



*This article is provided by FMES for your interest thanks to the kindness of the original publishers. FMES makes no representations or warranties of any kind, express or implied about the completeness, accuracy or reliability with respect to this document and any sentiments expressed are not necessarily supported by FMES. Any reliance you place on this document is therefore strictly at your own risk*

## Boiler modes of failure and explosions

This document was written by Peter Gardner and was originally published by Frimley and Ascot Locomotive Club in August 2007.

No, we are not planning any! I have recently been reading a book on the subject of locomotive boiler explosions (full size). It is a bit dry, mostly a succession of recorded boiler explosions with only a little analysis. The lack of analysis is a lost opportunity, but I will try to generalise and summarise, based on my own appreciation of what I have read.

In the very early days (1820 to 1860) it was generally the case that boiler explosions were recorded only when fatality resulted, i.e. at the coroner's inquest and so there were undoubtedly more boiler mishaps than we know about. Additional sources of data are company accounts where repair costs may suggest boiler failure as a cause for major rework. Even when the railway inspectorate started to take an interest, there was a lack of specialist knowledge and expertise.

The two main mode of failure in the early days were failure of the outer shell and collapse of the firebox. Considering boiler shell failure first, early boilers were generally made from wrought iron plates of small size. They were mostly constructed from rings which might be as many as four individual plated joined by riveted laps. The rings would then be telescoped together and riveted with annular lapped joints. When longer plates became available, boilers were sometimes constructed with these along the length of the boiler, rather than in rings (not a good idea!). Boilers with lapped joint construction could be found in service right to the end of the 19th century, usually on locomotives relegated to secondary duties. These methods of construction lead to one of the most common modes of failure in the early days. The stress calculations for a cylindrical boiler shell are very simple and reveal that the stress on a longitudinal seam is twice that on an annular seam. The lap joints in the boiler rings are thus more critical than the joints between the rings. Further, due to the offset from truly circular at the edge of the lap, there is additional cyclic stress at that region. Where a thorough inspection was made of a failed boiler, there was generally found to be a line of deep corrosion along the edge of the lap so that a  $\frac{5}{8}$  inch plate might be down to  $\frac{1}{16}$  inch in this region, particularly if the join was below the water line. The recommended solution, eventually, was to use a butt joint, with a lap strip inside and out, but a combination of lack of a formal code of practice and the precarious financial state of many small railways meant that no action followed, except for new build.

Clearly, the placing of the boiler plates along the length of the barrel made the worst possible use of the material guaranteeing the maximum length of highly stressed seam, hence 'not a good idea'.

The other main mode of failure was the collapse of the firebox. This continued right into the days of post grouping and even BR. In the first period, up to the end of the nineteenth century, poor maintenance practice was general, with little standardisation and continual pressure to minimise servicing and repair costs. Stays were of copper, threaded into the plate and riveted over to form a protective head. Fire erosion of the copper firebox and stays lead to thinning of the plates around the stay head and of the head itself. To keep an engine on the road, it was common practice to liberally apply the riveting hammer to leaking stays, ruining the remaining threads and in ignorance of the state of the plate, which might be locally very thin. Taken with the practice of forgoing a washout to save time and wedging a safety valve to cope with a heavy load, dramatic accidents were inevitable.

Hydraulic testing was never done, it was considered too time consuming, and so visual inspection and leaks were the only indication of a problem. Visual inspections were often cursory, again to save time and money.

Another cause of firebox collapse was due to poor application of girder stays on the crown of the firebox. With round top boilers, it was common to use girders, as there was no outer wrapper to which to attach rod stays. To do their job, these girders must extend fully over the front and back firebox plates. There were many explosions due either to these being too short and thus causing failure at the junction of the wrapper with the front or back plate, or due to inadequate inspection of the corrosion state of the girders. This may be why the Australian model associations do not permit girder stays, but they are ok if correctly designed.

Whist driver interference with safety valves was a cause of number of failures, a few were caused by incorrect assembly of a safety valve by fitters, compounded by the assumption by train crew that the gauge must be wrong when the needle was off the scale. It was easier to change a gauge than to change a safety valve!

One remaining factor in boiler explosions was low water level. This ran through right to the end of steam as a major cause of failure. Things improved greatly after the grouping, indeed, LNER never had a boiler failure despite some of its constituents having had quite a poor record. By this time, inspection and maintenance procedures had become uniformly good and failures that occurred did so because of low water either due to poor crew practice or because of obsolete or misguided design. There were cases of crew misreading an empty glass as full, after taking over a locomotive but more commonly unfamiliar or outdated or badly designed gauge glass systems were to blame. The GWR retained a single gauge glass plus try-cocks. Few could reliably interpret the use of a try-cock in the dark. The GWR and LMS coupled the upper and lower shutoff cocks, which made it impossible to diagnose problems with the steam and waterways, and this led to low water and boiler failures. The LMS employed levers at 45°, which could lead to incorrect assembly, i.e. closed when 'open' and vice versa. With a duplex system and an inability to independently test the top and bottom fittings, the crew would still not know which was the correct reading' and this led to at least one major boiler explosion.

Fusible plugs were no sinecure. They often failed to work due to scale or corrosion and on a large pacific, say, even two plugs could not be heard over the noise of the locomotive and when working hard the blast was powerful enough to be able to counterbalance the injection of steam into the firebox. American locomotives, brought in during the latter part of the war, had screw down shut off cocks, rather than the 90° plug cocks British crews were used to. If these were stiff or the shaft bent, the crew could think they were open when, in reality, they could be partially closed and give a false reading. This caused a couple of boiler explosions, which were basically down to lack of crew training.

One more boiler explosion is of interest to us. This was concerning a locomotive that was based where the local water had a relatively high concentration of sodium carbonate. Over a period, this attacked the copper firebox and stays, leading eventually to catastrophic collapse. Sodium carbonate is what remains in water that has been through an ion exchange water softener. This confirms my belief that such softened water should not be used in our locomotives

In summary, the procedures followed to ensure safety of locomotive boilers is far more rigorous today than it was even in the last days of steam. The removal of tubes, at ever more frequent intervals, is clearly done primarily as an aid to inspection. Tube failure in itself seems never to have caused a catastrophic boiler explosion. In the model world, we can fortunately, undertake hydraulic testing much more readily than in full size. However, Southern Federation has recently reported a case of a boiler, old but apparently commercially made, which failed due to insufficient penetration of silver brazing of stays, in spite of successfully completing a 2x working pressure hydraulic test. There is still no substitute for a careful visual check for sign of weeps and a check that the design is adequate and has been faithfully carried out.