HERITAGE RAILWAY ASSOCIATION

BOILER CODE OF PRACTICE (BCOP)

Ref No: HGR-B9221

Issue No: 01

Issue Date: August 2026

Review Date: August 2029

GUIDANCE NOTE

NON-DESTRUCTIVE TESTING (NDT)

Supporting the Steam Locomotive Boiler series of Guidance Notes

Purpose

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

Development

This document has been developed by boiler experts in consultation with His Majesty's Railway Inspectorate (HMRI) a directorate of the Office of Rail and Road (ORR). The document HGR B9000 sets out the background to setting up the Boiler Code of Practice Committee (BCOP).

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Supply

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Table of Contents

1. Introduction

This Guidance Note is one of a series dealing with Locomotive Boilers that were produced by the "Steam Locomotive Boiler Codes of Practice" (BCOP) practitioners' meetings.

Railway locomotive boilers are designed to create, store and distribute steam at high pressure. The working life of such a boiler can be considerably shortened if due care is not taken at all stages of inspection, repair, running maintenance and day-to-day running.

In the past there have been a series of accidents and explosions owing to work being undertaken without having due regard to the inherent risks involved. It is with that in mind that HMRI and HRA set up the series of meetings of boiler practitioners to discuss the issues, distil good practice and codify it into this series of Guidance Notes.

This guidance is written for the assistance of persons competent to perform these tasks. In places the terminology used may be specific to such practitioners.

This guidance should also be useful to those in a supervisory or more general role. However. no work should be undertaken unless the persons concerned are deemed competent to do so.

Where managements decide to take actions that are not in agreement with these recommendations, following appropriate risk assessments or for other reasons, it is recommended that those decisions are reviewed by the senior management body of the organisation concerned and a formal minute is recorded of both the reasons for and the decision reached.

2. Personal Protective Equipment

a) Before undertaking any work a risk assessment must have been conducted.

b) Protective equipment is to be supplied and used at work wherever there are risks to health and safety that cannot be adequately controlled in other ways.

c) The equipment must be:

   i) Compliant with the latest Personal Protective Equipment regulations.

   ii) Properly assessed before use to ensure it is suitable.

   iii) Maintained and stored properly.

   iv) Provided with instructions on how to use it safely.

   v) Used correctly by those undertaking the work.

3. Non-Destructive Testing, an Introduction

Various NDT techniques can be used for the examination of locomotive boilers and pressure vessels.

The following criteria should be used when choosing the technique to be employed:

- What defects are being looked for?
- What is the geometry of the area to be investigated?
- What is the material to be examined?

NDT techniques are formed of two distinct groups:

- Surface breaking.
- Volumetric (ie not surface breaking).

Surface Breaking Techniques are commonly Magnetic Particle or Dye Penetrant Inspection and are solely concerned with the location of surface breaking defects such as cracks. These techniques give no indication of defects within components or welds although Magnetic Particle Inspection can sometimes pick up defects a small distance (typically 1 to 3mm) below the surface.

Magnetic particle inspection is the preferred technique for location of surface breaking or near surface defects when examining areas on magnetic (ferrous) materials. For non-ferrous materials, for example a copper firebox, dye penetrant testing will need to be used.

Volumetric techniques are commonly Ultrasonic or Radiographic Examination. Both techniques can give excellent results with their employment much depending on the geometry of the area to be tested. With ultrasonic techniques a clear area to allow complete scanning is required, whereas, with radiography, changes of material section and general access to the test area may be a consideration for not using this technique. Hammer testing might perhaps also be considered a volumetric technique but differs from formal NDT techniques in needing nothing other than a hammer and some skill on the part of the user.

Thus, it can be seen that no one technique fits all investigations. Where a crack is visible on the exposed surface it may be sufficient to just use surface breaking techniques, then repair the crack by its removal and making good by weld. On completion of the welding operation the repaired area should first be tested for surface breaking defects (but not until at least 12 hours has elapsed for materials/welding techniques susceptible to hydrogen embrittlement type cracking). A volumetric test method should then be used to confirm the integrity of the body of the weld.

It is common practice to combine magnetic particle investigation for surface and near surface breaking defects with an ultrasonic survey to examine areas below the surface.

Ultrasonic testing can also be very usefully used to determine the thickness of platework for instance in the situation where the defect is waterside corrosion. The type of ultrasonic equipment used just for thickness testing is simpler, cheaper and requires much less skill to use than that required for crack detection.

When an NDT technique is to be used it is important to specify the extent of the tests to be carried out and the acceptance criteria to be employed. In addition, those persons carrying out the work should have the appropriate level of skill and knowledge. However a formal qualification for the technique being used may or may not be required depending on the method and the circumstances of the examination.

All techniques, acceptance levels and personnel qualifications must be agreed with the Competent Person, preferably before any tests are made.

For guidance it is recommended that British Standard BS EN 12953 Design and Construction of Shell Boilers (the successor to BS 2790) is consulted. Whilst this document is designed to be used in the construction of new boilers it gives good guidance to the acceptable standards required for repairs. Although BS EN 12953 is a good source for guidance, other references may need to be used.

4. Non-Destructive Testing Methods

a. Dye Penetrant Inspection

Dye Penetrant Inspection is a low-cost technique for detecting surface breaking defects such as cracks, weld overlap and porosity in non-magnetic materials like copper. It can also be used for magnetic materials but Magnetic Particle Inspection can arguably give more reliably results for those materials.

Test Method:

- Surface cleaning (degreased and mechanically cleaned of loose debris etc).
- Apply a penetrant and allow to seep into any cracks present.
- Remove excess penetrant.
- Apply a developer.
- Inspect test area, any cracks present will be shown as fine lines on the developer
- Clean area.

The timings of these various steps are important and the manufacturer's instructions must be followed. It should also be noted that the penetrant tends to seal any cracks and repeated tests on the same area do not always give good results. Similarly Dye Penetrant Inspection should not be used prior to Magnetic Particle Inspection of the same area.

b. Magnetic Particle Inspection (MPI)

Magnetic Particle Inspection is a cost-effective method giving excellent results for the detection of surface and near surface breaking defects in materials that can be magnetised. This is the primary NDT technique for crack detection.

The specimen to be tested is sprayed with a white contrast paint. A permanent magnet or electro–magnet poles are then placed on the area to be tested which produces a magnetic flux within the material. This magnetic flux will, if the material is sound, remain within the material. If however there is a surface or near-surface flaw the magnetic field in this area will become distorted causing a flux leakage. This flux leakage can then be displayed by covering the area with fine iron particles. These particles will collect in the area of the flux leakage and will show up against the white background paint as a dark line or dark area.

This method requires the magnet to produce magnetic force lines at a large angle to the expected defect. It is therefore normal to apply the magnetic force from two angles usually at 90º to one another. Whilst it is usual for the items to be magnetised in the way stated, other methods, such as inducing a magnetic field with a coil, may be used.

c. Ultrasonic Flaw Detection

Ultrasonic Flaw Detection, unlike the Dye Penetrant or MPI techniques, not only locates surfaces breaking defects but assesses the whole of the weld and parent material in the area under examination. It is therefore referred to as a volumetric technique.

The ultrasonic technique uses a beam of short wavelength high frequency pulses in the frequency range of 1 to 5 MHz with wavelengths in the range 0·1 to 1 mm (typical values). The velocities of these waves through material depends very much on the type of material being tested but are normally ranged between 1000-6000 m/s. Such waves can travel large distances in fine grain metal.

In a normal simple detection technique a pulsed beam of ultrasound is sent through an item via a single hand held probe which is placed on the material's surface. A display screen then shows the time it takes for a pulse to travel to a reflector, which may be the back surface of the material, a defect or any other free surface. The received signal of a reflector may then be interpreted. The height of the reflected pulse relates to the flaw size, but its position and what type of defect is being seen will require considerable operator skill to interpret. If there is no flaw present then the back surface of the plate becomes the reflector and the plate thickness can be determined.

The sound waves so introduced into the material are normally of two types - compressional, normally angled at 90º to the surface (0º probe), and shear (traverse). This will ensure complete scan coverage of the test area. The probes for these tests can be made such that the ultrasonic waves can be introduced to the material at nearly any angle; normally 45º, 60º and 70º probes are used (shear wave).

The main drawback to this technique is the fact that, in older instruments, a permanent record is not produced and the results rely on the skill of the operator. However modern Ultrasonic equipment is now able to produce a permanent record displayed in a more user-friendly way and can record all actions and values taken by the operator which can be attached to the report of examination.

It should be noted that readings obtained between the surface and around 2mm depth into the material should not be treated as accurate as figures obtained at a depth greater than 2mm. Flaw sizing is generally recognised as better than ±2 mm.

Advantages

- High Sensitivity – can detect small flaws.
- Good penetration powers – can inspect thick sections.
- Accurate data – thickness measurements, location and defect size.
- Access – portable equipment.
- Inspection – test can be made from one surface only.

Disadvantages

- Rough surfaces – can limit the inspection.
- Geometry of Components – may present scanning inspection difficulties.
- Coarse Grain Structure – may present inspection (interpretation) difficulties particularly with castings and austenitic stainless steels etc.
- Results are interpreter/operator based and rely on the expertise and experience of the operator.

d. Ultrasonic Thickness Measurement

An Ultrasonic Thickness Gauge works in the same way as an ultrasonic flaw detector but uses only a probe angled at 90º to the surface. The high frequency pulses travel at a known speed through the material being tested and are reflected back from the far side. The gauge measures the time taken and calculates the thickness of the item being tested. An Ultrasonic Thickness Gauge is considerably cheaper than an Ultrasonic Flaw Detector and being much easier to use requires very little training. The following must however be considered if accurate test results are to be obtained:

- The probe frequency must suit the material being tested.
- The Compressional Wave Velocity, ie the velocity of the high frequency pulses through the material being tested, must be known.
- Heavy coatings of paint need to be removed.
- Good coupling is necessary between probe and material surface.
- Internal material defects can give incorrect thickness results.

Typical probe frequencies are 5MHz for most metals including steel, or 2MHz for attenuative materials like cast iron and plastics.

The Compressional Wave Velocity for mild steel is 5920m/s and this differs by only a very small amount for other steel grades such as alloy steels and tool steels. Some Thickness Gauges are therefore pre-programmed with this value for the use on steels and if used on different materials like copper or aluminium the thickness measured must be corrected. Other gauges have the facility for either the material type or the Compressional Wave Velocity to be entered so that the gauge can read the thickness directly. However for some materials the velocity can vary considerably, in the case of cast iron for instance it can be in the region of 3500 to 5600 m/s. To measure such materials accurately the Thickness Gauge should be calibrated on the material under test by taking some readings in an area where it is also possible to measure the thickness using a micrometer or similar.

Good coupling of the probe to the item being measured is essential particularly if the surface is rough. A proprietary ultrasonic couplant would normally be used but grease can be as effective. The rougher the surface the more couplant that will be required to get a thickness reading.

If the material being tested has an internal defect, then there is a risk that the ultrasonic waves will be reflected back by the defect instead of the far side of the material. The thickness reading given would then be less than the actual material thickness, sometimes considerably so. Typical defects could be either inclusions or laminations in the plate, both normally caused during the rolling process. Any thickness readings considerably different to those expected should be treated with caution and further readings should be taken in the same area.

e. Radiography

Radiography is a volumetric technique that uses X-rays or gamma rays to penetrate a material to produce a permanent image on a photographic film. The image so produced is the natural size of the object.

X-rays and gamma rays are very short wavelength rays of electromagnetic radiation. The rays produced have the ability to pass through solid material with some of the energy being absorbed by the material. These rays affect all types of photographic film.

If a photographic plate is placed on one side of the material and a source of electromagnetic radiation on the other side an image will be formed. The image formed will mirror the way in which the electromagnetic energy is absorbed by the material such that variations in thickness will show on the film with no differentiation as to whether these variations are in the surface or internal (not surface breaking).

The sources of radiation come basically in two forms:

- X-rays - are produced when an electric current is passed across a cathode-ray tube. The higher the voltage the greater the penetrating power of the radiation. It is common for industrial X-ray equipment to range in voltage from 20 KV to 20 MV. The most powerful X-ray equipment can be used to penetrate 20” (500 mm) of steel and produce satisfactory photographic images.
- Radioactive isotope Iridium-192 gamma-radiography is commonly used for most general engineering applications, but where greater penetrating powers are required Cobalt-60 is often used. Other isotopes are suitable for use with this technique.

To obtain the best image definition it is desirable to have a small diameter radiation source. Typical X-ray and gamma ray source sizes range from 1 to 4 mm which give good results. This technique is relatively expensive both for the equipment used and cost of the photographic film. It is worth noting that it is becoming more common for the image to be formed digitally doing away with the expense of film.

Generally, gamma radiography requires a much longer exposure time than X-ray and produces a less sharp image. Gamma radiography however is less expensive and far more portable and is commonly used for site work.

Advantages:

- Provides a permanent record.
- Reveals internal flaws within materials without affecting the material.

Disadvantages:

- Normally access is required to both sides of the area being tested.
- Does not detect some flaws such as laminations.
- Equipment is expensive
- Safety issues with associated radiation.

f. Hammer Testing

Hammer Testing is often used to check for broken firebox stays, girder stay bolts and similar items. It is both low cost and quick, and with a little practice can give good results. The principle of the test is that when the end of a stay or bolt is hit with a hammer the resulting sound will be a metallic ring unless it is broken, in which case a dull thud will be heard. The size of hammer used is typically ¼ to ½ lb.

Some skill is required on the part of the operator but when firebox stays in the same row are hit one after another it is usually not too difficult to detect one or more that sound different. However it should be noted that even when no stays are broken, they will not all sound exactly the same. Stays in an area where the plate is well supported, for example adjacent to the firehole ring or in the area of the inner firebox directly opposite where an expansion bracket is attached to the outer wrapper, will sound different to stays located in the centre of the plate away from any addition support.

Stays can also be tested with Ultrasonic Flaw Detection equipment, or even an Ultrasonic Thickness Gauge if it has sufficient range for the length of stay being tested. The head of the stay will often require grinding flat and the process is much slower than using a hammer. It can however be used in cases of doubt.

