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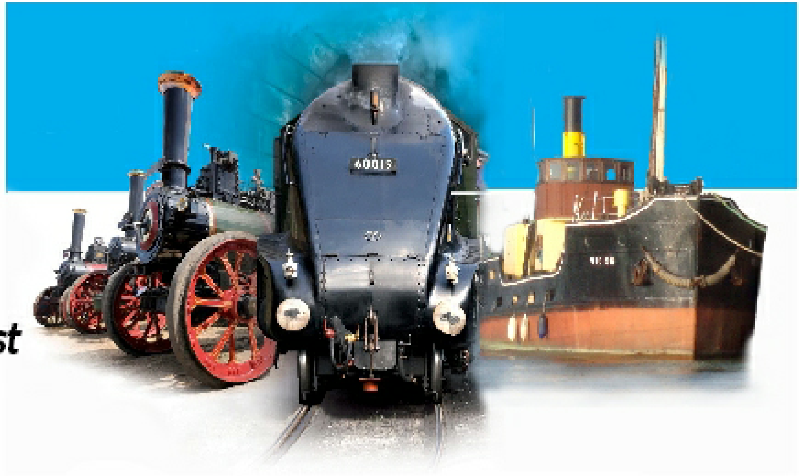
Boiler & Engineering Skills Training Trust



Please note that this Content may change.

These boiler training modules, incorporating sections of the HRA/ORR boiler code of practice, were prepared in 2013 as part of the HLF funded BESTT training plan project and will be progressively reviewed and updated by the BESTT Technical Committee.

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Defects in Steam Boilers and their thorough Inspection

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Module: BESTT Syllabus Assessment Plan

Defects in steam boilers and their thorough inspection.

Aim

This unit will give the learners an understanding of how to examine a boiler, spot defects and understand why they occur. It is to be used in conjunction with other relevant modules which are on the BESTT website. It is intended to be delivered and assessed through a masterclass.

Introduction

This unit will give practical knowledge of defects in:

1. Boiler Shell
2. Fire space
3. Water spaces
4. Crown and crown stays
5. Tube Nest
6. Smokebox
7. Foundation ring
8. Superheater elements

Assessment

Learners could demonstrate competence in this unit by:

- Documental evidence
- Photographic evidence
- Witness statements e.g. written or verbal statement from a competent person stating that they have completed tasks satisfactorily.
- Practical tasks

Guidance note

Defects in steam boilers and their thorough inspection.

Purpose

This document describes good practice in relation to its subject to be followed by Heritage Railways, Tramways Steam Road vehicles, Steam boats and similar bodies to whom this document applies

Endorsement

This document has not been endorsed by HRA or ORR.

Disclaimer

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Supply

This document has been prepared for BESTT and copies are available from BESTT.

Introduction

A steam boiler produces steam from clean raw water, which invariably contains a proportion of dissolved oxygen. The steam boiler is usually made from a composite of materials including steel, copper, bronze & monel. Whilst the copper bearing elements are generally immune to corrosion, steel, which is an iron alloy, tends to corrode in the presence of water containing oxygen. Although the oxygen contained in boiling water is much reduced by the effect of temperature, the addition of raw cold feed water to replace the evaporated steam, (as in a conventional boiler with cold water feed) inevitably gives the opportunity for fresh corrosion to occur.

This corrosion shows during regular boiler washout when quantities of red sludge (iron oxide) can be seen coming out of the boiler having been dislodged by the pressure washing process.

Throughout the nominal ten year between overhaul life of a boiler this corrosion can lead to failure as the steel plates, stays and tubes get thinner than the designed values. Whilst great efforts are generally made to minimise the effect of corrosion through water treatment and regular washout procedures, the long-term effect of corrosion reducing plate thickness can lead to a boiler becoming unsafe.

This module deals with why these features that threaten the safety of a boiler in use, as well as how and where to look for, and quantify, the effects of that corrosion. It also suggests how repair remedies should be applied.

In addition to corrosion, a further source of boiler deterioration occurs in the form of metal fatigue induced by the repeated heating and cooling of the metal surfaces from which the boiler is made. The expansion and contraction occurring during these cycles causes large distorting forces to be felt within the boilerplates and components. Inevitably this can lead to fatigue cracking in highly stressed areas. This effect is known as "grooving" and can occur in both copper and steel components. The areas specifically associated with these problems are generally above the foundation ring as well as the flange radii on tube plates and backhead.

This danger can be exacerbated by the fact that the boiler is made of different materials which when placed in close proximity to each other in the presence of a conducting liquid, forms a crude electric battery. The action of this electrolytic cell causes tiny metal particles to flow from one material to another through the conducting liquid, causing further wastage of parent material.

The combined effects of these three processes, corrosion, fatigue and electrolysis, can turn a perfectly good new boiler into a dangerous unfit piece of equipment over a ten year period of use. That is why regular statutory inspections are carried out so that signs of danger can be headed off in good time by remedial action.

The method of storing a boiler when not in use, might at first seem to be obvious that it should be drained and open to air circulation to eliminate any potential for corrosion, However it is actually very difficult to fully eliminate the moisture from the incipient tiny cracks developing as grooving, and so there is a strong argument that the best way of storing a boiler out of use is to fill it right to the top with de-ionised water to exclude all further oxygen. That is not always a practical proposition.

Inspecting a boiler, which has been taken out of service for a thorough washout, entails the careful use of flares and mirrors inside the water spaces and a critical look at all available boiler surfaces.

Unfortunately many of the surfaces where the above-mentioned problems occur are difficult to access with the boiler in its working condition. Corrosion of tubes, roof stays and side stays, grooving of tube plates and firebox wrappers can only really be thoroughly followed up when the tube nest has been removed and access to the inside water spaces of the boiler has been made possible. That is why at the end of a working period whether it be seven or ten years, the Responsible Person asks for the boiler to be stripped out to enable full-unfettered access. Some preserved railway companies go further in this quest for full diagnosis and understanding, by insisting that the foundation rings and front tube plates are removed as a matter of course once every ten years (e.g. K&WVR)

The purpose of this module is to ensure that those working with boilers know where to look, what to look for, and what methods to use to determine the best way to diagnose and refurbish worn out boiler components.

When something untoward is found and recorded during inspection, then the Responsible Person must be consulted and appropriate action taken.

General

These comments are based on general experience of looking at problems with boilers and it is perfectly possible that the defect that you find on your boiler is not included, or is indeed some very rare issue that has never come up before.

The keys to inspecting for defects in steam boilers are thoroughness, diligence and curiosity.

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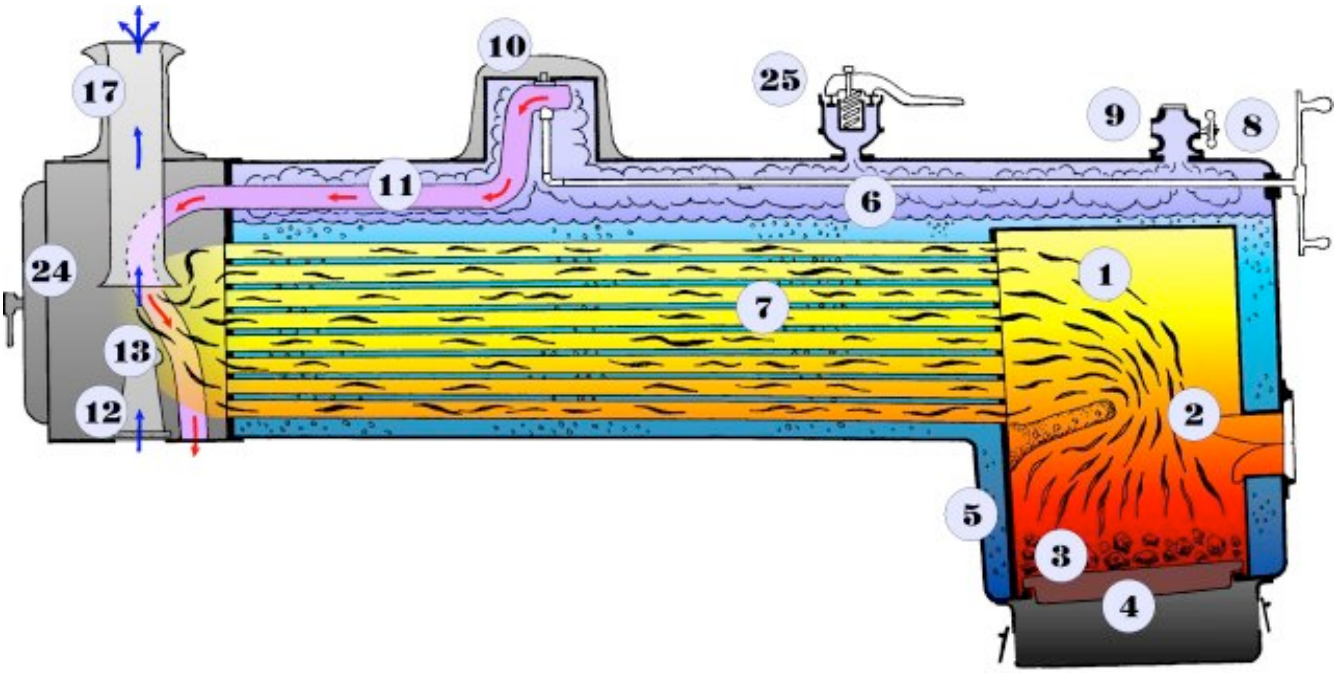
The next section of this module deals with the symptoms and visual clues as to damage that is likely to be found, and where it is to be found in a worn steam boiler. It is not intended that this information will be released onto the website until after the defects and thorough inspection masterclass has been run. It will however be made available to the trainees before the masterclass.



Section 1

Outside of boiler shell

See numbers 5 & 8 on image

1. look for staining from leakage
2. wastage of rivet heads especially between frames and outer wrapper
3. wastage of foundation ring rivet heads.
4. wastage inside front tubeplate area especially at lower half where acid attack takes place
5. wasted lap and rivet heads on front tubeplate
6. wasted or cracked ligaments between tube holes
7. Condition of smoke-tubes projecting into smokebox
8. Thickness of front tubeplate through washout plug holes
9. Leaking stays & wasted stay heads
10. Look to see if side stays have been ferruled back to size and if tubeplate has been ferruled in the past to reduce tube diameter
11. Corrosion where boiler firebox sides have been concealed by frames
12. Mechanical abrasion of outershell where wheels or linkages may have been rubbing

Section No.	LO	Objectives	Date achieved and Supervisors signature
1	LO1 1	Identify and look for staining from prior leakage	
1	LO1 2	Identify wastage of rivet heads – between frames and outer wrapper	
1	LO1 3	Check for wastage of foundation ring rivet heads	
1	LO1 4	Identify wastage inside front tube plate	
1	LO1 5	Check for wasted lap and rivets on front tube plate	
1	LO1 6	Look for wasted or cracked ligaments between tube holes	
1	LO1 7	Check the Condition of smoke tubes projecting into smokebox	
1	LO1 8	Measure Thickness of front tubeplate through washout plug holes	
1	LO1 9	Check for Leaking stays and wasted stay heads	
1	LO1 10	Identify if there are Ferruled side stays and tubeplate ferrules	
1	LO1 11	Examine for Corrosion where boiler firebox sides have been concealed by the frames	
1	LO1 12	Examine for Mechanical abrasion of outer shell where wheels or linkages may have been rubbing.	

Section 2

Inside fire space of firebox

See numbers 1 & 2 on image

1. Look for stains signs of past water leakage in tube plate, doorplate and lap seams
2. Look carefully at firebox sides checking for quilting with a short rule between the stays especially copper fireboxes.
3. Use ultrasonic thickness tester to survey firebox thickness all over.
4. Check the condition of all stay heads to make sure there is adequate material and that wastage has not reduced the stay head until it cannot support the plate.
5. Test the stays with ultrasound to search for broken stays. (Try the hammer test if you find a definitely broken one.)
6. Boilers in the USA have drilled stays, which have holes from both ends of the stay meeting close to the centre but not joining up. This is a really useful broken stay detection system.
7. Look at state of foundation ring rivet heads for erosion/corrosion
8. Look at thickness of lap seams and lap seam rivet condition, paying special attention to cracks in lap seams from rivet holes. Look carefully at how the lap seam meets the parent material. Has it been seam welded?
9. Look at state of fusible plug
10. Look at roof stay nuts condition and look for signs anywhere of over-caulking. Remember the nuts are there to protect the threads from burning away, not to support the firebox crown.
11. Look at side stays monitoring for signs of star cracking radiating from the stay centre.
12. Examine condition of tube ends in the firebox and look for signs of over expanding or faulty beading. Faulty beading will show where the shaping of the end of the steel tube cuts into the surrounding tube plate surface.
13. Look at state of brick arch. The arch will almost certainly exhibit cracks but what is important is to understand that the arch is supported on lugs in the firebox sides. These extremities must be secure and although radial cracks are acceptable cracks, which might allow sections to fall downwards out of the arch, are suspect.

Section No.	LO	Objectives	Date achieved and Supervisors signature
2.1	LO2 1	Identify past leakage in tubeplate, doorplate and lap seams	
2.2	LO2 2	Check for quilting	
2.3	LO2 3	Ultrasonic thickness test	
2.4	LO2 4	Examine condition of stay heads	
2.5	LO2 5	Ultrasonic test of stays for breakage.	
2.6	LO2 6	Drilled, tell-tale stays	
2.7	LO2 7	Examine state of foundation ring rivet heads for erosion/corrosion	
2.8	LO2 8	Examine thickness of lap seams and lap seam rivet condition	
2.9	LO2 9	Look at state of fusible plug	
2.10	LO2 10	Examine roof stay nuts condition and look for signs anywhere of over-caulking.	
2.11	LO2 11	Look at side stays monitoring for signs of star cracking radiating from the stay centre.	
2.12	LO2 12	Examine condition of tube ends in the firebox and look for signs of over expanding or faulty beading.	
2.13	LO2 13	Look at state of brick arch.	

Section 3

Water spaces in barrel

See numbers 6 & 7 on image

It is very difficult to carry out a meaningful examination of the water spaces when all the tubes are in place, so this examination assumes that all the smoke tubes and superheater flues if fitted have been removed from the boiler barrel. If the boiler has a dome regulator it is likely that this too will have been removed to enable access.

1. Pay attention to the state of the inside surfaces of the barrel at the waterline. This is often where corrosion and pitting will be found.
2. Look for corrosion and cracking at the base of the front tube plate where the tube plate changes from flat to flanged.
3. Look at the state of the front tube plate and holes condition. Check the tube plate for bowing.
4. Check the palm stays (In front of the brick arch) for corrosion and condition on both the fastenings and stays themselves.
5. Check the condition of the lower part of the barrel below the tube nest. Boilers that have seen a lot of use in hard water areas can exhibit build up of scale on the lower barrel, which is sometimes hard to recognise as a deposit and harder still to remove. Be sure you are looking at steel and not scale!

Section No.	LO	Objectives	Date achieved and Supervisors signature
3.1	LO3 1	Inspect the inside surfaces of the barrel	
3.2	LO3 2	Look for corrosion and cracking at the base of the front tubeplate	
3.3	LO3 3	Examine the front tube plate	
3.4	LO3 4	Check the palm stays	
3.5	LO3 5	Check the condition of the lower part of the barrel below the tubenest.	

Section 4

Water spaces around firebox, including firebox crown & crown stays

See numbers 1, 5 & 6 on image

1. Look for corrosion and wastage on the roof stays that support the firebox crown. Be under no illusions about how important this area of the boiler is. These stays can be expected to carry upwards of 300 tons at times and a 33% reduction in nominal stay diameter reduces its load carrying ability to less than half. Most of the stay wastage in copper fireboxed boilers occurs just above the crown roof where conditions are most severe. A welder's descaling hammer will reveal the true extent of wastage.

2. Look down the side legs of the firebox water spaces and spot out stay corrosion and even breakage.

3. Examine the curved surfaces of the inner firebox, as these are prone to fatigue cracking as the constrained firebox changes shape.

4. Pay particular attention to the inside surface condition of the mud door cavities. It is very tricky to accurately measure the profile of the inside mud door-mating surface where corrosion regularly occurs. It is possible to fit a perfect new mud door to a badly worn mud door outer and still have a dangerous result. The tapered seating of the mud door joint acts like squeezing a bar of soap in the bath, which can have disastrous results.

Section No.	LO	Objectives	Date achieved and Supervisors signature
4.1	LO4 1	Look for corrosion and wastage on the roof stays that support the firebox crown.	
4.2	LO4 2	Look down the side legs of the firebox water spaces for stay corrosion and even breakage.	
4.3	LO4 3	Examine the curved surfaces of the inner firebox	
4.4	LO4 4	Pay particular attention to the inside surface condition of the mud door cavities.	

Section 5

Tube Nest

See number 7 on image

1. Scale and corrosion have a marked effect on the performance of a tube as a heat transfer system. Iron oxide (rust) occupies four times the volume of the parent metal from which it has been formed, and so creates an effective insulating layer. This becomes a vicious circle as the inside surface of the tube gets hotter to cope with the heat transfer reduction and the corrosion gets more pronounced.

2. Tubes generally fail either through pinholes of corrosion, which can be caused by small quantities of oil settling on the tubes, or more likely they fail near to the expanded joint where the ends join the tube plates. Inevitably the tube wall has been thinned to create the expanded seal and this metal will be prone to corrosion. (That is why it is essential not to expand a tube beyond the thickness of the plate it is being sealed into)

3. Tubes also get thinner as the rasping action of the ashes from the fire under blast conditions scour the tube thinner. Steel tubes seldom have a life beyond the ten-year overhaul period of a boiler.

Section No.	LO	Objectives	Date achieved and Supervisors signature
5.1	LO5 1	Look at a tube to identify scale and corrosion	
5.2	LO5 2	Identify pin hole corrosion and thinning of tubes	
5.3	LO5 3	Look at the scouring effects of ash	

Section 6

Smokebox

See number 24 on image

1. The smokebox is subject to an additional hazard, which is not found elsewhere on the boiler. The hot flue gases condense in the relatively cold environment of the smokebox and sulphuric acid is formed which is highly corrosive to most metals. You can feel this burning your cheeks as soon as you enter a smokebox so PPE is especially important.

2. Steam locomotives tend to have the lower portion of the smokebox filled with fireproof concrete to seal all the pipe entries and exits, but the sulphuric acid can get behind this and corrode areas that you might assume are safe from wastage.

3. Steel steam pipes need to be carefully checked ultrasonically for reductions in wall thickness as they are thinned on the outside of the bend during manufacture and often that same surface is the one that the acid attacks.

4. The base of the tube plate and all the lower half rivets are subject to hostile conditions and extra attention must be given during inspection.

5. Wash out plug surroundings and threads must be carefully inspected for wastage.

6. Do not assume that the blower pipe and cylinder lubrication pipes will be exempt because they are copper. They too will waste under sulphuric acid attack.

Section No.	LO	Objectives	Date achieved and Supervisors signature
6.1	LO6 1	Correct PPE worn	
6.2	LO6 2	Check area around fireproof concrete infill	
6.3	LO6 3	Ultrasonic test of steam pipes	
6.4	LO6 4	Examine base of tube plate and rivets	
6.5	LO6 5	Inspection of wash out plugs	
6.6	LO6 6	Check copper pipe work for corrosion	

Section 7

Foundation Ring

See number 3 on image

The foundation ring is a really substantial steel rectangular ring of square or rectangular section. Rivets through the inner and outer sections of the boiler attach the inner firebox within the casing of the boiler. The foundation ring establishes the water space around the firebox surfaces but is of course subject to huge and changing shear loads trying to push the firebox out of the outer wrapper.

It is difficult to find all the defects in the foundation ring area without removing the foundation ring. This is a difficult and time-consuming operation.

It has already been mentioned that certain steam boiler users (e.g. K&WVR) remove foundation rings at ten-year overhaul so that they know exactly what they are dealing with.

1. The most vulnerable areas are those within the water spaces immediately above the foundation ring where the maximum flexing takes place. It is a troublesome place to inspect with the foundation ring in place and ultrasound scans can deliver difficult to interpret answers.

2. In some cases the lower sections of the outer wrapper are so wasted away that a new section is grafted in all the way round the firebox and the foundation ring goes back in against new steel sides.

3. The rivets in the foundation ring bring their own particular problems. It is very difficulty owing to the tight corners to get full rivet heads into the inside foundation ring corners as space is so confined inside and often contains a tapering lapped seam. In addition the inside rivet heads are often lying surrounded by ash in often damp conditions which causes corrosion of the heads in a place that is difficult to inspect without removing firebars.

4. Foundation rings are often fabricated from square bar, They can be inspected using ultrasonic probes.

Section No.	LO	Objectives	Date achieved and Supervisors signature
7.1	LO7 1	Check, if possible, water spaces above foundation ring	
7.2	LO7 2	Check lower sections of outer wrapper	
7.3	LO7 3	Check Foundation ring rivets	
7.4	LO7 4	Examine foundation ring for defects	

Section 8

Superheater elements

Superheater elements develop small pinhole leaks, which present a danger to the footplate crew if left unchecked.

These pinholes occur because the steam left inside during non-working periods remains as a few drops, which evaporate down to one of two concentrated blobs of Carbonic Acid. This has the ability to bore a pinhole through the bottom wall of the element.

It is difficult to inspect superheater elements meaningfully.

Overpressure testing is the safest way of determining their soundness.

There is a case for removing elements during long periods of inaction and storing them vertically with the closed ends upwards.

Superheater elements rot from the inside as above, and erode from the outside as the ash and char abrade the external surface.

Section No.	LO	Objectives	Date achieved and Supervisors signature
8.1	LO8 1	Examine scrap superheater elements to understand how defects develop	

BESTT
Boiler Defects and inspection

Assessment Record for: **Training Centre:** **Year:**

LO1	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Supervisor Initials and date when completed													
LO2	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Supervisor Initials and date when completed													
LO3	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Supervisor Initials and date when completed													
LO4	1	2	3	4	5	6	7	8	9	10	11	12	13
Supervisor Initials and date when completed													

LO5	1	2	3	4	5	6	7	8	9	10	11	12	13
Supervisor Initials and date when completed													
LO6	1	2	3	4	5	6	7	8	9	10	11	12	13
Supervisor Initials and date when completed													
LO7	1	2	3	4	5	6	7	8	9	10	11	12	13
Supervisor Initials and date when completed													
LO8	1	2	3	4	5	6	7	8	9	10	11	12	13
Supervisor Initials and date when completed													

Witness Statement

The trainee has completed the Learning outcomes to a satisfactory standard

Signed: **Print Name:** **Date:**

Verified by BESST Assessor **Name:** **Assessor Number:** 1 **Date:**