Figure 11.21 Drum end press

taken of all welded seams. Any defects, not acceptable to the code of practice are cut out, the defective area is re-welded and then non-destructively re-examined.

Drum nozzles and fittings

The drum is now marked off to identify the position of all nozzles, brackets, supporting saddles etc. The holes for the nozzles (stubs) are machined out using an Asquith horizontal borer which has both horizontal and vertical movement in addition to traversing a lengthy track (Figure 11.22).

The tube stubs, normally made from forged bar, are machined to size and then manually welded to the drum shell. To ensure sound penetration at the root of the weld two different methods can be employed. For relatively thin stubs, say 9 mm thick, a tungsten inert gas (TIG) process is used for the initial root run, the remainder of the joint being made by the manual metal arc method. For greater thicknesses a 'bored out' technique is used. In this particular case the bore of the stub is reduced in diameter by 9 mm and is welded to the drum by the manual metal arc process. When the welding of all nozzles is completed the drum is reset in line with the Asquith boring machine and the inside of the stubs bored out to their required size. In this way the root runs of the weld, those that are most likely to

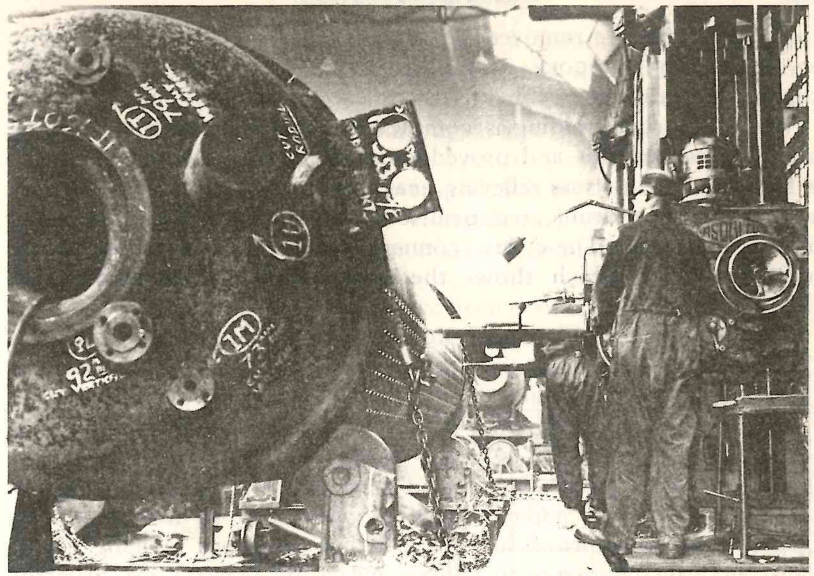


Figure 11.22 Asquith boring machine

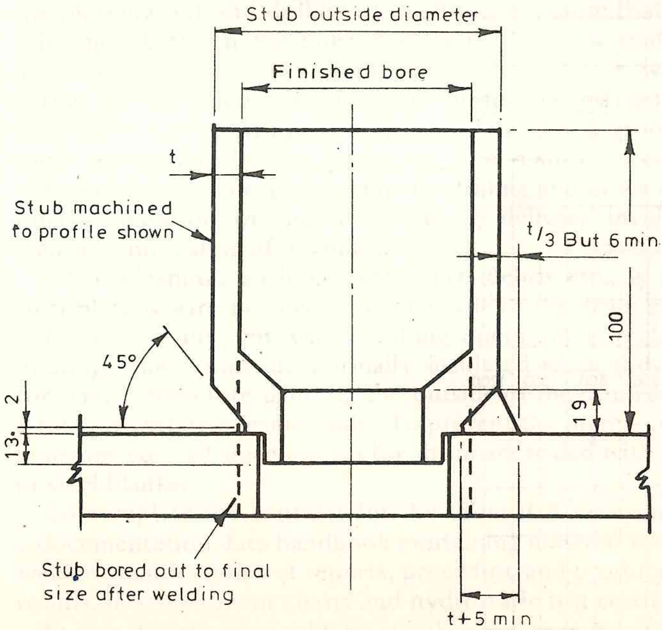


Figure 11.23 Typical detail of 'bored out' tube stub

contain defects, are removed (see Figure 11.23). Other fittings such as insulation supports, supporting saddles, and instrument connections, are then welded to the drum.

When all drum welding is completed and non-destructive testing has been carried out and proved satisfactory, the completed drum is subjected to a stress relieving heat treatment. Thermocouples are attached to the drum at critical locations on both the inside and outside surfaces. These are connected direct to a temperature recording chart which shows the complete heat treatment cycle (Figure 11.24).

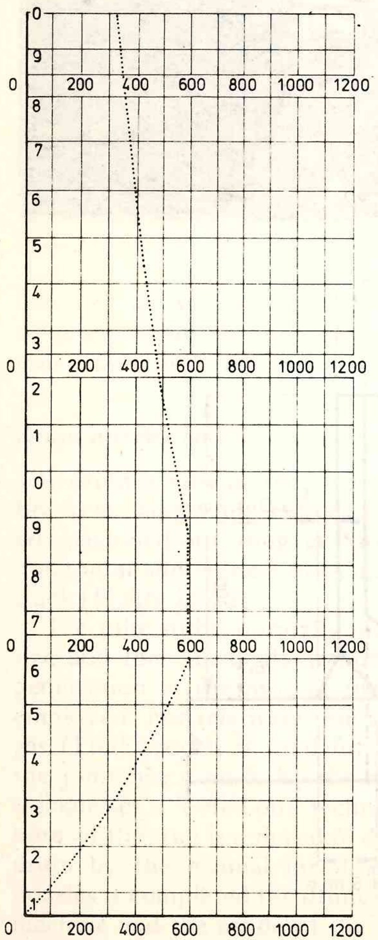


Figure 11.24 Temperature recording chart

The stress relieving operation consists of heating the drum at a specified rate to a temperature in the range 580–620°C (carbon steel), holding this temperature for a period of one hour per 25 mm of drum thickness and then cooling, again at a specified rate.

Any necessary welded test plates are also simultaneously stress relieved after which they are prepared for mechanical testing. In addition to the usual tensile, elongation, bend tests, etc, the inspecting authority may require macro and micro examination of the weld structure.

When satisfactory test results have been confirmed, all nozzles and branches are blanked off, manhole doors fitted and the drum prepared for a hydrostatic test. The drum is filled with water and the pressure raised to a specified pressure normally 1.5 × design pressure and then held at this pressure for a minimum period of 30 min.

As an alternative to attaching tubes to steam and water drums using protruding stubs they may be set into suitable holes machined in the drums. In this design a large number of holes are drilled in the shell of the drum and the riser and downcomer tubes (when installed for service) are either welded or expanded into the tube holes. It is extremely important that accuracy be maintained in the marking out and drilling of the drum to ensure that the ligament efficiency between the holes does not fall below that used in the drum design. Also critical is the tube hole diameter, which must be within the specified tolerance, and the tube hole finish which must be smooth and must not contain any detrimental grooves that may cause sealing and leakage problems. The required accuracy of tube hole position is achieved by template drilling and other methods. The final preparation of the drum before delivery involves cleaning, painting and sealing of openings.

When cleaning, all loose scale, dirt, debris etc., is removed, the steel plate is wire brushed and the inside of the drum carefully dried out. Occasionally, the wire brushing operation is replaced by shot blasting. The drums are normally insulated when they are installed for service therefore painting the outside of the drum is restricted to a rust preventative primer only. To prevent the ingress of dirt, debris, moisture etc., all openings on the drum are sealed with plastic covers or steel blanks.

To complete the contract for the drum it is necessary to compile a documentation data handbook containing material test certification welder qualification test reports, procedure and production test plate results, heat treatment charts and hydrostatic test certificate.

In conclusion it should be emphasised that in order to ensure complete compliance with the approved plans and requirements of the specified code of practice, each drum, from plate examination to final hydraulic test is subject to rigid inspection by the works inspection department in conjunction with the surveying authority responsible for its final certification.

TESTS OF WELDING

When seam welding is used for a boiler shell, whether it be for a tank boiler or water tube boiler drum, definite constructional regulations have to be observed. There are many so called 'codes' or tabulated rules governing the construction of welded boilers, both for marine and non-marine use.

One of the principal requirements for marine boilers is that the manufacturers making the boilers have initially to satisfy the inspecting authorities as to their ability to produce consistently good welded work. This is achieved by maintaining the plant in efficient condition, carrying out regular tests of the welding operators, having adequate testing facilities, suitable X-ray apparatus and also a suitable heat-treating furnace.

An engineering works that has proved its capabilities to, and is recognised by, the inspecting authorities for the construction of welded boilers has to make *each* boiler drum or shell in compliance with clearly defined rules. One of these rules, in effect, ensures by proof testing a facsimile or 'model' of the welded longitudinal joint that its strength or efficiency is as good as that of the actual drum or shell material.

The circumferential joints are welded in exactly the same manner as the longitudinal joints, and as under working conditions they are only subjected to half the stress, proof testing of the longitudinal joint 'model' is accepted as representing both longitudinal and circumferential seams.

The models of the actual longitudinal joints are known as test plates. Two test plates of steel, conforming to the same specification and of the same thickness as the shell being welded, have to be made for each boiler drum or shell.

These test plates are attached to the drum in such a manner that the edges to be welded are a continuation, and duplication of, the actual longitudinal joint (see Figure 11.25). In the case of machine welds, apart from the first and last few inches of seam, where there may be irregularities due to stopping and starting, the weld from A to B as laid down should be uniform in character, although in the case of hand welding it is unavoidable that the operator may actually take more care over the test plates than over the actual seam.

After the welding of the seam is complete the test plates suitably marked for identification are detached, straightened if warped and then subjected to the same heat treatment as is given to the boiler drum or shell.

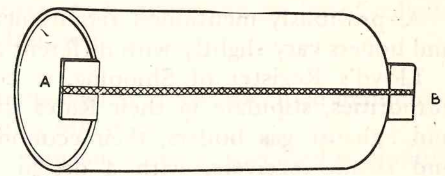


Figure 11.25 Fusion welded shell with test plates attached

The test plates, representing as far as practicable the actual longitudinal seam, are then cut up into test pieces to allow various tests to be made, i.e. tensile all-weld metal, bend, tensile of joint, macro and Charpy's (see Figure 11.26). These test pieces when tested have to meet the specified requirements of the Code or Rules of the inspecting authority.

The above description explains how, generally speaking, a satisfactory check is made on the physical properties of welded seams by means of test plates. However, it is necessary to ensure that the whole seam is as good as the test plates and with this object in view

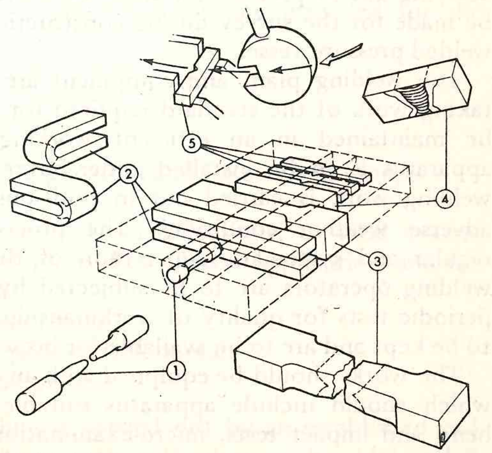


Figure 11.26 Test pieces cut from welded test plate
1. Tensile all-weld metal
2. Bend
3. Tensile joint
4. Macro
5. Charpy impacts

all the butt-welded seams, both longitudinal and circumferential, are radiographed so that any defects, at the discretion of the inspecting authority, can be cut out and rewelded prior to the stress-relieving treatment which has subsequently to be given to the welded drum or shell.

As previously mentioned, requirements for welded pressure vessels and boilers vary slightly with different authorities.

Lloyd's Register of Shipping, in common with most regulatory authorities, stipulate in their Rules that the pressure parts of fired and exhaust gas boilers, their economisers, superheaters, reheaters and steam receivers, with a design pressure above 0.34 N/mm^2 are to be constructed in accordance with their Class I requirements for fusion welding, which are as follows.

Preliminary conditions and tests for Class I fusion welded pressure vessels

Fusion welded pressure vessels constructed to Class I requirements will be accepted only if manufactured by firms equipped and competent to undertake high-quality welding. In order that firms may be approved for this purpose, it will be necessary for the Surveyors to visit the firm's works for the purpose of inspecting the welding plant, equipment and procedure and to arrange for the carrying out of preliminary tests. Furthermore, arrangements should be made for the survey during construction and testing of a full size welded pressure vessel.

The welding plant and equipment are to be suitable for undertaking work of the standard required for Class I welding and are to be maintained in an efficient working condition. The welding apparatus is to be installed under cover and so arranged that the welding work is carried out in positions free from draughts and adverse weather conditions. The procedure should include the regular and systematic supervision of the welding work, and the welding operators are to be subjected by the work's supervisors to periodic tests for quality of workmanship. Records of these tests are to be kept and are to be available for inspection by the surveyors.

The works should be equipped with an efficient testing laboratory which should include apparatus suitable for carrying out tensile, bend and impact tests, micro-examination of specimens and X-ray examination of pressure vessels. The works should also be equipped with a suitable heat-treating furnace having satisfactory means for temperature control.

Alternative arrangements which, in the opinion of the surveyors,

ensure an equally high standard of quality control may be submitted for consideration.

Preliminary tests to demonstrate the quality of the welding work are to be carried out by the firm under the supervision of the surveyors. The test requirements will be based on the grades of steels, and on the welding process to be used; the grades of rolled-steel plates shall be grouped as follows:

Group 1. Carbon and carbon manganese steels, specified minimum tensile strength not exceeding 500 N/mm^2.
Group 2. Carbon and carbon manganese steels, specified minimum tensile strength not exceeding 500 to 520 N/mm^2.
Group 3. Low-alloy steels.

The maximum plate thickness which would be approved in pressure-vessel construction would depend on the thickness of the test plates used in the preliminary tests; the test plates are, however, to be at least 20 mm thick.

The test plates and the full-size pressure vessel constructed by a firm for approval purposes are to be representative as regards materials and approximate shell thickness of the production vessels for which approval is desired.

The welded seams of the test plates are to be radiographed and the Surveyors are to select portions of the test plates containing the welded joint from which specimens are to be provided for the following tests:

1. *(a)* Tensile
   (b) Bend
   (c) Hardness
   (d) Impact } For Class I application and for steels in groups
   (e) Fatigue } 2 and 3.
2. Micrographs at 100 and 300 magnifications, of weld centre, fusion zone and parent plate. For Class I application and for steels in groups 2 and 3.
3. Macrograph of full section weld.
4. Chemical analysis of deposited weld metal.
5. Chemical analysis of test plates.

Note: Where the welding is carried out by an established and approved process, the fatigue tests and micrographs, 1*(e)* and 2 above, will not in general be required. Further, as an alternative to 5, a guaranteed analysis obtained from the steel-makers will be accepted.

If a firm intends to manufacture boiler drums or shells either of a different group of steel, or by means of a different welding process than used in the preliminary tests on which the original approval was based, further tests will be required to cover the proposed welding procedure. In such cases, full details of the material, plate thickness and welding process proposed are to be submitted for consideration when the requirements for further preliminary tests will be indicated.

Where firms desire their name to be included in Lloyd's Register's list of firms recognised as experienced manufacturers of Class I fusion-welded pressure vessels, they should make application at the initial stages of having their works approved. In addition to the preliminary tests, a full-size pressure vessel is to be constructed in accordance with the requirements of these Rules for Class I fusion-welded pressure vessels under the supervision of the surveyors.

On completion of the inspection and tests, the surveyor's report including the results of the preliminary tests and also, for Class I approval, the results of the tests of the full-size pressure vessel, is to be submitted for the consideration of the Committee of Lloyd's Register. The report should also include the radiographs and particulars of any fusion-welded pressure vessels previously constructed by the firm.

Routine tests for Class I fusion welded pressure vessels

Two test plates, each of sufficient dimensions to provide one complete set of specimens, should be prepared for each pressure vessel. They should be attached to the shell plate in such a manner that the edges to be welded are a continuation and simulation of the corresponding edges of the longitudinal joint. The welding process, procedure and technique are to be the same as employed in the welding of the longitudinal joint. Test plates are to be so supported, during welding so that warping is reduced to a minimum.

Alternatively one test plate may be prepared to provide all the test specimens and for retest pieces (see Figure 11.26).

The test plates are to be straightened before being subjected to heat treatment, and for this purpose the test plates may be heated to a temperature below that required for the final heat treatment.

Test plates need not be prepared for the circumferential seams, except in cases where a pressure vessel has circumferential seams only, or where the process for welding the circumferential joints is significantly different from that used for the longitudinal joints; in such an event, one test plate is to be prepared having a welded joint which, so far as possible, is a simulation of the circumferential seams.

The test plate is to provide all the test specimens required, as in Figure 11.26.

Where a number of similar vessels are made at the same time it will suffice if test plates are provided for each 30 m of circumferential welded seam. The test plates are to be cut from the shell plate or plates forming the appropriate seam and before being detached are to be stamped by the surveyor.

When there is insufficient material available on the shell plates for the provision of test plates, acceptance may be given to test plates cut from another plate provided this plate is from the same cast and in the same heat-treatment condition. The thickness of test plates is to be the same as that of the pressure vessel.

One set of test specimens is to be cut from the test plates as shown in Figure 11.26 for Class I pressure vessels. The results of the tests are to comply with the requirements detailed in the following paragraphs.

Retests

If any of the tests fail, the reason for the failure shall be investigated and two retest specimens shall be prepared and tested. Where two test plates have been prepared, the retests are to be cut from the second test plate. If it can be shown that the failure of the initial test has resulted from local or accidental defect and the retest values are satisfactory, the retest values may be accepted.

Tensile test for all-weld metal. Specimen No. I

One all-weld-metal tensile specimen shall be taken for Class I pressure vessels having a shell thickness not exceeding 70 mm. Where the shell thickness of a Class I pressure vessel exceeds 70 mm, two such specimens shall be taken one above the other.

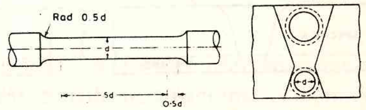


Figure 11.27 Specimen No. 1 tensile test for all-weld metal

The diameter of the all-weld-metal test-piece at the reduced parallel position is to be not less than 14 mm except in the case of thin plates where the largest practicable diameter should be used. The gauge length of the test-piece is to be five times the diameter.

The dimensions of the all-weld-metal test specimen and their location when two specimens are used are shown in Figure 11.27.

The tensile strength of the weld metal is to be not less than the minimum and not more than 145 N/mm² above the minimum specified for the plate.

The percentage elongation A shall be not less than given by

$$A = \frac{980 - R}{21.6} \qquad \left(A = \frac{100 - R}{2.2}\right)$$

where R is the tensile strength in N/mm².

In addition, this elongation shall be not less than 80% of the equivalent elongation specified for the plate.

Transverse-bend test. Specimen No. 2

Two bend-test specimens of rectangular section are to be cut from the test plate transversely to the weld, one to be bent with the outer surface of the weld in tension, and the other with the inner surface in tension.

The specimens shall have a width equal to 1.5 times the thickness of the specimen and the mid-portion is to coincide with the centre line of the weld. The edges shall be rounded to a radius not exceeding 10% of the thickness.

Where the plate thickness does not exceed 25 mm the thickness of the specimens shall be the full thickness of the plate. Where the plate thickness exceeds 25 mm the specimens, in all cases, shall have a thickness of 25 mm and shall be prepared by discarding metal from the surfaces which will be in compression when the test is applied (see Figure 11.28).

Where the thickness of the plate permits, the bend specimens may be prepared as shown in Figure 11.29.

For each specimen the weld reinforcement should be removed by

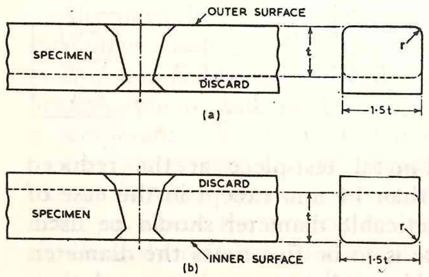


Figure 11.28 (a) Normal bend specimen
(b) Reverse bend specimen

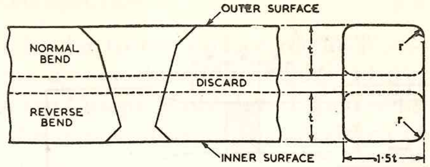


Figure 11.29 Specimen No. 2 bend tests
Normal and reverse bend specimens, cut from single piece of plate

grinding or machining so that the outer and inner surfaces of the weld are flush with the surface of the plate.

The specimen shall be mounted on roller supports with the centre of the weld midway between the supports. A former, with its axis perpendicular to the specimen, shall bend the specimen by pushing it through the clear space between the supports. The diameter of the former and the clear space between the supports will depend on the thickness of the specimens and these dimensions are shown in Table 11.3 in terms of t, the thickness of the specimen.

Table 11.3

Minimum specified tensile strength of plate	*Diameter of former*	*Clear space between supports*
N/mm² (kgf/mm²)		
< 460 (< 47)	$2t$	$4.2t$
⩾ 460 < 510 (⩾ 47 < 52)	$3t$	$5.2t$
⩾ 510 ⩽ 620 (⩾ 52 ⩽ 63)	$4t$	$6.2t$

After bending there shall be no crack or defect exceeding 1.5 mm measured across the specimen or 3 mm measured along the specimen. Premature failure at the edges of the specimen shall not lead to rejection.

Tensile test for joint. Specimen No. 3

One reduced section tensile test specimen is to be cut transversely to the weld, or in thick plate, as many tensile-test specimens as may be necessary to investigate the tensile strength throughout the whole thickness of the joint. The weld reinforcement should be removed by grinding or machining so that the outer and inner surfaces of the weld are flush with the surface of the plate. The dimensions of the reduced section tensile test specimens are shown in Figure 11.30. The width B at the reduced section shall be at least 25 mm.

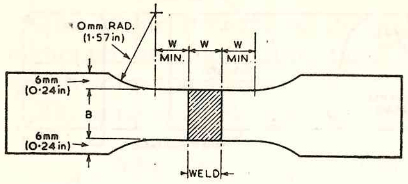


Figure 11.30 Specimen No. 3 tensile test for joint
B = Not less than thickness of plate with a minimum width of 25 mm

Where the plate thickness exceeds 30 mm the tensile test may be effected on several reduced-section specimens each with a thickness of at least 30 mm and a width at the effective cross-section of at least 25 mm.

The tensile strength obtained shall be not less than the minimum specified tensile strength for the plate material.

Macro specimen. Specimen No. 4

Macro-etching of a complete cross-section of the weld including the heat affected zone shall show a satisfactory penetration and fusion, and an absence of significant inclusions or other defects. Should there be any doubt as to the condition of the weld as shown by macro-etching, the area concerned shall be microscopically examined.

Notched bar impact test. Specimen No. 5

Three Charpy V-notch specimens are to be cut transversely to the weld, parallel to the plate surface and at midplate thickness. The notch is to be cut at approximately the centre of the weld, and the

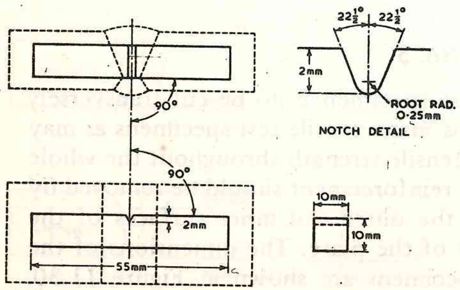


Figure 11.31 Specimen No. 5 Charpy V-notch impact test specimen

axis of the notch is to be perpendicular to the surface of the plate. The dimensions of the specimens are as shown in Figure 11.31.

The average energy value from the Charpy V notch test specimens is to be not less than 27J when the temperature of the specimen at the time of test does not exceed 50°C.

Where it is proposed to use impact tests other than the Charpy V-notch type, details are to be submitted for consideration.

NON-DESTRUCTIVE EXAMINATION

Radiographic examination

The extent of the radiographic examination of the welded seams in Class I pressure vessels shall be as follows.

All butt-welded seams in drums, shells, headers and pipes and tubes over 170 mm outside diameter, together with the test plate or plates, shall be subjected to 100% radiographic examination. For circumferential butt welds in extruded connections, pipes, tubes, headers and other tubular parts 170 mm outside diameter and less, 10 per cent of the total number of welds shall be radiographed.

Butt welds in furnaces, combustion chambers and other pressure parts for fired pressure vessels under external pressure, are to be subject to spot radiographic examination.

Where the surface finish of any weld which has to be radiographed is such that it will prevent accurate radiographic examination, the surface shall be machined or ground to provide a smooth contour to the Surveyor's satisfaction.

Lead-type shall be fixed to the plate adjacent to the weld so that each radiograph is marked in such a way that the corresponding portion of the welded seam can be readily and accurately identified.

The length of weld covered by each exposure shall be such that the metal thickness along the incident beam at the extremity of the exposure shall not exceed the actual thickness by more than 10 per cent.

Penetrameters (image quality indicators) of an approved type are to be placed at each end of each radiograph and on the surface of the plate facing the source of radiation.

Penetrameters of the step-hole type are to be placed alongside the welded seam parallel to its length and shall have a hole in each step of a diameter corresponding to its thickness at that step or shall have some similar device whereby the step thickness can be identified when the radiographic film is examined.

The radiographic technique employed is to be such that the smallest diameter hole visible in the radiograph shall not exceed 3 per cent of the weld thickness for welds not exceeding 50 mm thick, or 2.5 per cent for welds exceeding 50 mm thick. The steps shall bear these proportions to the weld thickness radiographed and the radiographic technique shall be capable of revealing changes of metal thickness of these percentages.

Penetrameters of the wire type are to be placed across the weld and the smallest diameter wire which can be seen in the radiograph must have a diameter not greater than 1.5 per cent of the weld thickness, if the weld thickness is between 10 mm and 50 mm and not greater than 1.25 per cent of the weld metal thickness if the thickness exceeds 50 mm up to 200 mm.

The use of gamma rays may be permitted in certain circumstances when details should be submitted for consideration and approval. Radiographs shall be examined by the Surveyors on the original films using a viewing device of suitable illuminating power.

Ultrasonic examination

In Class I pressure vessels where the plate thickness exceeds 50 mm ultrasonic examination may be accepted as an alternative to radiographic examination. Such examination shall be effected by an approved operator using an approved technique and an approved recording system. Supplementary examination by radiography at selected locations may be required.

Magnetic crack detection

In Class I pressure vessels the welds on standpipes, compensating plates, stubs and branches, etc., of ferritic steels which have not been radiographed shall be magnetically crack detected at the rate of 10 per cent of such welds. This rate may be increased or decreased at the discretion of the Surveyors. For non-magnetic materials dye penetrant examination will be accepted.

Repairs to welded seams

In the case of Class I pressure vessels when non-destructive tests show unacceptable defects in the welded seams, the defects shall be repaired and shall be shown by further non-destructive tests to have been eliminated to the Surveyor's satisfaction.

Post-welding heat treatment

All Class I pressure vessels of carbon and carbon-manganese steel over 20 mm in thickness, and all of low alloy steels, are to be efficiently heat-treated on completion of the welding of the seams and of all attachments to the shell and ends, and before the hydraulic test is carried out.

Heat treatment is to be carried out in a properly constructed furnace which is efficiently maintained, has adequate means for temperature control and is fitted with pyrometers which will measure and record the temperature of the furnace charge. The heat treatment is to consist of heating the vessel slowly and uniformly to a suitable stress-relieving temperature, soaking for a suitable period, followed by cooking slowly and uniformly in the furnace to a temperature not exceeding 400°C and subsequently cooling in a still atmosphere. The temperature and soaking periods are to be selected which will relieve residual stress without undue reduction of the properties of the material.

Recommended soaking temperatures and periods are given in Table 11.4.

Table 11.4

Type of steel	*Soaking temperatures*	*Time at temperature per 25 mm of thickness*
Carbon and carbon-manganese	580–620°C	1 hour (1 hour minimum)
1 Cr ½ Mo	620–660°C	1 hour (2 hours minimum)
2¼ Cr 1 Mo	650–690°C	2 hours (2 hours minimum)

In cases where other materials are used for pressure-vessel construction, full details of the proposed heat treatment are to be submitted for consideration.

Where pressure vessels are of such dimensions that the whole length cannot be accommodated in the furnace at one time, the pressure vessels may be heated in sections provided sufficient overlap is allowed to ensure the heat treatment of the entire length of the longitudinal seam.

Test plates should be heat treated in the same furnace and at the same time as the pressure vessels which they represent. In special cases, however, it may be permissible to heat treat the test plates separately from the pressure vessels provided the surveyor is satisfied with the means adopted to ensure that the following factors will be the same for the pressure vessels as for their respective test plates:

Rate of heating
Maximum temperature
Time held at maximum temperature
Conditions of cooling.

Where it is proposed to adopt special methods of heat treatment, full particulars are to be submitted for consideration. In such cases it may be necessary to carry out tests to show the effect of the proposed heat treatment.

Hydraulic test

Boilers, together with their components, shall withstand the following hydraulic tests without any sign of weakness or defect.

Having regard to the variation in the types and design of boilers, the hydraulic test may be carried out by either of the following methods:

1. The boiler on completion shall be tested to a pressure of 1.5 times the design pressure, or

2. *(a)* Where construction permits, all components of the boiler shall be tested on completion of the work including heat treatment of 1.5 times the design pressure. In the case of components such as drums or headers, which are to be drilled for tube holes, the test may be made before drilling the tube holes but shall be after the attachment of standpipes, stubs and similar fittings and also after heat treatment has been carried out.

(b) Provided all the components have been tested as in *(a)* above, each completed boiler after assembly shall be tested to 1.25 times the design pressure.

Where any of the components have not been tested as in *(a)* above, each completed boiler after assembly shall be tested to 1.5 times the design pressure.

MANUFACTURE OF FUSION-WELDED PRESSURE VESSELS

The following general requirements are applicable to all classes of fusion-welded pressure vessels.

Welding consumables

All consumables intended for use in the welding of pressure vessels are to be stored in a dry place. In order to ensure that the quality of the welding consumables is consistently maintained they are to be subjected to a regular system of periodic testing and inspection. Where routine tests are frequently carried out in respect of pressure vessels made in the normal course of production, such tests may be regarded as meeting the requirements of this paragraph.

Welding equipment

All welding plant and auxiliary equipment shall be maintained in good working order and adequate means of measuring current shall be provided. In the case of machine welding, means shall be provided for measuring the arc voltage. All electrical plant used in connection with the welding operations shall be adequately earthed.

Plate cutting

Plates shall be cut to size and shape by machine flame cutting and/or machining. Where the plate thickness does not exceed 25 mm, cold shearing may be used provided that the sheared edge is cut back by machining or chipping for a distance of one quarter of the plate thickness, but in no case less than 3 mm.

All plate edges, after cutting and before carrying out further work upon them, shall be examined for laminations, and also to ensure that any sheared edges are free from cracks. Visual methods may be supplemented by other techniques at the discretion of the surveyor.

Forming shell sections and end plates

Plates for shell sections and end-plates shall be formed to the required shape by any process that will not impair the quality of the material. Tests to demonstrate the suitability of a process may be required at the discretion of the surveyors. Shell plates shall be formed to the correct contour up to the extreme edges of the plate. As far as possible hot and cold forming shall be done by machine; forming by hammering with or without local heating shall not be employed.

All plates which have been hot formed or locally heated for forming shall be normalised on completion of this operation. If, however, hot forming is carried out entirely at a temperature within the normalising range, subsequent heat treatment will not be required for carbon and carbon manganese steels. In both instances alloy steels may, in addition, require to be tempered.

All plates which have been cold formed to an internal radius less than ten times the plate thickness shall be given an appropriate heat treatment.

Preparation of plate edges and openings for welding

Welding preparations and openings of the required shapes may be formed by the following methods:

1. Machining, chipping or grinding; chipped surfaces which will not be covered with weld metal shall be ground smooth after chipping.
2. Flame cutting.

Special examination will be required for cracks on the cut surfaces and the heat-affected zones in flame-cut alloy or high-carbon steels; preheating may be required in order to ensure satisfactory results when flame cutting.

Any material damaged in the process of cutting plates to size or forming welding grooves shall be removed by machining, grinding or chipping back to sound metal. Surfaces that have been flame cut shall be cut back by machining or grinding so as to remove all burnt metal, notches, slag and scale, but slight discoloration of machine flame-cut edges on mild steel shall not be regarded as detrimental. If alloy steels are prepared by flame cutting the surface shall be dressed back by grinding or machining for a distance of at least 1.6 mm unless it has been shown that the material has not been damaged by the cutting process.

After edges of the plates have been prepared for welding they shall be carefully examined for flaws, cracks, laminations, slag inclusions or other defects.

Care shall be taken to ensure that the weld preparations are correctly profiled.

Assembly of plates for welding

The plates shall be assembled and retained in position for welding by any suitable method; tack welds, where used, shall be removed so that they do not become part of the seam. Correction of irregularities shall not be carried out by hammering.

Where a root gap is specified the edges of butt welds shall be held so that the correct gap is maintained during welding.

Where welded-on bridge pieces, or other aids to fabrication are used, care shall be taken that the surfaces of the material are not left in a damaged condition after the attachments and rectification of scars by welding shall be undertaken before applying post-weld heat treatment.

Butt welds in plates of equal thickness

The surfaces of the plates at the longitudinal or circumferential seams shall not be out of alignment with each other at any point by more than 10 per cent of the plate thickness, but in no case shall the misalignment exceed 3 mm for longitudinal seams or 4 mm for circumferential seams.

Butt welds in plates of unequal thickness

Where a drum is constructed of plates of different thicknesses (tube plate and wrapper plate), the plates shall be arranged so that their centre lines form a continuous circle. For the longitudinal seams, the thicker plate shall be equally chamfered inside and outside by machining over a circumferential distance not less than twice the difference in the thicknesses so that the two plates shall be of equal thickness at the position of the longitudinal weld. For the circumferential seam, the thicker plate shall be similarly prepared over the same distance longitudinally.

For the circumferential seam, where the difference in the thicknesses is the same throughout the circumference, the thicker plate shall be reduced in thickness by machining to a taper for a distance not less than four times the offset so that the two plates shall be of equal thickness at the positon of the circumferential weld. A parallel portion may be provided between the end of the taper and the weld edge preparation; alternatively, if so desired, the width of the weld may be included as part of the smooth taper of the thicker plate.

Plates welded prior to forming

Seams in plates may be welded prior to forming, provided that on completion of forming and subsequent heat treatment they meet the specified mechanical test requirements and that they are examined radiographically throughout their length after forming. After forming, the surfaces of such seams in alloy steel parts, also carbon steel parts over 25 mm thickness, shall be ground smooth and inspected for cracks by magnetic crack detection, dye penetrants or other means at the discretion of the Surveyor.

Attachments and fittings

All lugs, brackets, branches, manhole frames and reinforcements around openings and other members shall conform to the shape of the surface to which they are attached.

The attachment by welding of such fittings to the main pressure shell after post-weld heat treatment is not permitted, except where the material involved is mild steel. In such cases welding will only be permitted provided it is necessitated by the method of construction being employed and prior approval of the surveyor must be obtained before any welding is carried out. In no circumstances is any welding to be done after heat treatment on vessels made of carbon or carbon-manganese steel with tensile strength exceeding 510 N/mm² or of alloy steel.

Attachments and fittings

When fittings, lugs and also flats and other attachments for supporting internal and external components, are welded to the main pressure shell, the welding is to be of comparable standard to that required for the vessel and the material used is to be of compatible composition.

The finish of all welds attaching pressure parts and non-pressure parts to the main pressure shell is to be such as to permit satisfactory examination of the welds. In the case of Class I pressure vessels these welds are to be ground smooth, if necessary, to provide a suitable finish for crack detection tests which are to be carried out to the Surveyor's satisfaction on completion of the hydraulic test.

Welding of main seams

When welding with the manual, semi-automatic, metal-arc or submerged-arc welding processes, the following requirements shall be applied. When other processes are utilised it may be necessary to modify or amplify these precautions to ensure satisfactory workmanship.

All surfaces to be welded shall be thoroughly cleaned of scale, rust, oil or other foreign matter down to a clean surface for a distance of at least 12.5 mm from the welding edge. Welding grooves shall be similarly cleaned.

Unless otherwise approved, seams shall be welded from both sides of the plate. When manual or semi-automatic arc welding is employed, the metal at the bottom of the first side shall be removed by grinding, chipping, machining or other approved methods so as to provide clean sound metal on which to deposit the subsequent welds.

The welding procedure for a butt joint welded from one side of the plate shall provide complete fusion. Special care shall be taken to ensure that the root is properly fused and that distortion due to the contraction of the weld metal is minimised.

Backing strips if used shall be of the same nominal composition as the plates to be welded and shall be removed and the surface dressed smooth by grinding prior to radiography.

The roots of butt joints and seams welded from one side of the plate shall be dressed smooth by grinding and before radiographic examination. The dressed surfaces shall be examined for root defects.

Each run of weld metal shall be thoroughly cleaned and all slag removed before the next run is deposited.

After welding has been stopped for any reason, care shall be taken in restarting to ensure that the previously deposited weld metal is thoroughly clean and free from slag, and that there is proper penetration into the plates and the previously deposited weld metal. Welding shall be carried out in the downhand horizontal position. In the case of circumferential seams means shall be adopted to ensure compliance with this requirement. Fillet welds shall be made so as to ensure proper fusion and penetration of the weld metal at the root of the fillet. Not less than two runs of metal shall be deposited at each weld affixing branch pipes, flanges and seatings.

The arc shall be struck only on those parts of the parent metal where the weld metal is to be applied or of the welding metal already deposited. Accidental arc strikes are to be removed by grinding followed by magnetic particle or dye penetrant testing to the Surveyor's satisfaction. Preheating is to be employed when necessitated by the joint restraint, thickness of the plate and composition of the material to be welded.

On completion of the welding, the seams are to be thoroughly examined before being dressed or machined. Parts showing evidence of blow-holes, slag inclusions, unsatisfactory penetration, porosity or any other defect are to be cut out and rewelded, and undercutting made good.

The outer surfaces of the welds may be flush with the surfaces of the plates joined, but no objection will be raised if the total thickness at the centre of the weld is greater than the thickness of the plates, provided the change of section is gradual.

In cases where it is proposed to adopt fusion welding processes in which it may not be possible to comply fully with the foregoing requirements regarding technique, full particulars are to be submitted for consideration.

Tolerances for cylindrical shells

The shell sections of completed vessels shall be circular within the limits defined in Table 11.5. Measurements shall be made to the surface of the parent plate and not to a weld, fitting or other raised part.

Table 11.5 Tolerances for cylindrical shells

Nominal internal diameter of vessel (mm)		*Difference between max. and min. diameters*	*Maximum departure from designed form*
Over	*Up to and including*		mm
–	300	1.0 per cent of internal diameter	1.2
300	460		1.6
460	600		2.4
600	900		3.2
900	1220		4.0
1220	1520		4.8
1520	1900		5.6
1900	2300	19 mm	6.4
2300	2670		7.2
2670	3950	19 mm	8.0
3950	4650	19 mm	0.2 per cent of vessel diameter
4650		0.4 per cent of vessel internal diameter	

Shell sections shall be measured for out-of-roundness either when laid flat on their sides or when set up on end. When the shell sections are checked while lying on their sides, each measurement for diameter shall be repeated after turning the shell through 90° about its longitudinal axis. The two measurements for each diameter shall be averaged and the amount of out-of-round calculated from the average values so determined.

There shall be no flats or peaks at welded seams and any local departure from circularity shall be gradual.

The external circumference of the completed shell shall not depart from the calculated circumference (based upon nominal inside diameter and the actual plate thickness) by more than the amount shown in Table 11.6.

In assessing the out-of-roundness of pressure vessels, the difference between the maximum and minimum internal diameters measured at one cross-section shall not exceed the amount given in Table 11.5.

Table 11.6

Outside diameter (Nominal inside diameter plus twice actual plate thickness)	*Circumferential tolerance*
300 mm up to and including 600 mm	± 5 mm
Over 600 mm	± 0.25 per cent

The profile measured on the inside or outside of the shell by means of a gauge of the designed form of the shell and having a length equal to one quarter of the internal diameter of the vessel, shall not depart from the designed form by more than the amount given in Table 11.5.

WATER TUBE BOILERS – CONSTRUCTION AND ERECTION PROCEDURE

As a basic design we will describe the modern external superheater type boiler. More often than not, two or more are built at the same time, and work progresses to a definite routine.

Many boiler makers order their drums outside, but if this is not being done, the first and most involved items to be constructed are the steam and water drums.

Assuming the boiler plans have been submitted and approved by the Classification Authority the first step to be taken in the construction of the drums and, in fact, the boiler as a whole, is a visual examination of all the plates, dished ends, nozzle and header forgings, and tubes, to verify that they are of correct scantlings and have been examined, tested and stamped by the inspecting authority as being in accordance with the plans and material specification.

Drums

The general procedure for drum construction has been described at the beginning of this chapter, i.e., the plates for the drums are cut to correct size and after pressing or rolling to shape are welded and fitted with ends. After nozzles have been attached and satisfactory radiographs of all seams witnessed, the drums with test plates are stress relieved, mechanical tests on the test plates witnessed and, if all is satisfactory, the drums are hydraulically tested. The drums are then marked off for drilling, and often drilling jigs are used. Earlier designs featured tube holes which were not normal to the drum surface, but in present day practice this has been abandoned.

Water drums are normally provided with sliding feet, which while taking care of drum expansion also transfer most of the weight of the boiler to the tank top. In some designs, however, the boiler proper is cradled into the casing, which in its turn again transfers the weight to the tank top. In both cases, apart from membrane walled types, flexible connections are embodied between the boiler and the casing to avoid high stresses and gas leakages occurring through differential expansion.

Headers

Headers for waterwalls, superheaters and economisers are normally fabricated from solid drawn round section steel tube, with ends, branches, feet and casing connections welded on before stress relief. After hydraulic testing the necessary machining for handhole plugs, and the drilling of tube holes is effected.

Tubes

In the past, all water tube boiler tubes were of solid drawn steel. Nowadays, however, electric resistance welded tubes are used for all purposes except for downcomers and risers and chrome-molybdenum superheater tubes, which are normally solid drawn.

The tubes for each row are bent to template, and in the case of membrane walls are built up into welded panels, it being important that the tubes are kept clean internally prior to assembly in the boiler. Superheater and economiser tubular elements are usually assembled as far as practicable, before being installed in their operating positions in the boiler casing.

In the case of boilers with expanded-in tubes, it is usual to perform a light preliminary expanding at a specified early stage in the boiler erection, and then later to finally expand and bell to a definite routine. This routine or sequence is necessary to avoid building-in stresses through increases in tube length which occur during the expanding operation.

In addition to the expanded-in tubes which are about 50 mm o.d., most designs incorporate external downcomers of about 250 mm o.d. These are welded to stubs near the ends of the drums and ensure adequate circulation in all conditions of steaming. Particular care has to be taken in the site welding of these large tubes, the welds usually being proved by radiography on completion.

Casings

Casings are of two types, double or single. In the first case the boiler superheater and economiser (if fitted), are double cased to permit the passage of pressurised combustion air to prevent gas leaks and reduce radiation of heat into the engine room. In the second case, the pressure parts form the casing, and all that is necessary is a backing of refractory between these pressure parts i.e. membrane walls, and a light-weight outer casing.

One of the main advantages of the membrane single-cased boiler over the double-cased, is that as the pressure parts form the casing, all parts have similar expansions and no sliding seals are needed.

Superheaters

In the external superheater boiler the all-welded superheater, either already assembled or in elements, is placed in the convection space and the membrane or tangent tube walls, are built around it. This is

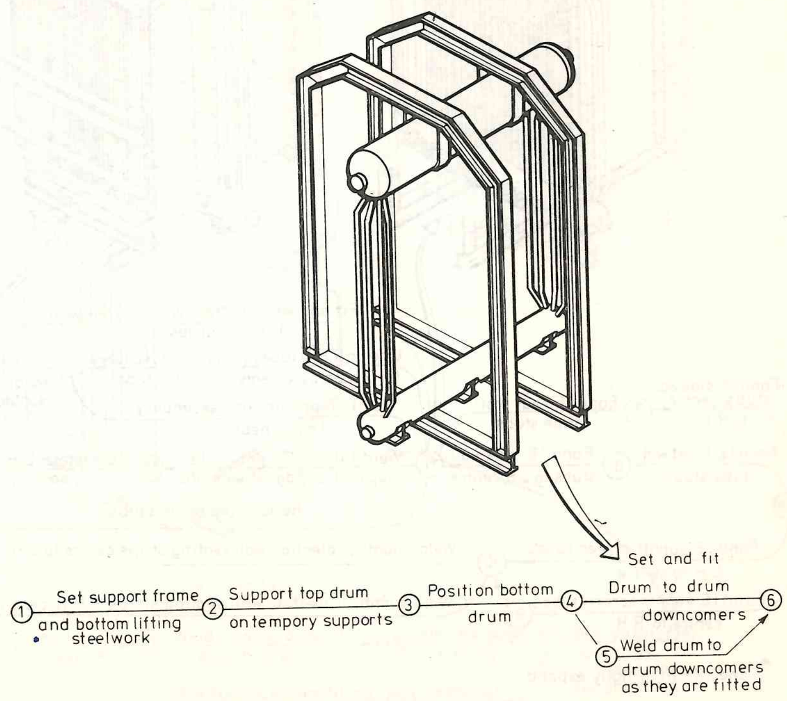


Figure 11.32 Erection of Foster Wheeler Type ESD III boiler

necessary as the terminal ends of the superheater elements pass through the side wall en route to their respective inlet and outlet headers.

It will be noted that in the case of the membrane-walled boiler in Figure 11.33 the superheaters are prefabricated and placed *in situ* en bloc, and that the tube ends of the membrane side walls and also part of the front and back walls are welded to stubs which have been expanded into the steam and water drums. The important question of superheater supports has been described in Chapter 9.

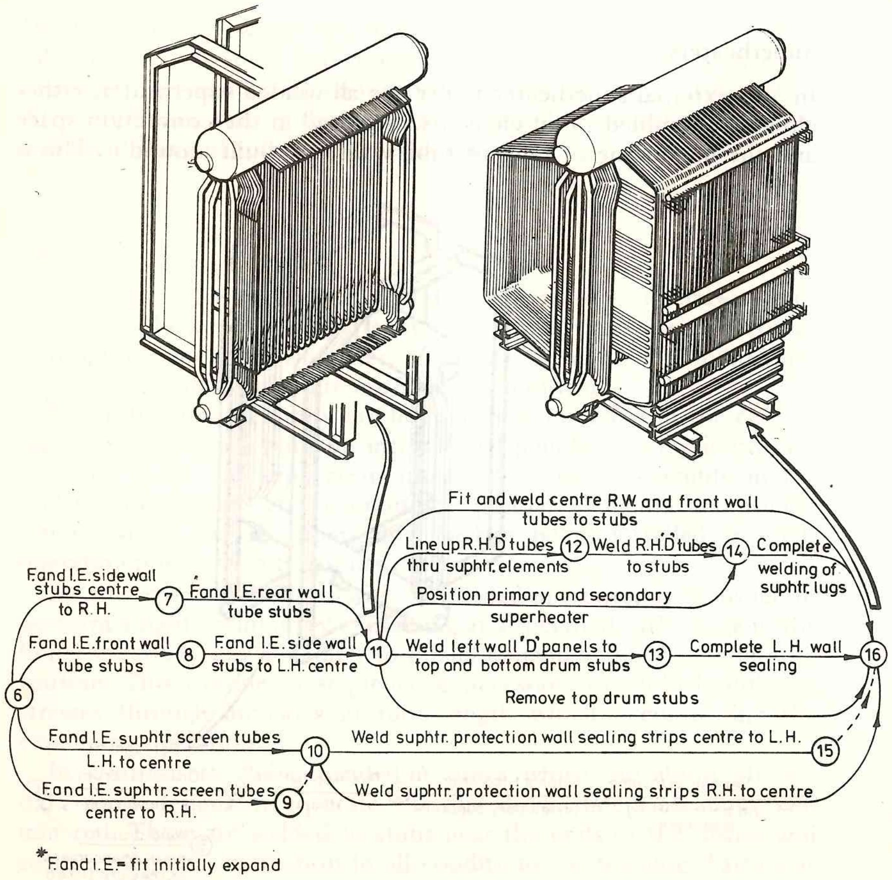


Figure 11.33 Erection of Foster Wheeler ESD III boiler (continued)

It is extremely vital that the correct superheater tube material is used for the various stages of superheat. Cases have occurred where mistakes have been made due to wrong material identification – carbon steel, 1% chrome, ½% molybdenum, and 2¼% chrome, 1% molybdenum steels being commonly used.

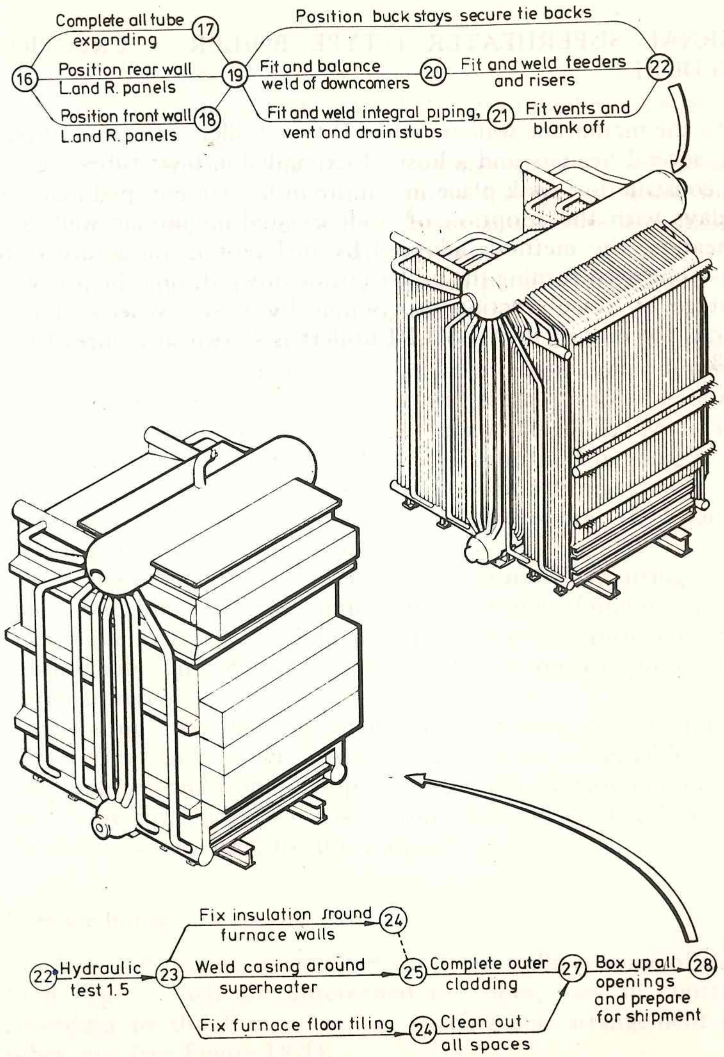


Figure 11.34 Erection of Foster Wheeler ESD III boiler (continued)

Economisers

Although not always fitted, economisers are normally situated in the boiler uptake and from the erection aspect can generally be regarded as an addition. Details of construction, etc have been dealt with in Chapter 9.

EXTERNAL SUPERHEATER D-TYPE BOILER – ERECTION PROCEDURE

Prior to the membrane wall era when D-type boilers consisted of two drums, several headers and a host of expanded-in bent tubes, actual boiler construction took place in a more or less stereotyped manner. Nowadays with the adoption of prefabricated membrane walls and superheaters, the methods adopted by different manufacturers are legion – one even turning the boiler upside down during the process.

A stage by stage erection programme by Foster Wheeler Power Products, for one of their ESD III boilers is shown in Figures 11.32 to 11.34.

12 Refractories and insulation

Refractories and insulation as used in water tube boilers serve several purposes:

(a) They protect the boiler casings from overheating and distortion with possible subsequent leakage of gases into the machinery spaces; reduce heat losses and ensure acceptable cold face temperatures for operating personnel.

(b) They are used to protect exposed parts of drums and headers which otherwise could become overheated.

(c) They can be used to form baffles either for protective purposes or for directing gas flow as part of the boiler design.

A refractory material is one that will retain its solid state even at very high temperatures, and furnace temperatures as high as 1650°C have been recorded in marine boilers. From the foregoing it will be apparent that the temperature conditions in a furnace must be such that refractories are not liquefied, and at the same time conditions are adequate for good combustion.

The basic material of firebricks is naturally occurring clay, the type used for firebricks composed of alumina (aluminium oxide), silica (silicon oxide) and quartz, the refractory properties varying considerably and being largely dependent on the proportion of alumina present.

Insulating materials, as their name implies, are used between refractories and outer surfaces to ensure acceptable working temperature conditions for operating personnel. Compounds of fire-clay, asbestos, magnesia and vermiculite, all having low thermal conductivities are used for this purpose.

Furnace linings

Furnace wall linings, apart from the front walls of some of the front fired types which are unscreened by tubes, vary in construction according to the furnace rating, spacing and arrangement of wall tubes, etc. (see Figure 12.1).

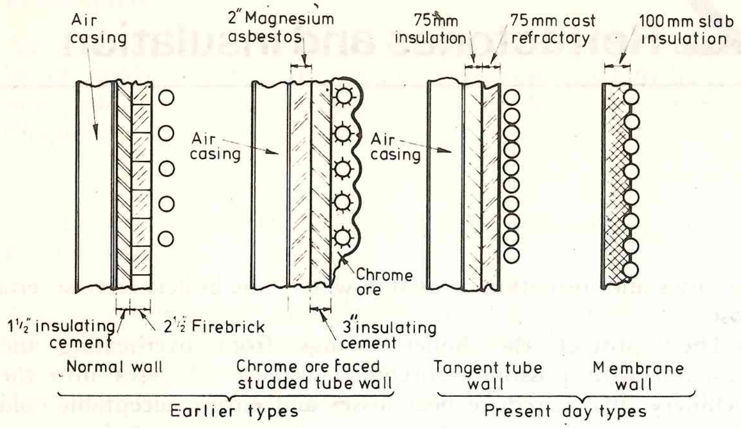


Figure 12.1 Furnace wall linings

In the case of studded tubes, which were used in some Babcock boilers, the amount of studding and extent of tube surface coated with chrome ore, was varied to suit the heat absorption rate required in the various zones of the furnace.

Furnace floors usually consist of two layers of 50 mm firebricks above the tubes, 100 mm of slab insulation below them, and a 2 mm cleading.

The floor tubes are either coated with bitumastic and the spaces between them filled with castable insulation, or the spaces are filled with crushed firebrick. In the former case the bitumastic burns away in service and leaves the tubes free to expand relative to the insulation.

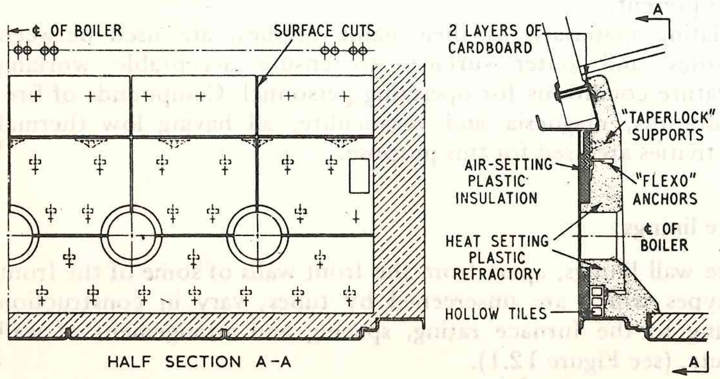


Figure 12.2 Plastic refractory front wall with fire guards in header-type boiler

Front fired boilers with unscreened front walls require additional refractory and insulation, and the total thickness is usually of the order of about 200 mm – this being made up of about 125 mm of mouldable refractory backed by 50 mm of castable or slab insulation, and 25 mm of asbestos millboard.

Burner openings in the front wall are usually formed by specially shaped quarl blocks or by plastic refractory moulded around a former *in situ*. When blocks are used they are usually secured by embedded brick bolts. The construction of a plastic refractory front wall with five quarls as applied to a header type boiler is illustrated in Figure 12.2.

Brick bolts and supports

Brick bolts in the main are of two types – those inserted in a hole which penetrates the whole thickness of the brick or tile, and those which are secured in a recess in the back of the brick (see Figure 12.3).

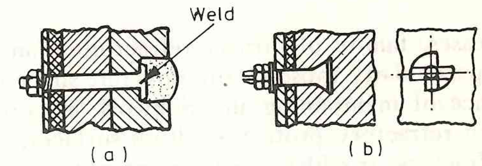


Figure 12.3 Brick bolts
(a) Head formed by splitting bolt end and flanging over
(b) Bolt pushed into slot and turned through 90°

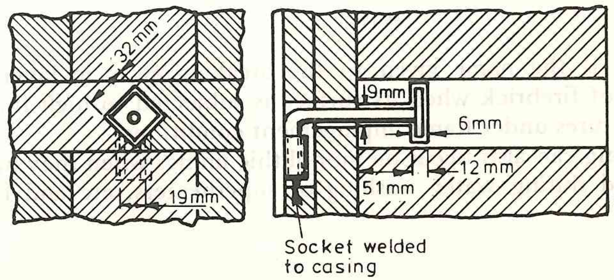


Figure 12.4 Heat resisting steel brick hook

Brick bolts necessitate holes in the bricks, which are a source of weakness, especially if any of the bolts are subjected to over-tightening. Babcock & Wilcox developed a method of attaching brickwork without piercing the casings for large numbers of brick bolts; this is illustrated in Figure 12.4. These hook-type bolts, made of alloy steel, fit into sockets welded to the boiler casing and are subsequently embedded in the brickwork, or ceramic keys for mouldable refractories.

The deterioration of furnace refractories is often one of the major items of maintenance costs in the older type of marine watertube boilers, and doubtless the reduction in size and weight, for the same output of their smaller more highly rated furnaces, made the operating conditions of their refractories even more arduous.

Apart from installations with membrane walls, it is usual to find the furnace, except for the gas outlet side, completely bounded by refractories, all the wall refractories with the exception of the front being screened by tubes. The front wall with its quarls receives the full radiant heat of the furnace and on that account is more susceptible to damage.

REFRACTORY FAILURE

In extreme cases, failure of furnace refractories can render a boiler inoperative, particularly those of the now rare single-cased type; and the importance of maintaining all brickwork in good condition, in particular any refractory protecting drum surfaces, cannot be overstressed. Refractory troubles most commonly met with in boiler furnaces are spalling, slagging, failure of brickwork securing devices, and shrinkage cracking.

Spalling

Spalling is the name given to the breaking away in layers of the surface of firebrick when its surface is subjected to high fluctuating temperatures under flame impingement conditions.

Spalling can also occur on monolithic linings when they have been saturated during water washing of superheaters, etc and fired too quickly.

Slagging

Slagging is, in effect, a softening, even up to the liquid state, of the surface of the firebricks. It is generally considered that slagging occurs through some form of sodium being present at the high temperature brick surfaces, this sodium either originating in the ash produced by burning the fuel, or being in the fuel as sea-water

contamination. The sodium acts as a flux and lowers the melting points of the firebrick, and in extreme cases on uncooled front walls, the semi molten refractory runs down the wall resulting in 'eyebrows' above each burner quarl due to the ingress of the cooler combustion air; reduced thickness of material on the wall exposing the anchorages to furance conditions, with resultant complete wall failures and a build-up of semi-molten material on the floor, which results in failure of the bricks and a decrease in combustion efficiency because of reduced burner clearances.

Failure of brick securing devices

Bricks which are secured by bolts have, due to the restraining action of the bolt, a tendency to crack, and once this occurs the bolts are exposed to the high temperature gases, which rapidly cause bolt failure through overheating.

Shrinkage cracking

Refractories are generally weaker in tension than in compression or shear, and it is only to be expected that brickwork, structurally sound and in all probability in compression at high temperature within a relatively cool casing, will be the subject of high tensile stresses and shrinkage cracking when suddenly cooled.

13 Boiler mountings

All marine boilers are required to be fitted with certain essential mountings. The minimum requirements are as follows:

2 safety valves
1 steam stop valve
2 independent feed check valves
2 water gauges (or equivalent)
1 pressure gauge
1 salinometer cock or valve
1 blow-down valve
1 low water level fuel shut-off device and alarm

SAFETY VALVES

The safety valve, which prevents over pressure is one of the most important fittings. For tank-type boilers and also for water tube boilers of moderate pressure, Cockburn's high-lift and improved high-lift are still commonly encountered in service today. Both these types of valve have a greater steam passing capacity than the older type of spring loaded valve which is referred to as the 'ordinary' although now being superseded by the smaller bore high capacity types.

In the case of the high-lift valve, the area required is only two-thirds of that calculated for 'ordinary' valves whilst in the case of the improved high-lift type, the area can be reduced to one half that of a similarly rated 'ordinary' type. The size of the waste steam pipes and that of the apertures in the boiler shells are correspondingly reduced.

High-lift valves

The improved high-lift valve is a development of the ordinary spring-loaded type, and both are shown in Figures 13.1 and 13.2. For

comparison the essential differences in construction are shown within the dotted circle. It will be seen that both types are similar, except that in the case of the improved version the valve lids are wingless, and the valves are made a closer fit on the spindle. The spindle itself is adequately guided by a ported guide-plate fitting in a recess in the top of the actual valve chest (Figures 13.1 and 13.3); this recess and the valve-seating holes are machined on the same centre line. The guide plate is ported to allow the passage of waste steam to the underside of the piston member on the valve spindle.

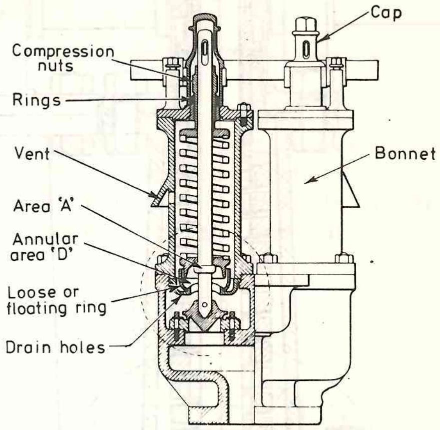


Figure 13.1 Improved type of high-lift safety valve

All marine direct spring-loaded valves make use of a lip on the periphery of the actual valve lid for the purpose of giving them additional uplift once they are raised from their seats by steam pressure. This additional uplift helps to counteract the increase in spring load as the spring is compressed by the valve lifting.

In the case of the Cockburn high-lift and improved high-lift valves, a further additional lift is obtained through the pressure in the waste-steam space acting on what is in effect a piston connected to the valve spindle; thus the waste steam pressure, which is detrimental to the lift of an ordinary safety valve, is made to assist the lift in these high-lift types (Figures 13.1 and 13.3).

In normal operation the waste-steam pressure acts on area *A* (Figure 13.1) of the piston member, moving vertically in a loose or floating ring held down by the pressure on the annular area *D*. In the event of the piston member and loose ring adhering the combination is still operative – the loose ring simply lifts with the spindle.

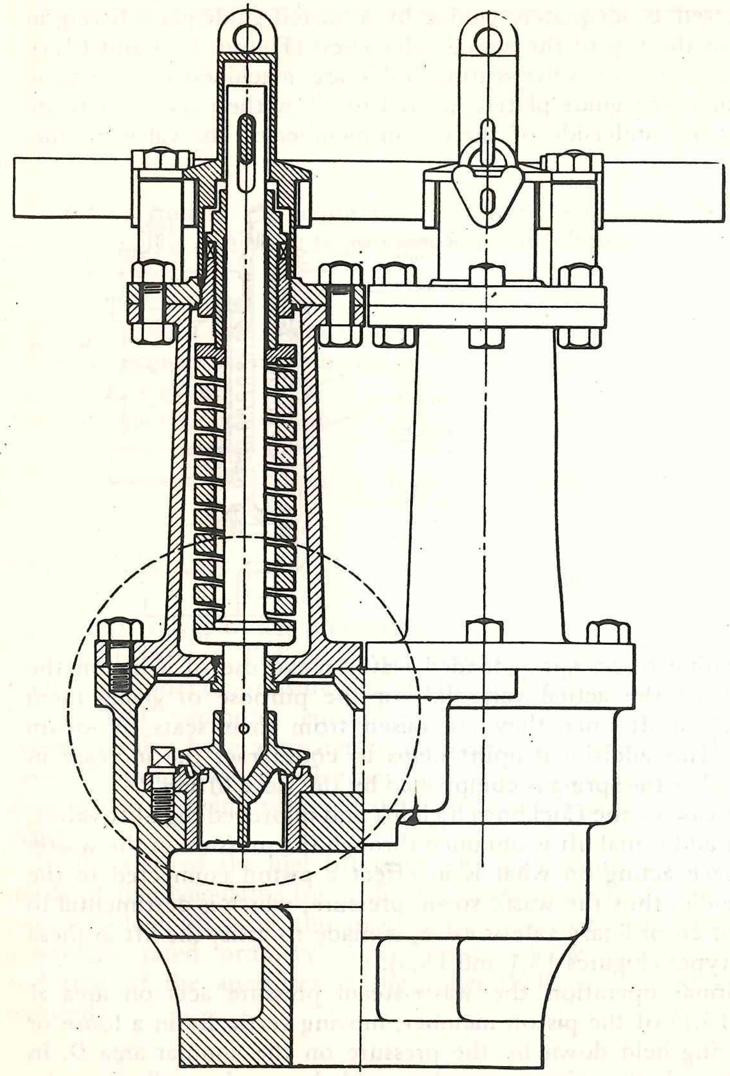


Figure 13.2 Ordinary spring-loaded safety valve

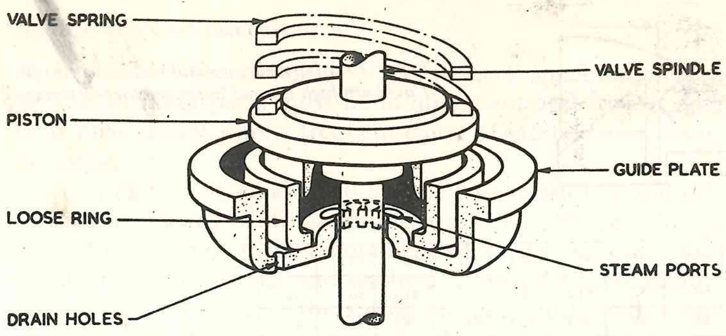


Figure 13.3 Arrangement of uplift piston Cockburn improved high-lift safety valve

Lip clearances and seating widths

The actual valves of many marine spring-loaded safety valves are of the winged type, and with the narrow seating recommended by the makers for steam tightness very little wear is permissible on the wings of the valves if efficient contact between valve and seat is to be maintained (see Figure 13.4).

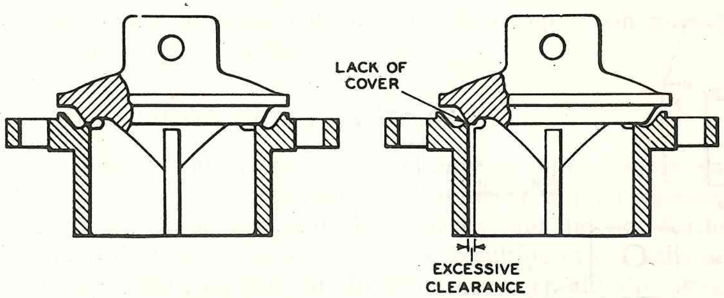


Figure 13.4 Safety valve lid slack at wings

For efficient operation it is imperative that the makers' specified lip clearances and seating widths are maintained, and with this object in view, these are reproduced in Figure 13.5 both for the high-lift and the improved high-lift Cockburn valves.

If, after grinding in, a ridge has been formed on either the valve or seat face, this must be removed as shown in Figure 13.6. This may be done when adjusting the breadth of faces as described later. In grinding in the valve from time to time, care must be taken to ensure that dimensions *A* and *B* are strictly adhered to, as the faces naturally broaden in grinding. After grinding operations are completed a cut will probably have to be taken off surface *C* to effect a 3.2 mm opening at *A*. The faces will also have become

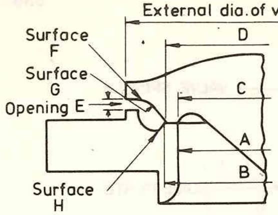


Figure 13.5 Lip clearance and seating widths for Cockburn high-lift and improved high-lift valves

A	38	44.5	51	57	63.5	70	76	82.5	89
B	43.5	50	57	63.5	70.5	77	83.5	90.5	97
C	37.5	45.5	50	56.5	62.5	69	75.5	81.5	87.5
D	42.5	49	56	62.5	69.5	76	83	89	96
E	17.24 bar 3.2 mm				20.68 bar 4 mm				

A	95.5	101.5	108	114.5	120.5	127
B	104	110.5	117.5	124	131	137.5
C	94	100.5	108.5	113	119.5	126
D	103	109.5	115.5	123	130	136.5
E	41.37 bar 4.8 mm					

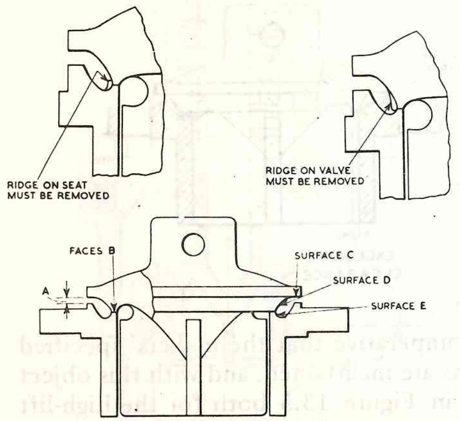


Figure 13.6 Removing ridge on valve or seat face

broadened, and will necessitate a cut being taken on surfaces *D* and *E* to effect the 1.6 mm breadth of faces *B*.

As the seats are pinned down and not driven in, the valve lids and seats may be taken to the lathe to effect the necessary machining operations. If the above specified dimensions are not maintained, the result will be feathering at the waste-steam pipe very considerably below blow-off pressure.

Maintenance of safety valves

Apart from the maintaining of the makers' specified clearances, etc, all the working parts must be in alignment and free in operation – bent valve spindles are a frequent cause of safety valves being sluggish in operation.

The practice of making up loss of compression in old safety-valve springs by means of distance washers fitted between the spring and its end caps is not to be recommended, as the end caps are spigotted to fit inside the spring, and washers fitted over these spigots tend to destroy the location of the spring on its spindle, with a consequent possibility of it fouling the inside of the casing. If the compression nuts are hard down when the valves are at blow-off pressure the circumstances should be investigated and the necessary renewals, either of springs or valves and seats, made so that the compression nuts are again operative.

When overhauling safety valves all parts should be marked so that they are reassembled in their correct places, drains should be proved clear to prevent overloading due to an hydraulic head on the valves. After assembly it should be possible to move the spindles sideways, to the extent of their clearance in the compression nuts, to prove that they are not binding.

HIGH-CAPACITY SAFETY VALVES

The advent of higher steam temperatures and pressures in water tube boilers made it increasingly important that high-capacity safety valves, which opened and shut smartly and did not feather, were developed. Feathering safety valves, resulting in cut valve seats and the accompanying loss of distilled water, entails the use of extra feed make-up with its possible hazards.

A good safety valve lifts smartly at its adjusted pressure and, after it has relieved excess pressure, shuts with equal smartness.

The ability of a valve to lift smartly and fully, without feather, is a matter of design; in all high capacity types it is achieved by allowing the steam from the initial lift to impinge on additional lifting surfaces, either in the form of a lip or piston, in a guiding cylinder.

Valves which embody the foregoing characteristics, other than the Cockburn Improved High Lift, are as follows: Full-bore, 'Hylif', Consolidated and similar types.

Full-bore safety valves

These safety valves have four times the discharge capacity of an ordinary spring-loaded valve, their arrangement is shown in Figure 13.7.

It will be noted from the drawing that each main valve is operated by its own control valve, and that both of these valves are in direct communication with the steam drum or superheater header on which they are mounted.

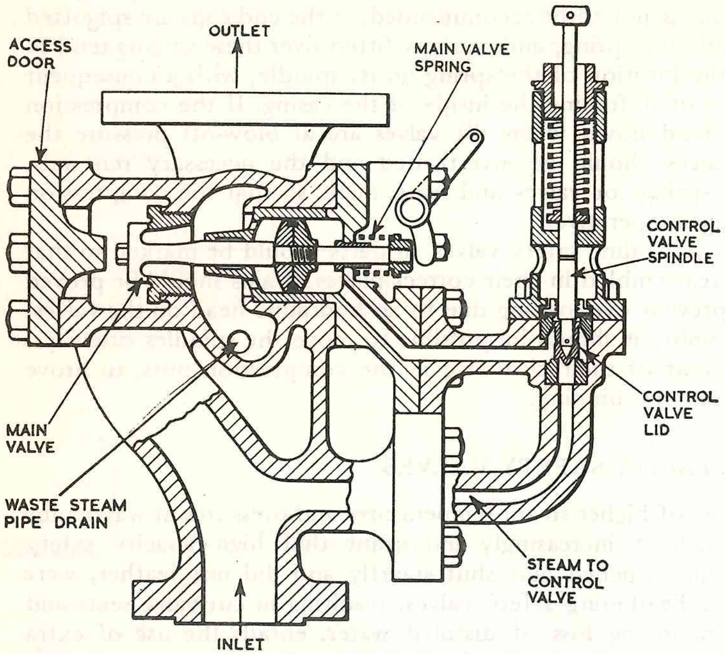


Figure 13.7 Cockburn full-bore safety valve

The action of the valve is as follows: Steam from the boiler exerts pressure on the underside of the control valve, which lifts at a predetermined pressure. In lifting, the top part of the control-valve lid blanks off ports leading to atmosphere and allows steam to pass through a passage leading to the piston on the main valve spindle, causing the main valve to open against the boiler pressure (the area of the piston is about twice that of the valve).

When the boiler pressure drops the control valve shuts down, and in so doing uncovers the ports above it which lead to atmosphere. This relieves the pressure from the main valve piston, and the boiler pressure then shuts the main valve. The foregoing is the action of one

control valve and its main valve; there are, of course, always two or more control and main valve units per boiler.

In view of the high temperatures at which the working parts of these valves have to work, it has been found advantageous in some high superheat installations to fit the control valves on the saturated-steam drum separate from the main valves, and to pipe the saturated steam from these valves to operate the main valves on the superheater header.

Difficulties have been experienced with this type of safety valve sticking when being adjusted after having been opened up for boiler survey. It is, therefore, suggested that the safety valves should not be adjusted immediately after the boilers are brought up to pressure following the survey, and without having been in service. Otherwise, for a few hours, any loose dirt or residue left over after boiler cleaning might accompany the steam through the safety valves — possibly with detrimental results.

The major advantage of this type of valve is the fact that the main valve is loaded by the steam pressure, and the higher the pressure the greater the closing load, which is the reverse of the conditions appertaining to the directly loaded spring valve. Other advantages are that there is no spring on the main valve to be affected by temperature, and the discharge capacity allowed by Classification Society Rules is four times that of an ordinary spring-loaded lift valve of equivalent size.

The main valve spring shown in Figure 13.7 is provided to ensure that this valve is seated when the boiler is out of service.

A similar type of valve of Japanese manufacture designed for pressure settings of up to 100 bar is illustrated in Figure 13.8. It will be noted that:

(a) the actual valve seat is of stellite-faced forged steel, welded into the valve chest;

(b) the valve and spindle are in one piece, of high-chromium steel, again with a stellited seating;

(c) the guiding cylinder for the valve is of high-chromium steel.

The Hopkinson 'Hylif' safety valve

These valves, incorporating a full-lift feature, are designed for working pressures of up to 62 bar, the arrangement being as shown in Figure 13.9. When the steam pressure rises to the set pressure, the valve discharges with a small lift on the principle of the ordinary safety valve. This initial opening allows the escaping steam to exert its pressure over the full area of the bottom of the valve and increases

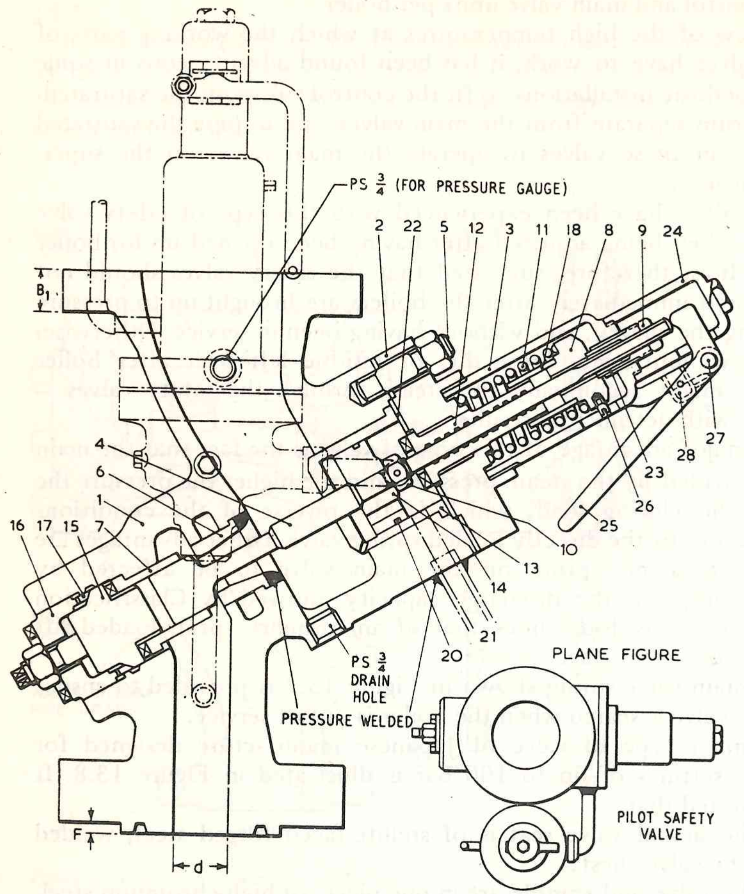


Figure 13.8 Safety valve of Japanese manufacture

1	*Body*	15	*Bonnet*
2	*Cover*	16	*Retainer*
3	*Spring case*	17	*Gasket ring*
4	*Stem*	18	*Spring cover*
5	*Joint bolt*	20	*Piston ring*
6	*Valve seat*	21	*Escape pipe*
7	*Guide bush*	22	*Seat packing*
8	*Spring seat*	23	*Adjusting screw*
9,10	*Locknuts*	24	*Cap*
11	*Spring*	25	*Easing lever*
12	*Bush*	26	*Locking bolt*
13	*Cylinder*	27	*Pivot*
14	*Piston*	28	*Lock*

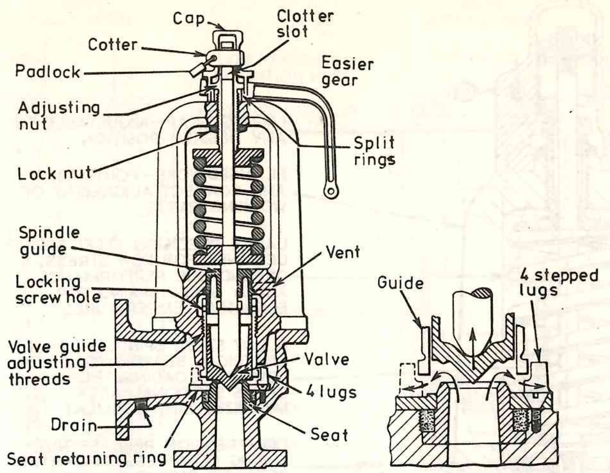


Figure 13.9 Hopkinson 'Hylif' single spring safety valve

	Material	*Platnam*	
Body	*cast steel*	*Nickel*	*54%*
Valve	*platnam*	*Copper*	*33%*
Valve guide	*platnam*	*Tin*	*13%*
Seat guide	*platnam*	*Iron*	*0.5%*
Valve spindle	*stainless steel*	*Aluminium*	*0.3%*

the lift until the bottom face of the valve has entered the valve guide; at this point the escaping steam is deflected downwards by the bottom edge of the guide, and the consequent reaction pressure lifts the valve to its full-open position (see detail). At this final stage of valve lift the discharge area between the seat and the valve is claimed to be equal to the net area through the seat throat, and the discharge capacity is at its maximum.

When the discharge pressure has been relieved the valve begins to close; as it emerges from the valve guide the reaction pressure ceases and the valve shuts down cleanly without simmer.

Consolidated safety valves

These safety valves, as illustrated in Figure 13.10 are of direct-spring type and are designed for pressures of up to 62 bar and 537°C.

The special features are:

1. Precision closing control.
2. Single-ring 'blowdown' or closing adjustment control.
3. Thermodisc valve seat.

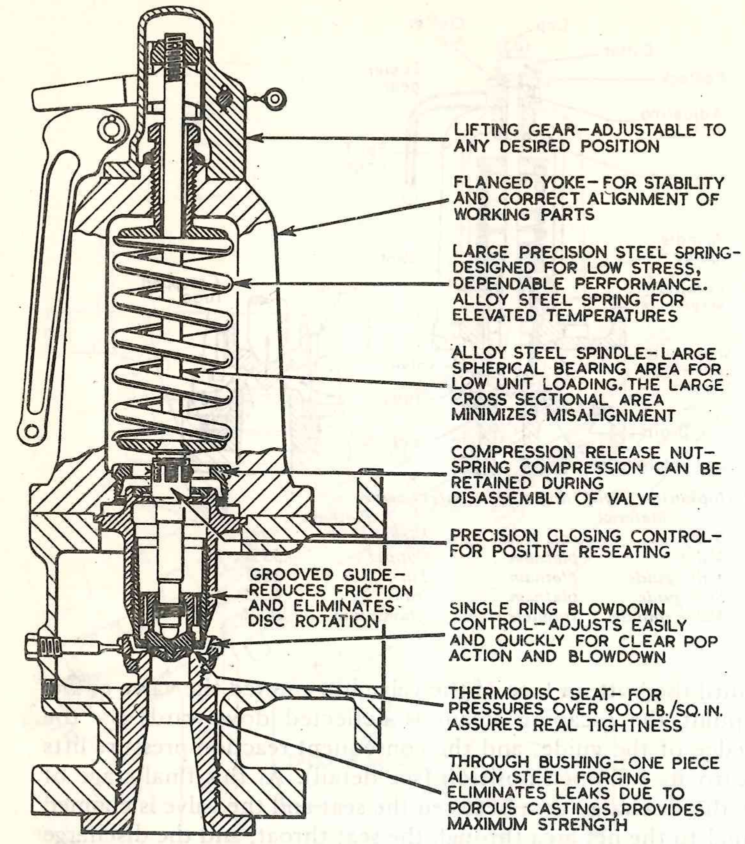


Figure 13.10 Consolidated steel safety valve

1. *Precision closing control.* Tight, positive and precision closing is obtained by a booster-cylinder arrangement (see Figure 13.11). With the valve in an open position and discharging (Figure 13.11a), steam is bled into chamber *F* through bleed holes *J*. At the same time the valve spindle has risen so that the large-diameter part *G* is above the floating washer *H*. The clearance between the floating washer and the spindle is thereby increased by the difference in the two spindle diameters. Under such conditions, steam in the chamber *F* escapes to the atmosphere through this clearance. At the instant of closing, the position of the step-up in spindle diameter *G* is so positioned that it has moved down into the floating washer *H*, thereby effectively

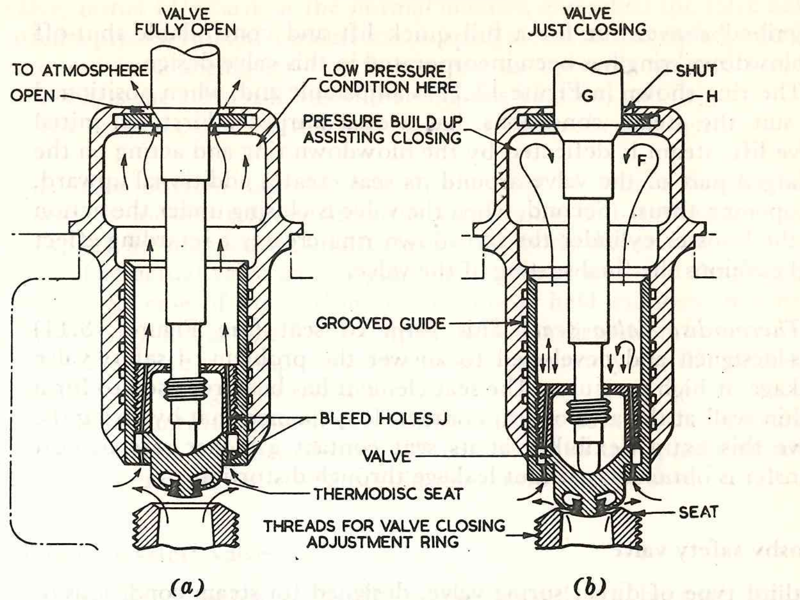


Figure 13.11 Detail of booster cylinder closing control (consolidated safety valve)

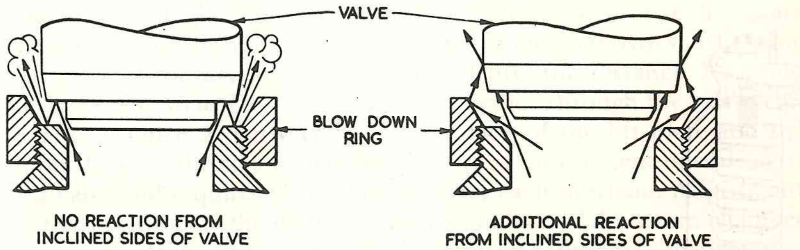


Figure 13.12 Single ring closing adjustment control (consolidated safety valve)

reducing the escape of steam from the chamber *F* (see Figure 13.11b).

The resulting momentary pressure build-up in the chamber *F* produces a downward thrust in the direction of the spring loading. The combined thrust of this pressure and the spring loading results in tight positive closing without wire drawing, or scoring of seat surfaces.

2. *Single-ring 'blowdown' or closing adjustment control.* The assistance given by the discharge steam in closing the valve has been

described above, but for a full quick lift and controllable shut-off a 'blowdown' ring has been incorporated in this valve design.

The ring shown in Figure 13.12 is adjustable and, when positioned to suit the steam conditions, has a dual purpose. First, on initial valve lift, steam is deflected by the blowdown ring and acting on the enlarged part of the valve around its seat creates additional upward, or opening thrust. Second, when the valve is closing under the action of the booster cylinder the blowdown ring creates a retarding effect and cushions the final seating of the valve.

3. *Thermodisc valve seat.* This form of seat (see Figure 13.11) was designed and developed to answer the problem of safety-valve leakage at high pressures. The seat element has been recessed to form a thin wall at the area of seat contact. It is claimed that by giving the valve this extra flexibility at its seat contact a higher rate of heat transfer is obtained, without leakage through distortion.

Crosby safety valve

A third type of direct spring valve, designed for steam conditions of 215 bar at 426.7°C or 134 bar at 537.8°C and incorporating a full-lift feature controlled by an adjusting ring is the 'Crosby'. In this

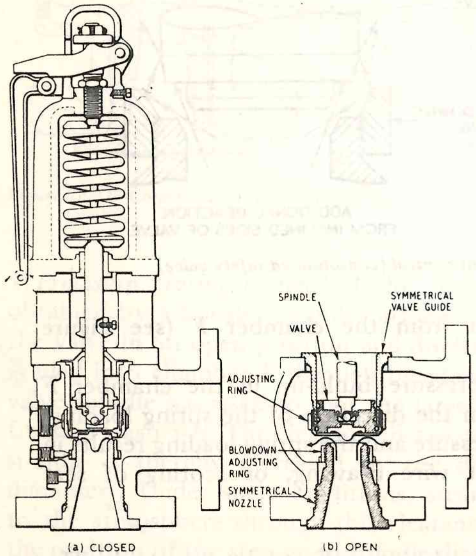


Figure 13.13 Crosby safety valve

valve, initial lift starts in the normal manner, and when the valve has lifted a predetermined amount the escaping steam strikes the adjusting ring and in changing its direction exerts an upwards reactive force which lifts the valve still higher. See Figures 13.13(a) and (b).

The makers claim the following advantages for their design:

1. The bottom tapered nozzle, the top of which forms the seat, is loosely screwed into the valve body and is thus free to expand independently, unaffected by any body distortion.
2. The actual valve and its guide are symmetrical, and the guide, as in the case of the bottom nozzle, is only held and located at its extremity and is thus free to expand without distortion.
3. The valve is completely free to seat accurately on the nozzle, both seats being perfectly flat.
4. The contact between the spindle and the actual valve is made by means of a hardened-steel ball embedded in the spindle which bears on a hardened-steel insert in the centre of the valve.

Leser-type safety valves

A safety valve which is rapidly gaining popularity because of its relative simplicity and consequent low cost is illustrated in Figure 13.14. Initial opening of the valve admits steam to the steam chamber at high velocity where it acts on the bronze lift plate thereby giving the valve superior discharge characteristics. To enable the valve to obtain maximum designed lift, the distance Y should never be less than $D/4$, where D is the orifice through the valve seat.

The distance X between the lower face of the lift plate and the upper face of the steam chamber, is critical for efficient operation of this valve and requires to be checked after each overhaul. Adjustment of the position of the plate relative to the face of the steam chamber can be made by means of the locking nuts on the valve spindle. Typical clearance values are given in Table 13.1. The valve is fitted with the usual coiled spring and adjusting nut with locknut similar to the arrangement shown in Figure 13.13. The usual easing gear capable of being locked in place is also provided. Such valves are

Table 13.1 Typical lift plate clearances for Leser type safety valves

Internal dia. of valve seat, mm	25	32	40	50	65	80	100
Dimension 'X', mm	1.5	2.5	7.0	8.0	12	14	22

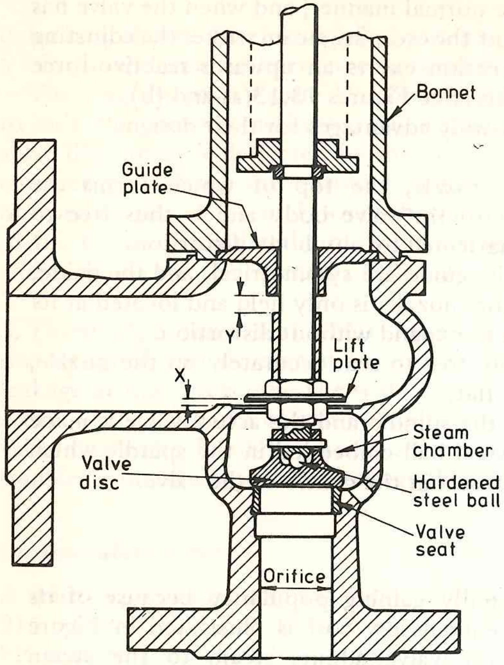


Figure 13.14 Leser safety valve

currently being fitted to auxiliary tank type and water-tube boilers of all capacities.

As with all spindle-type valves care must be taken to ensure that there is adequate clearance between the spindle and the guide plate, the spindle and the upper spring collar and also between the spindle and the bore of the adjusting nut.

Adjustment of safety valves of tank type boilers

Before attempting to adjust the safety valves of any boiler, it is essential that the accuracy of the boiler pressure gauge be verified. There is, unfortunately, at least one case on record where the malfunctioning of a boiler pressure gauge, at the time the safety valves were being set, resulted in a disastrous explosion. It is reported that the boiler in question had a working pressure of 10 bar and it is thought that the safety valves first lifted when the pressure gauge was registering about 2 bar. Thinking that the valves had lifted at a pressure far below that at which they were to be set, the operator

proceeded to screw down the compression nuts until the valves reseated. Shortly after this, the valves must have lifted again and as the pressure gauge continued to indicate that the working pressure had not been reached, further adjustments were made. Ultimately, the boiler shell failed through overpressure. It was subsequently found that the safety valve compression nuts were screwed hard down and that the single pressure gauge had been faulty with the result that the pointer indicated an incorrect low pressure. It was found by testing the safety valves in the screwed down condition that the boiler had exploded when the pressure had reached several times the normal working pressure and that the safety valve springs had been compressed 'coil to coil'.

Emphasis should therefore be placed on the importance of verifying the accuracy of the boiler pressure gauge against a standard gauge before proceeding to adjust any safety valves. It is, of course, preferable to have two gauges on line at such times. It is normal practice for classification society surveyors to temporarily mount a duplex standard gauge alongside the working gauge when safety valves are being adjusted following a routine survey.

Safety valves must be set at a pressure not exceeding 3% above the approved working pressure of the boiler. The correct working pressure of a boiler is usually to be found stamped on a manufacturers name plate which is permanently affixed in a prominent position on the boiler front.

Until recently, it was common practice to adjust the direct spring-loaded types of valve which have so far been described in this chapter, in the following manner:

> All boilers were connected up by opening the main stop valves and the pressure was brought up to within 0.2 or 0.3 bar of the desired blow-off pressure. Arrangements were then made to keep this pressure constant whilst the valves were being adjusted. It is worth noting that as two or more boilers were thus interconnected, several pressure gauges were on line to obtain a rough check on their accuracy. At this stage, the compression nuts of any valves that were lifting were screwed down until the valves seated and all was quiet. Each valve was subsequently adjusted, in turn, by slacking back its compression nut until the valve lifted. The compression nut was then screwed down sufficiently so that, when the valve spindle was lightly tapped down, the valve returned to its seat and remained closed.

When the safety valves of multi-boilered installations were adjusted in this way it was found by experience that they were uniformly loaded. To avoid confusion from steam and noise when making these adjustments, it was imperative that only the actual valve being adjusted was blowing.

With the gradual disappearance of multi-boilered installations fitted with the types of safety valves already mentioned, it is more usual these days to adjust safety valves with the main stop valve of the boiler closed; each set of valves then being adjusted independently using gags, see 'adjustment of water-tube boiler safety valves' (page 353).

Normally, the only time it is necessary to adjust safety valves is immediately after a boiler survey. If the valves are set under the supervision of the ship's engineers prior to the arrival of the surveyor, the latter's duties can be carried out without loss of valuable time. After the valves have been adjusted to the satisfaction of the surveyor, the distance between the lower face of the compression nut and the upper face of the column cover plate should be measured accurately so that suitable compression rings can be prepared, cut and locked in place. The sizes of these rings should always be recorded for future reference. The easing gear and the valve caps should next be refitted, the caps acting as a safeguard against compression ring removal.

It is good practice to fit the cotters which secure the caps to the spindles with padlocks or to fit lead seals so that the valves cannot be tampered with by unauthorised persons. Indeed, sealing of the safety valves may be a statutory requirement in some cases. Finally, the efficiency of the easing gear (often neglected) should be proved.

Waste-steam pipes and drains

Accidents have occurred as a result of the waste-steam pipes from safety valves of two or more boilers running into a common pipe before discharging to atmosphere. In one such case, two boilers, one an exhaust-gas and the other oil fired, were fitted with a common waste-steam discharge pipe. The exhaust gas boiler was acting as an economiser and therefore being operated in the 'drowned' condition. The safety valves of the exhaust-gas boiler were probably set to lift at the same pressure as (or slightly less than) that of the oil fired boiler with the result that each time the pressure in the system reached that to which the safety valves were set, water with a high salt content found its way back to the discharge side of the safety valves of the oil fired boiler. As the water subsequently evaporated the resulting precipitate effectively prevented the safety valves of the oil fired boiler, which were of a type requiring fine clearances, from

lifting. Inevitably, when the oil fired boiler was being operated independently, excessive overpressure occurred with most serious consequences. The Rules of the classification societies now require the safety valves of each exhaust gas heated economiser or boiler which may be used as an economiser to be provided with entirely separate waste-steam pipes. It is, in addition, recommended that safety valves for exhaust gas boilers which may be used as economisers, should be of ordinary type which do not rely on the maintenance of fine clearances.

All waste-steam pipes should be suitably supported and provided, where necessary, with expansion joints or bends in order to relieve the safety valve chests of undue loading. It is good practice to arrange for a scale trap and a means for cleaning this at the base of each waste-steam pipe.

A drain pipe must be fitted to the lowest part of each safety valve chest on the discharge side and this pipe should always be led clear of the hot surfaces of the boiler. The pipe must have no valve or cock fitted throughout its length and it should be directed with a continuous fall to the bilge.

In high temperature installations the safety valve drains may be led to a suitable tank where high temperature steam can be safely discharged. These drains are very important and should be regularly checked. Should they become choked there would be a danger of overloading the valves due to hydraulic head, damage being caused by water-hammer, serious corrosion of the discharge side of the valve chest or seizing of the safety valves due to deposits precipitating as trapped water evaporates.

Adjustment of water tube boiler safety valves

It is normal practice to adjust each safety valve independently and, in the case of multi-boilered installations to isolate each boiler for this purpose. In this way there is less likelihood of wastage of valuable distilled water. All but one of the safety valves of any one boiler should be held shut with 'gags' as shown in Figure 13.15 while the remaining valve is adjusted to the correct pressure.

The valve that has been adjusted is then gagged and another of the valves on the boiler is adjusted. This procedure is repeated until all the valves are correctly set. Care is needed in fitting these gags to avoid damaging the valve spindles and special attention should therefore be paid to ensuring that gags are only screwed up finger tight. When all valves are adjusted to the satisfaction of the authority responsible special provision should be made to ensure that all gags are removed and stowed in a safe place. Gags should never be fitted when the boiler is cold because the expansion of the valve spindle may be sufficient, as the temperature rises with increasing pressure, to cause it to bend.

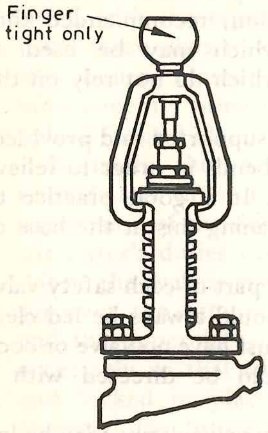


Figure 13.15 Safety valve gag

For future reference, a measurement such as that from the top of the adjusting nut to the upper face of the valve chest yoke should be obtained and carefully recorded. On completion, the easing gear should be refitted. It is recognised practice to set the superheater safety valves at a stipulated figure below the pressure to which the saturated valves on the steam drum are adjusted. This is done to ensure that the superheater is circulated at all times with 'cooling steam'. Should the valve not be adjusted in this manner the lack of circulation in the superheater caused by main drum valves lifting when the superheater valves remained closed could result in overheating and serious damage to the superheater elements.

To avoid losses of distilled water during adjustment of safety valves which may be as high as 20 tonnes in highly rated installations, some shipowners arrange for the safety valves to be adjusted, initially, under air pressure in a workshop, ashore. The valve chest is disconnected from the boiler drum, overhauled in the workshop and adjusted using compressed air. Afterwards, when the boiler is first put under steam, the valves are no more than 'popped' to prove that they will operate satisfactorily under working conditions.

Adjusting safety valves of double evaporation boilers

The adjustment of the safety valves of the secondary system in this double evaporation boilers poses no problems and is achieved in a

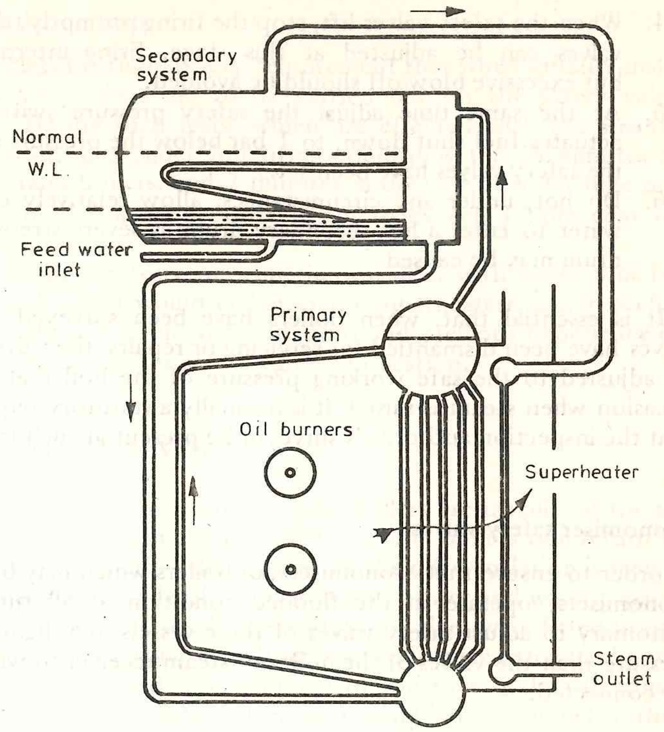


Figure 13.16 Double evaporation boiler

similar manner to that employed for any other water tube boiler However, the adjustment of the valve in the primary system deserves a special mention.

The following notes are included as guidance in cases where the boiler manufacturers instruction manual is not available. The pressure necessary for adjusting the primary safety valves can be obtained as follows:

1. Drop the water level in the *secondary* drum to the lower edge of the evaporating elements (see Figure 13.16). This is done so that the elements cannot transfer heat to the secondary boiler water.
2. Maintain a normal water level in the primary steam drum.
3. Raising steam from cold to maximum working pressure should take about 2 hours, the firing rate being lowest during the initial period, until a pressure of about 15 bar is reached. (It is assumed that the normal working pressure of the primary system is in excess of this.)

4. When the safety valves lift, stop the firing promptly, the safety valves can be adjusted at this stage, firing intermittently, but excessive blow-off should be avoided.
5. At the same time adjust the safety pressure switch which actuates fuel shut down, to 1 bar below the pressure to which the safety valves have been set.
6. Do not, under any circumstances, allow relatively cold feed water to enter a hot secondary drum as severe stresses in the drum may be caused.

It is essential that, when boilers have been surveyed or safety valves have been dismantled for servicing or repairs, the valves should be adjusted to the safe working pressure of the boiler at the first occasion when steam is raised. It is normally a statutory requirement that the inspection authority's surveyor be present at such times.

Economiser safety valves

In order to ensure that economisers, or boilers which may be used as economisers, operate in the flooded condition at all times, it is customary to adjust safety valves of these vessels to a slightly higher pressure than the valves of the boiler or steam receiver to which they are connected.

Safety-valve 'blowdown'

The pressure drop after overpressure has been relieved (which incidentally is loss of usable steam) is known as the blowdown.

Obviously the loss of usable steam during blowdown is governed by the promptness with which the safety valve, under the action of its spring supplemented by various other devices (dependent on the type of valve), reseats.

Most of the high-capacity direct spring valves are provided with a so-called blowdown ring, this being a ring which, screwed on to and encircling the valve seat (see Figure 13.12), is adjustable for vertical position from outside the valve chest.

The adjustments are made with a screwdriver or other instrument through a plug hole in the side of the valve chest while the valve is under pressure. The throttling effect obtained by adjusting the vertical position of the blowdown ring effectively controls the promptness with which the valve reseats, and the amount of blow-down.

Accumulation tests

It is a classification society requirement that when initially installed, accumulation tests are to be carried out on the safety valves of boilers. During such tests, which are effected with the steam stop valves shut, and under full firing conditions for 15 minutes in the case of tank boilers, and 7 minutes in the case of water tube boilers, the accumulation of pressure is not to exceed 10 per cent of the working pressure.

Accumulation tests are sometimes waived with water tube boilers when such a test would endanger the superheaters, and in such cases consideration is given to calculations and previous experience of the actual capacity of the safety valves in question.

STEAM STOP VALVES

Main stop valves for ordinary tank boilers are usually of the screw-lift type, whereas in the case of watertube boilers non-return valves are normally fitted — the reason for the differentiation is seen when a comparison is made of the evaporative power and water capacity of the two types of boiler. If screw-lift stop valves were fitted to each of a battery of four water tube boilers and while steaming hard a serious tube burst occurred, the contents of the four boilers (6 tons each against 30 tons for a Scotch boiler) could very soon be lost through the ruptured tube. The non-return or self-closing stop valves fitted to water tube boilers act, therefore, as a safeguard against loss of water.

Types of steam stop valve

The types of main stop valve in general use are legion, and it is not proposed to detail them all. The main stop valve as fitted to the ordinary tank-boiler shell is normally a right-angled cast-steel globe valve with a pressed-in pinned gunmetal seat, the gunmetal lid guided in the seat by wings or a centre pintle, and the screwed spindle attached to the valve by a nut and collar, working in an external bridge on the chest cover. The material of the valve lid and seat is Monel metal in the case of stop valves used in conjunction with superheated steam. In all cases the stop valve chests must be fitted with ample drainage arrangements.

The main stop valves of water tube boilers, mounted on the super-heater outlet header, operate under high temperature and pressure conditions, 454°C and 60 bar frequently being used. In view of the high temperatures to which these valves are subjected, it is important that suitable materials are used in their construction. Under the combined effect of high temperature and stress some materials alter their physical properties and progressively 'flow' or 'creep' in a manner similar to that of an extremely viscous fluid. The materials used must, therefore, have a creep strength in excess of their service loading throughout the operating-temperature range.

For stop valves dealing with superheated steam temperatures up to 425°C, it is usual for the valve chest to be made of normal cast steel, with a forged or cast-steel cover, the valve lid and seat being either Monel metal, stellited steel or stainless steel, according to temperature conditions. When the steam temperature is above 425°C heat-resisting alloy steels are used, 0.5 per cent molybdenum cast steel for the valve-chest cover and seat, stainless steel for the valve lid and creep-resisting steel for the cover studs.

Securing of valve seat

The valve seats are secured in the chests in several ways:

(a) The seat is made with a slight interference fit, pressed in cold, after which the chest is peened over the top edge of the seat (see Figure 13.17a).

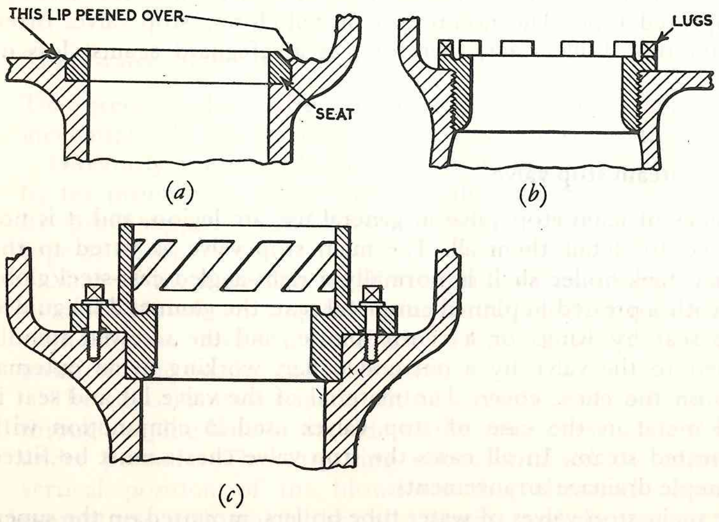


Figure 13.17 Three methods of securing valve-seat in chest

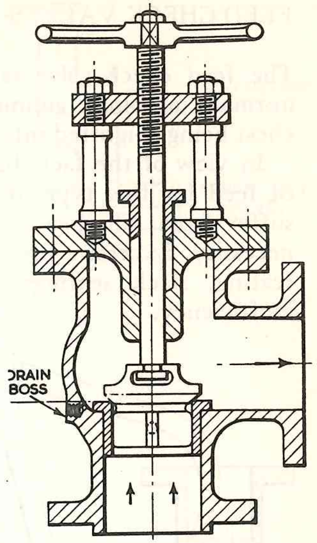


Figure 13.18 Cast steel main stop valve for tank boilers

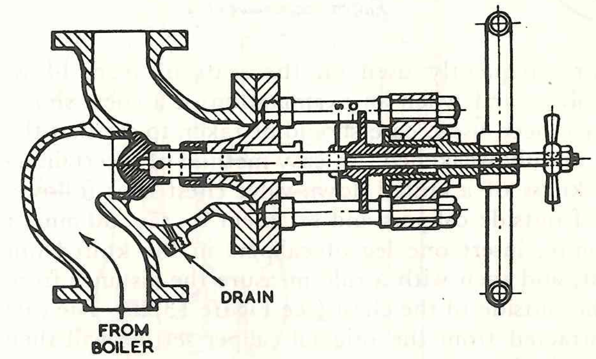


Figure 13.19 Cast steel self-closing main stop valve for water tube boilers

(b) The seat is screwed in with a fine thread, the top of the seat having a collar which lands on a facing in the chest (Figure 13.17b).

(c) The seat and guide for the valve are combined in one unit which is secured by set bolts to the valve chest, and is thus easily removable (Figure 13.17c).

Typical tank boiler and water tube boiler main stop valves are illustrated in Figures 13.18 and 13.19.

FEED CHECK VALVES

The feed check valve as fitted to the ordinary tank-type boiler is normally a robust gunmetal right-angle non-return globe valve, the chest being spigotted into the boiler end-plate.

In view of the fact that reciprocating pumps are the usual means of feed for this type of boiler, the valve lids and seating are apt to suffer from hammer action, and this makes regular overhauling a necessity. Excessive lift, slackness of valve in seat, excessive width of seating, slack seatings and too heavy a valve all contribute to inefficiency.

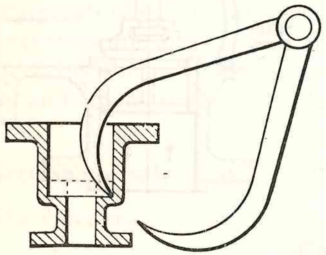


Figure 13.20 Checking thickness of a knifed-down valve chest

Knifing tools are frequently used on the seats of feed, blow-down and scum valves, and when an examination of a chest shows that these tools have been used, care should be taken to see that the chest has not been unduly weakened. An easy method of ascertaining the remaining thickness of a knifed down valve chest is as follows: Take a large pair of outside calipers and set them to, say, 50 mm or any convenient figure, insert one leg of calipers in the knifed out corner of the chest, and then with a rule measure the distance from the other leg to the outside of the chest (see Figure 13.20). The rule measurement substracted from the original caliper setting will then give the thickness desired.

Combined shut-off and feed valve

Some boiler makers fit a combined shut-off and feed valve, two valves in one chest, on both the main and auxiliary feed lines. The shut-off valve, a screw-lift valve, is between the feed valve and the boiler, and the boiler pressure is under this valve (see Figure 13.21).

When the above arrangement is fitted care should be taken when overhauling the valves to see that the attachment of the shut-off valve lid to its spindle is efficient, since if the valve becomes detached it will stop any feed entering the boiler.

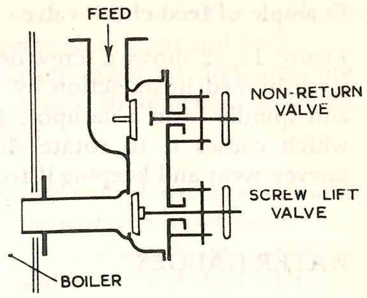


Figure 13.21 Arrangement of combined shut-off and feed valve

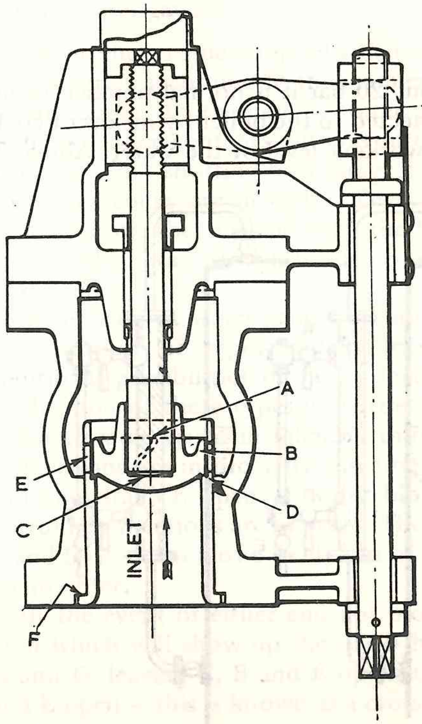


Figure 13.22 Screw-down non-return feed check valve
A Anti fouling arrangement
B Secondary piston valve
C Dashpot to cushion opening action
D Piston cushions closing action
E Port in seat
F Ground face

Example of feed check valve

Figure 13.22 shows a screw down non-return feed check valve, which is cushioned in its action by virtue of the fact that the actual valve and spindle form a dashpot. The valve has a spiral groove in its bore, which causes it to rotate slowly while working, thus eliminating uneven wear and keeping it free in operation.

WATER GAUGES

Water gauges play an important part in the safety of boiler operation. The following paragraphs describe the various types, their attachment to boiler shells and the methods of verifying their accuracy in operation.

Types of water gauge

For boiler pressures up to about 20 bar it is normal practice to use round glass tubes suitably connected to the boiler by means of cocks and pipes, for indicating the working level of the water. Above 20

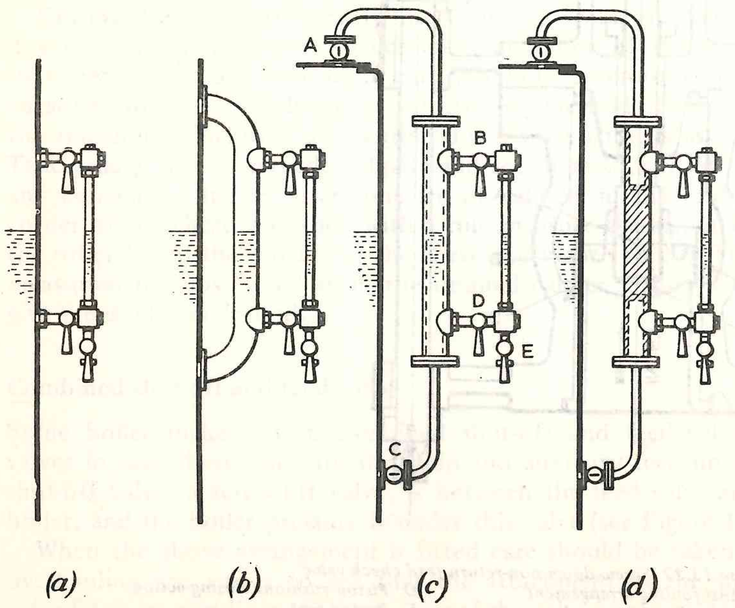


Figure 13.23 Arrangement of water gauges in tank type boilers

bar the glass tube is replaced by what is in effect a built-up rectangular-section box having a thick plate glass front and back.

Tank-type boilers, coming in the lower range of pressures, are invariably fitted with round glass-tube gauges, these being connected to the boiler in one of the following ways:

(*a*) Fitted directly to the boiler;

(*b*) Fitted to a large-bore bent pipe, one end of which communicates with the steam space and the other with the water space:

(*c*) Mounted on a hollow column, the ends of which are connected by pipes to shut-off cocks on the top and bottom of the boiler;

(*d*) Mounted on a column as in (*c*), but the centre part of the column is solid, the ends again being connected by pipes to shut-off cocks on the top and bottom of the boiler (see Figure 13.23).

Testing water gauges

The procedure to be adopted when verifying the water-level in water gauges varies according to the manner in which the gauge is mounted on the boiler. In the case of water gauges in direct communication with the boiler contents without intervening cocks, as in (*a*) and (*b*), prove, by first shutting both gauge cocks and opening the drain, that the gauge cocks are in order. Then with the drain still open blow through both the top and then the bottom cocks independently to prove a clear way though both top and bottom cocks, and the gauge glass itself.

In the case of water gauges mounted on columns as in (*c*) and (*d*), the addition of pipes and boiler-shell shut-off cocks brings in additional possibilities of faulty level indication, and the thorough verification of these types is a little more involved. To test a hollow-column water gauge installation thoroughly, first prove the bottom connections are in order by shutting cocks A and B, leaving C and D and the drain E open; if water blows freely out of the drain the bottom connections are in order. Then open cocks A and B, and shut C and D; if steam blows freely out of the drain E the top connections are in order.

In the event of either end not blowing freely, a cross test can be used which will show up the cock that is faulty. To cross test, close A and D, leaving C, B and E open, then close C and B, leaving A, D and E open – this is known as a cross blow.

In the case of water gauges mounted on a column with a solid centre part as in (*d*) a similar procedure to that specified in (*a*) and (*b*) is all that is necessary.

It is not always an easy matter to decide whether a tubular gauge glass is full or empty. It is obviously essential to make a correct diagnosis at such times. The difficulty can be avoided by using the principle of refraction and placing a board painted with alternate black and white diagonal stripes behind the gauge glass. Should the glass be full, the stripes will appear to be set in the opposite direction when viewed through the glass. If the glass is empty no obvious distortion of the stripes will be apparent. A pencil held at an angle behind the glass will give a similar effect.

Overhaul of water gauge mountings

Water gauge mountings should be overhauled at least at every boiler survey and, at this time, particular care should be taken to see that all passages through the cocks and also those through pipes and columns (if fitted) are clear. Cock-handles should always be fitted in such a manner that they are pointing vertically downwards when in normal working position i.e. with both steam and water connections to the gauge *open* and the drain cock *shut* (Figure 13.23). With the cock handles disposed in this manner it can be seen at a glance that all are correct and there is no danger of vibration causing a slack fitting cock to shut and thus give a possible false reading in the glass.

In cases where the gauges are fitted with valves instead of cocks the 'open' and 'closed' indicators should be checked. Any cocks or their handles which are twisted must be immediately renewed.

For the bottom shell connection in a tank boiler some boiler-makers fit a right-angle cock. This type of cock gives a better run for the pipe up to the column, but it is more liable to silt up than the straight-through type, and consequently is not to be recommended. The simple direct-mounted water gauge without any connecting pipes, double shut-off cocks or columns is always to be preferred, but water gauges must be in positions where they are readily visible. On that account, with double-ended boilers and single-ended boilers back to back, the gauge glasses are mounted on columns in front of the smoke boxes with connecting pipes and double shut-off cocks.

It is well to mention that water-gauge columns are sometimes bolted on to structures which are not rigid parts of the boiler, and in course of time, or maybe through damage, the overhanging weight of the column causes it to settle downwards, and consequently the safe working level becomes an unsafe one. In case of doubt it is advisable, therefore, to ascertain that with the vessel on an even keel there is a minimum of 100 mm of water cover over the chamber tops when the level is just showing in the bottom of the gauge glasses.

It is uncommon, these days for gauge glasses to fail in service but they may become cloudy with age and require to be renewed from time to time. When fitting a new glass, care should be taken to ensure that it is of the correct length. A glass which is too long may cause the steam connection to become restricted or even blocked. A glass which is too short, on the other hand, and has not been fully inserted in the packing sleeve, may result in the material of the sleeve working loose and blocking the end of the glass.

WATER TUBE BOILER WATER GAUGES

As mentioned earlier in this section, for pressures above 20 bar the round water gauge glass (see Figure 13.24) has been replaced by what is, in effect, a built-up rectangular-section box having a thick glass front and back (see Figure 13.25).

The double-plate glass type of gauge is normally illuminated from the rear by an ordinary filament electric lamp and the meniscus of the water-level appears as a brilliant concentrated light spot. The inner surfaces of the two plate glasses used are protected against any etching action of the steam by the fitting of thin sheet mica.

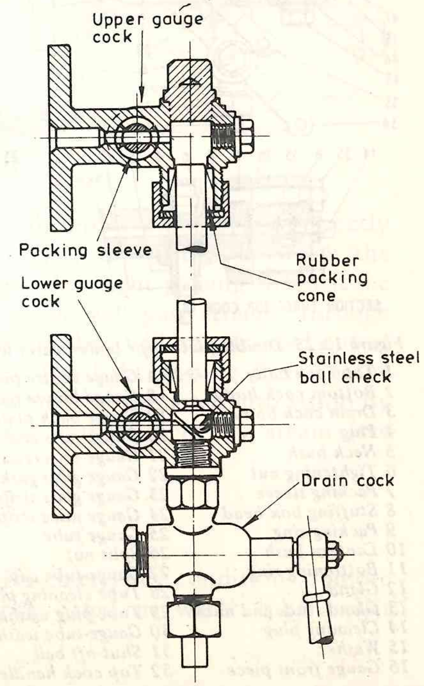


Figure 13.24 Klinger water gauge

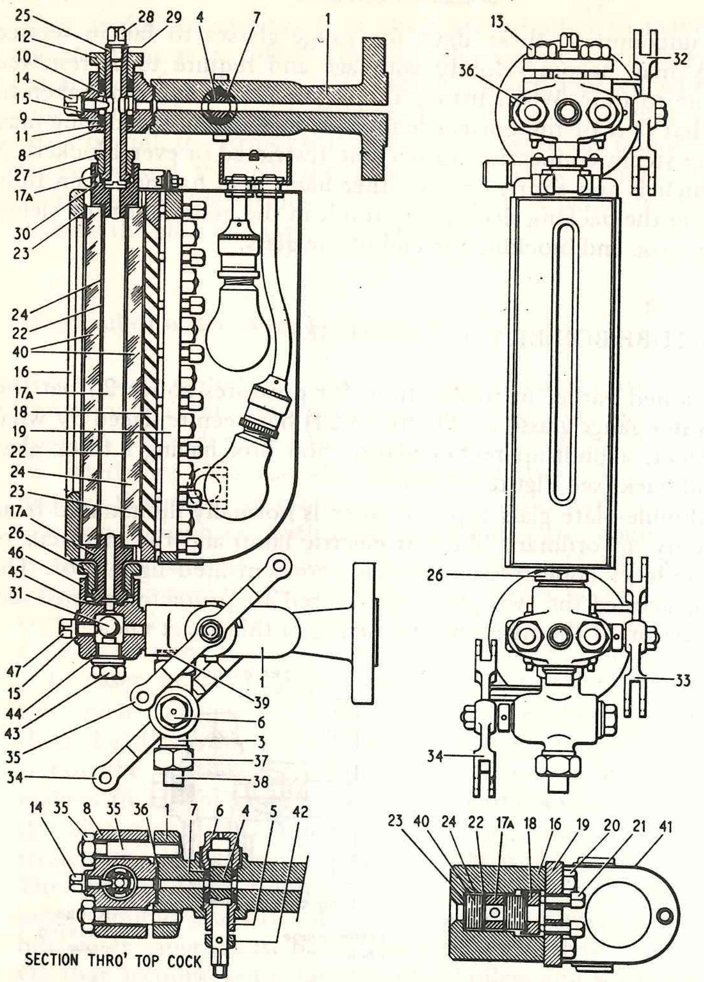


Figure 13.25 Double plate type boiler water level gauge

1 Top cock body
2 Bottom cock body
3 Drain cock body
4 Plug
5 Neck bush
6 Tightening nut
7 Packing sleeve
8 Stuffing box head
9 Packing ring
10 Lantern bush
11 Bottoming ring
12 Gland
13 Gland studs and nuts
14 Cleaning plug
15 Washer
16 Gauge front piece
17A Gauge centre piece
18 Gauge louvre plate
19 Gauge back plate
20 Gauge nuts and studs
21 Gauge setscrews
22 Gauge glass gasket
23 Gauge glass strip
24 Gauge mica-strip
25 Gauge tube
26 Split nut
27 Gauge-tube cap
28 Tube cleaning plug
29 Tube plug washer
30 Gauge-tube washer
31 Shut-off ball
32 Top cock handle
33 Bottom cock handle
34 Drain cock handle
35 Studs and nuts
36 Joint washer
37 Union nut
38 Tail pipe
39 Joint washer
40 Glass plate
41 Reflector
42 Retaining collar
43 Stuffing-box plug
44 Washer for above
45 Joint washer
46 Stuffing-box head
47 Cleaning plug

Bi-colour water gauges

It is quite common practice to have one or two basically similar water-level indicators on modern water tube boilers fitted with bi-colour equipment. The effect of different colours to indicate the steam and water space in such gauges is obtained by making use of the different refractive properties of steam and water.

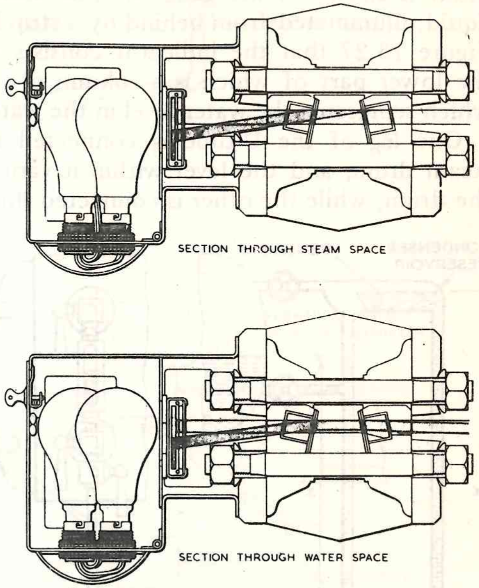


Figure 13.26 Showing light effects in bi-colour water gauges

Vertical screens of glass of two different colours, one directly behind and the other slightly offset, are fitted between the illuminating lamp and the gauge glass. The light passing through the coloured glass directly behind the gauge will pass straight through that part of the gauge containing steam, but will be refracted out of sight in that part containing water. The light passing through the *other* coloured offset glass will, however, be refracted into vision by water and will pass straight through out of sight by steam (see Figure 13.26).

Remote water-level indicators

As a valuable addition, particularly for emergency conditions, remote water-level indicators are sometimes fitted in water tube boiler installations. This type of indicator is also often fitted in the case of tank boilers of motorships which are usually remote from the engine-control platform. These are always additional to the normal classification society requirements for water-level indication.

The Igema distance boiler-water-level indicator is a device which enables the water level in a steam drum of high elevation to be read easily and accurately at eye level. The height of the water level in the drum is shown in the gauge of this indicator by a column of red liquid, illuminated from behind by a strip light. It will be noted from Figure 13.27 that the indicator consists essentially of a U-tube, in the lower part of which is a column of special red indicating fluid, which represents the water level in the water gauge.

One leg of the U-tube is connected to the water space of the steam drum, and the level within it varies according to the level in the drum, while the other is connected through a condenser reservoir

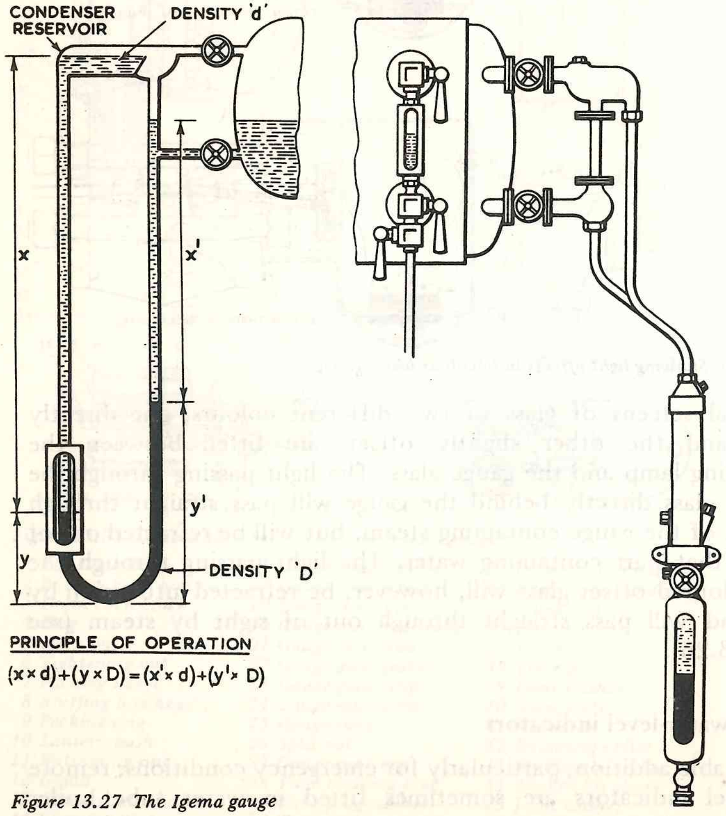


Figure 13.27 The Igema gauge

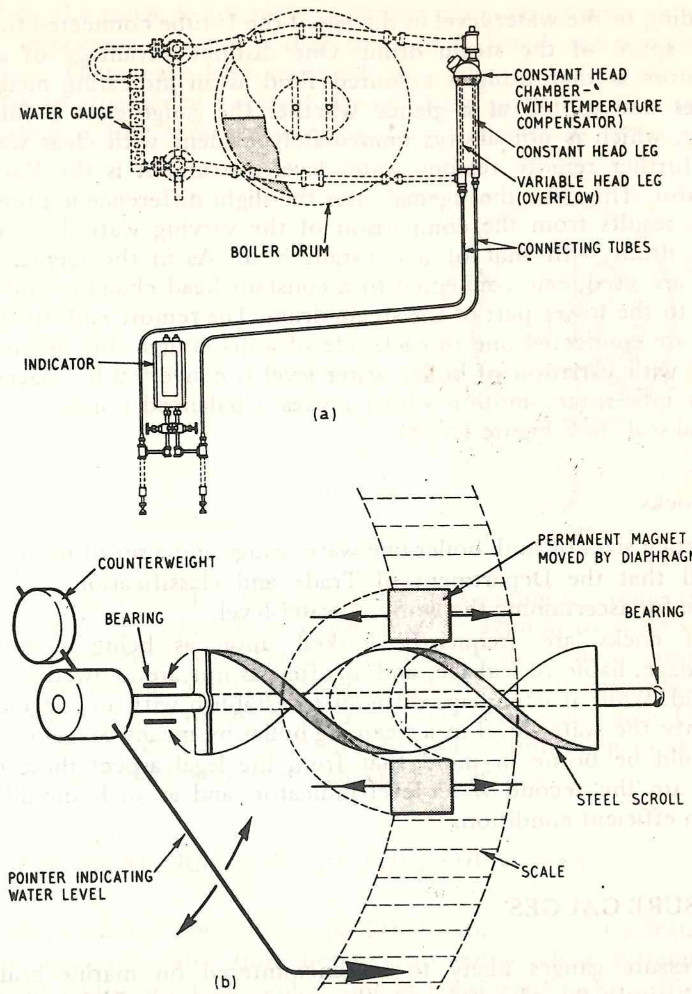


Figure 13.28 'Yarway' remote level indicator actuating gear
(a) diagram of connections
(b) diagrammatic arrangement

to the steam space — *thus being kept full at all times.* The indicating fluid is insoluble in, and of greater density than, water. In view of the fact that the sum of the individual heights of water and indicating fluid multiplied by their respective densities must balance for each of the legs of the U-tube (see Figure 13.27), it will be readily understood that the level of the column of indicating fluid will vary according to the water-level in the leg of the U-tube connected to the water space of the steam drum. One distinct advantage of such indicators is that using a coloured fluid as an indicating medium enables one to tell at a glance whether the gauge glass is full or empty, which is not always immediately evident with clear water.

A further remote reading water level instrument is the Yarway indicator. This, like the 'Igema', uses the slight difference in pressure which results from the comparison of the varying water-level in a steam drum with that of a constant head. As in the Igema, two tubes are used, one connected to a constant head chamber and the other to the lower part of the steam drum. The remote ends of these tubes are connected one to each side of a diaphragm, the flexure of which with variation of boiler water level is converted by magnetic means into rotary motion which moves a balanced pointer over a vertical scale (see Figure 13.28).

Test cocks

On certain sizes of tank boiler one water gauge and a set of test cocks are all that the Department of Trade and classification societies require for ascertaining the working water-level.

Test cocks are frequently looked upon as being a useless appendage, liable to leakage, and as often as not are allowed to salt up solid. While it is perhaps difficult to establish with any degree of certainty the water level in a steaming boiler by means of test cocks, it should be borne in mind that from the legal aspect these test cocks are the second water-level indicator, and as such should be kept in efficient condition.

PRESSURE GAUGES

All pressure gauges likely to be encountered on marine boilers operate on the Bourdon principle the construction of which is shown in Figure 13.29.

The main component is a phosphor bronze or stainless steel tube of oval cross section which is bent in the form of an arc being fixed at one end and free at the other. By applying pressure internally, the tube tends to straighten and the amount of movement at the free end is proportional to the pressure applied. Through a link attached to the free end of the tube motion is transmitted by means of a quadrant to a small pinion on the pointer which, in turn, pivots about the central axis of the gauge.

When the gauge is not under pressure, the pointer rests on a pin. It is important to ensure that this pin is fitted and remains in position. There have been cases where a missing pin has allowed a pointer to commence a second circuit of the gauge dial thus falsely indicating a low pressure when in fact a dangerous overpressure

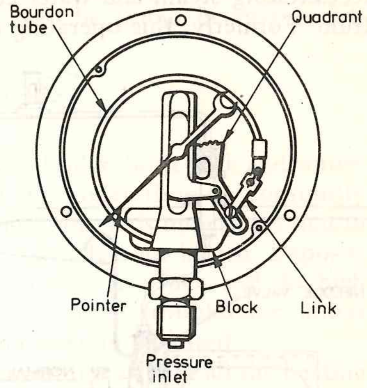


Figure 13.29 The Bourdon pressure gauge

situation has endured. Steam pressure gauges should be connected to a boiler through a length of coiled pipe or syphon to avoid steam coming into contact with the Bourdon tube. Gauges should never be too hot to handle. Steam pressure gauges are usually manufactured to give an accuracy of about 1% at the maximum scale value. Unless specially manufactured they should always be mounted in an upright position and should be regularly checked for accuracy.

LOW WATER ALARMS AND OIL FUEL SHUT OFFS

Nowadays, marine boilers must be fitted with low-water safeguards. In the case of water tube boilers two independent systems are specified whilst for tank boilers one is considered to be sufficient. All such equipment is to be capable of operating audible and visible alarms and also of automatically shutting off the fuel supply to the burners when the water level falls to a predetermined low level. Where boilers are fully automatic such alarms and shut offs may be incorporated in the general design of the control system (see chapter 14). In boilers built prior to 1969, low-water safeguards, if fitted, may not fully conform to current requirements.

In view of the small water content and high evaporative rate of water tube boilers it is usual to find low-water safeguards provided even in older boilers. These are intended to safeguard the boiler and its attendants should a tube burst or any other circumstance prevail which would cause a dangerously low water condition.

Low-water alarm and fuel shut off operating gear is either fitted inside the steam drum or as an external unit, the latter arrangement necessitating steam and water connections being made to the boiler drum. Formerly, this operating gear usually consisted of a ball float

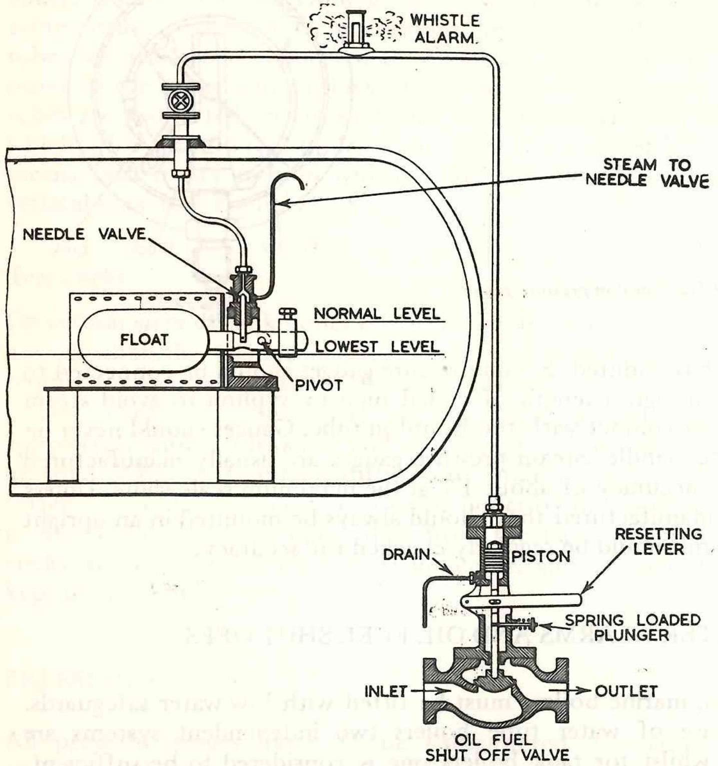


Figure 13.30 Arrangement of low water alarm installation showing water at low level, steam on whistle and oil fuel shut off

linked to a needle valve, this valve being kept on its seat by the action of the float while the water level is above the lowest permissible level. In the event of the water level dropping to a dangerously low level the needle valve opens and admits steam to the system thereby blowing an alarm whistle and shutting off the fuel supply to the burners. A low-water alarm installation of this type is illustrated in Figure 13.30.

Nowadays, low-water alarms and provision for emergency fuel shut off are often an integral part of a feed water control system and are no longer actuated, directly, by steam from a float controlled needle valve but by electrical switches or pneumatic relays which, in turn, are operated by the action of such devices as magnetic type floats, differential pressure instruments and capacitor type level controls. Reference to these systems will be found in chapter 14.

SOOT BLOWERS

In order that the heating surfaces of any boiler, both tank and water-tube types, may be kept clean, and the boiler thus be constantly available for service in an efficient condition, it is imperative that in addition to off-load cleaning, it is periodically soot blown. Deposits are formed in all gas passages when burning any fuel, and the high ash contents of the heavier fuel oils can be troublesome unless efficient soot blowers are installed and correctly operated.

Soot blowers are fitted in suitable positions so that all the heating surfaces, tubes, superheaters, economisers and air-heaters can be maintained in a clean condition, provided, of course, that the equipment is properly maintained and regularly operated (usually every twelve hours).

The cleaning operation is performed by jets of high-pressure steam or air, the jets being caused to move through an arc while in operation, so that they cover all parts of the heating surfaces.

Tank-type boiler smoke-tube blower nozzles, as shown in Figure 13.31 are situated in the combustion chambers, and the nozzles, of special heat-resisting steel, are so arranged that while not actually in

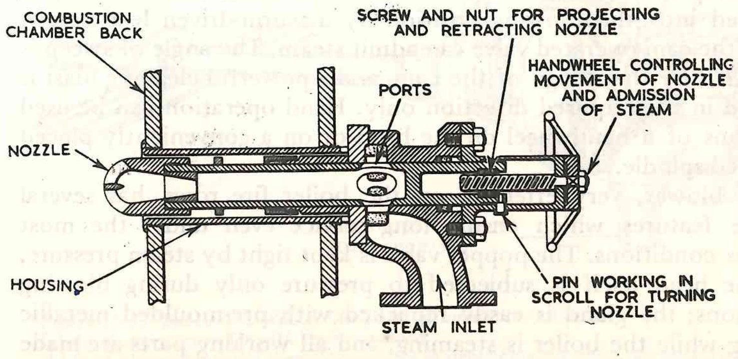


Figure 13.31 Typical soot-blower unit

operation they are drawn back within a protective housing. This housing is usually a tube which passes through the water space of the boiler between the back end-plate and combustion-chamber back, and is thus cooled.

In the case of water tube boilers, steam and air systems are available for soot blowing, the range of equipment including hand-operated units and automatic, sequence-controlled, power-operated equipment.

The retractable single-nozzle steam blower (Figure 13.32) is normally installed in the furnace and other high-temperature zones.

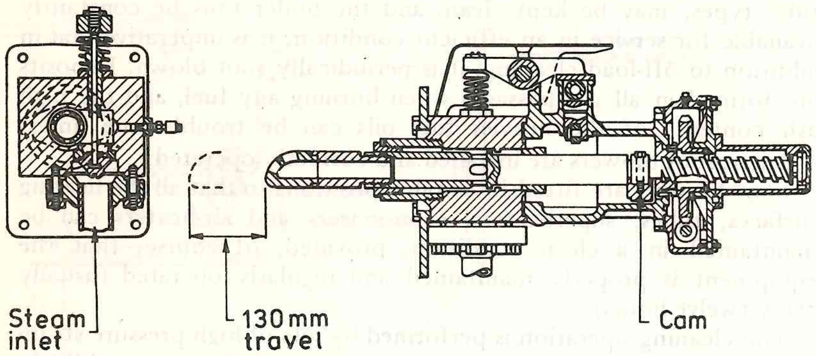


Figure 13.32 Sectional view of the Babcock & Wilcox marine-type retractable soot blowers (hand-operated)

Its multi-ported nozzle element is screened while retracted and is advanced into the blowing position by a worm-driven lead screw, before the cam-operated valve can admit steam. The angle of sweep is controlled by the design of the cam, and a powerful cleaning blast is directed in the required direction only. Hand operation can be used by means of a handwheel on the head or on a conveniently placed extended spindle.

This blower, very effective on the boiler fire rows, has several notable features which ensure long service even under the most arduous conditions. The poppet valve is kept tight by steam pressure, and the head itself is subjected to pressure only during blowing operations; the gland is easily repacked with pre-moulded metallic packing while the boiler is steaming, and all working parts are made from alloy materials selected to suit high temperatures.

These blowers are arranged either for direct hand operation or for remote operation by extended shafts and gearing. In cases where blower housings pass through furnace walls the nozzles are subjected to very high temperatures, even when withdrawn, and it is usual to fit a cooling-air connection to the housings from the forced-draught air supply, so that cooling air passes constantly over the nozzle surfaces into the furnace.

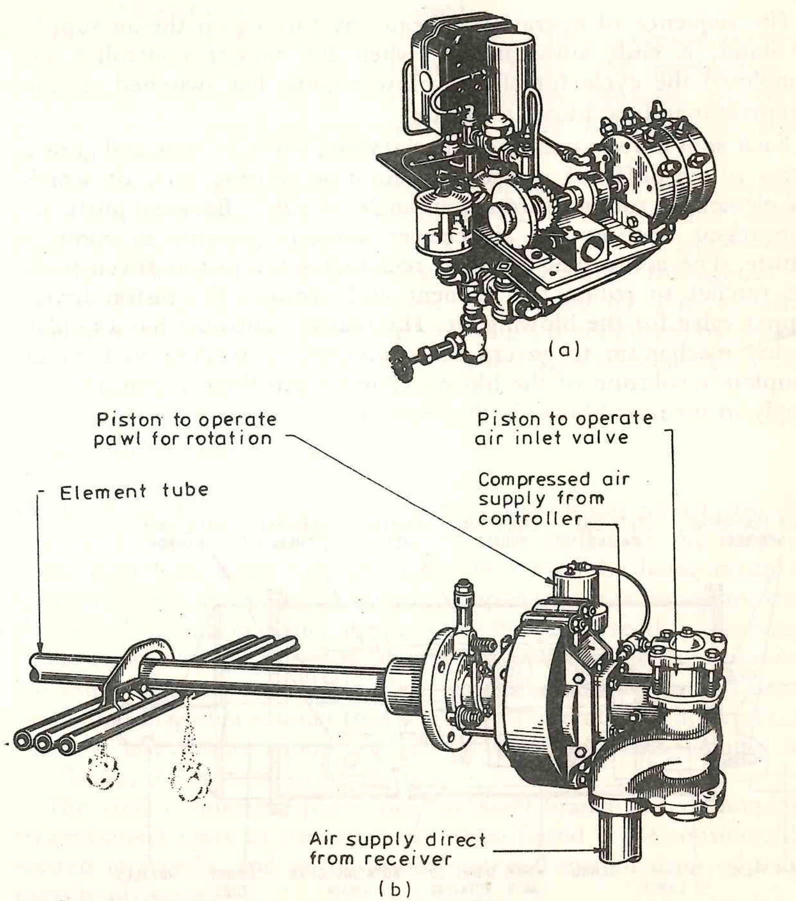


Figure 13.33 Babcock & Wilcox 'Air puff' automatic soot blower
(a) Air master controller with cover removed
(b) Soot blower head and element assembly showing how automatic air puffs clean boiler tubes

The use of the air-puff system, in which the operating and blowing medium is compressed air, reduces the quantity of make-up feed required, but it necessitates the installation of an air compressor for 3.5 m^3 of free air per minute at 8–14 bar, a receiver of 3.5 m^3 capacity is also required. With this system, the blower supply piping needs no lagging, warming up or draining off and, in addition, heavy discharge from the funnel is avoided because the operation is spread over a period of two or three hours. Figure 13.33a shows the controller, while Figure 13.33b shows the head of one of these blowers.

The sequence of operation is begun by turning on the air supply by hand; it ends automatically when the master controller has completed the cycle for all the blower units; has switched off the compressor and has blown a whistle.

Each soot-blower unit is of the rotating, multi-jet type and gives a series of air-puffs of one-second duration, during each of which the element is rotated through an angle of 17½°. Between puffs the compressor restores the air-receiver working pressure in about a minute. The controlling air then re-actuates the piston-driven pawl and ratchet to rotate the element and operates the piston-driven poppet valve for the blowing air. The master controller has a similar ratchet mechanism to govern the supply of controlling air for one complete revolution of the blower element and then to transfer the supply to the next blower in the sequence.

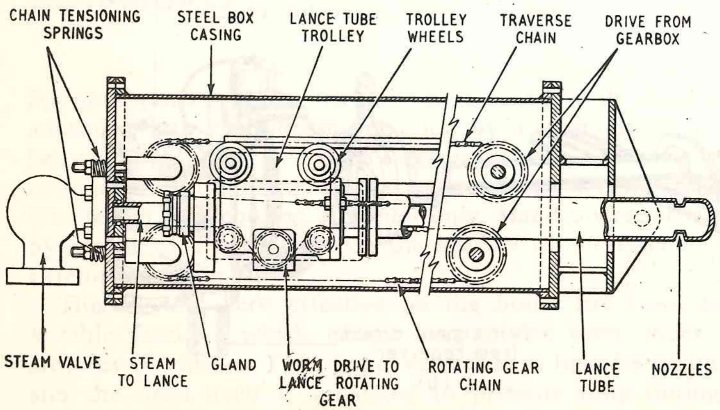


Figure 13.34 Long-stroke retractable soot blower

Long-stroke retractable soot blower

The short-stroke retractable blower has its limitations and with a view to getting at the high temperature zones of the present-day highly-rated boilers more intimately, the long-stroke retractable blower was produced. The lance for these blowers may be up to 4.5 m in length, and as it is retractable it requires considerable space for withdrawal. With front-fired boilers, such blowers are frequently arranged to operate downwards through the roof, whereas in the more recent roof-fired designs side operation is used.

The Clyde blower illustrated in Figure 13.34 is a typical example of the side-operating long retractable type. The mechanism is completely encased in a steel box which provides complete protection for the heat resisting steel lance tube and all other working parts.

The lance, attached to a trolley, is supplied with steam through a stainless-steel feed tube secured to the end of the box, and passing into the lance through a stuffing box. In operation, the lance moves once in and out rotating and blowing continuously throughout its stroke. The in and out movement is obtained by a motor-drive combined traverse and rotary gearbox, which is connected by driving chains to the travelling trolley carrying the lance (see Figure 13.34).

Maintenance of soot blowers

In the case of some water tube boilers, the blower nozzles for the heating surfaces remote from the furnace itself take the form of holes in a long heat-resisting steel tube, this tube being made to rotate through an arc as the blower is operated. It is important that the arc of operation, which may only be 90°, is correctly positioned. Boiler-casing repairs necessitating the removal of blower equipment are sometimes responsible for these very necessary accessories being assembled in such a manner that their arc of operation is incorrect. If there is any doubt about the arcs of operation these should be checked at the first opportunity.

The steel connecting pipes and cast-steel branch pieces coupling steam-blower units to the boiler are often found to be considerably wasted internally, and an occasional internal examination of these parts is advisable.

Water tube boilers are sometimes run for a year without being opened up for internal cleaning, and provided fuel and combustion are good, blowers efficient and regularly used, the same interval

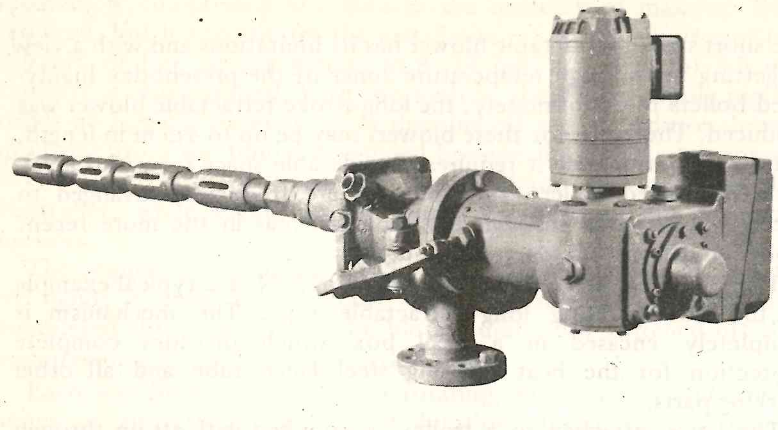


Figure 13.35 'Clyde' multi dual nozzle soot blower

between cleaning should apply to the fire side of the boiler. The specified sequence of blowing in large watertube-boiler units should be adhered to, although as previously indicated, in modern practice this is often ensured by having the blowers power-operated in automatic sequence.

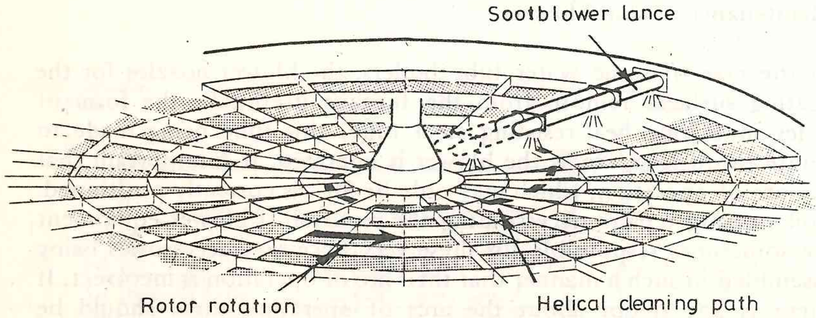


Figure 13.36 Air heater soot blower arrangements

Fixed position soot blowers

In the lower temperature gas zones of water tube boilers, ambient temperatures are such that fixed position soot blowers are feasible and are now widely used on generating banks, superheaters, reheaters, economisers and air heaters.

Figure 13.35 shows a multi-nozzle rotating type of blower whilst Figure 13.36 depicts the arrangement of multi-jet lance type blowers as fitted to a Lungstrom air heater. These lances are commonly fitted above and below the rotating element of the heater and are of non-rotating type. Although these lances are permanently installed in the heater they are designed so that they can traverse or track the surfaces of the heater. Such blowers are often provided with twin lances, the second lance being used for 'off load' water washing.

A soot blowing system of a modern water tube boiler installation may consist of a combination of blower types. For instance, a long stroke retractable blower would probably be fitted in the high temperature zone of the superheater and furnace screen tubes although short stroke, single nozzle retractable units are frequently fitted in these locations when lack of space precludes the use of the long stroke type. Fixed position, multi-nozzle blowers would be found in the lower gas temperature areas such as the economisers whilst tracking lances would serve the rotary type air heater.

It may be appropriate to mention that soot blowers are commonly fitted in connection with the waste-heat units of auxiliary boilers installed on motor ships and are standard fittings in exhaust-gas economisers of the extended surface or finned tube type.

BOILER DRUM INTERNALS

It is obviously an essential requirement for any boiler that steam supplied to the range or to the superheater should be free of water

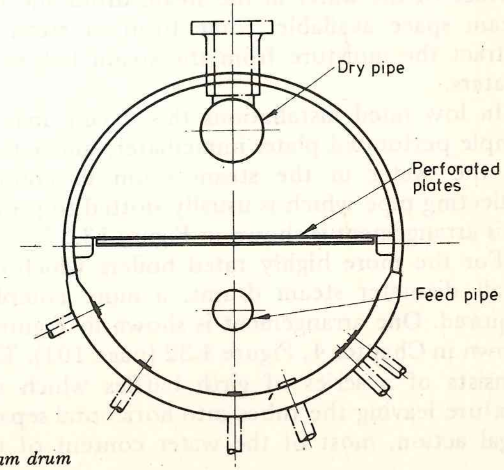


Figure 13.37 Section through steam drum

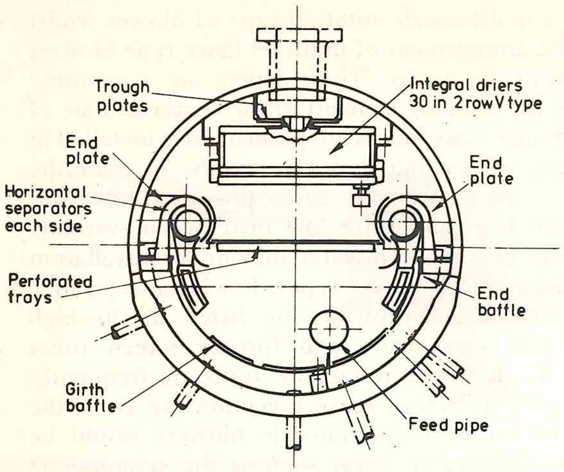


Figure 13.38 Section through steam drum

particles. In boilers having a high volume to generating capacity ratio, such as the older tank type boilers, no special provision is necessary to achieve this. The large steam space coupled with the low turbulence on the surface of the water is adequate to ensure that sufficient water particles gravitate out, for practical purposes, before the steam exits through the boiler stop valve.

In most water tube boiler installations, however, a better quality of steam is demanded and due to the high turbulence present on the surface of the water in the steam drum and the comparatively small steam space available, some form of steam drying is required to extract the moisture from the steam before it passes to the superheaters.

In low rated installations this drying may be achieved by fitting simple perforated plates immediately above the normal working level of the water in the steam drum in conjunction with a steam collecting pipe which is usually slotted to provide further separation. This arrangement is shown in Figure 13.37.

For the more highly rated boilers which often include relatively small diameter steam drums, a more complicated arrangement is required. One arrangement is shown in Figure 13.38 and a second is shown in Chapter 4, Figure 4.32 (page 101). The former arrangement consists of a series of girth baffles which direct the steam/water mixture leaving the tubes into horizontal separators. Here, by centrifugal action, most of the water content of the steam is extracted.

The final stage in this system takes the form of chevron driers, a series of perforated plates in 'V' form, where the last droplets of moisture are removed. This arrangement has the disadvantage that considerable dismantling requires to be done before a thorough inspection of the internal surfaces of the steam drum can be made.

14 Boiler controls

In early water tube boiler installations the regulation of fuel oil pressure and temperature, combustion air pressure and superheat temperature were all part of the watchkeeping engineer's duty and 'know-how' – he had to watch his funnel outlet and make all adjustments necessary to suit the characteristics of the bunkers he was burning. Boiler controls as such were non-existent – the first duty to be performed automatically being feed regulation and this was quickly followed by combustion control.

Automatic controls are an essential part of the modern high evaporation water tube boiler installation and in the event of complete failure of the control actuating medium, whether it be pneumatic or electric, it is doubtful if the installation could be steamed under manual control at anything but very low powers. Control systems have, however, been developed to take account of operators' requirements from the point of view of effective, efficient, economical and, last but not least, safety aspects.

The adoption of automatic controls for marine installations has been considerably slower than for their land counterparts, as apart from the differences in operating conditions caused by the marine environment, the designers of shipboard boiler control equipment, in their quest for reliability, have had to contend with the fact that some owners require that their ships can be operated with the machinery space unattended.

The object of a steam generating plant is to produce steam in any quantity, up to the designed maximum output, at a stipulated pressure and temperature. To attempt to control such a plant manually under the quickly varying conditions existing on a modern high evaporation marine boiler installation, would not be practicable; therefore automatic controls have been developed.

Automation, as applied to a modern high powered turbine vessel is extremely complex and could well be the subject of a separate publication. Boiler controls in general consist of three variably interconnected systems i.e. combustion control (including burner

management), feed control and superheat control – all of which are based on drum level, steam flow, final steam pressure and temperature.

In all such systems, arrangements have to be provided for transferring quickly and smoothly back to manual in an emergency and have to 'fail safe'. Otherwise, for example, the controls would revert to 'maximum firing rate' after a tube burst or, in some circumstances, after safety valves had lifted. Such control systems, which virtually replace manpower, can be said to have both brains and muscles. The 'brains' i.e. controllers and relays are generally operated either by air at about 2–3 bar or by electronic devices; the 'muscles', i.e. power devices for operating dampers, feed valves, fuel regulating valves, etc. by air pressure, hydraulic pressure or by electric motors. Air is the most favoured operating medium; it has no fire hazard, and is easily stored which gives reserve time for remedial actions in the event of compressor failure. Dirt is the most likely cause of trouble and it is essential that clean dry air is used.

CONTROL SYSTEMS

It will be appreciated that any controller will react to take corrective action and this will depend upon the input signal. This signal may be

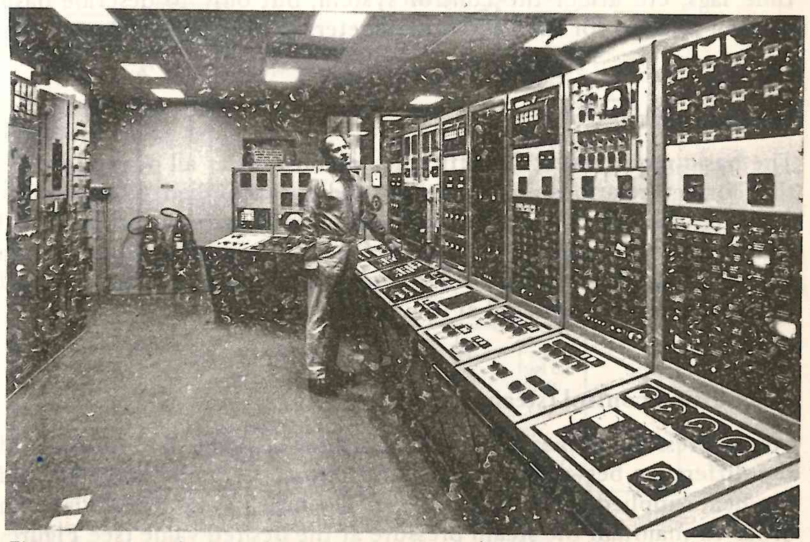


Figure 14.1 Typical machinery control room console (30 000kw) (Kockums Mekaniska Verkstads AB)

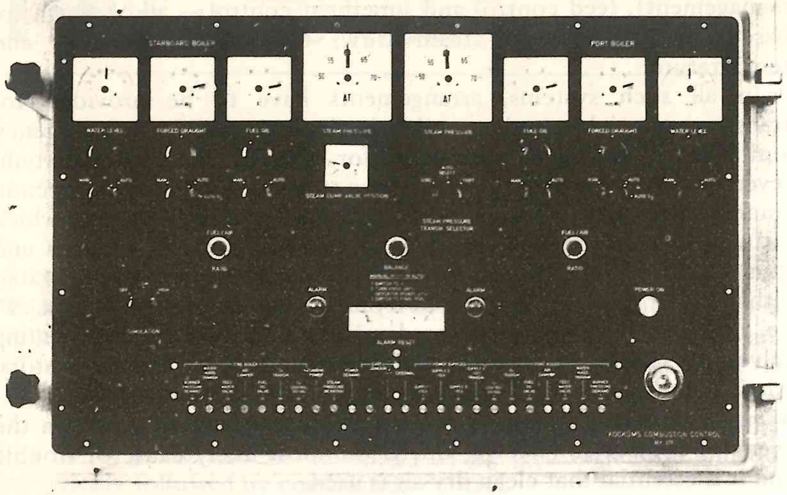


Figure 14.2 Twin boiler control panel

influenced by a number of factors, for example time lags. Control systems must therefore be designed to minimise the effects of these time lags and an understanding of their origin and nature is essential.

It is not within the scope of this chapter to describe how these time lags, etc affect the control system, but only to describe basic control systems for the various parameters in boiler controls.

Combustion control

The basic requirement for efficient combustion at all power levels is the correct relationship of the air and fuel supplied to the boiler furnace. The quantity of air required for combustion is proportional to the quantity and quality of the fuel being burnt. Normally an excess of air in the order of 5% is required, but greater amounts of excess air may be tolerated at low fuel flows.

Combustion control (steam pressure)

Steam pressure is measured and variations are used as a measure of the difference between the heat taken from the boiler as steam, and the heat supplied in the form of fuel. The heat supplied is adjusted in order to maintain the steam pressure at the desired value (see Figures 14.3 and 14.4).

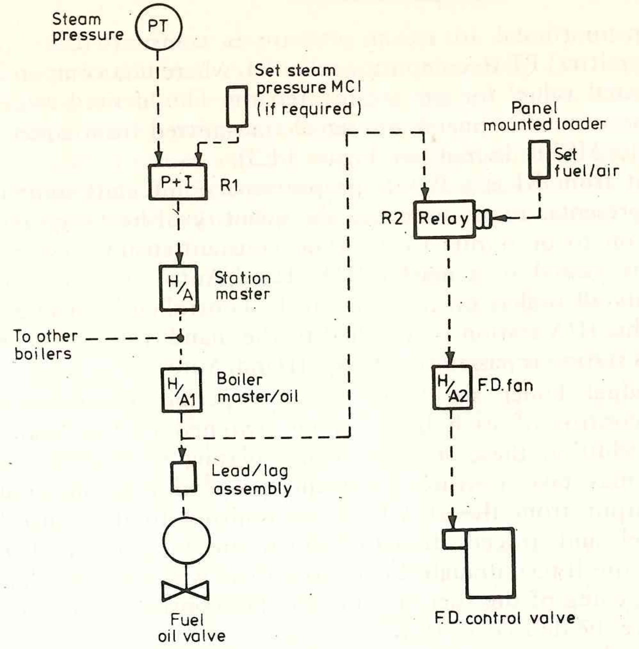


Figure 14.3 Pressure control system

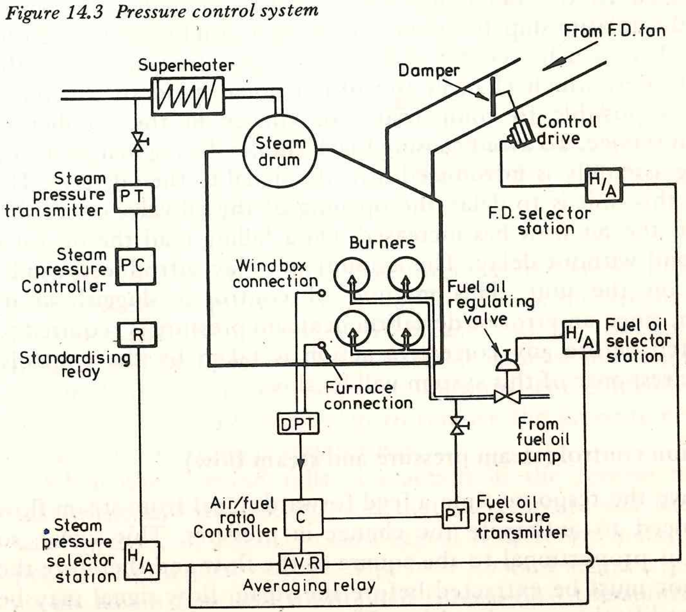


Figure 14.4 Combustion control system governed by superheater outlet pressure only

A signal proportional to steam pressure is transmitted by (a pressure transmitter) PT to computing relay RI, where it is compared with the 'desired value' for the steam pressure. The 'desired value' could take the form of a pneumatic signal transmitted from a panel mounted loader MCI if desired (see Figure 14.3).

The output from RI is a P + I (proportional + integral) control signal and represents, at any moment, the quantity of heat required (in terms of oil to be burnt) to maintain constant steam pressure. The output is passed to a master H/A (Hand/Auto) station. This station permits all boilers on the range to be controlled by a single knob when this H/A station is switched to the 'hand' position. The output of this station is passed to a H/A/I (Hand/Auto).

The individual boiler six H/A/I stations permit single knob combustion control of each boiler when switched to the 'hand' position. In addition these stations permit biasing so that one or more boilers may take a greater or smaller proportion of the total load. The output from the H/A/I's is transmitted to the control valves of fuel and forced draught, which are in parallel. The positioner on the forced draught fan control drive is so arranged that for a given opening of the fuel oil valve the fan control moves to a position to give the desired air flow.

The signal to the fan control drive passes via relay R2 which enables the relationship between the oil and combustion air to be changed. This is achieved by means of a signal transmitted by the manual loader, which changes the proportional band of the relay. Thus it is possible to compensate for change in the number of burners in service. To avoid causing black smoke during load changes, a lead/lag assembly is introduced into the signal to the oil valve. The effect of this unit is to delay the opening of the oil valve on a rising load until the air flow has increased. On a falling load the oil valve can respond without delay. The amount of delay introduced can be adjusted on the unit. This method of control is sluggish in its operation, since an error or deviation in steam pressure is required to be detected before any corrective action is taken by the controls, hence the response of this system will be slow.

Combustion control (steam pressure and steam flow)

To improve the response time a feed forward signal from steam flow is introduced to anticipate the change in pressure. This signal, so obtained, is proportional to the square of the flow and therefore the square root must be extracted before the steam flow signal may be used to modify the error signal (see Figure 14.5).

This system attempts to maintain the steam pressure at a constant figure under all conditions and therefore the steam pressure is measured and compared with a desired value. The output of the controller is proportional to the deviation between the desired and measured values and the output changes at a rate proportional to the deviation. If the control of the combustion was limited to this pressure control and a change in demand occurs there will be a

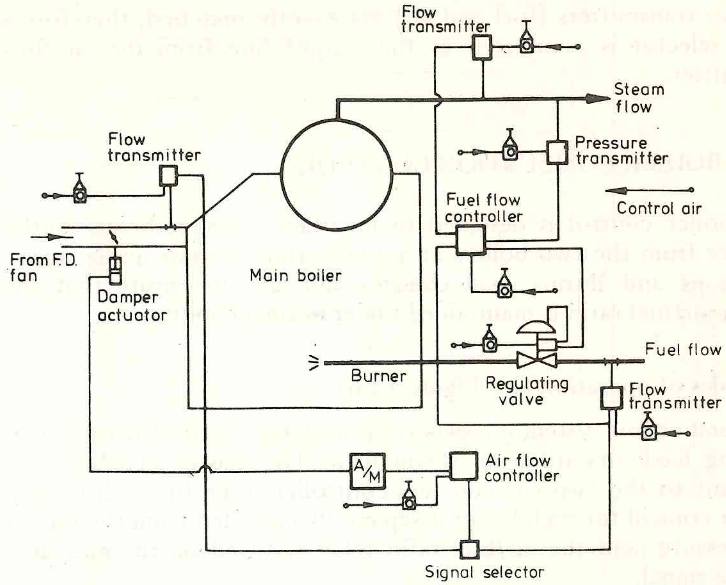


Figure 14.5 Pressure and flow control systems

'Process Lag' before a change in the measured steam pressure takes place. When the pressure does start to change due to the increase in heat demand the controller will react, but by this time the heat balance will be upset and a considerable increase in firing rate will be required to once more restore equilibrium. The controller will tend to over-react by integrating up to remove the pressure error and the danger of over-firing is very serious.

When the demand falls, a reaction in the reverse manner will take place and the likelihood is that the pressure will rise to lift the safety valves. A 'Feed Forward' signal is therefore included with the pressure controlled output. The feed forward signal is proportional to the steam flow and is obtained from a flow transmitter. The two signals are combined to form a master signal to control the fuel flow.

The result is therefore that an anticipatory signal is modulated by the steam pressure. If a high demand for steam is suddenly made when the pressure is high, the master signal will be modified to use some of the excess heat in the boiler but if the demand is made when the pressure is low, the demand signal will be increased.

The air supply is provided by the forced draught fans which are damper controlled. It is important that only the minimum excess air shall be used to provide complete combustion and it is unlikely that the two transmitters (fuel and air) are exactly matched, therefore a signal selector is connected in the output line from the air flow transmitter.

TWIN BOILER COMBUSTION CONTROL

Twin-boiler control is designed to maintain the superheater outlet pressure from the two boilers at a predetermined value under steady conditions and during load changes and also to ensure that the correct air/fuel ratio is maintained under normal conditions.

Principles of operation (see Figure 14.6)

The combustion system consists of a master pressure control, incorporating feed forward from steam flow. The master signal goes as set point to the two cascade fuel controllers (one for each boiler). The air control for each boiler is separately cascaded from the burner rail pressure, and the air/fuel ratio relay is fitted on the measured variable signal.

Master control

Steam pressure is measured by a pressure transmitter in the common line from the superheater outlets. The master controller compares the pressure signal with a manually adjusted set point, and the controller output is fed to a modifying relay where the steam flow feed forward signal is added to it.

Steam flow for each boiler is measured by a differential pressure transmitter connected across a flow nozzle in the steam line from the boiler drum to the primary superheater. The transmitter outputs are linearised by means of square root relays and are fed to the two inputs of a high select relay. The higher of the two steam flow signals is fed to the modifying relay where it is combined with the pressure controller output to form the master signal for the

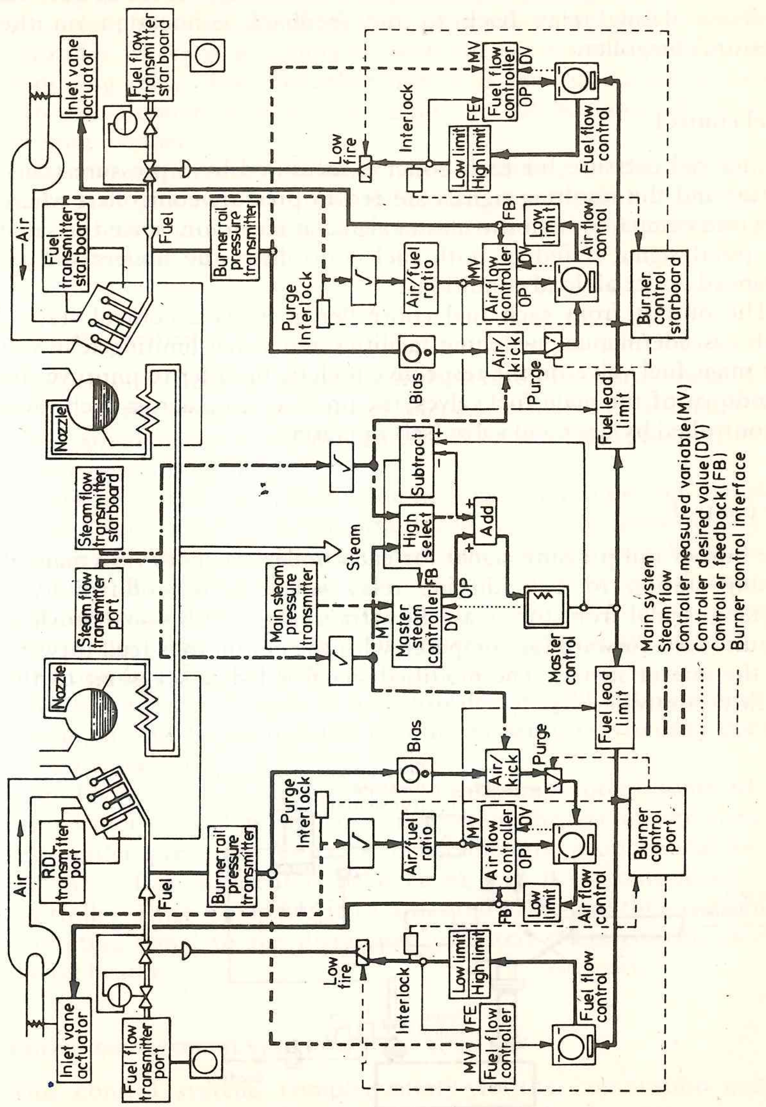


Figure 14.6 Typical boiler combustion control with twin boilers

combustion system. The master signal goes to the fuel controllers via a recording control station with auto/manual switching facilities and signal limiting relays. The output of the control station goes via a demodulating relay back to the feedback connection on the pressure controller.

Fuel control

Burner rail pressure for each boiler is measured by a pressure transmitter and the resulting signals are fed to pressure controllers where they are compared with the master signal as set point. Since the same set point signal is fed to both fuel controllers, the boilers will be balanced under all load conditions.

The output from each fuel controller goes via a control station with cascade/manual switching facilities and signal limiting relays to the main fuel valve on the respective boilers. In order to improve the turndown of the main fuel valves, the pressure drop across each valve is controlled by a second valve (self operating).

Air control

The burner rail pressure signal for each boiler also goes via a manual biasing station to a modifying relay where it is modified by a 'kicking' signal from the steam flow transmitter. This signal provides impulse feed forward (as compared with the continuous feed forward on the master signal). The modified signal is fed as set point to the air flow controller.

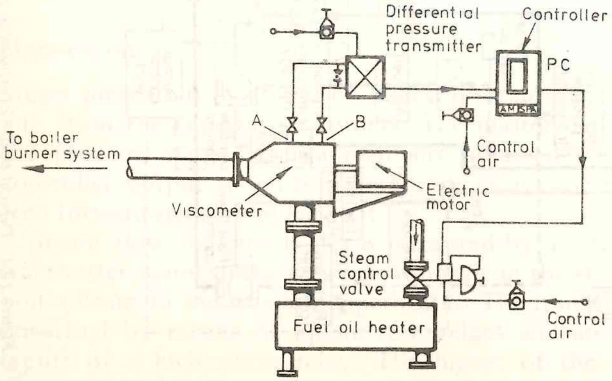


Figure 14.7 Fuel oil viscosity control

Air flow is measured by a differential pressure transmitter connected between the windbox and the furnace to measure the RDL (register draught loss). The RDL signal is linearised by a square root relay, modified in an air/fuel ratio relay, and fed to the flow controller where it is compared with the set point signal from the modifying relay. The controller output is fed via a control station with cascade/manual switching facility to the actuator on the F.D. fan inlet damper.

Control stations give indication (or recording in the case of the master) of process variations, indication of set point or controller output, and remote manual control with bumpless transfer to and from automatic control.

Viscosity control

Combustion efficiency is largely dependent on the correctness of the fuel/air ratio (excess air reduces thermal efficiency) although it is important that, as fuel quality varies, its pressure and viscosity at the burners remains correct.

Fuel oil is often of a low grade high viscosity type and therefore viscosity control is very important and is usually measured by an instrument which develops a differential pressure as a function of viscosity. The error signal between the 'desired value' and the measured viscosity is fed to a temperature control loop and used to control the steam to the fuel oil heater, to achieve the desired fuel condition (see Figure 14.7).

With the rapid changes of fuel flow demanded by the combustion system, it will be appreciated that a very sensitive viscosity control system is required.

In Figure 14.7 a motor driven gear pump forces some of the heated fuel through a capillary tube within the viscometer, the inlet and outlet pressures A and B being directly proportional to its' viscosity. The differential between A and B is transmitted to a controller which compares it to a desired value and then transmits a correcting signal to the diaphragm operated steam control valve of the oil heater.

Burner management system

This control system, complementary to the combustion control system, is frequently referred to as the burner logic system.

Its function, as the name implies is to sequentially control the operation of the main fuel oil shut-off valves and individual burner shut-off valves, the air registers, ignitors and air purging of the furnace.

Investigations into furnace explosions reveal that these occur during initial light off when steam is being raised; although there have been incidences reported when burners have been in service and when attempting to light off an additional burner results in a furnace explosion. It should be stressed that correct procedure must be carried out by operators when manually performing burner operations. Alternatively the automatic sequence of control must be designed to function with correct procedures, timing and also a high degree of reliability.

Figure 14.8 shows the sequence of operations which are carried out automatically. This is a typical burner logic diagram and it will be noted that the system is so arranged, that if certain conditions are not correct 'start up' cannot be effected. Each function occurs in the correct order and at the correct time until the flame is established and likewise when taking burners out of service.

Normally each function as it occurs will be displayed on the boiler control console by means of coloured lights, thus presenting the operators with a visual display of the functioning of the control system. Depending upon the degree of automatic controls provided to control the various parameters (i.e. fuel oil temperature, pressure, etc.) this will influence the sophistication of the burner's logic system.

Another important consideration in design of the burner control system is the arrangement of the fuel oil control and automatic shut off valves at the furnace front. In Figure 14.9 the various valves are shown for the control of fuel oil pressure, steam purging of burners, atomising steam pressure and fuel oil shut off valves. The following features in the design are worthy of mention:

1. Non-return valves should be provided on the steam supply to the burners thus minimising contamination of the steam system by fuel oil. To further avoid contamination of the boilers, this steam supply should be taken from an indirect source (e.g. a steam/steam generator).

2. The burner fuel oil shut off valves should be positioned as close as possible to the burners. They should close instantaneously with tight 'shut off'. An additional safeguard to prevent discharge of fuel oil into the furnace is to trip the main fuel oil shut off valves, in addition to the individual shut off valves when flame out occurs on all burners simultaneously.

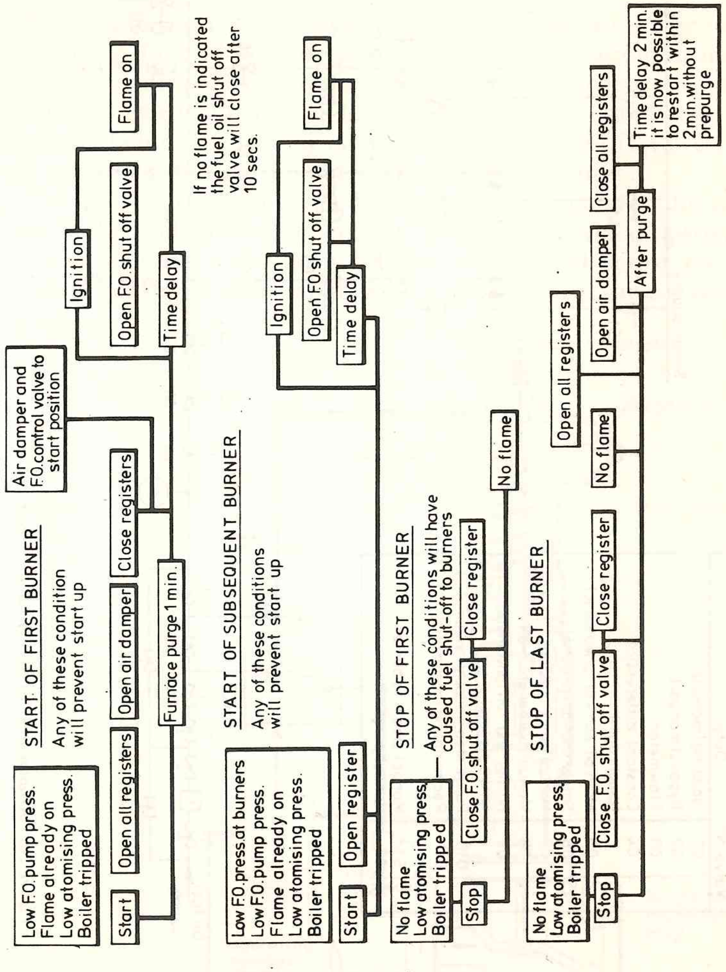
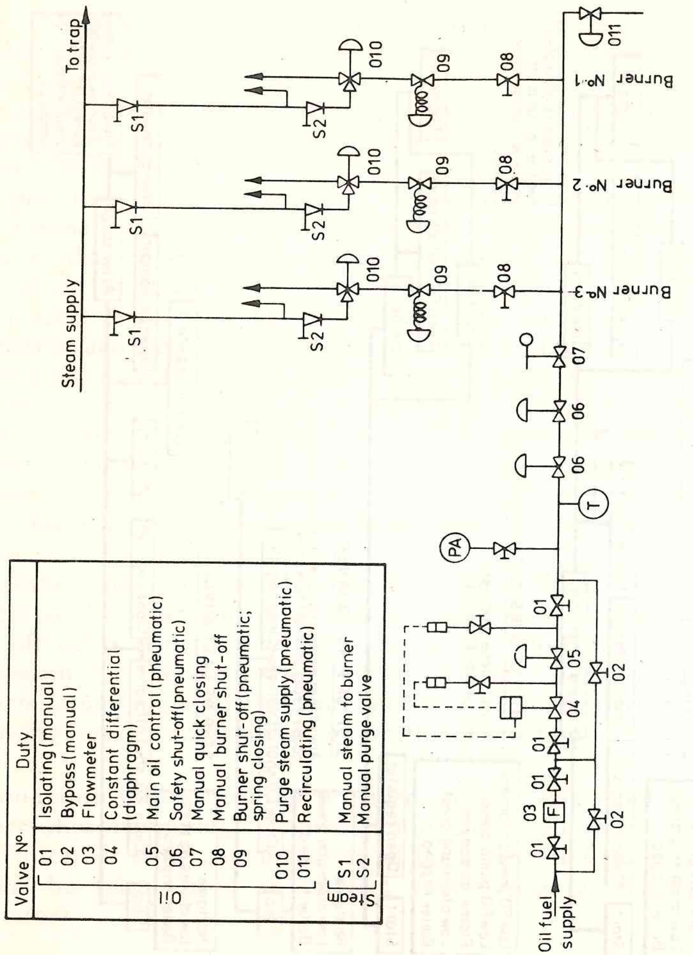


Figure 14.8 Typical burner control logic diagrams



Valve No		Duty
Oil	01	Isolating (manual)
	02	Bypass (manual)
	03	Flowmeter
	04	Constant differential (diaphragm)
	05	Main oil control (pneumatic)
	06	Safety shut-off (pneumatic)
	07	Manual quick closing
	08	Manual burner shut-off
	09	Burner shut-off (pneumatic; spring closing)
	010	Purge steam supply (pneumatic)
	011	Recirculating (pneumatic)
Steam	S1	Manual steam to burner
	S2	Manual purge valve

Figure 14.9 Arrangement of burner oil and steam valves

3. Provision of a system whereby fuel oil may be recirculated during warm up, and a system of steam jacketing of burner fuel oil pipes to ensure correct temperature at the burner nozzle is essential.

4. Provision of a pressure switch to hold fuel oil pressure at a minimum when lighting of the first burner is an important safeguard.

5. The combustion control system should incorporate a control loop to maintain fuel oil pressure at a minimum when raising steam from cold, and additionally to retain the fuel oil at a pressure to prevent flame out when boiler is at low load. It will be noted that in the event of failure of control air to the burner shut-off valves, these will fail to the shut position by the action of the spring.

The pneumatically operated control valve regulates the rate of flow of fuel oil to the burners, and a valve is provided upstream of the control valve to retain a constant differential across the valve. A typical example of a diaphragm operated control valve is shown in

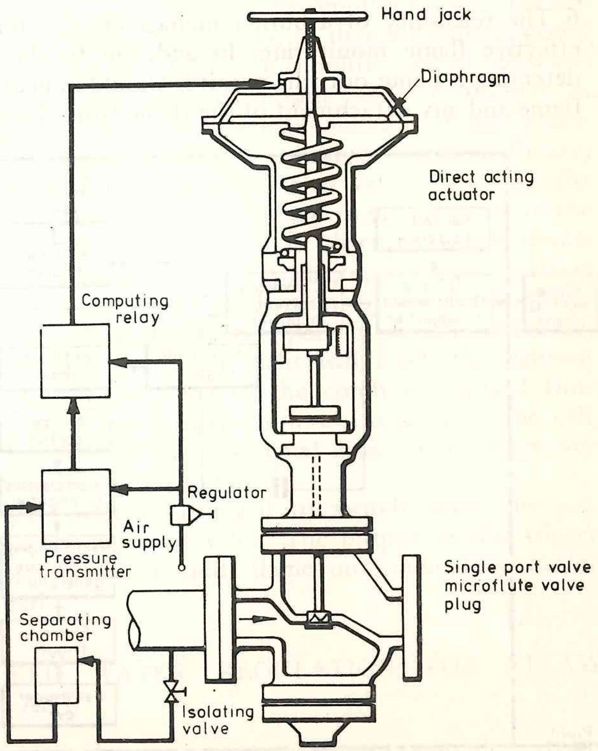


Figure 14.10 Diaphragm-operated fuel-oil regulating valve

Figure 14.10. The valve is diaphragm operated, and fitted with a pressure transmitter and a computing relay. These latter two are used to ensure the correct relationship between control air pressure and fuel pressure at the burners. For example the minimum fuel oil pressure is equivalent to 0.3 bar air pressure and the maximum to 1.7 bar. To elaborate further, the fuel oil control signal is received by the computing relay and balanced against the fuel oil pressure signal it receives from the pressure transmitter. When these two signals balance, the fuel pressure is proportionally correct to the load requirements. Should they not balance, the valve will set in the direction required to achieve this.

To prevent the fuel air pressure from falling below the minimum to produce effective burning a bias is applied to the exhaust valve of the master standardising relay. In all cases, an increase of air pressure to the diaphragm drives the valve stem into the valve body. A hand jack is provided to permit local manual control.

6. The reliability of a burner management system is dependent on effective flame monitoring. In addition to the primary object of detecting a flame out, the monitor should indicate the quality of the flame and any detachment of the flame from the atomiser nozzle.

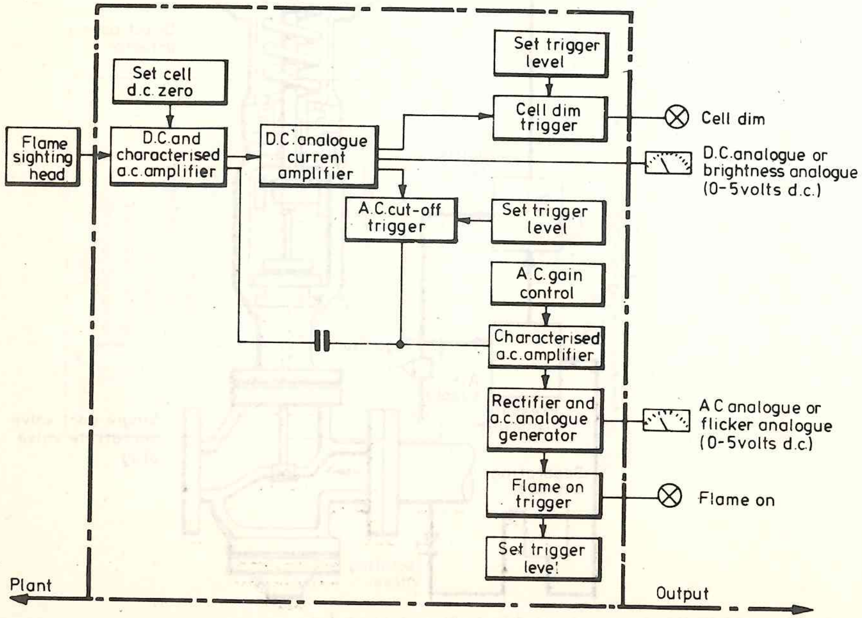


Figure 14.11 Flame monitor

For large capacity burners the flame scanners are of the optical type. Oil flames radiate energy in a continuous band, but of varying intensity, from ultra violet through the visible spectrum to far infra red. For effective flame monitoring the system should incorporate several methods of determining quality. This may be achieved by using:

(a) A brightness monitor
(b) A flicker monitor

One such system uses the low amplitude high frequencies (300 Hz) which are found only at the root of the flame and are confined to a very small area (see Figure 14.11).

Two basic signals are derived from the flame. One representing the brightness, is called the d.c. analogue and the other which represents the amplitude of the high frequency content of the flame is called the a.c. analogue.

Firstly it is necessary to present to the amplifier a d.c. voltage signal which varies with flame brightness, so that the superimposed a.c. ripple voltage can be passed to the a.c. amplifier. When the flame sighting head is viewing the flame, its output can be considered as being composed mostly d.c. with a small amount of a.c. superimposed. When the flame is healthy (i.e. having a vigorous flicker) the a.c. component attains a relatively higher value than when the flame quality is poor. The system is designed to take account of the light intensity dropping, because vision is obscured which results also in a decreasing flicker signal. This is accomplished by equating the a.c. to d.c. signals in the correct proportion. Although the system is designed to operate when the sighting path is partially obscured, obviously at some stage insufficient light will reach the sighting head. To provide advance warning of the condition, a Cell Dim indication is given when the brightness level, as seen by the cell reaches a pre-set low level. Thus this signal indicates the necessity to clean the viewer, as it is about to fail.

An internal trigger unit is arranged to switch when the a.c. analogue signal reaches a pre-set value. The output of this trigger unit thus provides 'flame on' and 'flame out' indication and/or interlocks as required.

AUTOMATIC FEED WATER REGULATION FOR STEAM GENERATING PLANT

The improvement of feed water regulation systems on modern steam generating installations has resulted in a better response from the boiler with respect to water level, steam pressure and steam temperature control.

Boiler drum level control

Control of boiler drum level on modern water tube boilers is normally achieved by one of three methods, i.e. single element, two element or three element control.

Level transmitters include pneumatic and electrical systems having measuring elements of the displacer, ball float, hydrostatic head and differential pressure types.

(a) *Single-element control (see Figure 14.12)*
As the name implies, only one variable is measured, this being boiler drum water level. Measurement may be by float type or differential pressure transmitter.

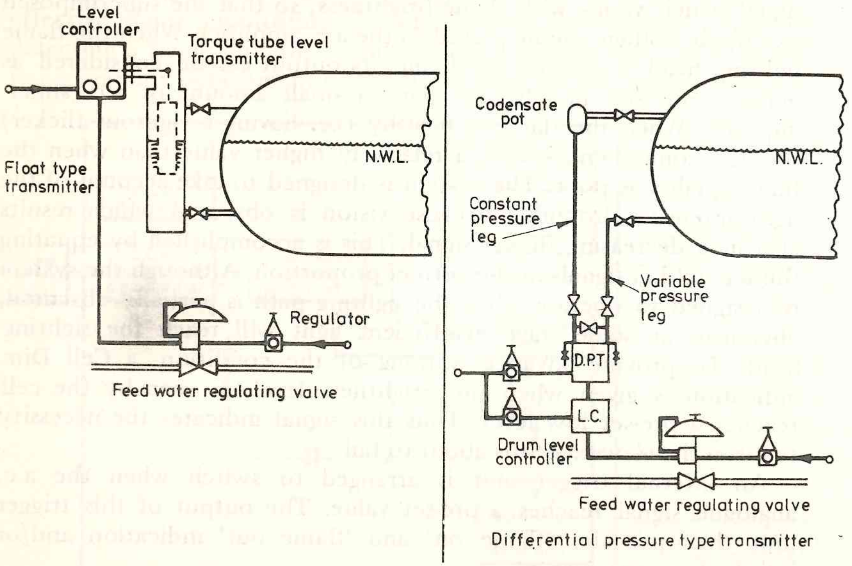


Figure 14.12 Single element feed level controls

Installation arrangements are shown on Figure 14.12. This mode of control is normally used for steam generators with moderate evaporation rates, operating with small load changes and at relatively low pressures (less than 18 bar).

(b) *Two-element control (see Figure 14.13)*
Two variables are measured for controlling the feed water supply, these being steam flow and boiler drum water level. A signal is generated from the steam flow transmitter which positions the feed water regulating valve to maintain equilibrium conditions between the feed water supply and the steam generated.

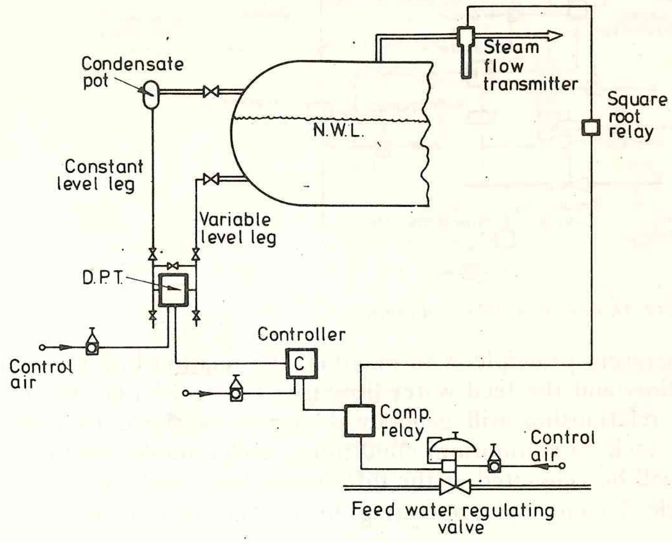


Figure 14.13 Two element feed level control

This control system on its own is not capable of maintaining the level in the steam drum due to the time lag between the steam flow being sensed and the feed regulating valve operating. The water level could vary considerably during this time interval. This problem is overcome by utilising a signal from the water level transmitter which connects the signal to the feed water regulator via a computing relay. The level controller is used as a trimming device to maintain the water level at the correct position during equilibrium conditions. Installation arrangements are shown in Figure 14.13.

(c) *Three-element control (see Figure 14.14)*
The three-element feed water control system is normally used on high evaporation rate boilers (say 100 000 kg/hr upwards). The three measured variables are:

(i) Drum water level.
(ii) Steam flow.
(iii) Feed water flow.

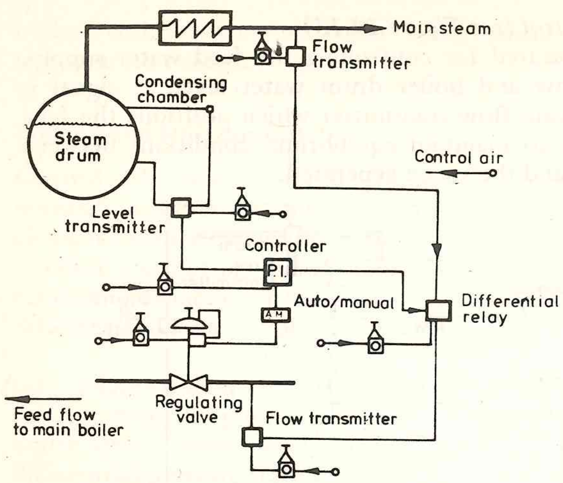


Figure 14.14 Three element feed level control

The operating principle is to maintain the relationship between the steam flow and the feed water flow (see Figure 14.14). Any change in this relationship will generate a correcting signal to bring the system back to equilibrium conditions. Under stable conditions, no signal will be generated at the differential relay and the system will be 'single element' only, operating the level in the boiler drum.

Alarms and safeguards

It is a requirement of classification societies that water tube boilers be provided with two means of indicating water level and also two independent water level detection systems.

The diagrammatic sketch in Figure 14.15 illustrates an arrangement of the various alarms, controls and safety systems which provide protection for the boilers in a modern marine steam installation. In this system it will be noted that the level indicators and level sensors are taken from two separate sets of connections on the boiler drum. The advantage of this arrangement is that a failure or malfunction in either of these systems will not prejudice the operation of the other system.

The two differential pressure transmitters derive their input signal from a measure of the differential pressure between two columns of water, one being of constant height and the other varying with the working water level in the boiler.

The output signal from the transmitters provides control signals

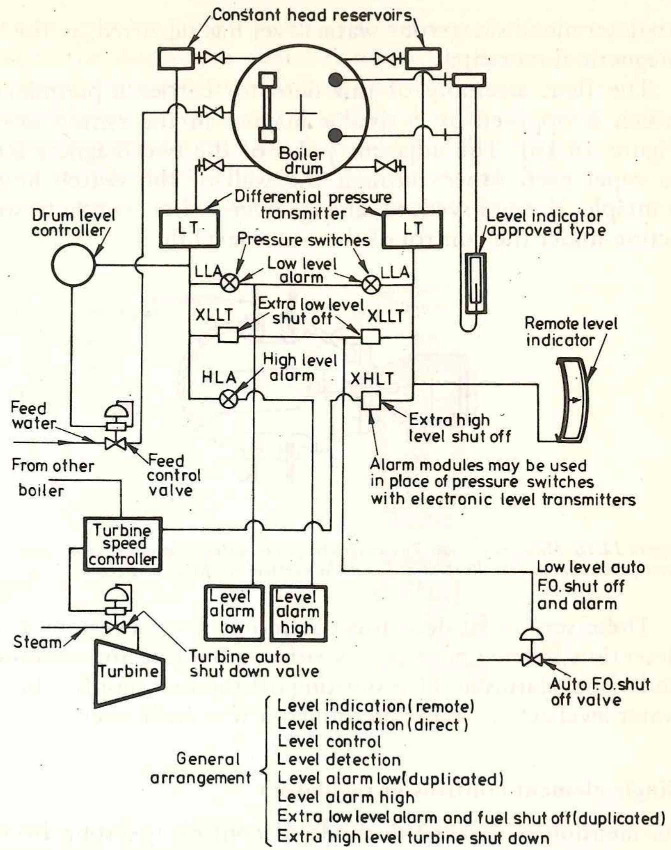


Figure 14.15 Typical arrangement of alarms and controls

to feed water level control and boiler drum level indication. Additionally these output signals may be used for water level alarms, automatic fuel oil shut off in the event of low water level, and main turbine trip at the manoeuvring valve for the extra high water level condition.

Level indicators and controllers

Level indicators have been comprehensively dealt with in chapter 13. It is well to mention here however that an indicator or detector commonly used to operate alarms and/or fuel shut-offs, when a