be seen in the end view.

From the foregoing, it would be expected that the original cylinder castings were similar to those surviving, but with a bore length, allowing for the top cover spigot insertion, of 30 to 31 in, giving a cylinder casting length of between 31 and 32 in, of which about 17 to 18 in was below the boiler crown, leaving about 13 in above the boiler. The bore would have been 9 in, but with sufficient material to allow boring out to perhaps 10 in. The casting top flanges would have had 'ears' for the attachment of slide-bars. The bottom internal flanges and covers would have been as shown in the scrap view in Fig. 17.4, based on those currently seen on Killingworth *Billy*.[356]

The surviving cylinders, while generally conforming to the standard pattern, differ from the latter in two significant areas. The first is that there are two steam exhaust routes on each cylinder, one either side, and the second is that there are no 'ears' for the attachment of slide-bars. The twin exhaust routes would have been required on a locomotive fitted with twin chimneys, and Section 3 explains that No.1 had twin chimneys between 1828 and 1834, so it is very likely that the surviving cylinders were fitted in 1828 and retained during the subsequent re-builds. The absence of 'ears' indicates that No.1 was fitted with parallel motion to guide the piston rods at the same time. The provision on the valve-chests of features for the attachment of the columns to support and locate valve-gear components and the parallel motion, shows that the valve-chests must also date from 1828.

The cylinder castings have been damaged and repaired (see below) but originally the surviving cylinder castings would have been about 33½ in long, around 2 in longer than those installed in 1825. This would have been to provide additional end clearances to allow for the vertical movement of the axles with the spring suspension installed in 1828 (Section 11). Of this length, about 19 in are below the boiler crown, which is about 2 in more than in 1825. This increase was acceptable in 1828 because the increase in boiler diameter to 4 ft 6 in left plenty of room above the central flue. The 1834 re-build with a 4 ft diameter boiler avoided a clash between the cylinder bottom and the flue by placing the main flue to one side, with the smaller return flue along the other side. However, the surviving central 24 in diameter flue had to be fitted very low in the 4 ft diameter boiler during the restoration at Shildon Works in 1857, leaving a minimal clearance between it and the bottom of the boiler (Sections 13 and 14).

The repairs to the cylinders raised the bottoms of the bores, which reduced the free bore length by about ¾ in. Assuming that the allowance of 2 in for axle-box movement was still required, this would have reduced the end clearances to a minimum of ⅜ in. This would have resulted in the piston covering the top steam passage at the top of its stroke, thereby slightly, but acceptably, delaying the start of the power stroke.

The maintenance records for the years 1837 and 1838 do not include many entries relating to the cylinders. Entries include: May 1837: "Men's time .... fitting and fixing bolt for cylinder top ... ", November 1837: "Men's time ... filing and fitting up new cylinder cover and gland … " and September 1838: "Men's time ... bushing the piston glands ...".

The National Collection includes a decorated valve-chest cover that is stated to be one of *LOCOMOTION*'s original valve-chest covers that was replaced prior to the 1875 Jubilee.[357] The cover has been cast with a flower symbol, but its representation has not been identified. The cover has broken edges, but measurements indicate that it would have been of the right size to fit the surviving valve-chests, and possibly those on *Active*.

Fig. 17.5. Decorated valve-chest cover.

[Displayed at Head of Steam Museum, Darlington]

ARCHAEOLOGY

Cylinders

The cast-iron cylinders (Fig. 17.4) are located on the boiler crown with their centres 61¾ in apart, the centre of the front cylinder being 27½ in from the very front of the boiler and the centre of the rear cylinder being 34 in from the very back. Both cylinders have been bored out to 10⅛ in diameter. The outer diameters are 11⅞ in, leaving wall thicknesses of ⅞ in. The rear cylinder casting is now only 31¾ in long, having lost 1½ in in the accident discussed below.

At the top, each cylinder has a 1 in thick flange with an external diameter of 15¼ in, with a ¼ in high and ⅞ in wide circular upstand above this, for sealing the cylinder bore to the top cover. The cylinders have vertical humped protrusions running from top to bottom to contain the steam passages. These passages are 4 in by ⅞ in section and enter the cylinders at top and bottom. The top of the bottom entry is 31½ in below the top of the upstand and the top opening is 1¼ in below this level.

Fig. 17.6. Front cylinder top flange with upstand.

Fig. 17.7. Front cylinder top steam passage.

These passages curve round to enter the port-face via steam ports 4 in wide and ⅞ in high, these ports being separated by 3¼ in. The port-face itself is 7¼ in high and 6 in wide. Midway between the steam ports is a further 1 in high port leading to the exhaust routes. These exhaust routes curve round both sides of the cylinder bore to exit via 3½ in diameter stub pipes terminating in 8½ in diameter flanges either side of the cylinder casting, for connection to the exhaust pipes (Section 21). Each port-face is surrounded by a shallow recess which in turn is partially surrounded by a flange. This flange rises from the boiler attachment flange (see below) on each side of the recess to an arch at the top. The flange is ¾ in thick and 3½ in wide, with a width across the flanges of 13½ in. The top of this arch is 1¼ in above the cylinder top flange and its back face is only 7 in from the cylinder centreline, requiring the top cover to be cut along a chord (see below).

Fig. 17.9 Front cylinder left side exhaust flange and flange for bolting to boiler.

Fig. 17.8 Rear cylinder port-face, within valve-chest and partly behind slide-valve. Slide-valve abnormally raised to show bottom steam port.

This flange is bolted along its sides and top to an identical flange on the separate valve-chest casting, which also has a boiler attachment flange. The locations of these six ¾ in bolts are constrained by the valve-rod gland housing (see below) and the two stub exhaust pipes, only leaving space for a bolt either side of the former and above and below the latter. There are no bolts joining these two castings at the bottom, where their boiler attachment flanges butt together. This was a feature of the 'standard' Killingworth-type design and appears in the other remaining early locomotive of this type, Killingworth *Billy*.[358]

Fig. 17.10 Valve-chest attachment flanges on rear cylinder.

Fig. 17.11 Front cylinder bolting-down flange.

The cylinders are bolted to the boiler via flanges, each using seven ¾ in bolts at a 6⅝ in pitch. These flanges are generally rounded at a 10½ in radius and 18½ in long in plan view (Fig. 13.2), The bottoms of the flanges are curved to suit the boiler shell and the flanges themselves are 1 in thick at their edges increasing to 1½ in at the cylinder barrels. The flange bolting faces at the boiler crown are 13¼ in below the tops of the cylinder castings.

The mode of construction of the boiler shell (Section 13) placed a line of rivets along the edges of these flanges on both sides. The end view (Fig. 17.4) shows that this left a gap of up to 1 in thick to be filled by a gasket compound. The make-up of the compound is unknown but may be similar to a compound, later used in America for these purposes, made from red lead, white lead, iron filings and boiled turpentine,[359] and it is expected that a similar compound was used on *LOCOMOTION*. The compound hardened to give a seal that was strong in compression and reliable. The compound had a widespread use on these early locomotives; it particularly avoided the need for machining or fettling cast components where they were to be joined. Its ability to provide thick layers meant that it could absorb minor dimensional errors in a design that was anyway tolerant to them.

The use of the compound meant that the only machining required on the cylinder castings was in the bores and on the top surfaces of the upstands. The port-faces would have required fettling.

At some time after 1828 the rear cylinder suffered a major accident, which resulted in the bottom (internal) cylinder flange being broken. It is likely that this was the result of a failure in the drive to the rear axle, perhaps a crank-pin failure, in which event the steam pressure would have accelerated the piston and crosshead to impact the flange forcefully. The cylinder was repaired (Figs.17.4 and 17.12).

Fig. 17.12. In-service repair to bottom of rear cylinder.

The obvious strength of the four tie-bars from the clamping ring to the replacement cylinder bottom cover indicates that the repair relied on more than friction to hold the clamping ring in place and the salt deposits on the surfaces indicate that the locomotive remained in-service for a considerable period afterwards. It is therefore suggested that the clamping ring has internal studs located in shallow holes in the cylinder wall, in which case the repair could have withstood the operating steam pressure.

This repair contrasts with a similar one on the front cylinder. Here the two tie-bars are slimmer and there are no salt deposits on the clamping ring, etc., indicating that the repair was made after *LOCOMOTION* was taken out of service. It is possible that, in preparation for steaming the locomotive during the 1875 'Jubilee' celebrations, it was found that the cylinder bottom flange was damaged and had to be removed. The repair, which provides a bar to hold a new spigotted bottom cover in place, was made on the basis that it only had to carry the very low pressure necessary to rotate the raised wheels.

Fig. 17.13. Post-service repair to bottom of front cylinder.

Cylinder covers

The cylinder top covers are dissimilar but still interchangeable. Both are of 15¼ in diameter with a straight cut along a chord 14½ in from the opposite side of the cover, thus removing a ¾ in wide piece. Each cover has five holes at 7¾ in centres for ¾ in bolts. The flange thicknesses are ⅞ in (front) and 1 in (rear), with spigot diameters of 10⅛ in (front) and 9¾ in (rear) and spigot depths of only ⅝ in (front) and 1 in (rear). Each cover spigot has a hole, normally closed by a screw, for the introduction of lubricant. The heads of the screws (again of different patterns) are made for turning with tommy bars. The stuffing boxes are also dissimilar, the front one having a 3 in bore and the rear a 3⅜ in bore. There would normally be a 1⅝ in diameter hole for the piston rod below these bores, but these holes have been bored out so that bronze bushes could be fitted that fill the stuffing boxes and run through to protrude some ⅞ in into the top of the cylinder bore. It is very likely that these bronze bushes were fitted in preparation for the 1925 Centenary parade, when *LOCOMOTION* was propelled by a petrol engine in the tender.

Fig. 17.14. Front cylinder top cover.

Fig. 17.15. Rear cylinder top cover.

Externally, the front stuffing box rises 3¾ in at 3⅝ in diameter and then increases to 6⅝ in diameter to provide a circular flange ⅞ in thick. This flange has two ¾ in diameter holes at 4⅞ in centres for securing the gland. The rear stuffing box rises 3½ in above the flange at 5 in diameter and then increases to form a flange 5¼ in diameter and 1⅜ in thick, with two lugs with a ¾ in diameter hole in each, the holes being at 6¼ in centres, for tightening the gland. The glands themselves have flanges to match those on the stuffing boxes and have been bored for further bronze bushes. Fig. 17.4 shows the rear top cover before these late alterations were made.

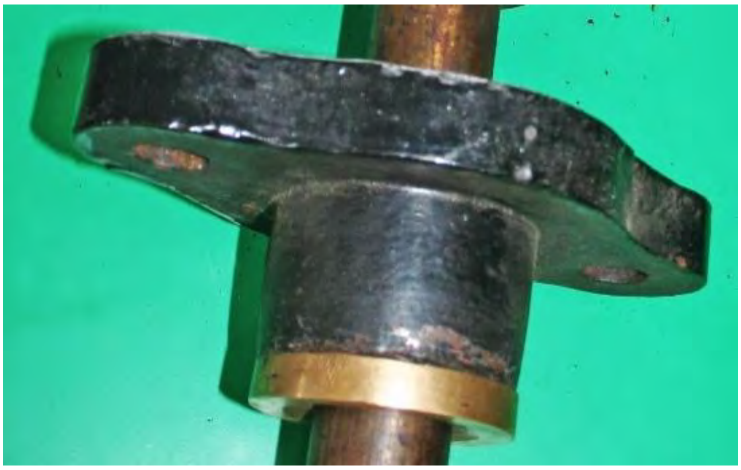


Fig. 17.16. Rear cylinder bushed gland with bronze bush

The cylinder bottom covers are replacements. Both cylinders seem to have lost their internal flanges and the replacement bottom covers spigotted into the cylinder bore. The heights of these spigots are such that the bottom steam passage would have been masked if the spigot edges had not been cut away locally (Fig. 17.4). The method of securing the replacement bottom cover on the rear cylinder is robust. Externally, the bottom cover is 3¾ in thick, with four equally spaced lugs supported by ¾ in diameter tie-bars suspended by a 1¾ in by ¾ in clamping ring (Fig. 17.12). This ring is in three pieces, one covering a semicircle, with a tie-bar supporting stub at mid-length, and two symmetrical quadrant pieces which curve round the steam passage protrusion. The bolts connecting these three pieces also carry the remaining three tie-bars. The replacement bottom cover on the front cylinder (Fig. 17.13) is held in place by a 2 in by ¾ in bar (approximately) running beneath it, the bar being supported at each end by a tie-bar suspended from a light two-piece clamping ring.

Valve-chests

The two valve-chests are identical with an overall length of 3¾ in. They are attached to the cylinder castings via flanges ¾ in thick, as described above. At the opposite ends they have smaller flanges for the attachment of the covers. This includes flanges running across the tops of the boiler attachment flanges. The tops of these flanges are 1 in below the flanges for the cylinder and the flanges themselves enclose a space 8 in high to the top of the arch, and 6¼ in wide. These flanges are generally 2⅝ in wide and are ¾ in thick. Five ¾ in diameter studs are screwed into each of these flanges for the attachment of the covers.

Fig. 17.17. Rear valve-chest, including side protrusions for the attachment of columns.

Either side of these flanges are vertical protrusions of 1⅝ in square section in plan view. These protrusions are 11¾ in apart and originally extended above the valve-chests as short square columns, to which wrought iron columns are bolted to support valve-gear components (Section 20). Three of the four such extensions have broken off at their tops, leaving them some 2¾ in short. The undamaged extension is on the right-hand side of the rear valve-chest.

Each valve-chest has a stuffing box rising 1 in above the cover flange at an external diameter of 2½ in, before broadening to 5¼ in to provide two lugs each 1 in thick and with a ⅝ in diameter tapped hole for securing the gland. Internally the stuffing box is 1¾ in bore above a hole ¾ in diameter for the valve rod. The gland is of a similar shape in plan to the top of the stuffing box, with lugs ⅞ in thick. In the absence of any packing material, two thick washers have been placed under the bolt heads.

Fig. 17.18. Rear valve-chest stuffing box.

Each valve-chest is bolted to the boiler via a separate flange that in plan view is a continuation of the cylinder boiler attachment flange (Fig. 13.2). The valve-chest flange is similarly bolted to the boiler with the extensive use of the gasket compound. Two ¾ in bolts are used, with square recesses in the flange so that the bolt heads are not visible.

Each valve-chest extends downwards to provide a steam passage, probably fan-shaped in section, from the regulator system in the boiler (Section 22) and through the boiler attachment flange into the valve-chest. The passage terminates about an inch below the boiler crown. The exact arrangement of this function is not clear, being obscured by later modifications (Section18), which include the insertion of a plate into the bottom of each valve-chest, but it is likely that the passages are similar to those on Killingworth *Billy*.

Fig. 17.19. Steam passage from boiler to bottom of valve-chest on Killingworth *Billy*.

The cast iron valve-chest covers are identical except that the cover on the front chest has a ridge for locating it in the valve-chest opening and is broken at the bolt holes in the bottom corners. A narrow plate, with bolt holes at each end and placed across the bottom of the cover, is used to retain it. These covers are profiled to match the adjacent flanges on the valve-chests and are curved at the bottom to match the boiler attachment flange curvature. They are 11½ in wide and ¾ in thick. The covers have central holes 1⅝ in diameter surrounded by three ⅝ in diameter tapped holes for the attachment of the steam supply pipework for the 1875 'Jubilee' celebrations. All these holes are now plugged. With the use of the gasket compound, the only machining required on the valve-chest castings was the drilling of the holes for the valve rods and the boring out of the stuffing boxes.

Fig. 17.20. Front valve-chest cover, showing locating ridge, broken bottom corners and plugged holes.

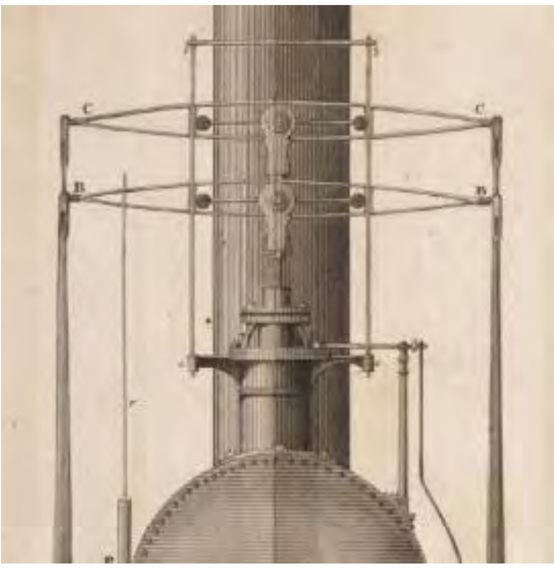
Fig. 17.21. Back of front valve-chest cover, showing retaining plate in bottom left corner.

18. Pistons, Crossheads and Parallel Motion

COMPONENT HISTORY

In 1825 the pistons would have been 9 in diameter and about 4½ in thick, fixed to their rods with broad cotters and packed with hemp. The hemp would have swelled in the condensate to give a good seal initially but becoming less effective as the fibres escaped into the cylinders. The first use of brass piston rings was in the spring of 1826, when George Stephenson enquired of Timothy Hackworth "How do the brass pistons answer?".[360] The brass rings were themselves packed with hemp in the early years of operation but the hemp was gradually replaced by springs to keep the rings steam-tight.[361] These springs acted radially and could be adjusted to maintain an adequate pressure between the rings and the cylinder bores.

The piston rods and clevises would have been much as they are at present. The contemporary Killingworth locomotives used very light crossheads, of wrought iron frames and it is possible that *Active* was also initially fitted with these. However, it seems more likely that cast iron crossheads were fitted. The early sketch by George Stephenson shows this form, which is not contradicted by the later pre-production drawing (Fig. 1.2).



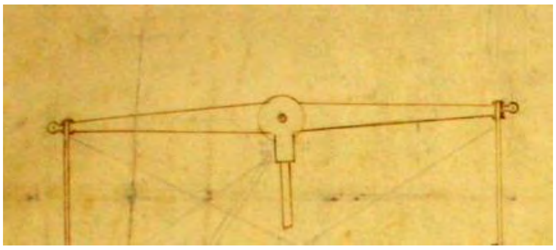


Fig. 18.2. George Stephenson's sketch, showing cast iron crosshead. [Fig. 1.1 – detail.]

Fig. 18.1. Killingworth locomotive crossheads and slide-bars. [Wood, 1825, Plate V – detail.]

Section 1 argues that *Active* was originally fitted with slide-bars rather than parallel motion. Such slide bars are shown in Fig. 18.1. They appear very slim. This is also evident with the Mount Moor locomotives of 1826, where the slimness survived until the photograph of its No.2 was taken by Bleasdale in 1862. It is estimated from scaling these views that the bars were only about ¾ in square in cross-section, with piston rods at 1⅝ in diameter.

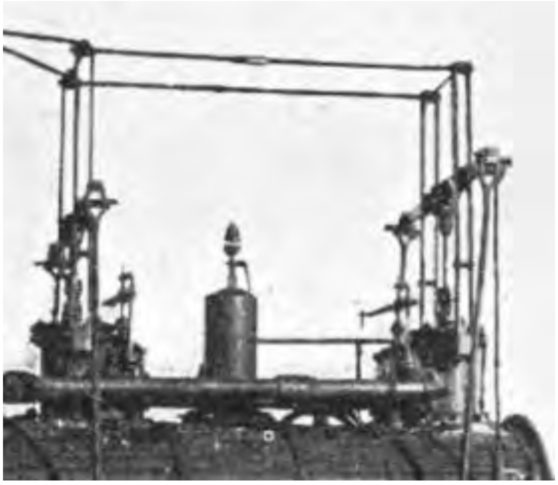


Fig. 18.3. Slide-bars on Mount Moor Colliery locomotive. [Fig. 1.4 – detail.]

Parallel motion was probably fitted to No.1 in 1828 (Section 4). It is not clear whether the surviving parallel motion (Fig. 18.4) is that fitted in 1827 or during the 1834 re-build. According to the 1834 valuation,[362] "the outside shell of the boiler and some of the Rods, belonging the parallel motion and connecting rods" from *DILIGENCE* were available at that time, and Section 13 argues that this boiler was used in the 1834 re-build. It is therefore possible that the surviving parallel motion dates from 1827, when *DILIGENCE* was built, although measurements taken during the survey do not confirm this. The 1827 report by Von Oeynhausen and Von Dechen[363] states that the early S & D R locomotives (which would have included *DILIGENCE*) had 'half-beams' 33¼ in long and 'counter-rods' (radius rods in Fig. 19.4) 15 in long. Those on *LOCOMOTION* are around 27 in and 7 in long respectively.

The pistons are now missing and the gland packing has been replaced by bronze bushes (see below). It is likely that this was undertaken in preparation for the 1925 Centenary parade when *LOCOMOTION* was propelled by a petrol engine in the tender. Modifications made before the 1875 'Jubilee' celebrations included the insertion of stanchions between the bottoms of the valve-chests and the flue (Section 22). These had a jacking effect so that the cylinders are now not vertical. This distortion of the boiler shell could have upset the parallel motion (see below) and it is likely that the simplest solution in 1925 was to remove the pistons.

Maintenance records for the years 1837[364], 1838[365] and 1839[366] contain many entries covering this equipment. Typical repairs include: March 1838: "Men's time ... repairing piston rod, fitting and fixing on a new arbour for radius rods … ", November 1838: "Men's time … taking out piston rod, straightening and putting same in … ", April 1839: "Men's time repairing crosshead, taking out, straightening and putting in piston rod, … ", October 1838: "Men's time repairing ... cylinder cover.... repairing the motions & fitting in new motion brasses ... ". In all, there are nine entries covering repairing, replacing and, most often, straightening piston rods and seven entries concerning repairs to the parallel motion (including replacing the brasses three times) over an eighteen-month period. The way in which the piston rods interacted with the parallel motion is discussed below.

ARCHAEOLOGY

Pistons, rods and crossheads

The pistons are missing, the piston rods having been sawn through, probably before the 1925 Centenary parade. A guide on their appearance is provided by an illustration in the 1924 British Empire Exhibition booklet.[367] Although not clear, it appears to show a central section, fixed to the piston rod with a broad cotter, and possibly containing springs for pressing the rings (not shown) against the cylinder bore, with a bottom plate held in place by a large nut, and a removable top plate, possibly for access to adjust the springs.

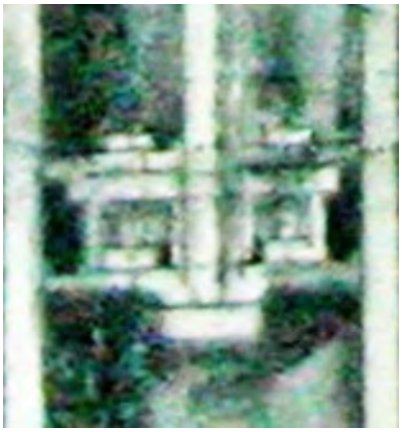


Fig. 18.5. Extract from the British Empire Exhibition booklet. [LNER, 1924, pp.12/13]

The wrought iron piston rods are 1⅝ in diameter, however their original lengths are not known. The top of each rod is secured in a cast iron clevis by a split cotter. Where the piston rod enters it, the clevis is 4⅛ in diameter, but it is necked down to 3 in diameter for 1½ in where the cotter fits. This split cotter is 7½ in long, ⅜ in thick and 1⅞ in wide at its head. The clevis is 6½ in long from the bottom to the centreline of the gudgeon pin, which is 1¾ in diameter with a 2½ in diameter head. The gudgeon pin is retained by a split pin.

Fig. 18.6. Clevis on front piston rod.

Fig. 18.7. Spherical joint at end of crosshead on Killingworth *Billy*, very similar to those on *LOCOMOTION*.

The gudgeon pin passes through a hole in the crosshead which has raised bosses on both sides to give an overall thickness locally of 2 in. Elsewhere the crossheads are 1¼ in thick and 5 in high at their clevises tapering down to 2 in high and then widening to 2 in diameter near their ends. The ends of the crossheads are formed into 2 in diameter spheres to work within the connecting rod top bearings, similar to those employed on Killingworth *Billy*. The centres of these spherical ends are 67½ in apart across the locomotive. The necks at these spherical ends are only 1¼ in diameter to carry half the piston load. It is likely that fatigue failure at a neck occurred occasionally and caused significant damage to the related cylinder (Section 17).

The rear crosshead has a ½ in square hole located on the right-hand side, 27¾ in from the piston rod centreline. It is very likely that this enabled the connection of a rod to drive a feed-pump set vertically at the side of the boiler (Section 23). At the time that this hole was used the associated boiler must have been no larger than 4 ft in diameter, otherwise the pump-rod would not have fitted past the side of the boiler.

Fixtures are clamped to the right side of the front crosshead for the top bearings of a rod connected to the lever that operates the feed-pump (Section 23).

Fig. 18.8. Square hole in right side of rear crosshead.

Fig. 18.9. Drive to feed-pump clamped to front crosshead right side.

Parallel motion

Each part of the parallel motion consists of three links (Fig. 18.4), the ‘oscillating pillars’ (or ‘swinging links’, in blue), the ‘half-beams’ (in green) and the ‘radius rods’ (in red), all made from wrought iron. There are two sets of linkages for each crosshead, operating either side of the cylinder.

The principle of this form of parallel motion is that the half-beams, which were pivoted on the crosshead at one end, would have described arcs of a circle if their other ends rotated on fixed pivots. To correct this, the radius rods forced points along the half-beams to describe 'counterbalancing' arcs in the opposite direction. To allow this, the ends of the half-beams remote from the crosshead had to be allowed to move sideways, and this was provided for by pivoting them on the tops of long vertical swinging links that could themselves pivot at their base. The performance of the motion surviving on *LOCOMOTION* is discussed later.

The swinging links are 1 in by ⅜ in section and are 41¼ in long between the bearing centres. At their lower ends they rotate on cross-shafts held in bearing frames attached to the boiler barrel. The cross-shafts are ⅞ in diameter, the spacing of the links across the boiler is 18½ in and the separation of the bearing centres in each frame is 6 in. The bearing frames themselves are 12 in long, with a general cross-section of only ½ in square, widening to 1¼ in at their ends.

Each pair of swinging links is cross-braced with 1 in by ¼ in bars forged together at their mid-points. Fig. 18.11 shows that the front cross-bracing is distorted towards the right-hand side in this view.

Fig. 18.10. Swinging link bearing frame bolted to boiler, with pivots for both front and rear linkages.

Fig. 18.11. Rear right swinging link on very left of view, with cross-braces for both sets of swinging links meeting at forged joints at lower centre, looking towards the rear.

At their tops, each pair of swinging links is joined by another ⅞ in diameter cross-shaft, which extends either side to provide pivots for the ends of the pair of half-beams. These half-beams extend from these pivots to pivot pins attached to the crossheads and carry adjustable bronze bearings for the ends of the radius rods.

Fig. 18.12. Pivots for rear left half-beam; that for the top end of its swinging link in left foreground and that for its connection to the crosshead in right background.

At the swinging link ends these half-beams are ¾ in diameter tapering up to 1 in diameter at the radius rod bearings and then tapering down to ¾ in diameter at the crosshead bearings. The centre distances from the swinging links to the radius rod bearings are 10½ in for the front mechanism and 10 in for the rear, while the centre distances from the radius rod bearings to the crosshead bearings are all 17 in. The half inch difference has a significant effect, as discussed below.

At their crosshead ends the half-beams carry bronze bearings that rotate on pivots extending sideways from cast iron blocks bolted to the crossheads (Fig. 19.12). 1 in diameter studs in the blocks pass through the crossheads and are secured by nuts at the back. These blocks hold the pivot centrelines 1¼ in from the front crosshead surface and 1½ in from the rear crosshead surface.

The radius rods are 7 in long between the bearing centres. They are of rectangular section, being ¾ in thick and 1⅝ in wide at the boss ends tapering down to 1 in wide at the bearing pin ends. The rods have 1¾ in diameter bosses 1⅜ in wide at their bearing pin ends. The pins themselves are 1 in diameter and 1½ in long within the bearings.

At their other ends the radius rod bosses, at 2¼ in diameter and 1⅜ in wide, are keyed to the ends of 1½ in diameter cross-shafts, 19¼ in long. These keys are ¾ in wide on the rear radius rods but only ½ in wide on the front radius rods. These keys would have resisted relative rotation of the radius rods, necessary to allow the crosshead to tilt to follow vertical movements of the wheels on an uneven track.

Fig. 18.13. Bearing on rear left half-beam for radius rod, and radius rod itself.

These radius rod cross-shafts are carried in bearings inboard of the radius rods, the bearings being supported by wrought iron columns bolted to extensions of the valve-chests (Sections 17 and 20). These columns are interconnected fore and aft by ¾ in diameter diagonal bracing rods (visible at the sides of Fig. 18.11), forged together where they cross.

Fig. 18.14. Bearing for left rear radius rod.

Discussion

The slide-bars on *Active* guided the piston rod against transverse loading at the crosshead due to the angularity of the connecting rods, and the maximum transverse loading (occurring at mid-stroke) under a typical cylinder pressure of 25 psi (Section 27) would have been about 200 lb, or 100 lb per slide-bar. Even with a totally flexible piston rod, this would have resulted in a maximum sideways deflection of a ¾ in square slide-bar, 30 in long and fixed at its ends, of only 0.02 in. The piston rods at 1⅝ in diameter were actually very strong and stiff, being able to carry transverse loads from the crossheads of at least 330 lb at mid-stroke without permanently bending and without any guidance at all. This load corresponds to a cylinder pressure of 42 psi with a nine-inch piston, much more than the pressure in normal operation. This indicates that the main purpose of guide bars was to prevent excessive wear at the piston rod glands, etc., rather than to protect the piston rods.

Turning to the Freemantle parallel motion, the particular form fitted to *LOCOMOTION* is a compromise. Ideally, the motion should consist of a half-beam free to slide horizontally at one end, with the other end pivoted on the crosshead, and a radius rod of half the length of the half-beam, with a fixed pivot at one end, the other end pivoting halfway along the half-beam. The straight-line motion would then be at right-angles to the line joining the slide with the radius rod fixed pivot. However, this geometry would have been impracticable because it would have required the radius rod fixed pivot to be in the path of the crosshead.

In the event, the most practicable solution was judged to be to pivot the radius rods above the columns supporting the valve-gear components (Fig. 18.4). This brought these pivots nearly 12 in from the optimum position, which required the radius rods to be shorter than their optimum length. In addition, it was common practise to use long swinging links in place of the slides to allow the horizontal movement of the ends of the half-beams. The sideways movement of the tops of these links would have lowered their top pivots marginally; however, the effect has been shown to be negligible.

Assuming that the fixed pivots for the swinging links remained fixed in space along with the fixed pivots for the radius rods, the errors in linearity of the crossheads with the surviving geometries have been calculated as follows. In the table a positive error is in the direction away from the other cylinder. The error has been intentionally set to zero at bottom dead centre, because otherwise the motion would have seized. It is assumed that the mechanism was adjusted by the insertion of packing behind the crosshead pivot blocks (Figs. 18.3 and 18.11) to achieve this.

Position of piston	Front cylinder error (in)	Rear cylinder error (in.)
Bottom dead centre	0	0
¼ stroke	0	+0.12
½ stroke	+ 0.03	+ 0.18
¾ stroke	0	+0.12
Top dead centre	0	0

The results for the front cylinder show that it was possible to achieve good linearity with this compromise geometry, if the above assumption held. To check this, an indicative analysis estimated that the top of the boiler local to a cylinder could have been lowered or raised by around ⅜ in under a reaction force of 2000 lb from the cylinder. Such a force would have resulted from its 10 in diameter piston being loaded by a typical pressure of 25 psi (Section 27). During a wheel revolution both pistons will have been acting in the same direction for half the time and in opposite directions for the other half. The resulting distortions of the boiler crown are indeterminate but might have led to situations where the bottom pivot of a swinging link moved vertically relative to the valve-chest, and hence the return crank pivot, by, say, ⅜ in. With the nominal horizontal separation of these two pivots of 15¾ in, this would have led to the motion trying to force the crosshead to follow a path about 1.5° from the vertical in either direction. Over a 2 ft stroke, this could have led to errors of ¼ in or more potentially adding to those tabulated above. Although the motion assembly had been stiffened up by the extensive cross-bracing, this could not have encompassed the bottom bearings of the swinging links. Thus, these sorts of errors could have persisted.

There is a clear contrast between the parallel motion surviving on *LOCOMOTION* and the slide-bar arrangement on *Active* and other early locomotives (Fig. 18.2) in the massiveness of the former and the lightness of the latter, with its slim slide-bars and minimal bracing. This contrast is emphasised by the fact that transverse loads from the crossheads would have placed the half-beams and radius rods in compression or tension, rather than bending, and in theory should have been satisfied by very slim components, less than ½ in diameter. However, 1 in diameter components (or equivalent) have been fitted. Only the swinging links, at 1 in by ⅜ in section, and their bearing frames attached to the boiler, retain the lightness expected of the entire mechanism.

It seems that the slide-bars merely guided the crossheads whereas the parallel motion was sized to force a crosshead to follow a particular path, despite the stiffness of the piston rod. If this path was not along the cylinder centreline, something had to give. An error of 0.18 in at mid-stroke (as above) could have imposed a sideways load on the top of the piston rod of 150 lb causing a sideways force on the top cover and gland of over 500 lb. As a consequence, rapid wear at the latter location would have occurred. Two entries in the above maintenance records for the 18-month period between 1837 and 1839 cover bushing the piston rod glands and similar, are a probable result of this. Additionally, the forces would have caused rapid wear in the motion bearings, and three entries in the 18-month period relate to renewal of these bearings. Much larger misalignments or seizure of the radius rod bearings would not have been resolved so easily; hence the thirteen entries covering work to replace or straighten piston rods or repair the parallel motion.

The thinking behind fitting such a robust parallel motion given the stiffness of the piston rods, where any error would have forced them to 'fight' each other, is not understood, but it must be assumed that thirteen years of experience and design evolution did not resolve the problem. The fact that the half-beams are at their strongest at their connections with the radius rods indicates that bending of the former, perhaps due to the inability of the latter to rotate independently when the crosshead tilted, might have been part of this experience. These issues could well have contributed to the initial problems with Nos.2 onwards that led to the S & D R Directors requiring that there should be no new locomotives with 'new and experimental apparatus' (Section 1). Of course, the absence, from 1828 onwards, of 'ears' on the cylinder top flanges for attaching slide-bars meant that the S & D R had no choice but to continue with the parallel motion.

19. Connecting Rods, Coupling Rods and Cranks

COMPONENT HISTORY

Connecting rods on early Killingworth locomotives were about 9 ft 6 in long between centres, about 1 in diameter (or less) at their ends, swelling to about 2 in diameter at their mid-lengths (scaled from Fig. 19.1).[368]

The rod ends were forged into closed 'eyes' to contain the bearing brasses, which were retained by double cotters. A similar design survived on the Mount Moor Colliery locomotive until at least 1862, except that 'eyes' were of a curious elongated shape, again with the brasses at the extremity of the 'eyes'. The 1821 Killingworth locomotive is also shown with this type of bearing 'eye'[369]. It is therefore very likely that *Active* was originally fitted with connecting rods of one of these designs, but shorter since *Active*'s boiler was mounted lower.

Fig. 19.1. Front connecting rod on early Killingworth locomotive. [Wood, 1825, Plate V – detail.]

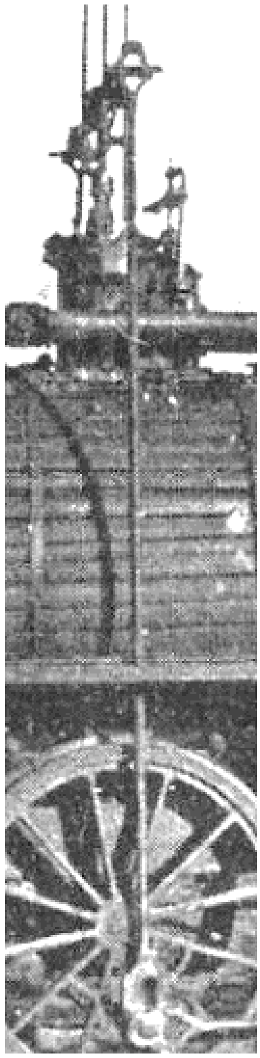


Fig. 19.2. Front connecting rod on Mount Moor Colliery locomotive. [Fig. 1.4 – detail.]

It would be expected that the connecting rods fitted in 1828 would have been more robust than the original rods to allow for the increased piston thrust resulting from the near 25% increase in piston area with the cylinders installed at that time (Section 17).

The coupling rods on the Mount Moor Colliery locomotive are also of an early slim design and are similar to the connecting rods in having closed 'eyes' at the front ends, but they have separate stepped straps at the rear ends. The coupling rods fitted to the Killingworth locomotives a few years later remained slim, and had separate straps, with gibs and cotters, at both ends to retain the very narrow brasses. Again, it is very likely that *Active* was originally fitted with one of these two designs of coupling rods, but shorter to suit the shorter wheelbase.

The design of coupling rod fitted in 1828 is not known. It is unlikely that *Active*'s original rods were retained; again because more robust ones would have been needed, and it is possible that the surviving coupling rods were fitted then.

The locomotive design concept provided a cylinder to each axle but required the connecting rods to operate at 90° to each other and this compelled the use of return cranks. On the Mount Moor Colliery locomotive these are straight and are on the front right and rear left wheels, whereas the return cranks added later to the Killingworth locomotives were curved and on the front left and rear right wheels. The return cranks fitted to *Active* were probably similar to the former. The design of the crank pins and return cranks fitted during the re-builds in 1828 and 1834 is not known, but the early form of two-piece wheel in 1826 had 2¾ in diameter holes for the crankpins, with keyways.[370] The surviving crank pins and return cranks would have been fitted in either the late 1830s or in 1856 (Section 10).

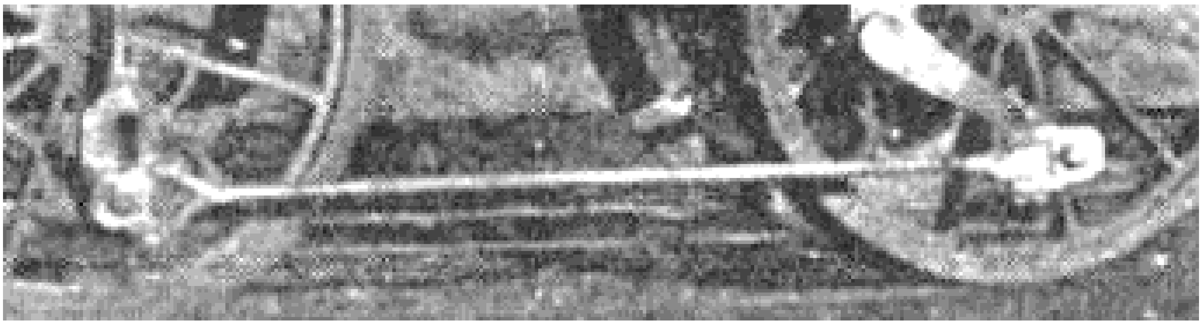


Fig. 19.3. Coupling rod on Mount Moor Colliery locomotive. [Fig. 1.4 – detail.]

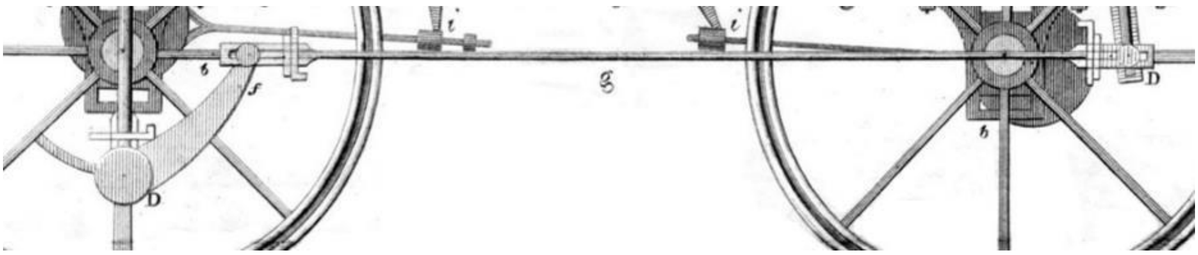


Fig. 19.4. Coupling rod and return crank on Killingworth locomotive. [Fig. 10.1 – detail.]

A potential issue with return cranks was that they would have exerted significant torques on their fixings within the wheels. Assuming that the effort from a cylinder on *Active* was shared between all four wheels, up to half this effort would have had to pass through one return crank, giving a typical torque of around 800 lb.ft, which could have doubled in icy conditions. It is therefore not surprising if slippage of the crank within the wheel occurred, even though these connections were keyed. The incident with a crank in December 1827, reported in Section 2, may have stemmed from this.

To give a firm fixing for the crankpins, a taper fitting would have been used and the boss in the wheel would have had to withstand the 'exploding' forces when the crank was hammered home. The Killingworth locomotives had comparatively weak arrangements to contain these forces although the relevant spoke is thicker than that with a plain crankpin and is connected to adjacent spokes. There is evidence from the archaeological survey of 'continuous development' to deal with this potential problem, with larger bosses and tapered holes in the wheels and with wrought iron reinforcing rings being shrunk around these bosses to contain these forces (Section 10).

ARCHAEOLOGY

Connecting rods and coupling rods

The wrought iron connecting rods are 8 ft 1 in long between the bearing centres. The top bearings contain 2 in diameter spherical recesses for the ball ends of the crossheads. Externally these split bearing brasses are 3 in wide, 3½ in high and 2 in thick. Their fixing straps are formed from wrought iron bar ½ in thick and 1½ in wide, with square corners at their tops, and are secured to the connecting rods by the traditional gibs and cotters.

Fig. 19.5. Top bearing on front left connecting rod.

Within these straps the tops of the connecting rods are nominally 2½ in wide and 1½ in thick. The surfaces of the rods at these points have been stamped. The front left rod bears both LFT and L1T and the rear left rod bears L2T, etc. The straps, gibs and cotters are also stamped, less meaningfully. Below these rectangular stamped sections, the rods are 1⅜ in diameter increasing to 1¾ in diameter at their mid-lengths, and then reducing to 1⅜ in diameter above their bottom bearing fittings.

The bottom bearing brasses had to be wider than those at the top to encompass the crankpins. The bottom ends of the connecting rods are 3 in wide and 1 in thick, with split bearings, externally 4 in wide by 4⅞ in high and 1¾ in thick. These are parallel bearings rather than spherical, as fitted at the tops of the rods. They are held in place by straps formed from 1 in by ⅝ in bar and are rounded around the brasses at the bottom. The straps are secured to the connecting rods by gibs and cotters. The bottoms of the connecting rods are also stamped. The front left rod bears LFB, which also appears on the strap, gib and cotter and the similar components on the other wheels are stamped in line with this.

Fig. 19.7. Front end of right coupling rod.

Fig. 19.6. Bottom bearing on front right connecting rod.

The coupling rods are 5 ft 1⅞ in long between centres. They are of wrought iron and are also 1⅜ in diameter near their ends and 1¾ in diameter at their mid-lengths. The coupling rod ends are of a different design to those on the connecting rods, being hollowed out. These ends are 2¼ in wide and 1 in thick, with square-cornered straps formed from 1 in by ½ in bar. The straps are secured to the rod ends by gibs and cotters, although unusually the gibs are positioned between the cotters and the brasses rather than close to the ends of the straps. The split brasses themselves are externally 2 in thick, 3¼ in wide and 3⅞ in long. Internally they have been machined to provide 2 in diameter spherical recesses. The front end of the left-hand rod and its brasses have been stamped L1. The front end of the right-hand rod is not stamped, but the brasses are stamped both R1 and R1F. At the right rear the brasses are stamped R2, but the rod seems to be stamped R1.

Crankpins and return cranks

There are two types of crankpins, those that serve the connecting rod ends and the coupling rod ends in line, and those that provide return cranks.

The plain crankpins, on the front left and rear right wheels, are 2½ in diameter where they emerge from bosses on the backs of their wheels for a length of ⅞ in and are secured by split pins. These pins appear to have been only 2 in diameter previously but then had sleeves shrunk on. At the fronts of these wheels, the pins have 3 in diameter ridges ⅝ in wide and are then turned down to 2½ in diameter for 1¾ in to provide the connecting rod bearing surfaces. Outside the connecting rods the pins are of 3 in diameter, tapering down to 2 in over a length of 3 in before the 1¼ in diameter necks of the 2 in diameter spherical pins for the coupling rods.

Fig. 19.8. Crankpin attachment at the back of the front left wheel.

Fig. 19.9. Plain crankpin with taper between bearing brasses on front left wheel.

The crankpins with return cranks, on the front right and rear left wheels, protrude further through the wheels. The protrusion behind the front right wheel is 2½ in diameter and 1½ in long whereas that on the rear left wheel is 3 in diameter and 2 in long. In both cases the pin is secured by a cotter which also keys into the boss at the back of the wheel, but the main precaution against the pins turning in their wheel sockets is provided by them being keyed into their wheels.

Fig. 19.10. Crankpin attachment at back of front right wheel.

Fig. 19.11. Crankpin attachment on back of rear left wheel.

The size of the crankpin where it passes through the wheel boss is 20% larger on the rear left wheel than on the front right wheel. This increase could have been to allow for an increase in the torque to be withstood with that particular wheel, when it was made, or to give added security with the same torque.

Outside the wheels, these crankpins provide bearing surfaces for the connecting rods, as for the plain pins, in the gaps between the return cranks and the wheels. The return cranks themselves are 16.97 in between centres and are orientated so that the (spherical) return crank pins are 90° round the wheels from the main crankpins and at the same 12 in radius from the wheel centres. The return cranks are 4½ in diameter at the crankpin ends tapering down to 2¼ in before the 3 in diameter ends carrying the 2 in diameter spherical return crank pins for the ball-joint connections to the connecting rods. The necks of these pins are 1¼ in diameter. The return cranks are 2 in thick at the crankpin ends reducing to 1½ in thick at the ball-joint ends.

Fig. 19.12. View from rear of return crank on rear left wheel.

Fig. 19.13. Three quarters view of return crank on rear left wheel.

Centres punched into the fronts of the return cranks in line with the main crank pins indicate that the return cranks were forged in one piece, with the turning of the pins being carried out on a large lathe.

20. Valve Gear and Slide-valves

COMPONENT HISTORY

In the era when *Active* was built, the most common form of valve-gear on locomotives used slide-valves driven by slip eccentrics on the axles, to give a cut-off in the steam supply to the cylinders at a fixed percentage of the piston power strokes. The operation of a slide-valve requires its position to be 90° or more in advance of the crankpin. The 90° position is appropriate for steam cut-off at 100% of the piston stroke, with the angle increasing with a decreasing level of cut-off. This means that, on reversing, the eccentric centre must change its position relative to the crankpin, that is, the axle must be allowed to slip within the eccentric between two fixed limits, with each limit set so that the eccentric is then in the correct orientation relative to the crankpin for the required direction of travel. This also means that the setting of these limits should be consistent with the degree of cut-off required.

Previous Stephenson locomotives had been equipped with a simple, effective and reliable form of slip eccentric valve gear, and any change from this requires explanation.

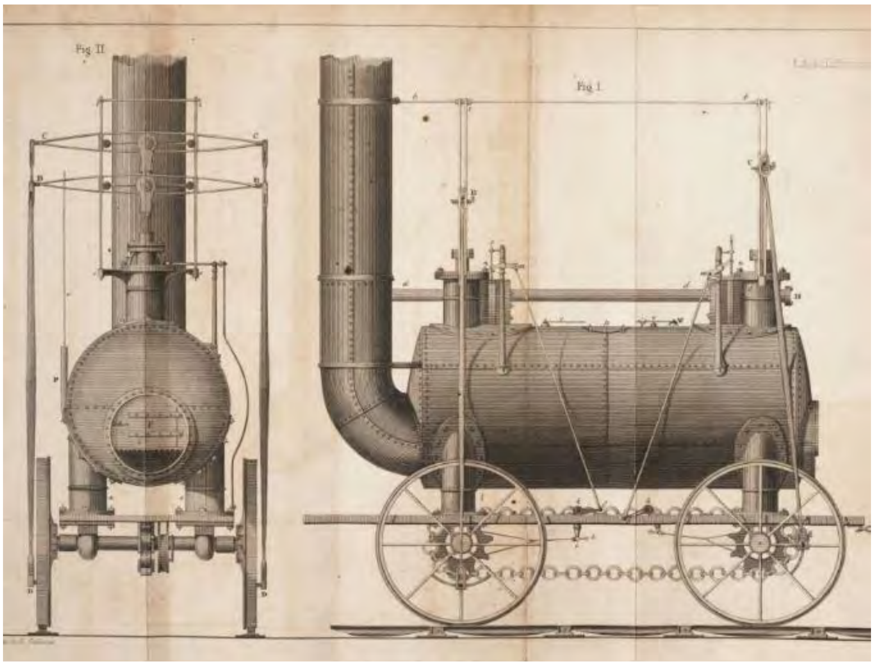


Fig. 20.1. Slip eccentric valve gear on a Killingworth locomotive in the 1820s.

[Nicholas Wood, 1825 - Plate V.]

The surviving arrangement of the valve gear on *LOCOMOTION* is shown in black in Fig. 20.2. This is very similar to that shown on the reversed extract from the original development drawing (Fig. 20.3), which shows two almost parallel rods rising diagonally from the left-hand front wheel to the mechanisms above the boiler. One rod rises from an eccentric strap at the back of the wheel and the other (fainter) from a bell-crank near the periphery of the wheel on the right-hand side.

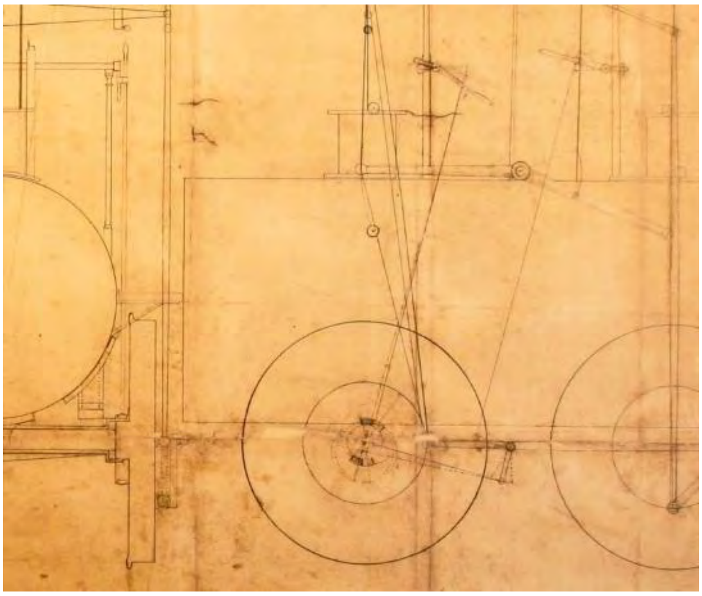


Fig. 20.3. Proposed valve gear.

[Fig. 1.2 - Reversed detail]

It is noteworthy that this original development drawing does not include any other options for driving the slide-valves. However, as explained below, the surviving arrangement is not suitable for long-term operation of the locomotive. It is therefore most likely that this arrangement was fitted by the Shildon Works team in 1857 as part of their endeavours to restore *LOCOMOTION* 'to its original state'. Even though the team did not have access to original drawings, they would have had guidance from those who operated, maintained, or saw the locomotive between 1825 and 1828. Differences between the surviving arrangement and that shown in Fig. 20.3 would in part be due to the team's aim to make the best use of the components already on *LOCOMOTION* at the time they began the restoration.

Based on the argument that the surviving valve gear was the result of the aim of the Shildon Works team to restore *LOCOMOTION* to its original form, *Active* would have had a single eccentric fitted behind the front left wheel working two drives, set at right-angles to each other. One drive directly operated diagonally upwards to work the slide-valve on the front cylinder via levers. The second, indirect, drive used a relatively short eccentric rod pointing slightly downwards (i.e., at right-angles to the forward drive) to connect with a bell-crank, which worked a further diagonal rod, almost parallel to the first, to operate the rear slide-valve, again via further levers. It is likely that the eccentrics and lever lengths were set to give a valve travel of 2 in. with a 90% cut-off, following the practice established on the Killingworth locomotives.[371] Provision would have been made for the manual operation of the slide-valves for reversing the locomotive.

The use of just one eccentric would have been the result of the adoption of a 'tilting' rear axle which incorporated 'cannon box bearings' (Section 9), precluding the fitting of an eccentric to that axle. The trunnion for this cannon box would have been fitted close to the underside of the boiler, thus putting the boiler low above the axles, as is evident in Fig. 20.3. This would have left no room for an eccentric between the frames, as was the previous practice (Fig. 20.1), so the eccentric on the front axle would have had to be directly behind the wheel. This outcome is also evident in Fig. 20.3. Lastly, the almost vertical direct drive to the front cylinder would have required the front axle bearings to be fixed, otherwise vertical movement of these bearings would have significantly compromised the operation of the associated slide-valve.

The extensive re-build of No.1 in 1828 introduced a leaf-spring suspension allowing independent vertical movement of the axles (Section 9). This would have ruled out the concept of placing the eccentrics above the boiler, between the cylinders and driven by vertical rods from the coupling rods, which was adopted on earlier S & D R locomotives, as illustrated in Fig. 2.3. This arrangement would have been problematic even if the axles merely tilted.

This independent suspension required the eccentric rods to be effectively horizontal to minimise the effect of vertical movement of the axles, with bell-cranks to operate the valve drive rods up to the cylinders, again with the capability for manual operation of the slide-valves. This represents a return to an arrangement similar to that used on the Killingworth locomotives (Fig. 20.1) and retained on Killingworth *Billy* to the end of its operating life in 1879.[372] This arrangement is shown for the rear cylinder in blue on Fig. 20.2. That for the front cylinder would have been a mirror image, set at 90° ahead to match the cylinder operation.

This concept would have been retained during the 1834 re-build and most of the associated components were used in the 1857 restoration by the Shildon Works team although their original dates of manufacture (1828 or 1834) are not known. Re-used components include the eccentric itself, the rear valve drive rod taking the eccentric movement to the top of the boiler, and all the components above the boiler, including the slide-valves themselves (albeit in modified forms).

Finally, further changes would have had to be made when *LOCOMOTION* was steamed in 1875 in preparation for the 'Jubilee' celebrations. Low pressure steam was then introduced directly into the valve-chests, with the locomotive wheels clear of the rails. The shortcomings of the restoration would have become evident and further changes made, as explained below.

The valve-gear required regular maintenance and repair, like the rest of the locomotive. The records for 1837 and 1838 include: December 1837,[373] "…. fitting and fixing on a new quadrant for the slide, …. grinding up and adjusting the slides…. ", May 1838,[374] "…. repairing guide for the slide spindle….", September 1838, "…. repairing the slide spindle….". The 'quadrant' was presumably one of the round-ended levers, which operated the valve-rods and were subject to wear (see below). It seems that the slide-valves were ground flat, as the port faces would have been.

ARCHAEOLOGY

Eccentric and eccentric strap

The eccentric with its integral catch-plate is an elegant piece of design. A view of it as seen from the adjacent axle bearing, looking towards the back of the front left wheel, is shown at the bottom of Fig. 20.2.

The cast iron eccentric is located between the front left wheel and its axle-box. It is a running fit on the axle and provides a surface 12½ in diameter and 2 in wide for the strap, with shoulders ⅜ in wide by ½ in high. It has an eccentric circle diameter of 5 in. The integral catch plate has a smaller diameter of 15 in and a larger diameter of 18½ in, which extends for 180°. It is generally ½ in thick, increasing to ⅞ in thick at the ends. The overall width of the eccentric is therefore only 3½ in.

The eccentric was driven by a 'catch' bolted to the back of the wheel (Figs. 20.2 and 20.5), acting on either of the radial edges of the catch-plate, as pertinent for the direction of travel. The width of the catch should reflect the degree of cut-off required, with a catch of zero width being associated with 100% cut-off. A 90% cut-off would have required a catch width of around 5 in, whereas the original width of the catch was around 7 in, corresponding to a cut-off of nearer 80%. However, the cutting away of the leading edge of the catch may have been to correct this for forward motion.

Fig. 20.5. Rear of eccentric, with integral catch plate and ball-joint housing on strap. Eccentric catch behind and below ball-joint housing. Securing bolt partly obscured by eccentric rod.

Fig. 20.4. Front of eccentric, with integral catch plate and strap.

The use of the catch has latterly been superseded by the bolting of the catch plate directly to the wheel, approximately in the position for forward travel. This must have been carried out after the locomotive was taken out of service and is discussed below.

The two-piece eccentric strap is rolled from ½ in thick wrought iron bar and is only 1½ in wide. The lower strap is extended rearward, see below, to locate a ball joint for the eccentric rod that drove the rear cylinder slide-valve. Eccentric straps were usually made of cast-iron (or cast bronze) to the full (2 in) width available, to control wear and reduce friction at the interface with the eccentric. These anomalies support the view that the strap was not intended for long-term operation and had been fitted by Shildon Works in 1857. The eccentric straps on *LOCOMOTION* before the restoration would not have included a provision for the attachment of the ball-joint and therefore could not have been re-used.

The two halves of the eccentric strap are bolted together by 1 in diameter threaded extensions of the forked end of the combined eccentric rod/valve drive rod for driving the front cylinder slide-valve. This arrangement provides a means of adjusting the effective length of this rod: however, the bolts have been slackened off and it is not now possible to determine the intended length. The use of a forked eccentric rod seems to have been a standard practice; a set were installed on the S & D R's *DERWENT*.

Fig. 20.6. Forked bottom end of front cylinder valve drive.

Fig. 20.7. Forked eccentric rods on *DERWENT*.

Eccentric rods and valve drive rods

The valve drive to the rear cylinder is indirect. The eccentric strap has half of the ball housing, 2 in square in section, formed on its lower half. The other half of the ball housing is bolted to it, capturing a 1½ in diameter ball formed at the end of the ⅝ in diameter eccentric rod. The other end of the eccentric rod has what is effectively a universal joint, comprised of a clevis and a short link for connecting to a bell-crank. The clevis is of cast iron and is screwed to the end of the eccentric rod. This allows adjustment of the effective length of the rod. The distance between the ball centre and the centre of the pin on the bell-crank is 22¾ in, putting this pin centre some 34 in from the eccentric centre.

Fig. 20.8. Eccentric rod ball-joint housing.

Fig. 20.9. Eccentric rod clevis, bell-crank and pivot.

The eccentric rod is significantly bent at the eccentric end (Figs. 20.2 and 20.5). This was necessary for the rod to be able to connect with the bell-crank in its existing position, as discussed further below.

Both arms of the wrought iron bell-crank have distances between centres of 7½ in. The arms are generally ½ in thick, but ¾ in thick at the ends and centre. The bell-crank rotates on a forged pivot whose centreline is 1½ in above the wrought iron bar to which it is bolted and 35 in behind the front axle centre. This 3 in wide by ½ in thick bar is supported at each end by the adjacent boiler support brackets.

Fig. 20.10. Bell-crank pivot with bell-crank on the right.

The valve drive rod for the rear cylinder (Fig. 20.11) rises diagonally from the top arm of the bell-crank. This rod is of wrought iron ¾ in diameter and 69 in long between the centre of the clevis pin on the bell-crank at its lower end and the centre of the pin on a lever to which it connects at the top. This rod is doglegged out below the boiler centreline to clear the side of the boiler and doglegged back above the centreline.

The valve drive to the front cylinder is direct. At its bottom end, the combined eccentric rod/valve drive rod is forged into two forks for attachment to the eccentric strap, as noted above. The rod then extends diagonally up the side of the boiler to actuate a pin on a lever, as for the rear cylinder drive. The effective overall length of this rod is 79½ in between the eccentric centre and the centre of the lever pin.

The lower part of this rod, above the forked end, is of rectangular section, ¾ in thick. It tapers down along its length from a width of 2½ in to a width of 1⅜ in at a point 14 in below the connection with the lever (Figs. 20.2 and 20.12). This part of the rod is doglegged out to clear the side of the boiler, but not doglegged back again; rather the rod is just bent. Above this section the rod narrows to ¾ in wide. The shape of this rod, fabricated in 1857, provided additional stiffness to withstand the torque due to friction at the eccentric/sheave interface arising from the forces needed to drive both slide-valves.

Fig. 20.11. Rear valve drive rod rising diagonally. Locking sleeve engaged.

Fig. 20.12. Forward eccentric rod/valve drive rod rising diagonally. Locking sleeve disengaged.

At their top ends both valve drive rods are identical. The rear valve drive rod and all the further valve drive components are worn, and it is clear that they were pre-existing, but modified by Shildon Works as part of the 1857 restoration.

The top end of each valve drive rod is ¾ in wide before broadening out to a rectangular Ɔ-shaped section ¾ in thick. This section is slotted to take a ⅞ in diameter pin fixed to a lever, as described below. A sliding sleeve on an upward extension of the valve drive rod provides a tongue that normally retains the pin in the slot. The sliding sleeves also act as handles.

Fig. 20.13. Upper part of front valve drive rod, with pin on lever, and disengaged pin locking sleeve.

Rocking shafts, round-ended levers and slide-valves

The levers actuated by the valve drive rods are keyed to rocking shafts. These levers are ½ in thick and have effective lengths from the centres of the pins to the centres of the rocking-shafts of 7½ in. The levers are extended to provide handles. The front cylinder lever has been significantly bent, so that the pin is about 2 in lower than it would have been if the lever was straight. This is discussed further below.

Fig. 20.14. Rear valve drive rod, lever and stanchion.

These handles were used to reverse the locomotive, by first lifting the locking-sleeve, then moving the valve drive rod sideways to disengage the rod from the lever pin, and then moving the slide-valve manually by lifting/lowering the lever, through the mechanism described below.

These levers actuate rocking-shafts. Each 1¼ in diameter rocking-shaft is located in a bronze bearing which is supported by a stanchion bolted to the side of the boiler. There are two such stanchions, one for each rocking-shaft, with their centres 35½ in apart (Fig. 20.2). In the area of the bolts securing the stanchions to the boiler these stanchions are ¾ in thick and 2 in wide, changing to 2 in square above this area. The stanchions are then machined to 1½ in diameter tapering to 1¼ in diameter below the bearings. The stanchions are connected by a ¾ in diameter bar (Figs. 20.2 and 20.14).

Each rocking-shaft is also located in two further split bearings, with each such bearing bolted to a column. These columns are 1⅝ in square-section at their lower ends, changing to 1⅜ in diameter above the split bearings, where the columns rise further to support the parallel motion (Section 19). The columns are supported by extensions on the valve-chest, and have tongues, 7½ in long and ¾ in thick, stretching over the faces of the extensions, to which they are bolted. These valve-chest extensions consist of square-section pillars rising vertically either side of the valve-chest cover, with a nominal separation of 12 in. They originally ended some 3 in above the rest of the valve-chest casting, but all except one of these extensions (that on the rear valve-chest, right-hand side) have apparently broken at their roots, with the breaks being filed flat and the columns modified to suit. The net result is that the centres of these rocking-shafts are 21¼ in above the boiler crown and 13¼ in from the cylinder centrelines.

Fig. 20.15. Columns, rocking shaft and split bearings for front cylinder valve gear.

Fig. 20.16. Column bolted to rear valve-chest extension.

The rocking-shafts carry round-ended levers midway between the split bearings. These cast iron levers have lengths between centres of 3⅝ in. The levers are generally ½ in thick, increasing to 1½ in wide on the shafts, and 1 in wide at the 'blind' round ends. The 'blind' ends operate in cavities formed in the valve-rods. These cavities are just over 1 in wide, 1¾ in high and 1¼ in from front to back, with the valve-rods being ¾ in diameter. Horizontally, the centres of the valve rods are 3½ in from the rocking-shaft centres and 9¾ in from the cylinder centres.

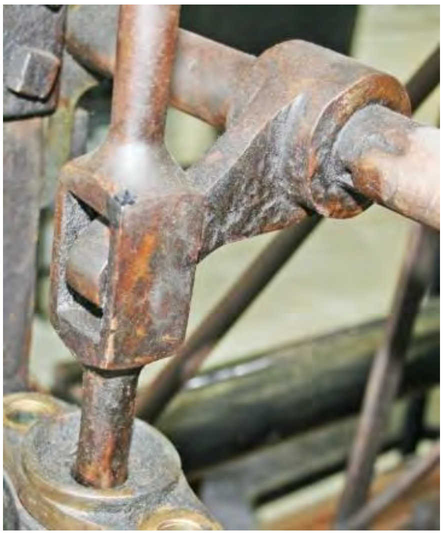


Fig. 20.17. Rocking-shaft, round-ended lever, and valve-rod for front cylinder.

The use of 'blind' round-ended levers for this duty was well-established; they are apparent in Fig. 20.1 and their use continued through to the *Planet* class, 1830 and beyond.[375]

The 'blind' ends of these round-ended levers have worn, with that for the rear cylinder having its vertical dimension reduced to about 1½ in from the original 1¾ in to fit the cavity. This backlash would have affected the operation of the slide-valve, as discussed later in this section.

The tops of the valve-rods are guided by bearings bolted to the tops of arch-shaped forgings, in turn bolted to the inner faces of the columns (Figs. 20.15 and 20.16). Below the lever cavities the rods pass through glands on the tops of the valve-chests (Section 17) and are then screwed into the tops of the slide-valve buckles, with locking-nuts.

Fig. 20.18. Slide-valve and buckle on rear cylinder (raised to expose lower steam port)

Fig. 20.19. Valve-rod, slide-valve and buckle on rear cylinder.

The buckles are of wrought iron and measure 5¾ in wide by 4 in high externally, with wall thicknesses of ⅜ in. They are a close fit round the backs of the cast bronze slide-valves. These valves have port-face contact areas 5½ in high and 6 in wide, with internal openings estimated to be 3 in high and 4 in wide. The back of the valve for the rear cylinder is stamped 'BV'. The port-faces are 7¼ in high and 6 in wide and are further described in Section 17.

Discussion

As a result of the bending of the eccentric rod serving the valve drive to the rear cylinder, the rod is not at the required right angle to the front cylinder eccentric rod/valve drive rod. The error is about 15°, which meant that, in forward motion (anticlockwise in Fig. 20.2), the valve events in the rear cylinder would have been about 15° late if those for the front cylinder were correct. It is probable that during the final stages of the 1857 restoration it was found that the pre-existing rear valve drive rod was too short to connect with the eccentric rod, via the pre-existing bell-crank, in the intended way, (although it is just the right length to suit the proposed pre-existing configuration shown in blue on Fig. 20.2). Consequently, the bell-crank pivot was raised to suit the unmodified valve drive rod, rather than extending this rod. The eccentric rod then had to be bent to meet its bell-crank arm. Fig. 20.2 shows in red an alternative solution to this issue by using longer bell-crank arms.

The bending of the front rocking-shaft lever was probably so that it would make a right-angle with the (sloping) valve drive rod, in line with good engineering practise. This supports the view that the previous valve drive rod for the front cylinder had been vertical (as for the blue line on Fig. 20.2). This bending also indicates that the last stages of the restoration had been hurried, since it would have taken longer to reposition the key. The rear cylinder lever is not bent, even though it does not make the required right angle with its valve drive rod. It is very likely that this was because, during the restoration, the top arm of the bell-crank was incorrectly set to point to the right when the valve drive rod was attached, leaving the rod almost vertical, so an adjustment was not considered necessary. This error, which would have left the locomotive inoperable, is apparent in the photograph, taken shortly after the restoration, which shows the rod emerging from behind the rear wheel. The error supports the proposed previous configuration shown in blue (Fig. 20.2), which also has the rear valve drive rod almost vertical. It is likely that the Shildon Works team merely repeated the previous configuration thinking it would be correct.

Fig. 20.20. Rear valve drive rod set vertically. [Fig. 8.1 – detail]

The dimensions of the slide-valves and those of the port-faces give valve laps of around ¼ in. The eccentric circle diameter of 5 in, taken through the levers, would have given valve strokes of 2½ in. The relatively small laps meant that the cut-off would have been about 96% with the full valve stroke of 2½ in, requiring an eccentric advance of about 12°. However, the backlash in the round-ended lever cavities would have reduced the rear slide-valve stroke to around 2¼ in. With the backlash, the cut-off would still have been 96% but now required an eccentric advance of about 18°, so the backlash had no effect, except perhaps to require the eccentric advance to be increased and to introduce dwell periods when the steam slots are fully uncovered. The delay in cut-off from the original 90% on *Active* would have had no benefit in increasing the power of the locomotive but might have been useful if the locomotive was used for shunting, with frequent reversals of direction. Alternatively, the slide-valves might have been shortened either in 1857, or in 1875 in preparation for the 'Jubilee' celebrations, see below.

This backlash was probably due to wear as the round-ended levers rotated and slid within the valve-rod cavities. The wear characteristics for cast iron are very variable, and the efficacy of any lubrication is uncertain, but a scoping calculation indicates that this amount of wear could have developed over between 4 million and 15 million wheel revolutions, equivalent to between 10,000 and 36,000 miles. These mileages indicate that the round-ended levers may have needed replacing every few years.

An issue is apparent from Fig. 20.2, which shows the position of the eccentric centre relative to the crank pin (and therefore relative to the piston position in the front cylinder) with the catch in its present orientation on the wheel. When the 15° slope of the combined eccentric rod/valve drive rod for the front cylinder is taken into account, along with the reversing effect of the levers above the boiler, it can be seen that the eccentric advance is actually set at about 60°, which would have been about 48° too early. The bend in the eccentric rod driving the rear cylinder slide-valve means that valve events there would have been about 33° too early. The reason for the mispositioning of the catch is not understood but may have been the result of the later stages of the restoration having been hurried.

This issue would have introduced difficulties when *LOCOMOTION* was being tested in 1875 in preparation for the 'Jubilee' celebrations, when low pressure steam was introduced directly into the valve-chests, with the locomotive wheels clear of the rails. The early valve events would have caused difficulties in starting the locomotive and might even have caused the cylinders to start in reverse. Additionally, when a test was completed, the weight of the crossheads, connecting rods and coupling rods could easily have caused the wheels to turn backwards. In either event, reversing of the wheel movement would have caused the eccentric catch to move away from the catch-plate, leaving the slide-valves stationary and in the incorrect position for a further attempt to start the locomotive. This is likely to be the reason why the catch-plate is now bolted directly to the wheel but still in the incorrect orientation. It is strange that this mispositioning was not identified and corrected, although the out-of-balance forces would have caused very irregular running anyway.

Fig. 20.21. Bolt holding eccentric catch at 17 minutes past, and bolt clamping eccentric catch-plate to wheel at 3 minutes to top of wheel. Both bolts in wheel centre.

The issues of an inappropriate material and size for the eccentric strap, the incorrect size of the eccentric catch for the existing degree of cut-off and the incorrect degree of eccentric advance mean that *LOCOMOTION* could not have operated in earnest in its surviving state. It is therefore most likely that these issues were introduced by Shildon Works during the 1857 restoration.

21. Exhaust Pipes

COMPONENT HISTORY

The earliest representation of the Stephenson locomotives on the Stockton & Darlington line suggests that a single exhaust pipe, shown on the left side of the boiler centre-line, was fitted in 1825. This followed the practice of the Killingworth-type locomotives operating on the Killingworth, Hetton and Mount Moor lines.

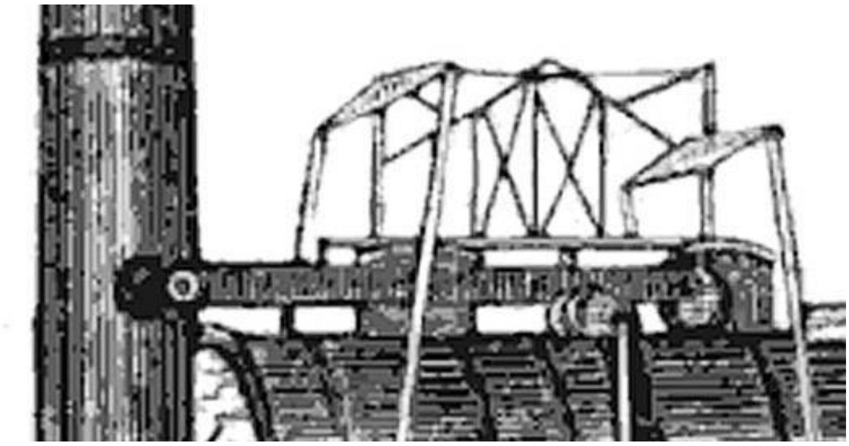


Fig. 21.1 Early S & D R locomotive, showing the exhaust pipe.

[Fig. 2.3 – detail. Brewster, 1829]

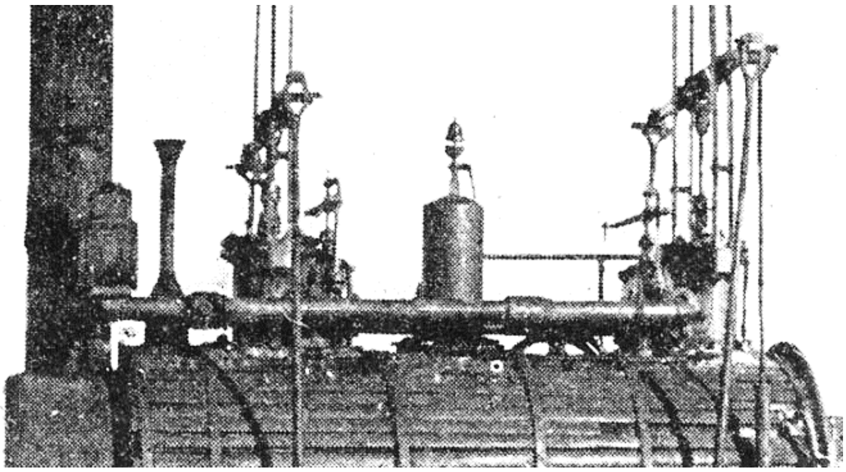


Fig. 21.2 Mount Moor Colliery No.2 – showing three lengths of exhaust pipe.

(Fig. 1.9 – detail. NRM - Bleasdale Collection)

The pipe would have been formed of cast iron with flanges bolted to the exhaust exit flanges from the two cylinder castings. It would have been formed of three lengths with two sleeves to receive the ends of the adjacent lengths.

With the provision of a new twin return-flue boiler at the end of 1828, No.1 was provided with a pair of new cylinders with exhaust exit flanges on both sides of the cylinder castings. Two exhaust pipes thus ran from flanges on the front cylinder casting to the front faces of the twin rear chimneys, collecting exhaust steam from the rear cylinder on the way. With the retention of the 1828 cylinders after 1834, it is most likely that these twin exhaust pipes remained in a similar position when the single return-flue boiler was fitted. The rear ends of the pipes would have been re-formed to turn into the side faces of the centrally located single chimney.

LOCOMOTION continued to operate as a locomotive in this formation not only until 1846, but also during its period as a stationary steam boiler/steam pump. When Shildon Works re-formed the locomotive in 1857 to look as similar to its 1825 appearance as it could reasonably be achieved, it was probably too costly to replace the cylinders and exhaust pipes to represent the single-sided exhaust arrangement that the locomotive had when it had been first built. Instead, the twin pipe arrangement was retained, but re-located to face forwards towards the single chimney which it entered from both sides. For this reason the locomotive, as now seen, retains the unnecessary characteristic of two exhaust pipes rather than one.

ARCHAEOLOGY

The two exhaust pipes are both formed of cast iron in three sections: Rear end bolted to the rear cylinder casting; centre section incorporating the front cylinder casting flanges; and the front extensions bolted to the sides of the chimney. Their overall length is 8 ft 4½ in between the front and rear flanges. The length of the centre section (over flanges) is 5 ft 4½ in.

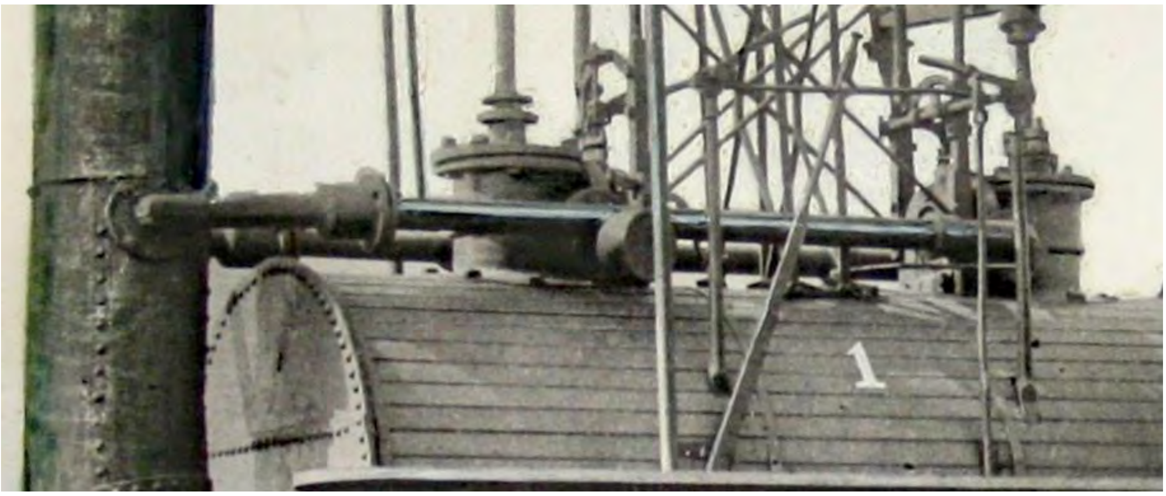


Fig. 21.3 Left-side exhaust pipe, showing the three lengths. [Fig. 8.1 – detail]

The outside diameter of the exhaust pipes is 3⅜ in. The rear sleeves are 3 in long and 4⅝ in diameter, with the flange being 1 in greater. The front sleeves are 5¼ in long and 5¾ in outside diameter. Whilst the centre sections have been inserted into the flanges of the rear castings, their front ends are bolted to the front castings using only the flanges. The sleeves of the front castings are therefore redundant. It is possible that the centre sections were cast afresh in 1856/7, their appearance indicating a regularity of finish not matched by the other two lengths. In addition, the front castings are slightly mis-aligned from the centre castings, the front-end being c1⅛ in lower than the rear end.

Fig. 21.4 Left-side exhaust pipe sleeves: Rear sleeve (left) and front sleeve (right), showing the different forms of joints.

The ⅞ in thick flanges for bolting to the rear cylinder castings are 8½ in diameter, and 8 in diameter for the front, a further indication that they were cast at different times. A significant thickness of filling material, measuring ½ in thick, has been inserted between the flanges of the cylinder castings and the exhaust pipes.

Fig. 21.5 Left-side, rear cylinder casting flange (left) and front cylinder casting flange (right).

22. Boiler Fittings

Inspection Hatch

An oval inspection hatch is inserted into the rear of the boiler crown, its rearmost point being some 4⅛ in from the backplate angle iron's leading edge. The oval opening has a maximum length of 15¼ in, and maximum width of 10⅞ in.

Fig. 22.1 Inspection hatch and cover

Fig. 22.2 Inspection hatch with cover removed

The cover is a cast iron oval plate, profiled to the boiler barrel, the internal under-rim having a maximum length of 18¾ in, and maximum width of 14 in. A 1¾ in wide perimeter for the outer cover helps to seal the hatch from steam loss. The 1¼ in diameter bridge-securing bolts are placed along the boiler centre-line, 7½ in apart, and rise to 5½ in above the cover. A 3¾ in tall, and 3 in wide, 'ring' handle is centrally located on the cover.

Fig. 22.3 Inspection hatch cover

The two cast iron bridge arms are 13 in long, with a maximum width of 1½ in, and an overall height of 3¾ in. The arms are tapered from ¾ in to 1 in wide. The bolt hole is 1½ in diameter and the nuts are 2⅛ in A/F.

Fig. 22.4 Inspection hatch bridge arms

Safety Valve

The safety valves used on the earliest Stephenson locomotives were all of a similar pattern. The safety valve body, bolted to the boiler via a flange over a hole in the boiler crown, would have been of cast brass, and would have comprised a flanged upright hollow cylinder, the top of which was reinforced externally by a lip and internally machined to a taper. Lower down, the body would have included a central internal guide for the valve. The flange would have provided a pivot for the end of a lever. The valve itself would also have been of cast brass, comprising a round-topped plug, tapered to seal in the above taper, with a central rod beneath it to engage in the guide and a central conical hole in its top. A short pointed wrought iron rod fitting into the conical hole in the top of the valve was pinned to the lever. This rod would have held the valve down in its seating under the influence of a weight at the free end of the lever. The outer end of the lever had a circular weight which was slid on and tightened down with a butterfly screw.

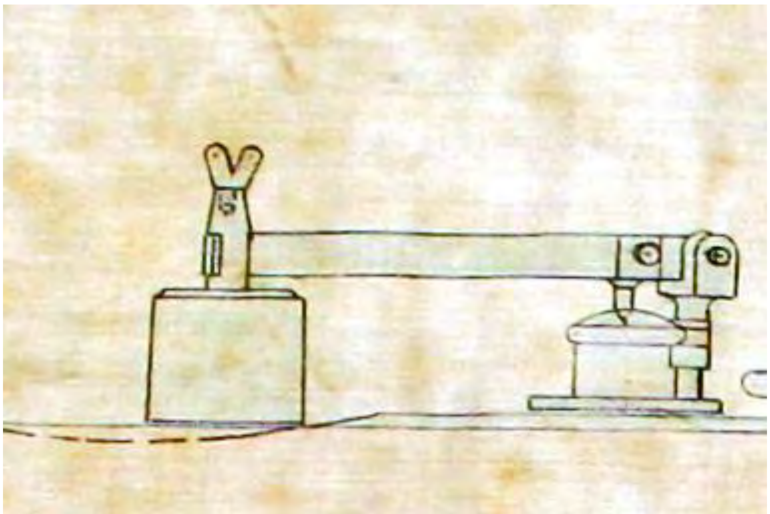


Fig. 22.5 Original drawing of a Stephenson safety valve, dating from 1828.

[Drawing of Stephenson Travelling Engine No.11 – detail. Tyne & Wear Record Office]

As the boiler now fitted to *LOCOMOTION* was formerly fitted to *DILIGENCE*, built in 1827, it is most probable it was originally of similar form to that shown in Fig. 22.5.

As viewed today the safety valve is located on the centreline of the boiler crown, its centre being some 23¼ in behind the centreline of the leading cylinder. The 3 in diameter hole in the crown is fitted with a safety-valve similar to that described as fitted to its original boiler. Its flange is estimated to be 7½ in diameter fitted to the boiler with 8 x ½ in diameter bolts.

Fig. 22.6 Interior boiler view of safety valve

The safety valve assembly was installed with the lever at 45° to the boiler centreline. The top of the tapered plug is 215/16 in diameter and the centre of the pointed pin that engages with it is 3 in from the lever pivot. This wrought iron pivot is screwed into the flange fitting. It would have had to carry an enormous load, about ¼ of a ton with the present weight, so it needed to be strong and wear resistant.

Fig. 22.7 Safety valve, lever and pivot

The lever arm is cranked up to clear the left-side exhaust pipe. Its effective (i.e. horizontal) overall length is 30 in. and is formed of ⅜ in thick wrought iron section that is tapered from 1⅜ in deep at the safety valve to 1⅛ in at the outer end. A circular section weight is hooked over and suspended from the extremity, retained in place by a lip on the end of the lever arm. The cast iron weight is 7¾ in diameter and 4 in wide, weighing nearly 50 lb. giving a blow-off pressure of 80 lbf/in^2. This would have been about twice what it would have been in service, but it is not known why such a heavy weight should have been fitted in 1857.

Fig. 22.8 Safety valve lever arm cranked over the exhaust pipe, with circular weight

Regulator valve

Extensions to the bottoms of the steam chests penetrate the boiler shell by about 1 inch. These contain segmental steam passages which were covered to a greater or lesser extent by fan-shaped regulating valves to control the steam flow. The valves were operated by interior rodding connected to a double-ended lever on a spindle attached to a regulator handle on the outside. This spindle is 15 in behind the safety valve centre. The regulator spindle passes through a brass stuffing-box before being connected to a double-ended lever, which survives.

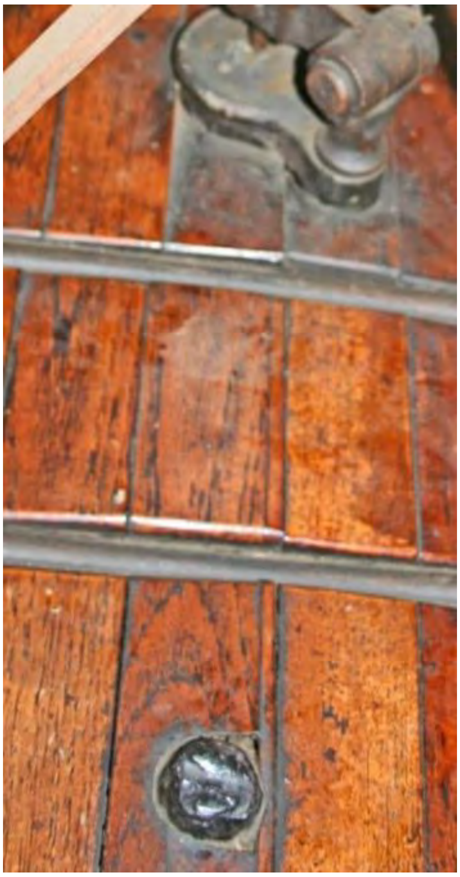


Fig. 22.9 Exterior view of surviving stub of the regulator spindle.

Fig. 22.10 Interior view of the double-ended lever and stuffing box.

The right-hand arm of this double-ended lever would have been connected to the front cylinder regulator valve and the left arm to the rear by rods.

The arrangement is very similar to the design of the regulators on the Killingworth Colliery locomotive fleet, including Killingworth *Billy*. On the front steam chest the valve pivot is to the left and the spindle that connected the valve to its operating rod is to the right. The reverse arrangement applies to the rear steam chest because the steam chest castings are not handed. It is apparent that, with this arrangement, the driver, on his seat, would have moved the regulator lever away from himself to open the regulating valves and towards himself to close them. There would probably have been a pair of stops, fixed to the boiler shell, to define the fully open and fully closed positions.

Two views of the steam regulator valve on the front cylinder of Killingworth *Billy*:

Figs. 22.11 Upwards view revealing segmental steam passage and 22.12 Side view showing pivot and linkage.
[Killingworth *Billy* report 2018, Fig.15.5]

The regulator handle, and internal connecting rods to the fan shaped steam inlet valves on *LOCOMOTION*, are no longer present. They would have been removed in 1875 when the locomotive was being made ready for its Jubilee appearance under steam, supplied from the North Road workshops boiler. The cranked regulator handle, at least, remained in position after the 1857 ‘restoration’ and could be seen in photographs taken of the locomotive prior to the Jubilee. In 1875 however the handle was cut off, leaving the stub of the vertical rod in place on the boiler crown centreline.

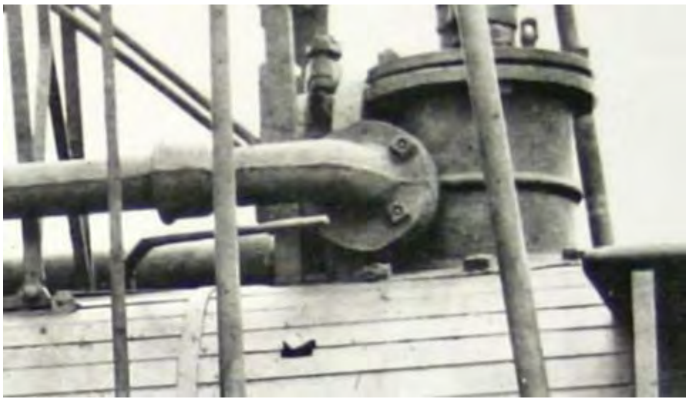


Fig. 22.13 Pre-1875 photograph showing the cranked regulator handle and its proximity to the driver’s ‘seat’

The segmental steam inlet passages to the valve chests are formed into the cylinder castings. They had to be blocked off in 1875 when steam was allowed directly into the valve-chests to rotate the wheels and motion, and it was considered important to prevent steam flowing back into the boiler. A short-term arrangement was employed for the two-day event, and this remains in place. To maintain a steam-tight seal for the front steam inlet passage, a prop was installed formed of a threaded iron bar with a large nut on the top placed directly under the regulator valve, then disconnected from the regulator handle and connecting rods. The prop was placed over the crown of the flue, with a wooden load spreader. To prevent any risk of the prop giving way when steam passed into the steam chest, a stay was inserted between the prop and the side of the boiler. With the restricted access to see the arrangement for the rear cylinder, it was not possible to see that modification and it is assumed that a similar arrangement was installed.

Fig. 22.14 Interior view of the front cylinder showing the regulator valve arm, prop and stay

Try-cocks

Two try-cocks were inserted into the rear boiler back-plate, above and below the normal water line, with a height separation of 5¾ in. The lower try-cock is a nominal 4 in above the top of the flue. The upper try-cock was removed by a passer-by in 1965 and has not been replaced.[376] The tapped holes are 1 in diameter. The remaining brass cock has a quarter-turn conical plug valve. A 'T' is stamped on the top.

Fig. 22.15 The lower try-cock on the boiler back-plate, together with the hole of the upper try-cock.

Bell

A cast brass bell is fitted to the forward part of the boiler crown. It was donated to the locomotive on the occasion of the National Exposition of Railway Appliances in Chicago, Illinois in 1883. The cast words read:

STOCKTON & DARLINGTON RAIL-ROAD 1831

It is not known what the date, 1831, was meant to signify, and it may simply have been an error for 1825.

The bell is suspended from an iron rocking-shaft that can rotate within a pair of upright brackets. The brackets are secured to the adjacent exhaust pipe flanges. At the left side of the rocking-shaft an upright handle is fitted and secured by a split-pin, the top of which is formed into a ring, to which is tied a bell-chord that trails back to the driver's seat. When pulled, the handle would rotate the rocking-shaft causing the bell to oscillate and its clapper to chime.

Fig. 22.16 Brass bell mounted above the leading end of the boiler barrel

Nameplates

No.1 was first identified by the application of a brass number fixed to its chimney from 1827 (Section 2). The name *LOCOMOTION* was first applied, in addition to No.1, from July 1833. No contemporary record has been found to suggest that a cast name was fitted from this time, or that a painted name was applied to the boiler cladding.

There is no contemporary record that would confirm that the surviving cast iron nameplate sections, now held in the Baltimore & Ohio Railroad Museum, had actually been fitted to the locomotive (Section 8). Although the dates of the Johnson family's movements make it possible that the plates were once fitted to the locomotive, there remains no specific evidence to confirm this.

A replica *LOCOMOTION* nameplate was cast in brass a short time after the artefact was placed on the plinth at North Road station in Darlington in 1857. It was fitted to the left side of the boiler barrel that would be seen by all the users of that station (Fig. 8.3).

In 1889, when the locomotive was being prepared for the Exposition Retrospective du Travail in Paris, new brass plates were made showing 'No.1' and '1825'. They were fitted to the boiler together with a *LOCOMOTION* nameplate and remained there until removed in 1961 during the locomotive's restoration in the North Road Works. They were retained at the works until the re-engagement of the Works Manager, Mr. Peter Gray MBE, when they were mounted on to a plaque and presented to him. They remain in the possession of Mr. Gray's grandson, David Gray, who kindly made them available for metallurgical analysis during this study (Section 8).

Samples of these plates were taken for analysis by a consultant metallurgical historian, Dr. Peter Northover. These show that they were cast from an alloy with lead and a small amount of tin. Their composition was the same as the *LOCOMOTION* nameplate, indicating that the latter was probably cast at the same time. The assembly was fitted, using lead, to a wrought iron plate which was fitted, tangentially, to the left side of the boiler (Fig. 8.13), with a profiled, probably wooden, backing.

In 1892, the locomotive was re-located to Bank Top station in Darlington which allowed it to be viewed from either side by users of the station. This apparently prompted the replication of a further set of '1'/*LOCOMOTION*/1825' plates for fitting to the locomotive's right side, in similar layout to that on the left side. This second set of plates were not made to the same standard as those on the left side. The brass number and date plates are from an alloy cut from sheet brass which was either soldered or riveted to the iron backing plate. They would be a bit 'yellower' than the original cast set. Due to the location of the boiler feed-pump on the right side, the wrought iron plate and its probably wooden backing had to be fitted towards the rear of the barrel (Fig. 8.23).

The cast brass nameplates were retained and fitted to the boiler cladding on both the left and right sides of the locomotive and they remain *in situ*.

Fig. 22.17 Presentation plaque to Peter Gray MBE, with the surviving number and date plates removed from *LOCOMOTION*'s boiler in 1961.

23. Boiler Feed-Pump

COMPONENT HISTORY

The earliest form of water feed pump fitted to *Active* would have been similar to those adopted on the locomotives then operating on the Killingworth, Mount Moor and Hetton colliery railways. Often fitted to the left-side of the boiler barrel towards its rear end, the pumps were fitted just above the running board. The c2 in bore pumps had a stroke of 2 ft, their pump-rods being connected to, and driven by, the rear crossheads. Water was drawn from the tender via a flexible (probably leather) pipe to a short (probably copper) pipe connected to the pump itself. A clack valve was located on the boiler centreline.

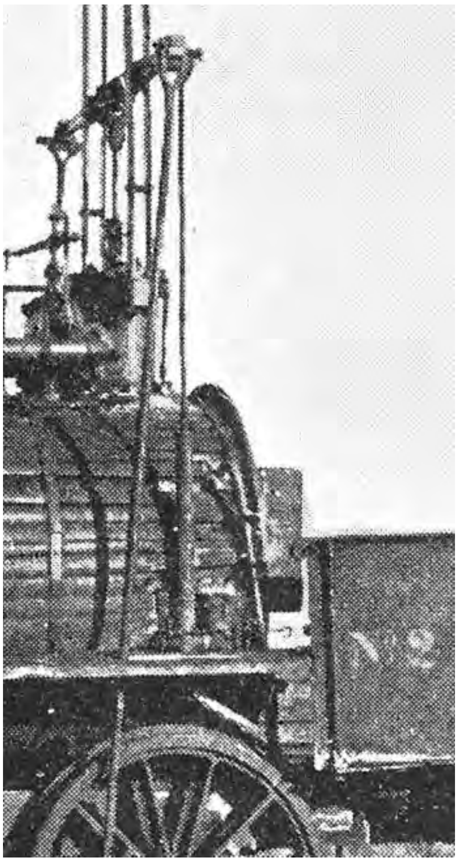


Fig. 23.1 Mount Moor Colliery No.2 – showing water feed-pipe, feed pump, pump cylinder and piston rod.

[Fig. 1.9 - detail]

There is no evidence available that indicates the form of boiler feed-pump in use after 1828, when the new double return-flue boiler was used. The 1834-fitted boiler, still carried by *LOCOMOTION*, has a clack-valve opening on the right side of the boiler, approximately 7 in forward of the rear cylinder centreline and positioned above the running board. The opening could not be reached to measure it, because of the cladding presence, but the c2 in hole has been covered over with a 'tunnel'-shaped plate, c7 in wide and c9 in high, using eleven rivets.

Fig. 23.2 Former clack-valve opening, covered by a plate.

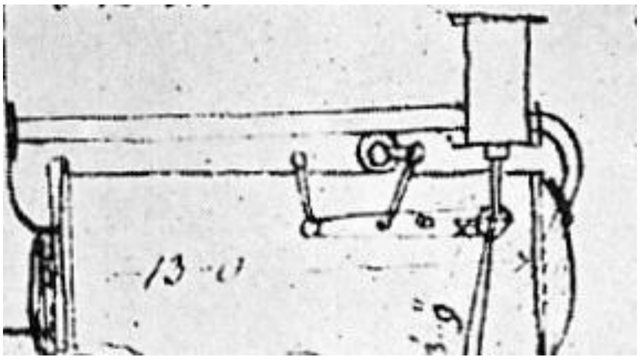
[Fig. 8.28 – detail]

At some unknown later date the feed-pump was replaced by another feed-pump, apparently reclaimed from an early locomotive. It was positioned again on the right-side of the boiler barrel, the centreline of which is about 27¾ in behind the front cylinder centreline. The formation of the pump and its driving method determines that previously it had been used by a vertical cylindered locomotive.

Fig. 23.3 1961 view of the surviving water feed-pump and operating lever arm.

[Fig. 8.28 – detail]

Comparison has been made between this feed-pump and the known components of the S & D R's early vertical cylindered locomotives, to see which might have been the host locomotive for this fitting. It cannot be confirmed without documentary evidence, but the design is comparable to that once adopted for the No. 5 locomotive, *ROYAL GEORGE*. This locomotive was sold, second hand, to Wingate Colliery at the end of 1840, and it is likely that its feed-pump remained on the locomotive at this time. It is possible however that this component had been 'duplicated' by the railway in case of failure of the primary component, and that this remained at Shildon after 1840. Documentary evidence is again lacking, but when No.1 came briefly out of retirement during 1846, this duplicate may have been adapted for use with it, and that it remained on the locomotive through its time at Pease's West Colliery. Alternatively, if the earlier feed-pump had failed at the colliery, it is possible that the pump was retro-fitted by Shildon Works in 1857.



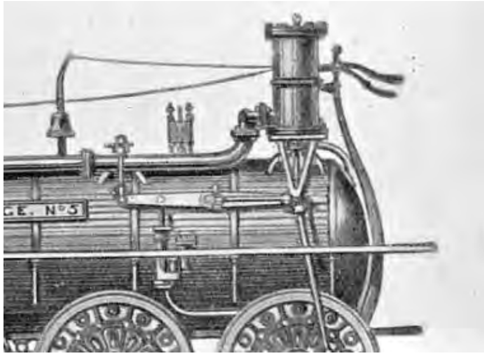


Fig. 23.4 (left) Sketch of *ROYAL GEORGE* as seen by J.U. Rastrick in 1829 – detail showing multi-function lever with no identified feed-pump; (right) Early sketch (artist unidentified) – detail showing multi-function lever operated by the piston rod, and activating the feed-pump.

[(left) J. Rastrick's notebook, 1829, in Goldsmith Company's Economic Library, University of London, (right) 'an old drawing', Robert Young, 1923, p.158]

ARCHAEOLOGY

The feed-pump is positioned immediately beneath the running board. The upper end of its pump-rod is pinned to the rearmost hole of a five-holed, multi-function lever arm, which was driven by a connecting rod coupled to the leading crosshead. Its 2 ft stroke was reduced by the lever arm to a 3⅞ in pump-rod stroke.

The ⅞ in diameter wrought iron pump rod is fitted to the pin through the lever arm by a strap, retained by a gib and cotter. The lever arm is formed of two parallel wrought iron plates, ⅜ in thick and 1⅜ in. apart. They are 2¼ in wide, broadened out to 2½ in wide around the holes. It has been cut short at its leading end which was formerly probably of similar form to the trailing end, with the two plates forged together. The arm is 37½ in long overall, 35 in between the centres of the connecting rod pin and the rocking shaft fitted to a motion bracket, and 29¼ in between the connecting rod and the pump rod pin centres. The five holes are evenly spaced, the centres being 6½ in apart, the first hole at the front end being 3⅝ in from connecting rod pin and the fifth hole being 5½ in from the rocking shaft.

Fig. 23.5 Boiler feed-pump, pump rod, lever arm and connecting rod.

A 1 in diameter hole has been drilled at the upper end of the lever arm to accommodate a 2⅝ in long pin fitted through the bottom of the connecting rod with a strap retained by a gib and cotter. The connecting rod has been fitted to a pivot beneath the crosshead to which it is attached by two straps secured by gibs and cotters. The centre-line of the pivot is 3½ in below the centre-line of the crosshead. The connecting rod is 42½ in long between the centres of its top and bottom pivots, and is broader at its centre (13/16 in) than its ends (⅞ in).

Fig. 23.7 The connecting rod pivot fitted beneath the front crosshead

Fig. 23.6 The connecting rod fitted between the crosshead and the lever arm.

The rear end of the lever arm is fitted to a rocking shaft on a bracket fitted to the boiler. The wrought iron bracket is of 1½ in square section protruding 12 in out from the boiler. The centre-line of the rocking shaft is 2¾ in above the bracket. The shaft pivots between two bearing brasses held within 1 in wide upright straps, 9⅛ in apart, rising to 4¼ in above the bracket. The bracket is supported at its outer edge by a 1 in diameter wrought iron diagonal stay, approximately 17½ in long, rising up from the boiler to which it is bolted with a 4 in long x 1⅝ in wide palm bracket.

Fig. 23.8 Rocking shaft bracket

The pump itself is 13¾ in tall with a 5 in outside diameter, suggesting a 4 in bore. It is bolted to the boiler using two sleeve brackets and rectangular flanges with rounded ends, located at the top and just above the inlet flange. The sleeves have a diameter of 6 in. Water was drawn through a bottom inlet from the 1½ in diameter water-pipe, the connection using a ¾ in thick x 9 in diameter flange. The body of the pump has cracked at some stage in its life and has been repaired using two clamps. The upper clamp is formed of two half-rings, 1½ in wide and ⅜ in thick, with external flanges tightened using bolts and nuts. The lower clamp, which surrounded also the valve body, has one half ring, 2¾ in wide and ½ in thick, tightened around the unit using tie-bars 1¼ wide x ½ in thick.

Fig. 23.10 Rearward view of feed-pump

Fig. 23.9 Forward view feed-pump

The feed-water hole in the boiler is c19¼ in behind the front cylinder centreline and is c2 in diameter. The clack valve body has a diameter of 4 in and height of 5 in. The clack valve flange faced onto the boiler is circular, about 6 in diameter held in place by six ½ in bolts. It is ¾ in thick, the use of filler material compensating for the curvature of the boiler. The clack valve body is surmounted by a 6½ in diameter x ¾ in thick flange. This top flange carries a gland around a shaft for the screw-down facility on the clack valve, to isolate the boiler from the boiler feed system. A handle at the top of this shaft is located above the running-board which allowed the crew to alter it as required.

Fig. 23.11 Handle for clack-valve screw-down facility.

Between the pump body and the clack-valve body water was drawn through an intermediate passage which is 4 in wide and 3 in high externally. A bleed-valve is fitted to this passage, which is 1½ in diameter, but there is no surviving operating lever for it.

Fig. 23.12 Bleed-valve fitted to the side of the intermediate passage.

24. BOILER CLADDING and RUNNING BOARDS

COMPONENT HISTORY

The boiler cladding was formed of planks of deal during its operating career. There are a few references to this provision in the railway's contemporary notes about the locomotive, but the illustration of one of the other early Stephenson locomotives suggests that the boilers were completely wrapped by cladding held in place by straps.

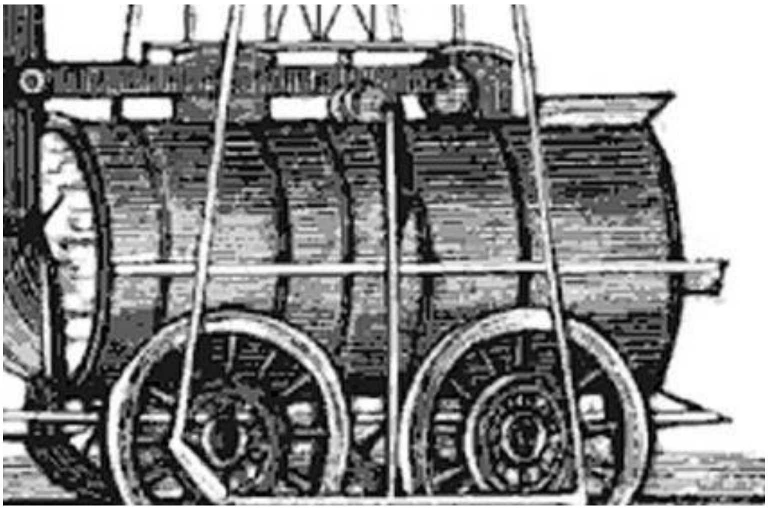


Fig. 24.1 Contemporary view of an early Stephenson locomotive, showing cladding and straps around the boiler.

[Fig. 2.3 – detail. Brewster 1829]

There are occasional references in Hackworth's maintenance files, between 1837 and 1840, to replacing the 'cleading' bands and renewing lengths of deal on No.1. For example, in July 1837, "5 straps for cleading" weighing 45 lbs were replaced on *LOCOMOTION,* whilst shortly after 28 feet of 1 in thick deal was renewed.[377] In November further lengths of deal were supplied for the locomotive, 39 ft of which was 1 in thick, 56 ft of 1¼ in thick, 28 feet of 1½ in thick and 15½ ft of 1¾ in thick. Replacement of lesser lengths of deal took place on three or four occasions in each year, suggesting that occasional burning of the cladding was taking place but with the price of the deal (between 4d and 5d per foot) it was an accepted expenditure. When the locomotive was restored at Shildon in 1857, it received cladding for the upper half of the boiler only, held in place by four straps.

Running-boards were fitted when the locomotive was made in 1825. A contemporary report states that a 9 in wide 'platform' was provided "just above the wheels".[378] Running-boards would have remained in use during both its operating career and its preservation life. They enabled the train crew to lubricate the movable components whilst stationary, and to reach the regulator lever and safety valve on the left side of the locomotive, and to reach the boiler feed-pump on the right side.

The boards may well have been replaced a number of times with similar, or even like for like replacements, during its career. The earliest photographs of the locomotive feature similar boards to those now seen on the locomotive. The 1906 Darlington Works apprentice drawing shows them to be unchamfered, rounded-end, rectangular boards, 2 in thick, of unspecified timber, each being 11 ft 9 in long and 1 ft 4 in wide. At each end, on the boiler side of the boards, a 1 ft long x 4 in wide section is shown to have been removed, the retained full-width section being inserted up to the boiler plates between the boiler-end angle-irons. The resulting ends are rounded into semi-circles.

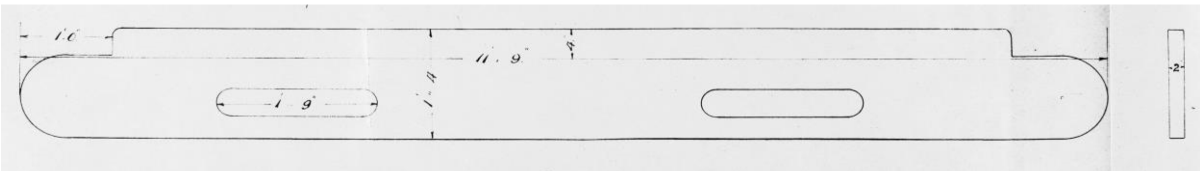


Fig. 24.2 1906 Darlington Works apprentice drawing of the left side running board. [NERA 1967-1]

The Boards appear to have been replaced since 1906 on at least one occasion. Photographs of the locomotive have usually been taken as broadside views, thus making it difficult to determine the end profiles of the Boards. However, the front view of the artefact taken in 1925 shows that full width Boards with rounded ends had been employed on that occasion, and it is possible that they had been installed, new, during the locomotive's restoration in 1924.

Fig. 24.3 1925 view of the centenary parade train. The leading ends of the running-boards are extended beyond the boiler front-plate with rebates for the angle irons. [NRM Historic Photos. – file 812]

ARCHAEOLOGY

Boiler cladding

The cladding was removed during the locomotive's refurbishment at the Darlington Locomotive Works in 1961. It is apparent that fresh oak cladding was supplied and installed. Although evidence to confirm this has not been traced, photographs taken after the refurbishment appear to show fresh timber. Following the application of the boiler's coat of protective paint, the cladding was fitted over the upper half of the boiler barrel in the paint shop at Darlington, and coats of varnish were applied to its surface.

Fig. 24.4 Freshly varnished cladding fitted to *LOCOMOTION* in June 1961 on the conclusion of its refurbishment in Darlington Locomotive Works. [York HQ Photos, Box 9, No. 8792]

No records can be traced to indicate what was inserted between the boiler and the cladding at that time. At the commencement of this project however the authors were advised by the National Railway Museum that traces of asbestos had been found beneath the cladding in early 2022. This has prevented the cladding being removed to allow inspection of the upper boiler plates by the authors.

The cladding is formed of 32 strips of 2½ in wide timber (probably oak) fitted between the boiler end-plate angle irons. It is retained in place using four 2½ in wide steel bands around the front and back of the barrel and two in between the two cylinder flanges. The lower ends of these bands are riveted to threaded retaining clasps, passing through the running-boards and tightened to their underside with nuts.

Fig.24.5 The left-side rear retaining clasp above and below the running-board.

Running-boards

The left-side board is 11 ft 8 in long, whilst the right-side board is 11 ft 9¼ in long. Both are 2 in thick and 1 ft 3½ in wide for their entire length, with rebates to accommodate the boiler-end angle irons. Their front ends are 9½ in ahead of the front of the boiler. They are chamfered on the underside around the perimeter, with the rim protected by an iron or steel band along its length. It is likely that the 1906 apprentice drawing has simplified the arrangement of the boards, showing only the 1 ft 9 in long openings for the two connecting rods.

Fig. 24.6 Underside of the right-side running-board, showing chamfered edge.

There are nine holes cut into each board as follows:

Left-side Running-board holes

From the front, the first hole, on the boiler side of the Board, is 4½ in long and 3 in wide with rounded corners, the mid-point of which is 18¼ in from the board's leading edge. The inner edge of the hole is ½ in from the outer face of the cladding. The hole was used to accommodate lifting slings when the artefact was being moved to or from the Bank Top plinth.

The second hole is an elongated arc, with a maximum length of 7¼ in and maximum width of 2¾ in, the mid-point of which is 34¾ in from the front. The inner edge of the hole is adjacent to the cladding, to accommodate broader lifting slings from those adopted for the first hole.

The third hole is that through which the front connecting rod passed. It is 21½ in long and 4¼ in wide, with rounded ends. Its mid-point is just under 3 ft from the leading end and 9½ in from the inner edge alongside the boiler.

The fourth hole, again with rounded edges, is that through which the leading valve rod is fitted. It is again inserted on the boiler edge of the running-board, the valve rod requiring the boiler cladding to be rebated to accommodate its movement. The hole is 7 in long and 3 in wide, with its centre point being 3 ft 9 in from the front.

The fifth hole, again formed adjacent to the boiler plates, is that inserted to accommodate the rear valve rod. It is 10½ in long by 4 in wide, again with rounded ends. Its mid-point is 5 ft 8¼ in from the front of the running board.

The sixth hole is small and rectangular, adjacent to the boiler plate, and is 2⅜ in long and 2¾ in wide. Its mid-point is 6 ft 6¾ in from the leading end of the running-board. It is not evident what the purpose of this hole might have been.

Fig. 24.7 Left-side running-board facing forwards, showing the leading six holes.

The seventh hole is an arc adjacent to the boiler plate that has a maximum length of 8 in and a maximum width of 3¾ in. Its centre is some 8 ft from the front of the running-board. It would have accommodated a lifting sling for the rear of the locomotive.

The eighth hole allowed for the rear connecting rod to pass through. It is 22½ in long and 4 in wide, with its centre some 8 ft 1½ in from the front of the running-board and 9½ in from its inner edge.

The ninth hole is 4½ in long and 2½ wide with rounded ends. Its centre is 10 ft 6¼ in from the front of the running board and 1¾ in from the inner edge. There is thus a ½ inch separation from the outer surface of the cladding and would have been used for a narrow lifting sling.

Fig. 24.8 Left-side running-board facing rearwards, showing the seventh, eighth and ninth holes.

Right-side Running-board holes

The first hole is 4¼ in long and 2½ wide with rounded corners, with its centre point some 1ft 4 in from the leading end of the running-board. Its inner edge is ½ in from the outer edge of the cladding which is similar to the matching hole on the left-side running board.

The second hole is an arc, with a maximum length of 7 in and a maximum width of 2¾ in. Its centre-point is 3 ft 4¼ in from the leading end. This hole matches the left-side hole No.2 and would have been used for lifting-slings.

The third hole accommodated the front connecting rod movement. It is 21½ in long and 4 in wide, with rounded ends. Its mid-point is 3 ft 1 in from the leading end of the board and 8 in from the boiler plate.

Fig. 24.9 Leading end of the right-side running-board facing rearwards, showing the first, second and third holes.

The 4th, 5th and 6th holes accommodate the boiler feed-pump components. The 4th hole is for the spindle for operating the screw-down clack-valve. It has a slot 4¾ in wide from the boiler plate and is 1 in deep, with its centre-point being 4 ft 7½ in from the front of the running-board and 2½ in from the boiler plate. The 5th hole is for the feed-pump arm and is circular with a diameter of 4¼ in. Its centre is 5 ft from the front of the board and 4 in from the boiler plate. The 6th hole is for a feed-pump pivot bracket. The 2in long hole is formed as a slot from the boiler plate, some 3¾ in deep. Its centre-point is 5 ft 8¼ in from the front of the board and 3¼ in from the boiler-plate.

Fig. 24.10 Right-side running-board from its mid-point facing forwards, showing the 4th, 5th and 6th holes for the boiler feed-pump components.

The 7th hole is in the form of an arc radiating from the boiler plate, with a maximum width of 4 in outside the cladding and a maximum length of 6¾ in. Its centre-point is 8 ft 5¼ in from the front and 4¾ in from the boiler plate. It would have been used for a lifting-sling, matching the 7th hole on the left-side running board.

The 8th hole is that made to accommodate the rear connecting rod. It is 21½ in long and 4 in wide. Its mid-point is 8 ft 2½ in from the front of the beam and 9¾ in from the boiler plate.

The 9th hole is oval, its maximum length being 4½ in and its maximum width being 3½ in. Its mid-point is 10 ft 6 in from the front of the running-board and 5¼ from the boiler plate. It would have been used for a lifting sling matching the left-side 9th hole.

Fig. 24.11 Rear of the right-side running-board facing forwards, showing the 7th, 8th and 9th holes.

Running-board support brackets

In 1906 the running-boards were shown in the Darlington Works apprentice drawing to have been fitted with two-piece brackets riveted to the boiler barrel above and below the board level. The upper brackets appear to have been made with a c½ in thick angle section, the boiler facing piece of which was curved to follow the barrel alignment and had three rivets.

The lower bracket, of c¼ in section, providing under-support for the upper bracket, was also forged in a curve, the boiler facing piece again following the barrel alignment, and secured with three rivets. A counter-sunk bolt through the running-board was tightened with a nut on the underside of the assembly.

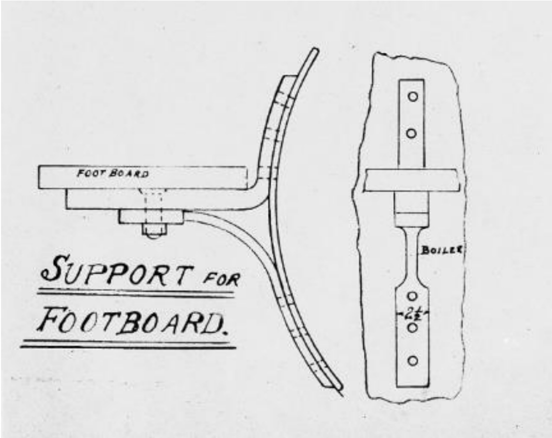


Fig. 24.12 Part of the 1906 Darlington Works apprentice drawing showing cross-section and elevation views of running-board brackets.

[NERA 1967-1]

However, the examination of the surviving three brackets on each side shows several different designs and fittings which are quite different from this 1906 portrayal, and there is no evidence of either these main upper brackets or the lower support brackets being present. It is possible that the surviving brackets may have been fitted during the 1924 renovation in North Road Works, Darlington.

The brackets are mostly bolted to the boiler barrel using flanged extensions turned to face the boiler plates. On the left side these are above running board level, but on the right side they are below running board level, probably due to the boiler plate overlap. Two of the flanges for the right-side running-board are of an earlier 'heart'-shaped form with two adjacent rivets in horizontal alignment. The front bracket has been cut short and is redundant, whilst the rear one has been re-used for the bracket arm.

Fig. 24.13 Right-side front bracket, with redundant 'heart'-shaped flange to its right

Fig. 24.14 Right-side rear bracket, with 'heart'-shaped flange supporting replacement bracket arm.

The surviving brackets, all of forged iron, are different from each other and do not form a 'set'. They are all supported by forged iron diagonal stays, which are either straight or curved. The stays are forged at the upper ends, to allow the use of bolts and nuts to fix them to the brackets, with similar flanges at the lower ends, with bolts tapped through the barrel plates.

On the left-side the leading bracket is 14 in long x 2 in wide x ½ in thick, the middle is 12 in long x 1½ in wide, also ½ in thick, and the rear is 15 in long and ⅝ in square. Although the authors were unable to see the bracket fixings because of the retention of the boiler cladding, the photographs taken during the 1961 refurbishment reveal this method of securing them. It also confirms that the brackets survived that refurbishment and have been on the artefact since at least the 1924 works visit. Each bracket is supported by diagonal forged iron stays bolted to the outer end of the bracket and to the boiler plate. The leading stay is straight, 15½ in long, and formed of ½ in square iron. The centre stay is c15 in long, curved and forged from iron that is 1⅜ in wide and ½ thick. The rear stay is c15 in long, curved and forged from ⅝ in square iron.

Fig. 24.15 Left-side forward facing view of the boiler, as photographed during the 1961 refurbishment, showing the running-board brackets bolted to the barrel.
[ARPT photograph - detail]

On the right-side, however, there are no similar photographs to check on the method of securing the brackets before 1961. The front right bracket is 13½ in long x 2 in wide x ½ in thick, supported by a 17 in long straight stay of ½ in x ¾ in section. The central bracket has been relocated at some stage. The earlier bracket has been cut off leaving a lower 'palm' still bolted through the boiler. The surviving bracket, with a bolted flange, is 11¾ in long x 1⅜ in wide and is tapered from ½ in to ¼ in thick. Its diagonal stay, of ½ in square section, is 15 in long. The rear horizontal bracket arm is not bolted to the barrel, but to the ledge of the earlier 'heart-shaped' bracket flange (Fig. 24.13). It is 13 in long x 2 in wide x ⅜ in thick. Its curved support stay is c14½ in long formed of ½ in square section.

Fig. 24.16 Right-side running-board central bracket, bolted to the boiler plate beneath the horizontal section.
The cut off remains of the earlier bracket are to the rear of the boiler feed-pump.

Driver's seat

The hazards of driving the locomotive from the left-side running board were recognised by the provision of a wooden seat for the driver mounted towards the rear of the boiler barrel. Such a seat was provided from new and was referred to in a contemporary report as "a higher plank by which all parts of the engine can be reached, and the valve gear adjusted."[379]

The seat, probably of oak, was restored in 1961. It measures 20 in long and 16 in wide, and is $1\frac{3}{8}$ in thick. Its sides have been rounded off. When first preserved, the seat had just one vertical iron support at its leading end, which was secured on to the running-board. However subsequent photos taken in the 19th century and throughout the 20th century all show a second matching support at its rear end. The iron supports are 18 in high, $1\frac{1}{4}$ in wide and $\frac{1}{4}$ in thick.

Fig. 24.17 Driver's seat from 1857 photo. [Fig. 8.1 - detail]

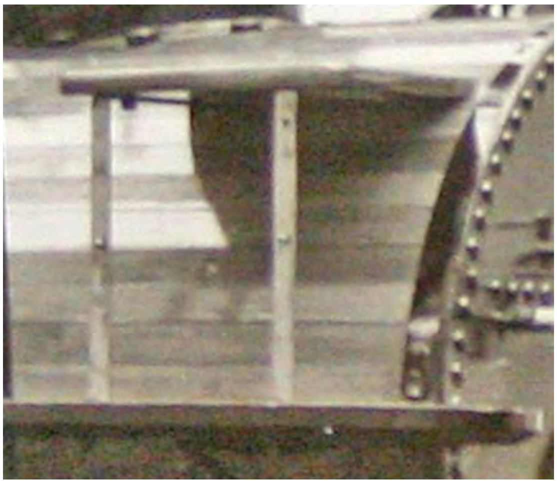


Fig. 24.18 Detail of driver's seat as restored in 1961. [NRM Historic photos file, 812 R-175-3]

25. Tender

COMPONENT HISTORY

The first tender attached to the *Active* locomotive was a simple four-wheeled waggon, although the vehicle's manufacturer went un-recorded. It was said to have been fitted with a 'huge water barrel' that was made by Mason Brotherton of Blackwellgate, Darlington.[380] The barrel was said to be so large that it had to be assembled in the street outside the cooper's premises as it would not have fitted through his gate. The tender was not shown in any detail on the three contemporary sketches of the opening day, to confirm the presence or size of the barrel (Figs. 1.4 – 1.6). Indeed, fifty years later it was admitted that the lithographs and other illustrations of the opening day 'were incorrect in this particular'.[381] However, a contemporary drawing of a locomotive for the Hetton Colliery railway shows the form of tender then in use just prior the construction of the S & D R locomotives.

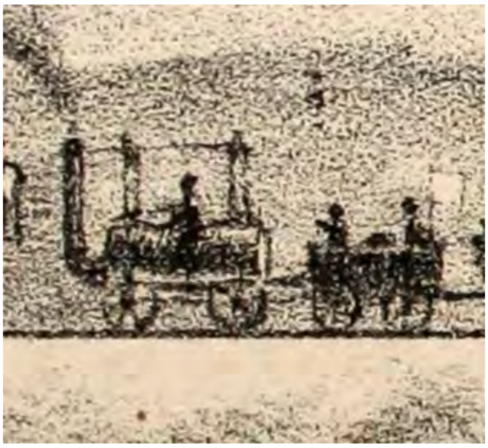


Fig. 25.1 Tender sketch

[Fig. 2.2 – detail. Account of the Stockton and Darlington Rail-Way, 1826]

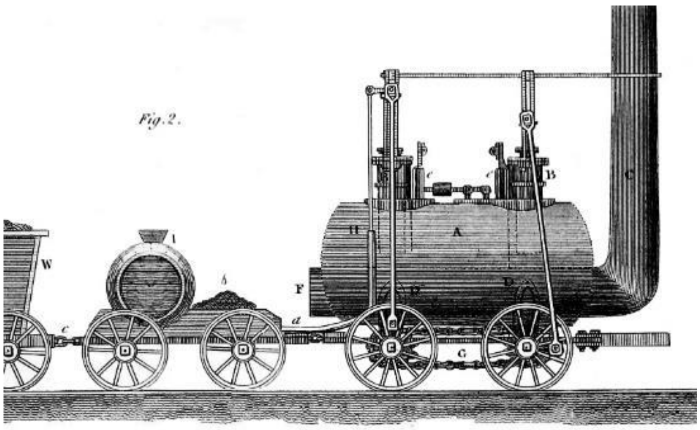


Fig. 25.2 Tender of locomotive built for the Hetton Colliery Railway in 1822

[Thomas Tredgold, 1835, Plate 1, Fig. 2 – detail]

When No.1 was re-formed in 1828 with a double return-flue boiler it was almost certainly fitted with two tenders, a water tender at the front and a coal tender at the rear, similar to other locomotives in the railway's fleet. Contemporary views of the *MAGNET* locomotive, built by Timothy Hackworth in Shildon in 1835, and of one of the rebuilt early Stephenson locomotives show the possible form of No.1's tenders from that time.

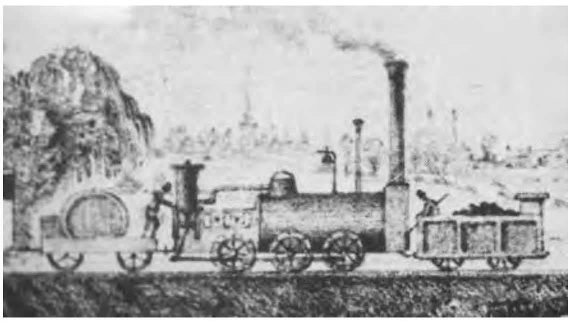


Fig. 25.3 *MAGNET* locomotive of 1835, showing coal and water tenders, possibly similar to those fitted to No.1 from 1828

[Darlington Public Library]

Fig. 25.4 Early Stephenson locomotive converted to a return-flue boiler, showing separate tenders for coal and water.
[Undated painting from c1830 – detail. Preston Park Museum, Eaglescliffe, Ref. STCMG:1971.0566]

There is no evidence in the railway's archive papers to indicate the form of tenders that might have been used following *LOCOMOTION*'s further rebuilding in 1834, until the termination of its regular use in 1840/41. However, with the longer journey times between Brussleton and Middlesbrough from 1834, following the opening of the Stockton Bridge, the water barrel was probably increased in capacity to minimise the number of stops to replenish water that would have been needed. An example of the larger tenders that were used from that time is shown for the *WILBERFORCE* locomotive, built by R & W Hawthorn in 1833.

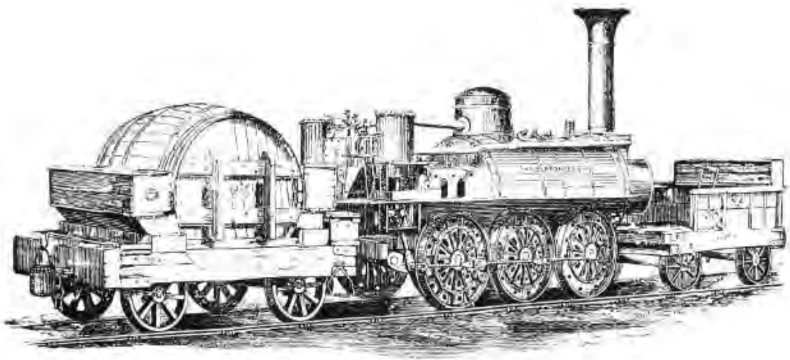


Fig. 25.5 The *WILBERFORCE* locomotive fitted with extra capacity water tender.

[*The Engineer*, October 31st 1879]

With the retirement of *LOCOMOTION* from 1841 it is probable that its tenders were allocated to a central pool at Shildon, allowing them to be used for any other locomotive whose operating requirements needed them to be substituted. The locomotive's return to service in 1846 could, correspondingly have adopted any of the tenders that were available from the Shildon pool. There is no evidence that any type of tender(s) accompanied the locomotive during its sojourn at Roddymore Colliery providing steam for a pumping engine, and land-based supplies of coal and water may have been provided.

When No.1 returned to Shildon Works in 1856, for restoration prior to being displayed on the plinth outside North Road station in Darlington, separate water and coal tenders were no longer applicable. In keeping with the remit to display the locomotive in as near 'original' condition as possible, Shildon Works had no option other than to replicate what was perceived to be an 1825 design of tender.

The basic frame, wheel bearings and wheelset arrangement from that time was probably adopted in making the vehicle, as seen in contemporary plans for wagons made in Shildon Works. The replica body and water tank would have been specially made.

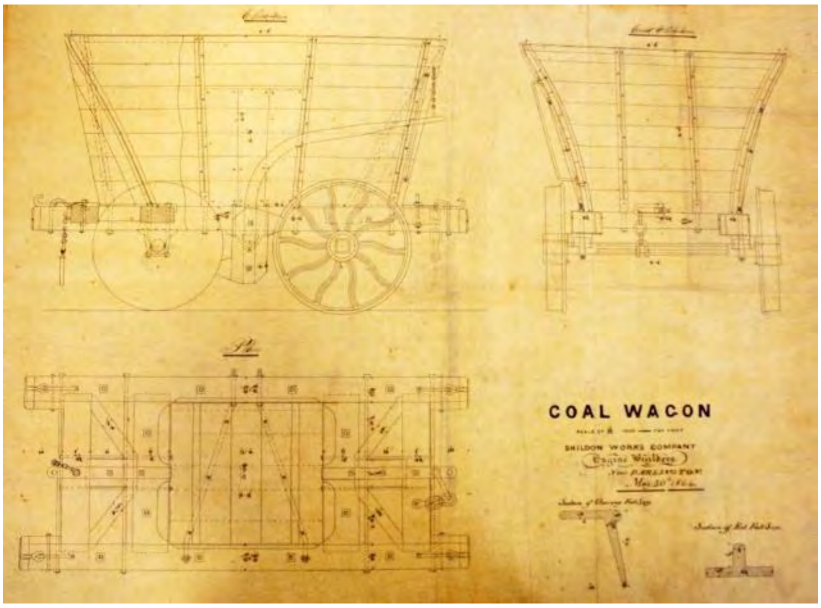


Fig. 25.6 Drawing of Standard coal wagon built by Shildon Works, dated 1854. [NRM, NEC&W collection]

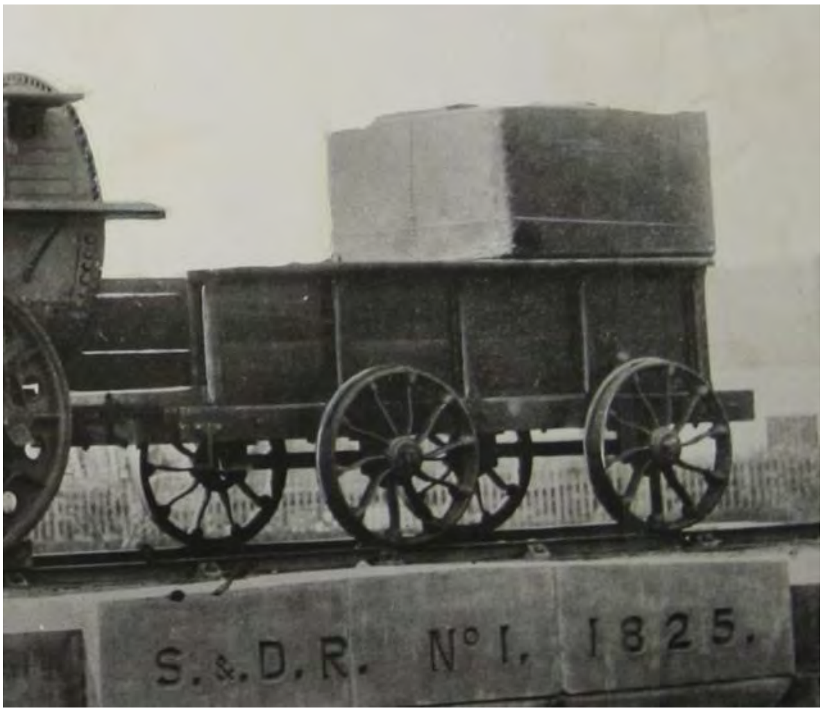


Fig. 25.7 The newly-made replica tender shortly after being placed onto the plinth outside North Road Station, Darlington [NRM, York HQ Photos. Box 9, 1065 & x35789 – (detail)]

The timber tender and its wrought iron tank were exposed to all weather conditions between 1857 and 1892, and to all conditions of humidity and aerial contamination between 1892 and 1961 during its external display years. It decayed and corroded badly and its restoration in Darlington Works in that latter year was extensive. The authors believe that a careful replication of the decayed timbers was carried out to provide a vehicle that closely matched the pre-1961 version of the vehicle. The iron components, notably the wheelsets, were however conserved and re-used.

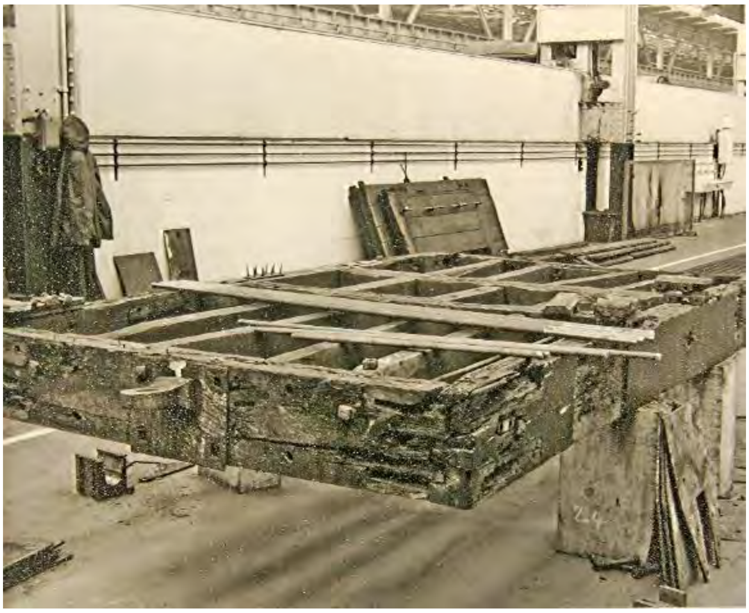


Fig. 25.8 *LOCOMOTION*'s tender frame stripped down inside Darlington Works in 1961, showing the poor condition of the timberwork. [NRM Historic Photos. File 812, R 167-10]

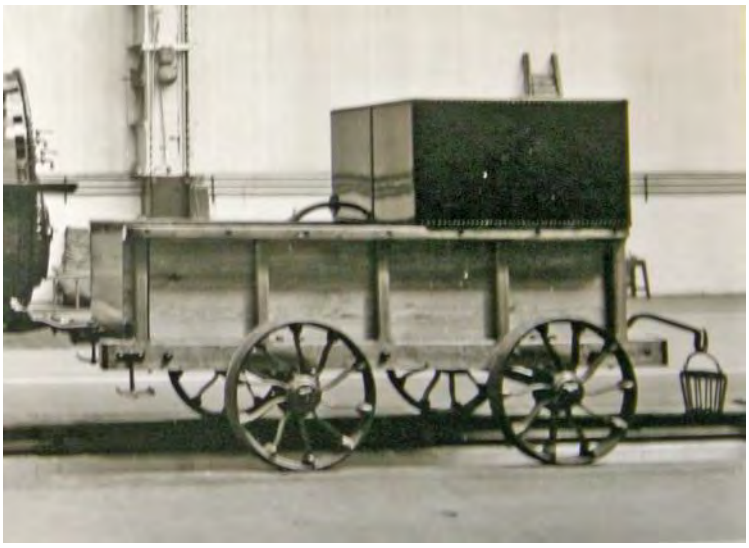


Fig. 25.9 Tender following its 1961 rebuild. The wheel-sets and horns/bearings were retained.

[NRM Historic Photos file 812 – R175-5]

ARCHAEOLOGY

Frame

The length of the frame, over buffers, is 10 ft 4⅜ in, and the vehicle's wheelbase is 4 ft 9 in. The two longitudinal exterior beams forming the sides of the frame are 4¾ in wide and 5⅜ in high. Their buffer extensions at the front and rear are reinforced with 1 in wide wrought iron bands. The buffer centres are 22 in above rail level. The top outer corners are chamfered. Two further intermediate longitudinal beams are 4¾ in deep and 3¾ in wide. At the front and rear, transverse beams are fitted to complete the frame rectangle. These beams are 36¾ in long x 5⅞ in high x 3½ in thick. Two intermediate cross-members of similar section are inserted between the longitudinal inner beams to stiffen up the frame. Wrought iron tie-bars are fitted to the frame. Three ¾ in diameter bars are fitted in the centre of the tender and at a separation of 47½ in forward and rear. The frame is topped by boards forming the coal space which are 1¾ in thick and 7¼ in wide, with the exception of the centre board which is 10½ in wide. The floor of the vehicle stands 24½ in above rail level.

Fig. 25.10 Longitudinal and transverse frame members beneath the floor-boards of the coal-space (upward view)

Body

The two side-walls and the rear end are composed of two 10½ in wide planks, one above the other, which are ⅞ in thick. The side walls are 9 ft 2½ in long and the rear end is 3 ft 2¾ in wide. Three vertical tie-bars of ⅜ in diameter, on each side, pass through the side walls and are tightened beneath the frame. Five upright buttresses on each side, and two at the rear, support the side-walls on the outside. The buttresses, which are fixed by mortice and tenon joints, are 2¾ in wide, 2¼ in deep and 21 in tall. Both their outer corners are chamfered. The assembly is topped by a rail, 3¼ in wide, and 2¼ in deep running the full length of the side-walls. Its upper face is extended outwards using a cantilevered side timber which is 2 in thick and 3⅝ in wide. The boarded area forms the coal space. It has a lip at the leading end, to retain the coal from vibrating forward, which is 3 in high and 2⅞ in wide.

Fig. 25.11 External view of the left side

Fig. 25.12 Interior view of the left side.

Tank

This replacement tank has no bottom plate, and its edges are supported on timbers above the side-wall top-rails. The tank-height is 2ft 3 in, its length is 4 ft and its width is 4 ft 7 in. Its rear face is flush with the outer face of the side-wall rails. It is made of 6-gauge mild steel. The top surface has a forward oval hole, with a maximum width of 15¼ in and maximum length of 13 in. Its centre is 10 in behind the leading edge. Its cover is wooden, topped by a steel plate. A rear hole on the tank top is 4¾ in diameter and covered with a wooden cover. Its centre is 10 in from the rear edge and 13 in from the left-side.

The water outlet is a 1½ in diameter pipe that leaves the front right corner of the tank near its bottom fitted with a 5 in diameter flange, some ⅜ in thick. The pipe is directed down diagonally to a brass regulator tap positioned adjacent to the tender's front right buffer.

The leading face of the tank is supported across the coal space by a cross-timber, the leading face of which is 2 in back from the front of the tank. The cross-timber is 2⅝ in thick and 3¼ in wide. Iron strap corner reinforcements in each of the rear corner spaces are 2¾ in wide and 3/16 in thick and are 10 in long.

Fig. 25.13 Front right view of water tank, showing supporting timber and outlet pipe.

Draw-Bar

A 1 in thick wrought iron draw-bar runs the length of the tender. It is 3 in wide at the leading end and broadens out towards the rear to become 3½ in wide. The draw-bar eye is 2½ in wide, with a vertical pin of 1⅜ in diameter and a length of 4¾ in, and is secured by a split-pin and washer. The draw-bar eye at the rear has a 1½ in diameter hole into which a 1⅛ in diameter pin is inserted. The pin is 7 in long with an upper diameter of 1⅜ in.

Fig. 25.14 Leading draw-bar pin

Fig. 25.15 Rear draw-bar pin

Wheel-Sets

The tyre-less, cast iron, 30 in diameter wheels are similar to those formed at Shildon in the 1850s. The wheels are 4 in wide, including the ⅞ in width of the flange, and which is ⅝ in in height.

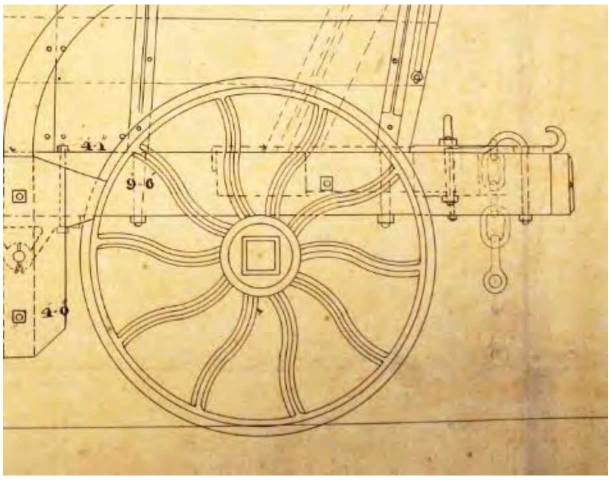


Fig. 25.16 Shildon Works coal waggon wheel, 1854. [NRM, NEC&W collection]

Fig. 25.17 Surviving wheel on No. 1's tender.

The wrought iron wheel-spokes are ½ in thick and inserted into sleeves on the rim. The maximum width of the cast iron hub is 6¼ in, although to avoid the back of the wheels rubbing against the vehicles frame, spacer washers have been inserted between the hubs and the bearings. The wheels are bolted to the axles, which are thus threaded on their ends to receive the bolts. The 2¼ in A/F square-headed bolt-heads suggest that a thread diameter of 1¼ in was adopted. The back to back separation between wheels on each wheel-set is 4 ft 6¼ in. The axles are 2¾ in diameter, and are not reduced where fitted to the wheels.

Bearings

The four axle bearing assemblies are bolted to the side frames. Their side members are extended upwards through the side frames as threaded rods, secured by nuts at their tops. Each assembly has a 4 in long half-bearing on the upper surface of the axle, and a lower keep, with longitudinal bolts holding the assemblies together. The bearing assembly is topped by a 7¾ in long contact block, on which sits the inner longitudinal frame members. The vehicle is springless and track inequalities would have been taken up by the frame flexing.

Fig. 25.18 Rear left horn assembly.

Footsteps

Wrought iron foot-steps are provided at the leading ends of the buffer arms on both sides of the tender, to which they are bolted. The step height is 4 in below the bottom of the frame and 15½ in above rail height. The steps are 6½ in deep and 7 in wide.

Fig. 25.19 Right-side footstep

PART III –

OPERATION AND PERFORMANCE

26. Driving the Locomotive

The ‘Engine Men’ were responsible for preparing and driving the locomotive and for the safe conduct of themselves and their firemen. They reported any accident damage or other maintenance requirements to the Shildon Works foremen to rectify.

Preparation for service

Lubrication of the locomotive, undertaken before and during a run, was made to avoid components running hot. Whale oil, at 4d per gill cost, was largely adopted for lubrication of axle bearings, pistons and driving motion, with lesser amounts of ‘pale oil’ (probably linseed oil), at 5d per gill cost, probably used for reciprocating movements of parallel and valve motion.[382]

There is no longer any surviving evidence of the original means of lubricating the wheel bearings, and later access would have been made through the bottom plates of the boiler brackets. However, these plates appear to have become badly corroded following prolonged exposure to the weather from 1857, and have been covered over by further plates, probably in 1892, (Sections 8, 11 and 12).

Fig. 26.1 Front right boiler bracket showing 1892 plate inserted onto its base, thereby covering evidence of lubrication access.

Provision was made for oiling the pistons within the cylinders using an access hole in the cylinder covers. A removable spigot is inserted into the access hole when operating.

Fig. 26.2 Cylinder cover with lubricant feed hole (fitted with a spigot).

Provision for lubricating the piston rod bushes, was made using collar reservoirs which allowed lubricants all-round penetration with the piston rods themselves.

Fig. 26.3 Piston rod bush with collar lubricant reservoir.

Other lubrication entry points remain *in situ* for some of the motion components such as coupling rods and valve rocking shafts.

Fig. 26.4 Coupling rod crank bearing with lubrication access hole.

Fig. 26.5 Valve rocking shaft with lubrication access hole.

The valve rod bushes were similarly lubricated using collar reservoirs that allowed the oil to trickle through to the valve chests themselves.

Fig. 26.6 Valve rod bush with collar reservoir for oiling the bush and valve chest.

Other consumables were taken on board the locomotives by the engine men for use during their operating duties. Candles for use in lanterns were booked out for use on the journeys, as were quantities of 'spun yarn', no doubt used by the men to handle hot surfaces and to clean up component surfaces from oil spillage and coal dust. Firemen were issued with shovels and fire-irons.

Tenders were replenished with water from six wells along the line - at Brussleton Bankfoot, Shildon, Heighington Lane, Darlington, Goosepool and Stockton. Some of the watering points had men on the ground aiding the footplate crews and ensuring that a supply of water was maintained at all times.

Tenders were filled with coal at the commencement of every run. From 1830 a coaling platform was provided at Brussleton Bankfoot.

Somewhat surprisingly, only in November 1834, did the railway's sub-Committee resolve, as a safety measure, that fire-lamps should be provided to all engine men to fix to the rear of each train they operated.[383]

Driving Procedures

Before departure, the engine men secured the locomotive's safety-valve lever with rope to prevent its vertical movement and momentary release of steam from the valve occasioned by the motion of the locomotive over the track. This was on the strict understanding that the rope would be removed when motion had ceased, to allow any surplus steam to be released from the valve when occasion required (Sections 2, 4 and 5).

For normal operation the engine men sat on the wooden seat on the left side of the boiler within reach of the regulator handle (Section 24).

Starting the locomotive, and controlling its speed, was undertaken by a gradual opening of the regulator valves with the regulator handle. There were no brakes employed on the locomotive or tender. Stopping a train would have been achieved by shutting the regulator and relying on the resistances of the locomotive and train to bring it to a halt.

Change of direction would have been achieved only when stationary. Having brought the locomotive to a halt, the engine men would have stood up, stepped round the rear left connecting rod to the centre of the running board to release the locking handles by first lifting the locking-sleeves, then moving the valve drive rods sideways to disengage them from the lever pins, and then moving the slide-valves manually by lifting/lowering the levers.

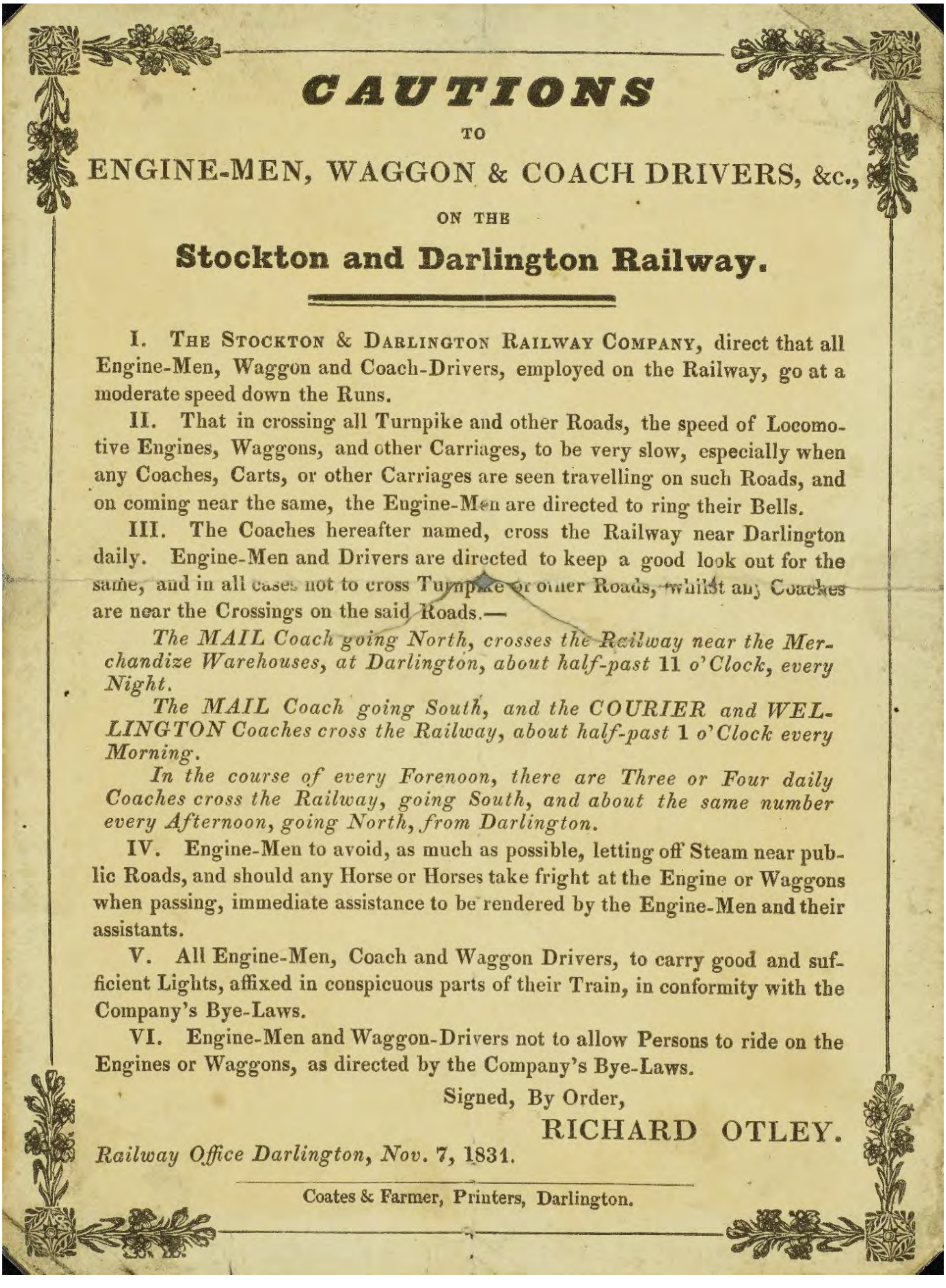
The engine men were obliged to follow the firm's bye-laws, or be subject to fines if these were breached. Fig. 26.7 shows the published directions for engine men concerning the crossing of turnpike roads, issued in 1831. They were provided with hand bells to sound warnings at road crossings.

One of the responsibilities of the train crew was to lubricate the bearings of the chaldron waggons whilst on the move. On a level stretch of line the driver would set his train in motion at two miles an hour before he and his fireman climbed down onto the track and applied oil (presumably whale oil) to the bearings from a tin using a long-handled brush.[384] When the train had passed them, increasing its speed by benefiting from the lubrication, the crew would need to climb onto the last waggon and clamber over the coals forwards to the locomotive to regain control.

The firemen were responsible for maintaining the fire to ensure a continuous supply of steam when required, and for ensuring that the tender barrel had an adequate supply of water for the upcoming journeys. Firemen also undertook the disposal of the locomotives at the completion of the day's journeys, withdrawing the fire from the grate, and cleaning out the flue.

Following the serious fires that occurred to plantations of trees alongside the line (Sections 4 and 5) it was a further requirement for firemen to position themselves on the trains of wagons keeping a lookout for any signs of fire that may have occurred by sparks emitted from the locomotives as they passed the plantations.

In 1827 it was noted that two additional men were required on each train "for attending to the 16-20 wagons."[385] This practice may have been discontinued shortly afterwards as there are no further references to the employment of such train crews in the railway's minute books.



CAUTIONS

TO

ENGINE-MEN, WAGGON & COACH DRIVERS, &c.,

ON THE

Stockton and Darlington Railway.

I. The Stockton & Darlington Railway Company, direct that all Engine-Men, Waggon and Coach-Drivers, employed on the Railway, go at a moderate speed down the Runs.

II. That in crossing all Turnpike and other Roads, the speed of Locomotive Engines, Waggons, and other Carriages, to be very slow, especially when any Coaches, Carts, or other Carriages are seen travelling on such Roads, and on coming near the same, the Engine-Men are directed to ring their Bells.

III. The Coaches hereafter named, cross the Railway near Darlington daily. Engine-Men and Drivers are directed to keep a good look out for the same, and in all cases not to cross Turnpike or other Roads, whilst any Coaches are near the Crossings on the said Roads.—

The MAIL Coach going North, crosses the Railway near the Merchandize Warehouses, at Darlington, about half-past 11 o'Clock, every Night.

The MAIL Coach going South, and the COURIER and WELLINGTON Coaches cross the Railway, about half-past 1 o'Clock every Morning.

In the course of every Forenoon, there are Three or Four daily Coaches cross the Railway, going South, and about the same number every Afternoon, going North, from Darlington.

IV. Engine-Men to avoid, as much as possible, letting off Steam near public Roads, and should any Horse or Horses take fright at the Engine or Waggons when passing, immediate assistance to be rendered by the Engine-Men and their assistants.

V. All Engine-Men, Coach and Waggon Drivers, to carry good and sufficient Lights, affixed in conspicuous parts of their Train, in conformity with the Company's Bye-Laws.

VI. Engine-Men and Waggon-Drivers not to allow Persons to ride on the Engines or Waggons, as directed by the Company's Bye-Laws.

Signed, By Order,

RICHARD OTLEY.

Railway Office Darlington, Nov. 7, 1831.

Coates & Farmer, Printers, Darlington.

Fig. 26.7 Notice for Engine men of the Stockton & Darlington Railway, issued on November 7th 1831, by Order of Richard Otley, the railway's Company Secretary.

[Durham County Record Office, D/PS 5/2 (ii)]

27. Locomotive Performance

Introduction

The three operating versions of the locomotive were very different, particularly in the arrangement of the flue(s) within the boilers and in the cylinder bore diameters. This section assesses the relative performances of these versions, concentrating on the effects of changing these two aspects of the designs. In order to separate out the effects of these changes, it is useful to consider them one at a time. The assessment therefore included a notional version, which did not actually exist. This results in four versions to be assessed. The versions are described as:

Version 1: The locomotive as built and operated from September 1825 to July 1828, with a single straight flue and 9 in diameter cylinder bores.

Version 2: This is the notional version, where the 9 in diameter cylinder bores are retained, but the flue is changed to that of Version 3. The results of this assessment of this version therefore focus on the effect of fitting this new flue.

Version 3: The locomotive as re-built by Timothy Hackworth and operated from late 1828 to 1834 with a double-return flue and 10 in diameter cylinder bores. The results of this assessment then concentrate on the effect of fitting the larger cylinders.

Version 4: The locomotive as again re-built and operated from 1834 to 1846, with a single return flue and 10 in diameter cylinder bores. The assessment results focus on the effect of fitting the smaller return flue.

The assessments used published methods and data.[386] These methods were used successfully to emulate, and then extrapolate from, published performance data on early locomotives, which included coal and water consumptions with different train weights and speeds. For this locomotive there is little such reliable data, apart from the typical train weight and speed with Version 1. However, an appropriate coal firing rate was deduced for Version 1 and the other versions were then assessed using the same rate, to give a set of comparative results.

Data

The key parameters of each version of the locomotive are shown in Table 27.1. In all cases the fire grate was taken to be 4 ft long, in line with standard practise at that time. The flue areas on Versions 2, 3 and 4 must be taken as indicative since the geometry of the tapering 'U' bends for their return flues is not known.

Locomotive version	Weight. Ton.cwt.	Wheel dia. In.	Flue wetted area. Sq.ft.	Flue area for radiant heat. Sq.ft.	Flue area for conducted heat. Sq.ft.	Grate size. Sq.ft.	Piston dia and stroke. In.
1	7.17	47	75	12.6	46.6	8.0	9 x 24
2 (Notional)	10.16	48	158	12.6	124	9.0	9 x 24
3	10.16	48	158	12.6	124	9.0	10 x 24
4	9.0	48	100	11.1	73.0	7.7	10 x 24

Table 27.1 Key Parameters

Thomas Storey, the engineering superintendent of the S & D R, wrote that 298 tons of coal were used by the four engines during the months of May and June 1827 to convey nearly a quarter of a million tons of coal one mile.[387] This translates to 246 return journeys of 40-odd miles over the 53 working days, with each locomotive hauling 20 waggons. An average speed in both directions of 5 mph was reported at the time.[388] With an allowance for steam raising at the start of the day, this equates to nearly 2500 lb of coal being fired over a return journey with Version 1, i.e. an average of 310 lbs of coal fired per hour. Ranging calculations indicated that this might have been an overstatement, if the bituminous coal was of saleable quality and all the allocated coal was actually fired. This is discussed further below.

Method

The required pressure of the steam entering the cylinders depended on the train's rolling resistance and the effects of gradients and wind/air resistance. For simplicity the studies leading to the results explained below assumed that the trains were travelling on level track on a still day. The required steaming rate was then a function of this pressure and the train speed, allowing for condensation in the cylinders and steam losses. The rate of condensation depended on the cylinder size, the steam temperature and the time per stroke. The steam losses, e.g., via the safety valves, were consistently set at 7 per cent of the steaming rate.

The actual steaming rate was set to match the required rate to give sustainable operation. This rate depended on the performance of the fire, and the rate of heat transfer to and through the flue. A key parameter affecting the performance of the fire was the amount of air drawn through the grate per pound of coal burnt. While the stoichiometric ratio is about 10, the analysis of the typical day to day performance of each locomotive used a higher air/coal ratio, derived at the start of the analyses. The transfer of radiant heat from the fire to the area of the flue above it was very dependent on the fire temperature and too high an air/coal ratio would have resulted in the fire being cooled, reducing the radiant heat transfer and requiring the coal firing rate to be increased to meet the required steaming rate. The rate at which unburnt coal was carried from the fire and up the chimney has been shown to be dependent on the grate size and the firing rate itself, and so an excessive air/coal ratio would have led to a high rate of ejection of unburnt coal. The 'grate limit' is the point at which half the coal fired would have been lost in this way.

The transfer of heat by conduction in the rest of the flue was relatively poor and depended on the speed of the flue gasses through the flue as well as the surface area, the former being more important than the latter. Thus, within limits, a smaller diameter flue would have performed better than a larger one.

All these factors are allowed for in the analyses.

Results

As a basis for this comparative study, Version 1 was modelled first, and its performance hauling 20 waggons from Shildon to Stockton and back on a still day was assessed. The analysis used a mean downward gradient of 1 in 255 over the 19.1 miles (taken from reported data)[389] with loaded waggons, and the same (adverse) gradient with empty waggons. The results showed that the run with loaded waggons was by far the easier, requiring an average cylinder steam pressure of only 5 psi, with an average of 21 psi being needed for the return run with empty waggons. To have used the reported 2500 lb of coal would have required the air/coal ratio to be extremely high (over 20 for the downhill journey). A more reasonable value was assumed, which when worked through gave a coal consumption for the round journey of 85 per cent of the stated value. The air/coal ratios were still high, but not excessively so. There are several possible reasons for this assessed under-usage of the allocated 2500 lb of coal. The coal may have been of poor quality, not all the allocated coal might have reached the fire grates, or the uphill journeys might have been against headwinds. An analysis showed that the trains were very susceptible to the latter, a persisting 10 mph headwind would alone have almost made up the shortfall.

The results gave a set of operating characteristics for Version 1, which were then applied to its operation with a train of 20 loaded waggons on a level track. This gave a required coal firing rate of 440 lb/hour, with an air/coal ratio of 15. These two parameters were then applied to the models of the other versions, to give a set of steaming rates. The results were then used to derive a set of typical trains that would have required these steaming rates, and the horsepower required to move each along a level track on a still day. The same approach was taken in deriving the maximum horsepower that each locomotive could achieve, at the 'grate limit' and at the same speed as the typical train. These results are shown in Table 27.2.

Locomotive version	Heat to boiler. kW	Steaming rate. lb/hr	Cylinder steam pressure. psi	Appropriate train.	Loco HP	Loco max HP
1	405	1200	25	20 full waggons at 5 mph	12	22
2 (Notional)	570	1700	31	25 full waggons at 6.4 mph	21	40
3	570	1700	26	25 full waggons at 5.8 mph	18	36
4	500	1500	21	20 full waggons at 5.7 mph	14	25

Table 27.2 Typical locomotive performance

In selecting the 'appropriate train', account was taken of the work done by the locomotives in operation, as shown in Figs. 2.4, 4.2 and 5.2. It is evident that, relative to Version 1, Version 3 generally achieved about 25 per cent more work, while Version 4 achieved about twice the work. This supports the view that Version 3 hauled longer trains, whereas Version 4 hauled similar trains, but routinely undertook two return journeys in the day. Having settled on the ‘appropriate train’ a speed was calculated that would have used the derived steaming rate, for each entry in Table 27.2. Thus, there is a basis for considering these ‘appropriate trains’ as being fairly realistic. The listing of train speeds to within 0.1 of a mile per hour may seem unduly pedantic, but it is only way to show the small differences between the capabilities of the locomotive versions.

The results of the analyses of Versions 1 and 3 are shown in greater detail in Fig. 27.1. Those for Version 4 are closer to Version 1 than to Version 3. The top pie charts show what would have happened to the latent heat energy (1.60 MW) in the coal fired. It is immediately apparent that around half this heat would have been lost via the chimney, with associated flue gas temperatures at the chimney bases of over 1000 C in Version 1 and over 900 C in Versions 2, 3 and 4.

While the radiant heat transferred to the boilers would have been similar on all the versions, the heat transfer by conduction would have been significantly greater with the double-return flue on Versions 2 and 3, giving a 40% increase in the steaming rate for the same firing rate.

The pie charts showing how the resulting steam would have been used are sized in proportion to the steaming rates. Each ‘cylinder filling’ slice shows the amount of the steam entering the cylinder that merely raised the pressure to atmospheric, the remainder of the steam then raising the pressure to the operating level. By definition, this ‘cylinder filling’ steam did no work and was therefore wasted. This wastage particularly affected steam engines with large cylinders operating at low pressures and has been separated out for that reason. In conjunction with the cylinder condensation, this accounted for 55% to 60% of the supplied steam. Table 27.2 shows that the notional Version 2 with the smaller cylinders would have been capable of producing more useful power than Version 3 itself. This would have been because these steam wastages would have been smaller with the smaller cylinders, leaving more steam to power the locomotive.

While the ‘useful’ steam makes up a fair proportion of each pie chart, it must be accepted that only a small part (about 9 per cent) of the energy in this steam went towards hauling the train; the majority of the energy was still present in the exhaust.

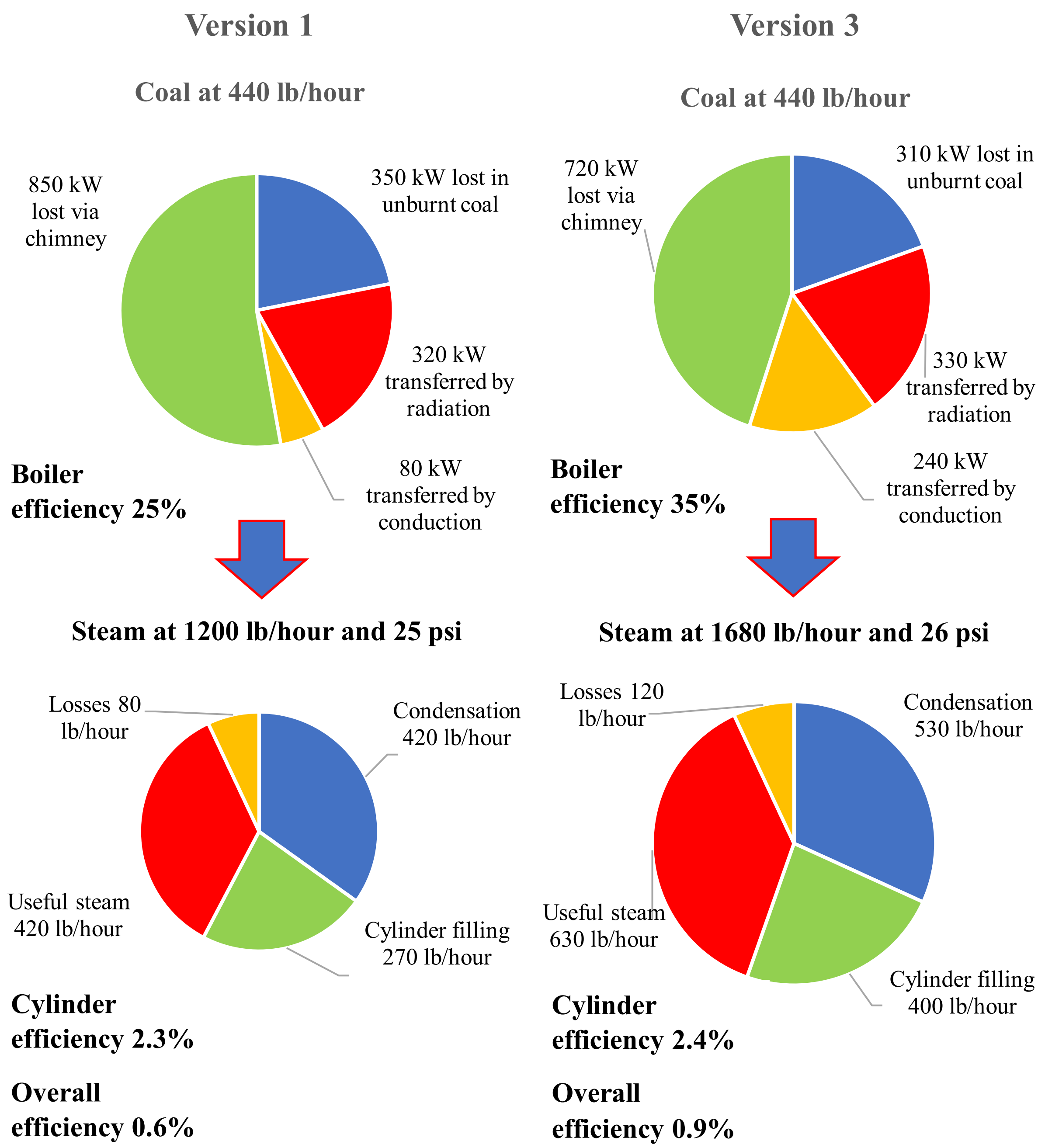


Fig. 27.1 Comparison between Version 1 and Version 3

Discussion and Conclusions

The first main conclusion from the analyses is that the introduction of twin return flues in Version 3 in 1829 was successful in that they provided 40% more steam than the single flue in Version 1. This is discussed in more detail below. This development was then a useful stepping-stone towards the use of multiple small bore return tubes, originated in Hackworth's '*Wilberforce*' class of 1831. With its larger fire grate and 100 1¾ in return tubes, this design benefitted from both the fivefold increase in heat transfer area and the twofold increase in the speed of the flue gasses through the return tubes, compared with Version 3. The class are recorded as having had a steaming rate of 5,000 lb/hour,[390] three times that of Version 3.

The second main conclusion is that the increase in cylinder bore diameters from 9 in to 10 in in Version 3 gave no theoretical benefit. The change actually led to a reduction in the calculated power and efficiency of Version 3 compared with the notional Version 2. However, a practical advantage of the change is that it would have reduced the required steam pressure by about one fifth, which effectively meant that heavier trains could have been hauled by Version 3 with a steam pressure of only 26 psi, similar to the 25 psi required on Version 1.

The analyses covered a single operating point for each version of the locomotive. They could all have produced more power to increase the train speed, with an increase in the firing rate. Increasing the firing rate automatically reduced the air flow to the grate per lb of coal burnt and setting this ratio to 15 in the analyses gave margins to ensure complete combustion at these higher powers. On the other hand, reducing this ratio by design would have reduced the amount of unburnt coal ejected through the chimney at a particular operating point. Setting the size of the exhaust orifice(s) in the chimney (s), which determined the ratio at the operating point, would in practise have been a compromise which depended on the duty expected of the locomotive.

The intentional setting of the air/coal ratio at the relatively high value of 15 in the analyses, in order to approach the coal usage recorded for Version 1, did result in a rather inefficient use of the coal. The steam raised per lb of coal fired was assessed as 2.7 lb/lb for Version 1, 3.9 lb/lb for the notional Version 2 and for Version 3, and 3.4 lb/lb for Version 4. These figures compare with the 3.6 lb/lb calculated for the Killingworth locomotives with their softer exhausts.[391] However, setting the air/coal ratio in these analyses at the Killingworth value, whilst reducing the coal consumption and thereby raising the boiler efficiency and overall efficiency of the locomotive by perhaps 15 per cent, would not have affected the calculated steam consumption rates or the horsepowers required to move the trains, as listed in Table 27.2.

It is apparent from the analyses that the wetted area of a flue is a weak indicator of its heat transfer performance. The increase in heat transfer of 40 per cent required this area to be doubled on Versions 2 and 3, compared to Version 1. This is because the heat transfer by conduction was so poor. Even with the double-return flues giving an overall flue surface area away from the fire of 124 sq.ft., the heat transferred by conduction was only three quarters of that transferred by radiation directly from the fire to the area of 12.6 sq.ft above it. Nevertheless, the double-return flue design did lead to a 50 per cent power increase and the same increase in overall efficiency, although it also increased the weight of the locomotive by 3 tons.

The usefulness of this power increase might be considered disappointing in that it seems, from the operating records and from the analyses, to have only allowed the train length to be increased by five waggons, while travelling at a marginally increased speed. In that sense, the operating performance of the lighter Version 4 with just 20 waggons outdid the previous versions, but that improvement was due to the installation of the second track on the S & D R routinely allowing two return journeys a day, rather than to the locomotive itself.

The maximum sustainable horsepowers shown in Table 27.2 are somewhat abstract in that they imply that the locomotives could apply significantly greater tractive efforts. However, the style of locomotive where the separate cylinders drove separate axles seems to have been particularly prone to wheel-slip, with about half the adhesion to be expected from its weight.[392] This itself may have limited the train sizes on the adverse gradients between Darlington and Shildon. The alternative, of using the power margins to increase the speeds of the trains was ruled out by the imposed speed limits of 8 mph in 1833 (Section 4) and then 6 mph in 1835 (Section 5). Additionally, the 40 horsepower quoted in Table 27.2 for the notional Version 2 is based on the calculated steam pressure available of 58 psi; the safety valve, if not tied down, would have limited this to 50 psi, giving a maximum of 34 horsepower.

The finding that Version 1 only needed an average cylinder pressure of 5 psi to take a 90 ton (gross) train from Shildon to Stockton helps to explain the apparent ease with which it hauled the train on the ‘Opening Day’. The load carried by this train is estimated at about 80 tons (Section 2). Adding the weights of the locomotive and 34 waggons gives a gross train weight of about 140 tons, which on the downhill gradient would have required an average cylinder pressure of only 9 psi, giving about 4 horsepower. Therefore, provided the driver, George Stephenson, maintained (or built up) sufficient speed to carry the train over adverse gradients (the locations of which he would have been well aware), the journey would not have challenged the power of the locomotive.

CONCLUSION

The study has revealed that *LOCOMOTION* played a full and successful pioneering role in the creation of the world's railway system, contributing to the profitability of the Stockton & Darlington Railway and earning a return on the investment for all its shareholders. The new railway industry and the engineering profession had much to learn about the design and operation of steam locomotion, and *LOCOMOTION* played its full part in the development of locomotive engineering. Its pedigree from the earlier Killingworth Colliery locomotives ensured that its performance on the railway's opening day in 1825 was very successful, although subsequent component innovations on sister locomotives showed the shortcomings from a lack of pre-service trials.

Operating experience revealed design shortcomings and the need for strong regulation of safe practice, particularly following *LOCOMOTION*'s boiler explosion in 1828, and the death of its driver, John Cree. The rebuilding coincided with the search for improved performance from the locomotive fleet. This led Timothy Hackworth to search for more heating surface to increase the locomotive's steam raising ability. The increase in heating surface was characterised in its first reincarnation, through the adoption of a larger boiler with a double return-flue and twin chimneys. This led to an increase in power of some 50 per cent, enabling it to haul an increasing number of wagons, but at the expense of additional weight which contributed to the deterioration of the early trackwork.

The need for the railway to develop stronger track to withstand the rigours of multiple coal train movements in the early 1830s was compounded by the need to reduce the axle-loading of the locomotives and the speed at which the services ran. This major expenditure for the railway was compounded by the extension of its route to the more attractive deeper water reaches of the River Tees in Middlesbrough. This was dependent upon the less than successful suspension bridge over the river at Stockton. Its eventual temporary strengthening allowed locomotive hauled trains to reach Middlesbrough from 1834. *LOCOMOTION*'s second reincarnation from that year, with a smaller re-used single return-flue boiler, reduced its weight. This enabled the locomotive not only to continue leading coal to Stockton and Yarm, but also to reach the new staithes at Middlesbrough across the suspension bridge. The provision of a second uni-directional track for the railway from the early 1830s enabled the locomotive to double the number of trains that it operated each day, thus off-setting the reduction in trainload brought about by the smaller heating surface.

Throughout the 1830s, several more powerful locomotives of new design were introduced to the line and, by 1839, it was clear that *LOCOMOTION*'s coal-leading days were at an end. It was cascaded to the haulage of general merchandise and works trains before being retired in 1840 or 1841. It was then stored out of use at Shildon rather than sold second-hand as happened to other early locomotives in the railway's fleet. A shortage of motive power in 1846 saw it returned to service on merchandise trains, but it was again returned to storage before being adopted for stationary pumping duties at Pease's West Colliery near Crook in 1850.

LOCOMOTION's return to Shildon in 1856 prompted consideration of its future. The railway's directors recognised its importance in the short history of their endeavour, and the decision was taken to retain it and place it on a plinth for the users of Darlington's North Road station to witness. Its form was deemed unsuitable however as it did not look like the progenitor from 31 years previously. It thus was subjected to a third reincarnation, to return it to a form that was reminiscent of its 1825 appearance. This re-creation retained the 1827 boiler barrel from a sister locomotive, this being an historic artefact in its own right as the oldest surviving for a standard gauge locomotive.

What has since become an iconic artefact of locomotive history is however quite inaccurate in several respects. Its wheels probably date from the 1840s. The distinctive parallel motion had not been fitted in its first three years of operation, whilst the duplication of the exhaust pipes begs the observer to ask the question as to why they are both there? Inaccurate replacements for the flue, chimney and boiler endplates were installed in 1857 to complete the illusion that the locomotive had been returned to how it had looked in 1825. The tender however has no historical accuracy, rather representing wagon-building practice of 1857 itself.

The quality of the wrought iron components on the locomotive, regardless of their date of manufacture, is very similar. Samples taken during the project by historical metallurgical consultants has shown that its quality was generally quite poor, and was phosphoric with significant amounts of slag inclusions, which was not uncommon in the first half of the 19th century. Indeed, the development of the locomotive industry from 1830 demanded a supply of superior quality wrought iron, particularly for boiler plate, which prompted the growth of the West Yorkshire (Low Moor and Bowling) and Staffordshire iron industries which thereafter supplied much of the locomotive industry's requirements.[393]

The preservation of *LOCOMOTION* in 1857 was itself a world first, preceding the collecting of other, sometimes earlier, locomotives in national collections. It became the iconic object of early railway development, and as the interest in railway history grew, it was exhibited at more and more places around the country and, indeed, the world in the latter part of the nineteenth century. It became 'the' early locomotive form that was instantly recognisable by any discerning person with an interest in railways. It is thus surprising that no attempt has hitherto been made to understand its true operating and preservation history. We hope that railway curators and historians will find these results informative for a locomotive that is about to begin its third century of existence.

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[200] NA, RAIL 667/1117, reports for July and August 1838.
[201] *The Newcastle Daily Chronicle* , Tuesday, 28th September 1875.
[202] *The Newcastle Daily Chronicle*, Tuesday, 28th September 1875.
[203] *The Northern Echo*, Tuesday, September 28th 1875, p.2.
[204] *Shields Daily Gazette and Shipping Telegraph*, Tuesday, December 4th 1883, p.4.

[205] *The Newcastle Daily Chronicle*, Tuesday, 28th September 1875.
[206] *The Northern Echo*, Tuesday, September 28th 1875, p.2.
[207] *The Northern Echo*, Tuesday, September 28th 1875, p.2. Also NA, RAIL 667/1117, several reports in 1838.
[208] *Stockton Herald, South Durham and Cleveland Advertiser*, Saturday, 26th November 1904, p.6.
[209] Beamish Open-Air Museum library, ref NEG 86451.
[210] *Northern Weekly Gazette*, Saturday, 3rd August 1907, p.10.
[211] *Stockton & Thornaby Herald*, Saturday, 13th May 1899, p.3.
[212] *The Northern Echo*, April 14th 1880, p.4.
[213] Durham County Advertiser, Friday 7th November 1884, p.5.
[214] *Shields Daily Gazette and Shipping Telegraph*, Saturday, September 29th 1883, p.3; also *Durham County Advertiser*, Friday, November 7th 1884, p.5.
[215] *The Northern Echo*, Tuesday, September 28th 1875, p.2.
[216] *Hartlepool Northern Daily Mail*, Monday 7th July 1924, p.2. Also *North Eastern & Scottish Magazine*, Vol. XV (1925), p.274.
[217] In 1843, 1844 & 1845 (NA RAIL 667/763), and 1849-'1859' (NA, RAIL 667/1376).
[218] Letter John Harris, for the S & D R W Co. putting out to tender four redundant locomotives, including their water and coal tenders, namely the *MAJESTIC*, *CORONATION*, *WILLIAM 4th* and *SHILDON*, December 26th 1836. (NA, RAIL 667/1078).
[219] *Northern Echo*, 23rd September 1875, Supplement, p.3.
[220] Minutes of the S & D Ry Sub-Committee, entry for 11th February 1846, NA, RAIL 667-34.
[221] Minutes of the S & D Ry Sub-Committee, entry for 14th May 1846, NA, RAIL 667-34.
[222] *Northern Echo*, 23rd September 1875, Supplement, p.3.
[223] *The Durham Chronicle,* Friday 5th June 1846, p.8.
[224] Minutes of the S & D Ry Sub-Committee, entry for 11th June 1846, NA, RAIL 667-34.
[225] *Newcastle Daily Chronicle*, Tuesday, 28th September 1875, p.5.
[226] Note: 'Preserved Locomotives' by Ken Hoole, Ken Hoole library, Head of Steam Museum, KH 326.
[227] Letter, John Graham to Edward Gilkes, New Shildon, April 12th 1849, (NA, RAIL 667/1239).
[228] Letter, Robert Stephenson to Edward Starbuck, Suez, 1st January 1851, NRM, ROB/5/10, re-classified from Folder 18.
[229] NA, RAIL 667/1176
[230] John Dixon notebook, dated June 30th 1851, (NA, RAIL 667/660).
[231] Letter, William Bouch to the Power Committee of the Stockton & Darlington Railway, Shildon Engine Works, April 26th 1856. (NA, RAIL 667/773).
[232] Letter Nicholas Wood to a Mr. Scott, March 21st 1824, Tyne & Wear Record Office, N. Wood's letter and report book, DX 198/1.
[233] Note: 'Preserved Locomotives' by Ken Hoole, Ken Hoole library, Head of Steam Museum, KH 326.
[234] Letter, William Bouch to the Power Committee of the Stockton & Darlington Railway, Shildon Engine Works, April 26th 1856. (NA, RAIL 667/773).
[235] Undated note (but probably December) prepared by the S & D Ry of "S & D Engines that have done No Work and little work in 1856". (NA, RAIL 667/728).
[236] Letter, William Bouch to the Power Committee, Shildon Engine Works, April 26th 1856, NA, RAIL 667-773
[237] Bailey and Glithero, 2000, reprinted 2001, pp.41-43.
[238] Letter, William Bouch to the Power Committee, Shildon Engine Works, April 26th 1856, NA, RAIL 667-773
[239] Article in *North Eastern and Scottish Magazine*, Vol.XV (1925), p.274.
[240] Letter Thos. MacNay to multiple recipients, Darlington May 20th 1857, NRM, *LOCOMOTION* object file.
[241] *North and South Shields Gazette*, Thursday, 11th June 1857, p.4.
[242] *Durham County Advertiser*, Friday 12th June 1857, p.3.
[243] Black and white photographs, presumably taken by the B & O R/R Museum, of the two nameplates have been added at an unknown date to the National Railway Museum's collection, Historic Photos file [812 (2)].
[244] John Hewish, *The Indefatigable Mr. Woodcroft: The Legacy of Invention*, The British Library, n.d. but 1970s
[245] Letter, Bennet Woodcroft to Francis Pettit Smith, April 4th 1862, Science Museum Collection unregistered file of letters from H.W. Dickinson's office. Also, list of F.P. Smith's expenses, Science Museum Collection, T/1862/2. The authors are grateful to Mr. John Liffen, Emeritus Curator of the Science Museum, for bringing these papers to their attention.
[246] J. S. Jeans, 1875, re-published, 1974.
[247] Railway Jubilee Committee Minute Book, p. 18, entry for August 25th 1875, NA RAIL 667/165.
[248] *The Northern Echo*, Tuesday, 28th September 1875, p.2.
[249] *The Engineer*, 1st October 1875, p.227
[250] Reed, 1972, p. 21.
[251] For example see *Northern Echo*, 23rd September 1875 and its Supplement.

[252] Note contained in the NRM Object file for *LOCOMOTION,* which has been repeated by authors on several occasions.
[253] *The Centennial Exposition: Described and Illustrated* by J.S. Ingram, Philadelphia, 1876.
[254] Duncan (Ed.), 1975.
[255] *The Engineer*, 17th June 1881, p.449.
[256] Minute Paper, Patent Office Museum, Paper No.8, June 13th 1881, from Samuel Ford to Col. H. Stuart Wortley. The authors are grateful to Mr. John Liffen for bringing this letter to their attention.
[257] Letter, A H P Stuart Wortley, to Henry Reader Lack, Clerk to the Commissioners of Patents, July 4th 1881, Science Museum technical file for Sir David Dale's model of *Locomotion*. The authors are grateful to Mr. John Liffen for bringing this letter to their attention.
[258] *The Northern Echo*, Saturday, 24th March 1883, p.4.
[259] 'National Exposition of Railway Appliances', *Railway World*, Philadelphia, June 2nd 1883, Vol. 27, p.538.
[260] Letter, A.H. Stuart Wortley to the Mayor of Darlington, 19th June 1883, Patent Office Museum letter book, Z23/2, Science Museum Collection. The authors are grateful to Mr. John Liffen for bringing this letter to their attention.
[261] *Newcastle Daily Chronicle*, Monday 13th June 1881, p.2. The authors are grateful to Mr. John Liffen for bringing this letter to their attention.
[262] *The Northern Echo*, Monday, 11th April 1887, p.3.
[263] *Engineering*, Vol. 47, (1889), p.500.
[264] *The Northern Echo*, Wednesday 17th April 1889, p.3.
[265] *Engineering*, Vol. 49 (1890), p.735.
[266] Memorial from the Mayor, Aldermen and Burgesses of Darlington to the North Eastern Railway, 6th day of March 1890, NA, RAIL 527/1693.
[267] *Northern Daily Mail*, Tuesday 12th August 1890, p.2.
[268] *Richmond & Ripon Chronicle*, Saturday 30th April 1892, p.5
[269] *Sunderland Daily Echo*, Saturday, 21st May 1892, p.1.
[270] *Sunderland Daily Echo*, Monday 31st December 1923, p.3.
[271] *The Locomotive Carriage & Wagon Review*, April 15th 1924, p.112.
[272] *The Railway Magazine*, Vol. 54 (1924), p. 474.
[273] Memorandum from A.S. Pearson to E.M. Bywell, first Curator of York Railway Museum, undated but pre-November 1924, NRM, Clapham file CLAP/S/8/YL62
[274] Bailey and Davidson, 2019.
[275] National Railway Museum Object file.
[276] *The Railway Magazine*, Vol. 57 (1925), p. 123.
[277] *Ibid*, p.127.
[278] Programme for 'Exhibition of Railway Rolling Stock', York, June 1951, NRM, 2002-7967.
[279] NRM Object file note.
[280] Memo by R.J. Hunter to J. Scholes, 12th July 1963, NRM, CLAP/S/8/YL64.
[281] Memo by R. Cogger, 14th June 1966, NRM, CLAP/S/8/YL64.
[282] Report by R. Gosling, 16th June 1970, NRM, CLAP/S/8/YL64.
[283] *Journal* of the Stephenson Locomotive Society, Vol.57. (1981), p.35.
[284] Measured from the drawing of an 1818-built Killingworth locomotive in Wood, 1825, Plate V.
[285] Timothy Hackworth's expenses claim, 28th January 1828, NA, RAIL 667/1158/12.
[286] Shildon maintenance records, entry for 30th April 1837, NA, RAIL 667/680.
[287] Bailey, 1978-79, p.113.
[288] Wood, 1825, pp.247-302.
[289] Letter Timothy Hackworth to R. Stephenson & Co., November 15th 1825. University of Michigan, Special Collections Research Centre. Copy letter in NRM, Search Centre, HACK 1/1/2.
[290] Sub-Committee minutes, 18th November 1825, NA, RAIL 667/31,
[291] Letter, George Stephenson to Timothy Hackworth, Newcastle, January 12th (1826), NRM, Hack 1/1/5.
[292] Brewster, 1829, p.479.
[293] Von Oeynhausen and H. Von Dechen, 1971, pp.16/17.
[294] Expense claim of Timothy Hackworth dated 27th December 1827 – visit to Bedlington Iron Works and Killingworth wagonway to see newly rolled wrought iron flanges in use, NA, RAIL 667/1158.
[295] J.G.H. Warren, 'John Nuttall's Sketch Book, with Notes on Wrought Iron Wheels and Wheels for Early Locomotives', *Transactions of the Newcomen Society*, Vol. XI (1930-31), p.73.
[296] T. Hackworth's notebook, NRM, HACK 1/3/1, entry for February 5th 1828.
[297] Letter, John Rastrick to Timothy Hackworth, Stourbridge, 3rd February 1829, NRM, HACK 1/1/17.
[298] T. Hackworth's notebook, NRM, HACK 1/3/1, undated entry, but probably for April 1828.
[299] T. Hackworth's notebook, NRM, HACK 1/3/1, undated entry.

[300] T. Hackworth's notebook, NRM, HACK 1/3/1, undated entry, but probably for July 1828.
[301] T. Hackworth's notebook, NRM, HACK 1/3/1, entry for August 1st 1828.
[302] Letter, Michael Longridge to Joseph Pease Jr., December 17 1828, NRM, HACK 1/1/14.
[303] Expense claim of Timothy Hackworth, December 27th December 1828, NA, RAIL 667/1158.
[304] Letter, Bedlington Iron Works to the S & D R, June 8th 1830, NA, RAIL 667/1014.
[305] Letter, Bedlington Iron Works to the S & D R, September 1st, 1831, NA, RAIL 667/1029.
[306] Sub Committee minutes, entry for 1st August 1834, NA, RAIL 667/33.
[307] John Graham's notebook, entry for 7th October 1836, NRM, GRA-3, p.117.
[308] George Graham's notebook, (1831-1861), NA, RAIL 667/427, p.21, entry for January 16th 1835.
[309] James Kennedy, An Inventory and Valuation of Locomotive Engines etc., April 1st 1837, NA, RAIL 667/770.
[310] Timothy Hackworth's monthly maintenance report for July 1837, NA, RAIL 667/680.
[311] Timothy Hackworth's monthly maintenance report for October 1837, NA, RAIL 667/680.
[312] Timothy Hackworth's monthly maintenance report for January 1838, NA, RAIL 667/1373.
[313] Timothy Hackworth's monthly maintenance report for February 1838, NA, RAIL 667/1373.
[314] Timothy Hackworth's monthly maintenance report for March 1838, NA, RAIL 667/1373.
[315] Timothy Hackworth's monthly maintenance report for September 1838, NA, RAIL 667/681.
[316] Timothy Hackworth's monthly maintenance report for July 1839, NA, RAIL 667/1374.
[317] Wishaw, 1840, p.419 and Plate 19.
[318] Bailey and Davidson, 2018, p.31.
[319] John Crompton, 'The Hedley Mysteries', in MJT Lewis (Ed.), *Early Railways 2*, The Newcomen Society, 2003, p.157. This page also shows the *Wylam Dilly* boiler plate arrangement with only five plates per ring, but none larger than the largest plate on *Puffing Billy*.

[320] Wood, 1825, p.250, which describes 'locomotive-engine' II, larger than the other of the pair subjected efficiency trials reported here.
[321] Brewster, 1829.
[322] Bailey and Davidson, 2018, p.32.
[323] Tredgold, 1838, p.253.
[324] Von Oeynhausen and Von Dechen, 1971, p.16.
[325] Von Oeynhausen and Von Dechen, 1971, p.16.
[326] Wood, 1825, p.250. This covers Locomotive No. II, No. I from 1816 having had a 20 in diameter flue.
[327] Wood, 1825, p.275.
[328] Wood, 1825, p.146.
[329] The locomotive *ALBION* (c1849) in the Nova Scotia Museum, has such a door. Similar doors, 5½ in by 5 in, survive on Killingworth *Billy* and the Hetton *Lyon*.
[330] Davidson, 2019, p.138.
[331] NA, RAIL 667/680
[332] NA, RAIL 667/680
[333] NA, RAIL 667/682
[334] Bailey and Davidson, 2018, Section 8. Also Bailey and Davidson, 2019, Section 8.
[335] Bailey and Davidson, 2020, Fig. 8.7.
[336] Von Oeynhausen and Von Dechen, 1971, p.16.
[337] Robert Stephenson's Narrative in Smiles, 1862, Vol.III, p.501.
[338] Von Oeynhausen and Von Dechen, 1971, p. 16.
[339] Robert Stephenson & Co's ledger, entry for November 30th 1828, NRM, ROB/4/1, folio 164.
[340] Minutes of Sub-Committee of directors, entry for August 10th 1833, NA, RAIL 667/32.
[341] Kitching/Whessoe Album, Durham County Record Office.
[342] List of locomotives employed on the S & D R, probably prepared by J. Graham, published in *Engineer*, 31st October 1879.
[343] Wishaw, 1840, p. 419.
[344] References to the 'smokebox' contained in Timothy Hackworth's maintenance records, NA, RAIL 667/680, entries from June 1837.
[345] Timothy Hackworth maintenance record, NA, RAIL 667/680, entry for 30th April 1837.
[346] Timothy Hackworth maintenance record, NA, RAIL 667/680, entry for 30th June 1837.
[347] Timothy Hackworth maintenance record, NA, RAIL 667/680, entry for 31st August 1837.
[348] Timothy Hackworth maintenance record, NA, RAIL 667/681, entry for 30th June 1838.
[349] Timothy Hackworth maintenance record, NA, RAIL 667/681, entry for 31st August 1838.
[350] Timothy Hackworth maintenance record, NA, RAIL 667/681, entry for 30th September 1838.
[351] Timothy Hackworth maintenance record, NA, RAIL 667/681, entry for 31st October 1838.

[352] Timothy Hackworth maintenance record, NA, RAIL 667/681, entry for 31st December 1838.
[353] Timothy Hackworth maintenance record, NA, RAIL 667/1374, entry for 31st March 1839.
[354] Bailey, 2019, pp.79-102.
[355] Bailey, 2019, pp.86-89.
[356] Bailey and Davidson, 2018, Fig. 9.4.
[357] The valve-chest cover is on long-term loan for display at the Head of Steam Museum in Darlington.
[358] Bailey and Davidson, 2018, Fig. 10.2.
[359] C. B. Lindstrom, *Boiler Repairs*, International Textbook Company, Scranton, Pa., 1925, p.17.
[360] Letter, George Stephenson to Timothy Hackworth, Newcastle, May 3rd 1826, Science Museum, Ref. INV 1934-703.
[361] Marshall, 1838, pp.28-30.
[362] George Dodds, A Valuation of Locomotive Engines and Other Articles etc. , Preston Park Museum, Stockton, Ref. P.143/1974.
[363] Von Oeynhausen and Von Dechen, 1971, p.17.
[364] NA, RAIL 667/680.
[365] NA, RAIL 667/681.
[366] NA, RAIL 667/682.
[367] Booklet entitled '*The LNER Exhibit at the British Empire Exhibition, Wembley, 1924'*, p.13.
[368] Wood, 1825, Plate V.
[369] Bailey, 2019, p.91, Fig.10.
[370] Forward, 1943, p.120.
[371] Davidson, 2019, pp.129 and 130.
[372] Bailey and Davidson, 2018, Fig. 14.3.
[373] NA, RAIL 667/680.
[374] NA, RAIL 667/1373.
[375] Warren, 1923, p.278.
[376] Memorandum, R.J. Hunter to the Curator of Relics, John Scholes, 30th September 1965, NRM, Object File correspondence.
[377] NA, RAIL 667/680, entries for August and October 1837.
[378] Von Oeynhausen and Von Dechen, 1971, p.17.
[379] Von Oeynhausen and Von Dechen, 1971, p.17.
[380] *Northern Echo*, 23rd September 1875.
[381] *Northern Echo*, 23rd September 1875.
[382] NA, RAIL 667/680, RAIL 667/681, RAIL 667/682, RAIL 667/ 1373, RAIL 667/1374, *passim* entries.
[383] Sub-Committee minutes, entry for November 7th 1834, NA RAIL 667/33.
[384] George Graham's notebook, NA, RAIL 667/427, p.22.
[385] Von Oeynhausen and Von Dechen, 1971, p.16.
[386] Davidson, 2019, pp.144-146.
[387] James Walker, *Liverpool and Manchester Railway. Report to the Directors on the Comparative merits of Loco-motive and Fixed Engines, as a Moving Power*, London, 1829, p.24.
[388] Von Oeynhausen and Von Dechen, p.15.
[389] Von Oeynhausen and Von Dechen, p.11.
[390] Warren, 1923, p.297.
[391] Davidson, 2019, p.132.
[392] Bailey and Davidson, 2019, p.97.
[393] Bailey, 2021, pp.105/6.