BRITISH STANDARD

BS 7201-1:
1989

*Incorporating Amendment Nos. 1, 2 and 3*

# Hydraulic fluid power — Gas loaded accumulators —

## Part 1: Specification for seamless steel accumulator bodies above 0.5 L water capacity

ICS 23.100.99

# Committees responsible for this British Standard

The preparation of this Part of this British Standard was entrusted by the Machinery and Components Standards Policy Committee (MCE/-) to Technical Committee MCE/18, upon which the following bodies were represented:

Advanced Manufacturing Technology Research Institute
Association of British Mining Equipment Companies
Bath University Library
British Compressed Air Society
British Fluid Power Association
British Hydromechanics Research Association
British Steel Industry
British Telecommunications plc
Department of Trade and Industry (National Engineering Laboratory)
Electricity Supply Industry in England and Wales
Federation of Manufacturers of Construction Equipment and Cranes
Institution of Mechanical Engineers
Ministry of Defence

This British Standard, having been prepared under the direction of the Machinery and Components Standards Policy Committee, was published under the authority of the Board of BSI and comes into effect on 30 March 1990



The following BSI references relate to the work on this standard:
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# Contents

# Foreword

This Part of BS 7201 has been prepared under the direction of the Machinery and Components Standards Policy Committee. It is the first of a series for the materials, design, construction, testing and maintenance of accumulator bodies intended for use in fluid power hydraulic systems. When fully assembled the accumulator body houses an elastomeric separator bag which is precharged with nitrogen gas. This Part of this standard closely follows the requirements for transportable gas containers specified in BS 5045-1. If additional steelmaking processes are included in BS 5045-1, they may also be added to this standard.

It is expected that the manufacture, inspection and testing of accumulator bodies will be carried out to the satisfaction of an independent testing authority.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

**Compliance with a British Standard does not of itself confer immunity from legal obligations.**

**Summary of pages**

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 28, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

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# Section 1. General

## 1 Scope

This Part of BS 7201 specifies requirements for the materials, design, calculations, manufacture and performance of seamless steel accumulator bodies having a water capacity greater than 0.5 L.

It does not specify requirements for the design of body end shape and dimensions.

It includes appendices which give examples of design calculations and specimen certificates, and which describe methods for pressure testing and ultrasonic examination of the accumulator body.

NOTE The titles of the publications referred to in this Part of this British Standard are listed on the inside back cover.

## 2 Definition

For the purposes of this Part of this British Standard the following definition applies.

**independent inspecting authority**
a third party certification body, independent of the manufacturer, who verifies that accumulator bodies comply with this Part of this standard

## 3 Symbols

For the purposes of this Part of this British Standard the following symbols apply.

| Symbol | Description | Unit |
|---|---|---|
| $C$ | The compressibility of water | mL |
| $D_1$ | Maximum internal diameter of accumulator body | mm |
| $e$ | Minimum spherical wall thickness to resist pressure and external forces but excluding any additional thickness for corrosion and any other influences | mm |
| $E_p$ | Permanent expansion of accumulator body | mL |
| $E_t$ | Total expansion of accumulator body | mL |
| $E_v$ | Total volumetric expansion of accumulator body | mL |
| $f_b$ | Nominal hoop stress at which destruction of accumulator body occurs | N/mm$^2$ |
| $f_e$ | Maximum permissible equivalent stress at design pressure (see Table 2), either: $f_e = 0.5\ Y$ of the material of construction, or $f_e = 0.38\ T$ of the material of construction, whichever is the least | N/mm$^2$ |
| $K$ | Factor for the compressibility of water (see Table 5) | — |
| $l$ | Length of additional reinforcement of area Y (see Figure 3) | mm |
| $m$ | Mass of water at test pressure, $P_1$ | kg |
| $P$ | Pressure, i.e. design or maximum permissible | bar[a] |
| $P_1$ | Test pressure (applicable to design $P_1 = 1.5\ P$) | bar |
| $P_b$ | Internal pressure at which destruction of accumulator body occurs | bar |
| $R$ | Percentage ratio of permanent expansion to total expansion | % |
| $S_o$ | Minimum elongation | % |
| $t$ | Minimum cylindrical wall thickness to resist pressure and external forces but excluding any additional thickness for corrosion and any other influences | mm |
| $t^1$ | Actual wall thickness of accumulator body | mm |
| $T$ | Tensile strength of material of construction (see Table 2) | N/mm$^2$ |
| $Y$ | Minimum specified yield stress (see Table 2) | N/mm$^2$ |

[a] 1 bar = 0.1 N/mm$^2$ = 0.1 MPa.

## 4 Information to be exchanged

In addition to the definitive requirements, this Part of this standard also requires the items detailed in Appendix A to be documented. For compliance with this Part, both the definitive requirements and the documented items have to be satisfied.

## 5 Certificate of compliance

The manufacturer shall certify that the manufacture, inspection and testing of the accumulator body were carried out in compliance with the requirements of this standard.

NOTE It is expected that an independent inspecting authority will verify the above certification. A suitable form of certificate is shown in Appendix B.

# Section 2. Materials

## 6 General

Accumulator bodies shall be made only from materials whose compositions are given in Table 1. The mechanical properties of the finished container shall be as specified in Table 2.

## 7 Chemical composition

**7.1** The ladle analyses shall comply with the appropriate requirements of Table 1.

In the event of one melt being divided between more than one ladle, samples shall be analysed from each ladle and separate analyses provided for each ladle. Each of these ladles shall subsequently be regarded as a specific cast and identified accordingly.

**7.2** Variation between the product analysis and the ladle analysis, which occurs because of heterogeneity arising during the casting and solidification of the ingot, shall not exceed the permissible deviations given in Table 3 and Table 4.

NOTE 1 Product analysis is any analysis of the steel subsequent to the ladle analysis.

The deviations are permitted in the individual elements either above or below the specified range but shall not be applied both above and below the specified range for any one element from any one ladle of steel.

NOTE 2 When maxima only are specified in Table 1, the deviations are positive only.

**7.3** Any ingot, bar or container that, on chemical analysis, is outside the limits of permissible deviation from the composition range specified in Table 1 for a specified element shall be deemed not to comply with the requirements of this Part of this standard.

**7.4** In the event of a single sample falling outside the permissible deviations given in Table 3 and Table 4 on the product analysis, further samples shall be selected for check analysis from the remainder of the consignment, as follows:

a) at least two samples from the same ladle for delivered mass up to 5 t;

b) at least five samples from the same ladle for delivered masses up to 20 t;

c) at least eight samples from the same ladle for delivered masses over 20 t.

These samples shall fall within the permissible deviations given in Table 3 and Table 4. If any of these further samples are proved to be outside the permissible deviations for any specified element, the consignment shall be deemed not to comply with the requirements of this Part of this standard.

**7.5** Samples for product analysis shall be taken in accordance with BS 1837.

## 8 Steelmaker's certificate

The steelmaker shall have supplied a certificate stating:

a) the steelmaking process, and

b) the ladle analysis.

## 9 Identification of steel

The steel shall be marked and records shall be kept so as to enable the cast from which each body is made to be identified.

**Table 1 — Steelmaking process and chemical composition**

| Material | Code | Steelmaking process | Chemical composition | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Carbon | | Silicon | | Manganese | | Phosphorus | Sulphur | Chromium | | Molybdenum | | Nickel | |
| | | | min. | max. | min. | max. | min. | max. | max. | max. | min. | max. | min. | max. | min. | max. |
| | | | % | % | % | % | % | % | % | % | % | % | % | % | % | % |
| Carbon steels | M | Electric furnace or basic oxygen process. Steels made by the oxygen process shall not contain more than 0.008 % of nitrogen | 0.15 | 0.25 | 0.05 | 0.35 | 0.40 | 0.90 | 0.050 | 0.050 | — | — | — | — | — | — |
| | C | | 0.35 | 0.45 | 0.05 | 0.35 | 0.60 | 1.00 | 0.050 | 0.050 | — | — | — | — | — | — |
| | | | — | 0.45 | | 0.40 | | 1.05 | 0.045 | 0.045 | — | — | — | — | — | — |
| Carbon manganese steels | Mn and MnH | | — | 0.40 | 0.10 | 0.35 | 1.30 | 1.70 | 0.050 | 0.050 | — | — | — | — | — | — |
| Chromium molybdenum alloy steel | CM | Electric furnace or basic oxygen process | — | 0.37 | 0.10 | 0.35 | 0.40 | 0.90 | 0.050 | 0.050 | 0.80 | 1.20 | 0.15 | 0.25 | — | 0.50[a] |
| | | | 0.31 | 0.38 | 0.10 | 0.40 | 0.60 | 0.90 | 0.035 | 0.035 | 0.90 | 1.20 | 0.15 | 0.40 | — | 0.50[a] |
| Nickel chromium molybdenum alloy steel | NCM | | 0.27 | 0.35 | 0.10 | 0.35 | 0.50 | 0.70 | 0.050 | 0.050 | 0.50 | 0.80 | 0.40 | 0.70 | 2.30 | 2.80 |

[a] Residual nickel.

**Table 2 — Heat treatment and mechanical properties of steel in finished accumulator bodies[a]**

| Material | Code | Heat treatment | Tensile strength (*T*) Min. | Tensile strength (*T*) Max. | Minimum yield stress (*Y*)[b] | Maximum permissible equivalent stress at design pressure ($f_e$) | Minimum elongation on $5.65\sqrt{S_o}$ | Maximum radius of bend test forming tool[c] |
|---|---|---|---|---|---|---|---|---|
| | | | $N/mm^2$ | $N/mm^2$ | $N/mm^2$ | $N/mm^2$ | % | |
| Carbon steels | M | Normalized or normalized and tempered | 430 | 510 | 250 | 125 | 22 | 1½ $t_a$ |
| | C | Normalized or normalized and tempered | 570<br>550 | 680<br>680 | 310<br>310 | 155<br>155 | 19 | 2 $t_a$ |
| Carbon manganese steels | Mn | Normalized or normalized and tempered at not less than 550 °C and cooled in air | 650 | 760 | 445 | 222.5 | 20 | 2½ $t_a$ |
| | MnH | Hardened from 800 °C to 850 °C and tempered at 530 °C to 670 °C | 890 | 1 030 | 755 | 338 | 14 | 3 $t_a$ |
| Chromium molybdenum alloy steel | CM | Hardened from 850 °C to 920 °C and tempered at 550 °C to 720 °C | 890<br>900<br>960<br>965 | 1 030<br>1 040<br>1 100<br>1 105 | 755<br>710<br>780<br>810 | 338<br>342<br>365<br>367 | 14 | 3 $t_a$ |
| Nickel chromium molybdenum alloy steel | NCM | Hardened from 820 °C to 850 °C and tempered at 550 °C to 660 °C | 890 | 1 030 | 755 | 338 | 14 | 3 $t_a$ |

[a] For hardness properties see Figure 1.

[b] Yield stress refers to the upper yield stress ($R_{eh}$) or, if applicable, the 0.2 % non-proportional elongation proof stress ($R_{p0.2}$). Values in excess of this should not be used for calculation purposes.

[c] $t_a$ is the actual thickness of the specimen.

**Table 3 — Permissible deviation on product analysis from specified range for carbon and carbon manganese steels**

| Element | Maximum of the specified range | Permissible deviation on product analysis[a] |
|---|---|---|
| | % | % |
| Carbon | ⩽ 0.25 | 0.02 |
| | > 0.25 to 0.50 | 0.03 |
| Silicon | | 0.03 |
| Manganese | ⩽ 1.0 | 0.04 |
| | > 1.0 to 1.5 | 0.08 |
| | > 1.5 | 0.10 |
| Phosphorus | | 0.008 |
| Sulphur | | 0.008 |

[a] Maximum and minimum values do not apply simultaneously for individual elements (see **7.2**).

**Table 4 — Permissible deviation on product analysis from specified range for alloy steels**

| Element | Maximum of the specified range | Permissible deviation on product analysis[a] |
|---|---|---|
| | % | % |
| Carbon | ⩽ 0.25 | 0.01 |
| | > 0.25 to 0.50 | 0.02 |
| Silicon | | 0.03 |
| Manganese | ⩽ 0.70 | 0.03 |
| | > 0.70 to 1.0 | 0.04 |
| | > 1.0 to 2.0 | 0.05 |
| Phosphorus | | 0.004 |
| Sulphur | | 0.005 |
| Chromium | ⩽ 0.60 | 0.03 |
| | > 0.60 to 1.25 | 0.04 |
| Molybdenum | ⩽ 0.50 | 0.02 |
| | > 0.50 | 0.03 |
| Nickel | ⩽ 1.0 | 0.03 |
| | > 1.0 to 3.0 | 0.05 |

[a] Maximum and minimum values do not apply simultaneously for individual elements (see **7.2**).

# Section 3. Design

## 10 Design calculations for cylindrical wall thickness and spherical formed ends with openings

NOTE An example of design calculations is given in Appendix B.

### 10.1 Thickness of cylindrical wall

The thickness of the cylindrical wall, $t$, in mm, shall be equal to or greater than the value given by both equation (1) and equation (2):

$$t = \frac{0.3\,P\,D_i}{7\,f_e - P} \qquad (1)$$

$$t \geqslant 2.48\sqrt{\left(\frac{D_i}{T}\right)} \qquad (2)$$

where

- $P$ is the pressure (in bar);
- $D_i$ is the maximum internal diameter of accumulator body (in mm);
- $f_e$ is the maximum permissible equivalent stress at design pressure (in N/mm$^2$);
- $T$ is the tensile strength of the material of construction (in N/mm$^2$).

NOTE Influences other than those of internal pressure and external forces due to ordinary handling may require the provision of additional wall thicknesses above the calculated values. Additional thickness may be necessary to allow for corrosion during service (see **B.1**).
The variety of conditions occurring in practice make it impracticable to give general requirements for the necessary allowances. They should be carefully considered and agreed upon in each particular case by the manufacturer and the user of the accumulator.

### 10.2 Thickness of spherical formed ends

The thickness of the spherical formed ends of the body, $e$, in mm, shall be not less than the value given by:

$$e = \frac{[PD_i]}{40\,f_e - 1.2P} \qquad (3)$$

### 10.3 Reinforcement of openings in spherical formed ends

Openings in spherical formed ends shall be reinforced by compensating for the material removed.

NOTE One empirical method, which is widely used and which has been proved to be satisfactory for bodies produced by forging or spinning the spherical ends, is described in Appendix B.

# Section 4. Manufacture

## 11 Approval of design and construction details

Before manufacture is commenced, three copies of detailed drawings showing each new design of accumulator body together with the method of manufacture shall be submitted to the independent inspecting authority for approval [see **A.2** g)].

NOTE Alterations should not be made to the design or method of manufacture after approval unless such alteration has received prior agreement of the independent inspecting authority.

## 12 Manufacturing processes

The accumulator body shall be made from:

a) billets, pierced hot or cold (back extruded) followed by hot and/or cold drawing, or

b) plates, cupped hot or cold, followed by hot and/or cold drawing, or

c) seamless tube manufactured by extrusion or other process and subsequently hot and/or cold drawn as necessary.

The bodies shall be made only by processes, including heat treatment, that have been shown to produce accumulator bodies free from cracks or other flaws.

Where closure of a tube is necessary in order to form a neck or a base, this shall be carried out by forging, cupping or spinning.

Ends shall not be welded on and metal shall not be added at any time during or after the closing operation.

NOTE Ends may be bored to accept the required end fittings.

## 13 Heat treatment

Each accumulator body, after the completion of all forming operations except the end machined bores, shall be uniformly heat treated to produce the mechanical properties specified in Table 2.

The operations involving heating shall be carried out in temperature controlled furnaces.

NOTE 1 The accumulator body should be maintained at the stipulated temperatures for the length of time necessary to ensure that all parts have reached the required temperature and all necessary metallurgical changes have been effected.

When hardening is involved the quenchant shall be one of the following:

a) oils commonly used for this purpose;

b) liquid quenchants, other than oil.

NOTE 2 The quenching severity should be similar to that of oils commonly used for this purpose.

NOTE 3 The choice of quenchant should take into account the type of steel, size and thickness of accumulator body and changes in profile and section.

The temperature of the bath, concentration of quenchant (where quenchants other than oil are used), time of immersion and the accumulator body temperature on withdrawing should be controlled to ensure that all necessary metallurgical changes have been completed and that possibilities of quench cracking are minimized.

Where normalizing, i.e. air cooling from the austenitizing temperature, or tempering is involved, the accumulator body shall be uniformly cooled in still air.

## 14 Tolerances

The difference between the maximum and minimum external diameters, measured at any cross section of the cylindrical portion of the container, shall not exceed 2.5 % of the mean external diameter at that section.

The wall thickness shall not at any point be less than the thickness of the cylindrical shell, $t$, calculated in accordance with **10.1**.

# Section 5. Performance and testing

## 15 Hardness

When each accumulator body, after final heat treatment, has been hardness tested in accordance with either BS 240 or BS 891-1, using a spherical indentor, the hardness values shall be in accordance with Figure 1 for the tensile range specified in Table 2.

The diameter of the ball and the applied load shall be in accordance with BS 240 or BS 891-1 and shall be such as not to damage the accumulator body.

The indentation shall be placed on the cylindrical portion of the accumulator body. The surface of the accumulator body shall be prepared by lightly polishing, where the impression is to be placed, but the thickness of the wall shall not thereby be reduced below the minimum calculated in accordance with **10.2**.

## 16 Verification of mechanical properties

### 16.1 Test samples

One test sample shall be taken from every batch[1)], except where the number in the batch exceeds 200 accumulator bodies, in which case one sample shall be taken in every 201 or part thereof.

The test sample shall comprise either:

a) material from a finished accumulator body; or

b) in the case of accumulator bodies of large capacity (over 300 mm external diameter) where it has been agreed by the independent inspecting authority that no destructive test shall be carried out, a sample shall be cut from one end of an accumulator body before closure. It shall be in the form of a ring of sufficient size to provide the requisite test pieces, and subjected to a heat treatment such that its mechanical properties are representative of the accumulator body in the batch.

The following tests shall be carried out on each test sample:

1) a tensile test in accordance with **16.2**;

2) a bend test in accordance with **16.3**.

### 16.2 Tensile properties

**16.2.1** The tensile test specimen shall either be:

a) made from a strip cut longitudinally from a finished accumulator body or test ring, and its form and dimensions shall be in accordance with BS 18; or

b) if the dimensions of the accumulator body are such as to preclude the manufacture of a standard test specimen then a non-standard specimen may be used with the agreement of the independent inspecting authority.

The cross section shall be either formed by a portion of the wall of the accumulator body or, when the wall thickness permits, be circular with a diameter of not less than 7 mm for the central portion.

**16.2.2** The tolerance on form, i.e. the difference between maximum and minimum values of a given dimension in any one test piece, for the machined surfaces of a test piece shall be in accordance with grade IT 9 of BS 4500-1.

For test pieces of circular cross section, the machining tolerance on nominal dimensions, i.e. the tolerance that permits the nominal cross section to be used in computing the test results without calculation of the individual cross-sectional area for each test piece, shall be in accordance with grade IT 12 of BS 4500-1.

**16.2.3** The gauge length for test pieces shall be as specified in BS 18. Non-proportional gauge lengths may be used and the conversion, if elongation values are obtained using such lengths, shall be in accordance with BS 3894-1.

**16.2.4** Tensile testing shall be carried out in accordance with BS 18. If individual measurements of the thickness of a test piece, whose two faces are formed by the surfaces of the accumulator body wall differ somewhat from one another, the minimum thickness shall be taken for calculation.

When the parallel length of the specimen, as specified in clause **6** of BS 18:1987, is in excess of the gauge length, either a series of overlapping gauge lengths shall be marked, or gauge marks shall be applied every 5 mm, 10 mm or 20 mm along the parallel length so that the elongation on the specified gauge length can be determined by interpolation.

[1)] The term "batch" indicates a group of accumulator bodies of the same size, design and material heat treated under the same conditions of temperature and duration.

**16.2.5** The tensile testing machine shall comply with grade A of BS 1610-1.

**16.2.6** After the test, the test specimen shall comply with the requirements specified in Table 2.

### 16.3 Bend properties

**16.3.1** Cold bend tests shall be made on four strips cut from the accumulator body or test ring used to provide the tensile test piece. The strips shall be taken either from one ring, or two rings if one is insufficient, cut from the accumulator body or from the test ring where appropriate for large bodies. The width of the test specimen shall be 25 mm or four times the design thickness of the accumulator body (including any corrosion allowance) whichever is the greater.

Where bending of the full thickness of a thick body is impracticable, the test piece may, at the discretion of the independent inspecting authority, be thinned uniformly from the inside surface, in which case the width of the specimen shall be not less than four times its thickness.

**16.3.2** The test pieces shall not be machined on the surfaces corresponding to the outside and inside surfaces of the accumulator body (except for thick accumulator bodies, see **16.3.1**) but the corners may be rounded-off to a radius approximating to 0.25 times the thickness of the test specimen.

The test specimens shall be bent round a forming tool of radius not greater than that given in Table 2 until the gap between the ends of the specimen is not greater than twice the radius of the forming tool. The face of the test specimen that corresponds to the outside surface of an accumulator body shall be in tension during the test and shall remain uncracked.

NOTE The diameter of the rolls supporting the test piece and the distance between them may be varied to suit the specimens being tested in order that the radius of curvature of the forming tool may be made to correspond with that of the specimen.

**16.3.3** The test pieces shall be inspected and shall be unbroken and free from visible cracks on the outside surface.

NOTE Small cracks at the edges of the test pieces may be disregarded.

## 17 Examination for thickness, surface defects and neck folds

### 17.1 Minimum thickness

Each accumulator body shall be examined to determine the minimum thickness, calculated in accordance with clause **10**, either by mechanical means or by the ultrasonic method described in **C.2**. When mechanical means are used, the examination shall be carried out before the closing operation.

### 17.2 Internal and external surface defects

**17.2.1** *Accumulator bodies* ⩾ 375 mm *diameter*. Each accumulator body shall be examined for internal and external surface defects as described in **C.1**.

Any accumulator body having a defect with a dimension more than 5 % of the minimum wall thickness, calculated in accordance with clause **10**, in a direction normal to the inner surface, or with a length greater than 25 mm, shall either have the defect ground out, provided that the final thickness is not less than the minimum wall thickness, or shall be deemed not to comply with this Part of this standard and shall be rendered unserviceable.

Any removal of surface defects by local dressing shall be such that the wall thickness of the dressed area is not less than the minimum wall thickness shown on the manufacturer's drawing.

**17.2.2** *Accumulator bodies* < 375 mm *diameter*. Each accumulator body shall be examined for internal and external surface defects either visually or by the ultrasonic method described in **C.1**. Accumulator bodies continuing to show defects after removal by grinding, as described in **C.1**, at points of minimum design thickness, shall be deemed not to comply with this Part of this standard, and shall be rendered unserviceable.

Any removal of surface defects by local dressing shall be such that the wall thickness of the dressed area is not less than the minimum wall thickness shown on the manufacturer's drawing.

### 17.3 Neck folds

Each accumulator body shall be examined for neck folds by such means as an introscope (see Figure 2). If neck folds are visible, the accumulator body shall be deemed not to comply with this Part of this standard.

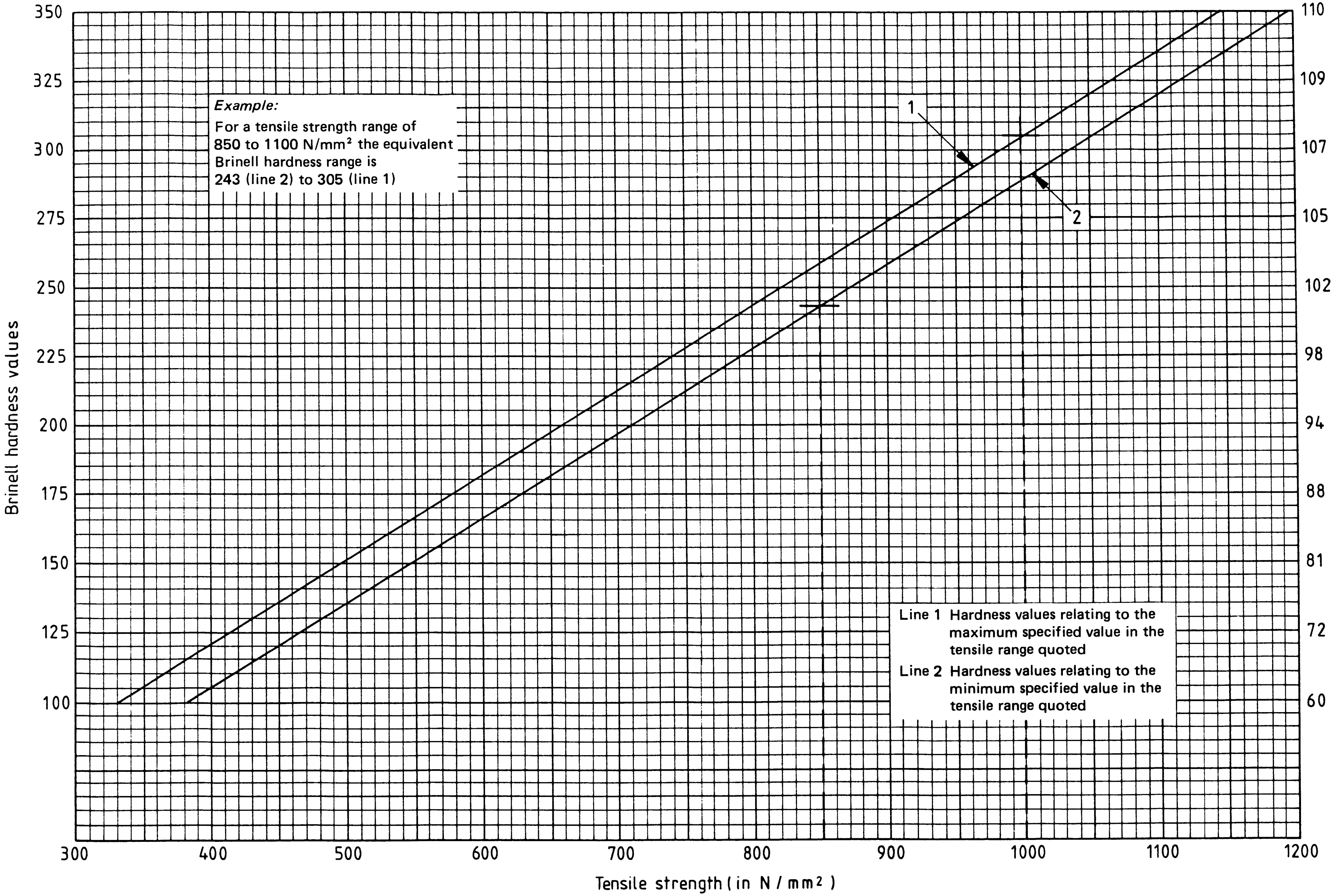


**Figure 1 — Hardness values related to tensile strengths**

## 18 Resistance to hydraulic pressure

### 18.1 General

All accumulator bodies shall be subjected to a hydraulic test.

When the examinations specified in clause **17** are carried out by ultrasonic method, each completed accumulator body other than those used for the tests specified in clause **16**, shall be subjected to either a proof pressure test in accordance with Appendix E or a volumetric expansion test in accordance with Appendix D. When an ultrasonic method is not used, then each completed accumulator body shall be subjected to the volumetric expansion test described in Appendix D.

### 18.2 Test pressure

The test pressure, $P_1$, shall be calculated as described in clause **10**. No pressure greater than 80 % of the test pressure shall have been applied to any accumulator body before this test.

### 18.3 Volumetric expansion

The permanent volumetric expansion, expressed as a proportion of the total expansion under the test pressure, shall not exceed 5 %, when tested either in accordance with Appendix D or another method which is capable of measuring the total and the permanent volumetric expansion, if any, of the accumulator body. If the test is made by the "non-jacket method", the accumulator body shall show no signs of leakage when subjected to the test pressure.

If the permanent volumetric expansion exceeds 5 % of the total expansion under the test pressure, the accumulator body shall be either deemed not to comply with this Part of this British Standard or, provided the accumulator body has no visible deformation, it shall be re-heat treated in accordance with clause **19** and then re-tested.

### 18.4 Proof pressure

When tested in accordance with Appendix E, the accumulator body shall show no signs of leakage, visible deformation or other defects.

## 19 Re-heat treatment

### 19.1 General

No accumulator body shall be normalized or re-heat treated more than three times or tempered more than four times. If, after the permitted number of treatments, an accumulator body does not comply with Table 2 or clause **18**, the body shall be deemed not to comply with this Part of this standard and shall be rendered unserviceable.

If more than five accumulator bodies in a batch are re-heat treated, they shall constitute a new batch for the purposes of **16.1** except in the following cases.

a) When accumulator bodies are found to be too hard, in respect of the requirements of clause **15**, or show too much expansion in respect of the requirements of **18.4**, and are re-heat treated, they need not be considered as constituting a new batch except where the austenitizing temperature of the tempering temperature differs by more than 20 °C from the original temperature.

b) When accumulator bodies are found to be too soft, in respect of the requirements of clause **15**, or show too much expansion in respect of the requirements of **18.4**, and are re-heat treated, they need not be considered as constituting a new batch except where the austenitizing temperature of the tempering temperature differs by more than 20 °C from the original temperature.

### 19.2 Normalized and normalized and tempered steels [codes M, C and Mn (see Table 1)]

Accumulator bodies that have only been normalized shall be either tempered or re-normalized or re-normalized and tempered. Accumulator bodies that have been normalized and tempered shall be either re-tempered or re-normalized or re-normalized and tempered.

### 19.3 Hardened and tempered steels [codes MnH, CM and NCM (see Table 1)]

Accumulator bodies shall be either re-tempered or be re-hardened and tempered.

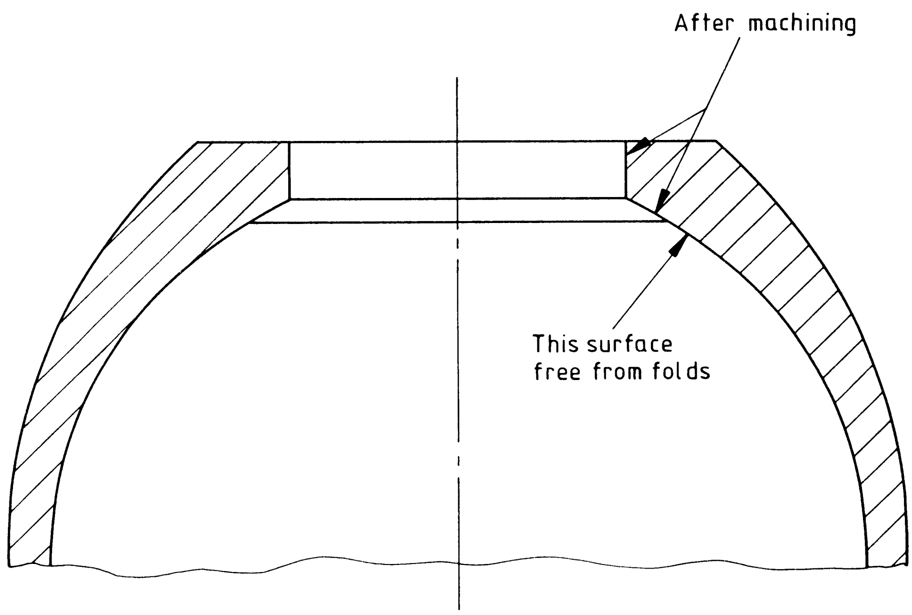


**Figure 2 — Accumulator body after machining**

## 20 New design

For the purposes of **21.1.1** and **21.1.2**, an accumulator body shall be considered a new design compared with an existing approved design when:

a) it is manufactured in a different factory; or

b) it is manufactured by a different process; or

c) it is manufactured from a steel of different nominal chemical composition; or

d) it is given a different heat treatment; or

e) the base profile and the base thickness have changed relative to the accumulator body diameter and calculated minimum wall thickness; or

f) the guaranteed minimum yield stress has changed by more than 50 N/mm$^2$; or

g) the length of the accumulator body has increased by more than 50 % (accumulator bodies with an L/D ratio less than 3 shall not be used as reference accumulator body for any new design with an L/D ratio greater than 3); or

h) the diameter has changed by more than 5 %; or

i) a change in hydraulic test pressure requires a change in design wall thickness. Where an accumulator body is to be used for a lower pressure duty than that for which design approval has been given, it shall not be deemed to be of a new design.

## 21 Prototype accumulator bodies

### 21.1 Pressure cycling and burst resistance

**21.1.1** ***Pressure cycling***

**21.1.1.1** Three accumulator bodies from the first batch made to a new design (see clause **20**) shall be submitted to the following pressure cycling test in addition to the tests specified in clauses **15**, **16**, **18**, **20** and **23**, except for large accumulator bodies, or small batches where this test is impracticable.

NOTE The independent inspecting authority should be consulted.

**21.1.1.2** The test shall be carried out using a non-corrosive fluid with the difference between the maximum and minimum pressure equivalent to either 0.9 or 0.6 times the test pressure of the accumulator body. The value of the lower cyclic pressure shall not exceed 10 % of the upper cyclic pressure. The frequency of reversals shall not exceed 15 cycles/min. The temperature measured on the outside surface of the accumulator body shall not exceed 50 °C during the test.

The accumulator bodies shall complete either:

a) 12 000 cycles over a range equivalent to 0.9 times test pressure; or

b) 80 000 cycles over a range equivalent to 0.6 times test pressure;

without any signs of leakage.

**21.1.2** *Burst resistance.* Following the test specified in **21.1.1**, two of the accumulator bodies shall be hydraulically pressure tested to destruction. The remaining accumulator body shall be either hydraulically pressure tested or pressure cycle tested in accordance with **21.1.1** to destruction. Each accumulator body shall remain in one piece after bursting.

The nominal hoop stress, $f_b$, in N/mm$^2$, corresponding to the pressure at which destruction occurs shall be calculated from the equation:

$$f_b = \frac{P_b D_i}{20t'}$$

where

- $P_b$ is the internal pressure at which destruction occurs (in bar);
- $D_i$ is the internal diameter of the accumulator body (in mm);
- $t'$ is the actual wall thickness of the accumulator body being tested (in mm).

The value of $f_b$ shall be not less than 0.95 of the minimum tensile strength of the material of the accumulator body given in Table 2.

## 22 Checking of water capacity

The water capacity of each accumulator body shall be at least the minimum specified water capacity [see **24** e)]. It shall be checked and recorded.

NOTE Water capacity may be checked by either filling the accumulator body with a calibrated volume of liquid or by other means approved by the independent inspecting authority.

## 23 Records and retests

**23.1** A record shall be kept of all tests made at the manufacturer's works.

**23.2** If any of the test specimens do not comply with the mechanical tests specified in clause **16**, at the manufacture's discretion, the following shall apply:

a) either the test in which the failure occurred shall be repeated on the accumulator body or test ring originally tested and, in addition, the tests specified in **16.2** and **16.3** shall be carried out on another accumulator body or test ring from the same batch. If both accumulator bodies or both test rings then comply with **16.2** and **16.3**, the batch shall be deemed to comply with this Part of this standard; or

b) the batch shall be re-heat treated as specified in clause **19** and retested in accordance with **16.2** and **16.3**. In the case of accumulator bodies that have been re-heat treated the tests shall be carried out on an accumulator body that has not been previously tested, but in all other cases the retests shall be carried out on material cut from the original test accumulator body provided that this material has been subjected to the same re-heat treatment as the batch of accumulator bodies it represents.

**23.3** If any of the test specimens fail to pass the retests specified in **23.2**, the batch may be subsequently re-heat treated and retested to the maximum number of times specified in **19.1**.

Not more than five accumulator bodies or test rings from one batch shall be retested.

**23.4** If after the specified number of retests and re-heat treatments the test specimens do not comply with clause **16**, the batch represented shall be deemed not to comply with this Part of this standard and shall be rendered unserviceable.

## 24 Marking of accumulator bodies

Each accumulator body shall be permanently and legibly marked with the following information:

a) the manufacturer's mark and accumulator body serial number on the spherical formed ends;

b) the design or maximum permissible pressure (in bar);

c) the test pressure (in bar) and date of the hydraulic test specified in clause **18**, indicated by the month and year or by the year, and the identification mark of the person or organization who carried out the test;

d) the identification mark(s) of the independent inspecting authority;

e) the number and date of this Part of this British Standard, i.e. BS 7201-1:1989, and the appropriate code mark (see Table 1) of the material of construction, e.g. BS 7201/1/89/CM;

f) the gas volume of the accumulator body.

All the markings specified in items a) to f) shall be placed on one of the spherical formed ends where the thickness of metal is greater than the minimum design thickness. The markings shall not be made on the parallel surface of the body.

To establish the thickness of the metal at the ends of the accumulator body and the areas suitable for marking, a prototype accumulator body shall be sectioned at the ends and the suitable areas should be agreed between the manufacturer and the independent inspecting authority.

Another prototype accumulator body shall also be similarly sectioned and examined after marking. The marking shall cause no change in contour of the accumulator body. The characters in the marking should normally be at least 6 mm in height, on small accumulator bodies this height may be reduced, but in no case shall the characters be less than 3 mm in height.

## Appendix A Exchange of information

### A.1 Information to be supplied by the purchaser to the manufacturer

The purchaser shall inform the manufacturer of his requirements selected from the following, as appropriate:

a) volumetric capacity of the accumulator body;

b) material of construction;

c) preferred dimensions;

d) external/internal finish required;

e) any special or adverse conditions under which the accumulator body will be required to operate and any corrosion allowance required (see note to **10.1**);

f) any requirements additional to those specified in this Part of this British Standard;

g) the name of the independent inspecting authority.

### A.2 Information to be supplied by the manufacturer to the purchaser

The manufacturer shall provide the purchaser with the following information:

a) sectional drawing of the accumulator body showing the minimum metal condition;

b) volumetric capacity;

c) material of construction;

d) test pressure;

e) design or working pressure;

f) proof design approval (see clause **11**);

g) method of manufacture;

h) drawing showing layout of stamped marking (see clause **24**);

i) test certificates for the material and accumulator body (see Appendix F).

## Appendix B Design examples

### B.1 Reinforcement of openings in spherical formed ends

The following method of compensation is widely used and experience has proved it to be satisfactory for accumulator bodies produced by forging or spinning the spherical ends.

Compensate for the locally removed material (cross-sectional area X in Figure 3) by adding material around the opening which has a cross-sectional area (area Y in Figure 3) equal to or greater than the area of material removed.

An example of such a calculation for reinforcement is shown in **B.2.2**.

### B.2 Design calculations

**B.2.1** ***Example 1. Cylindrical wall thickness***

An accumulator body having an internal diameter of 202 mm, $D_i$, is to be made from nickel chromium molybdenum alloy steel to the chemical composition given in Table 1 for a design pressure, $P$, (or maximum allowable working pressure) of 345 bar and a machined opening at the spherical end equal to 90 mm diameter. The minimum yield stress and the minimum tensile strength specified by the accumulator body manufacturer are 755 N/mm$^2$ and 890 N/mm$^2$ respectively.

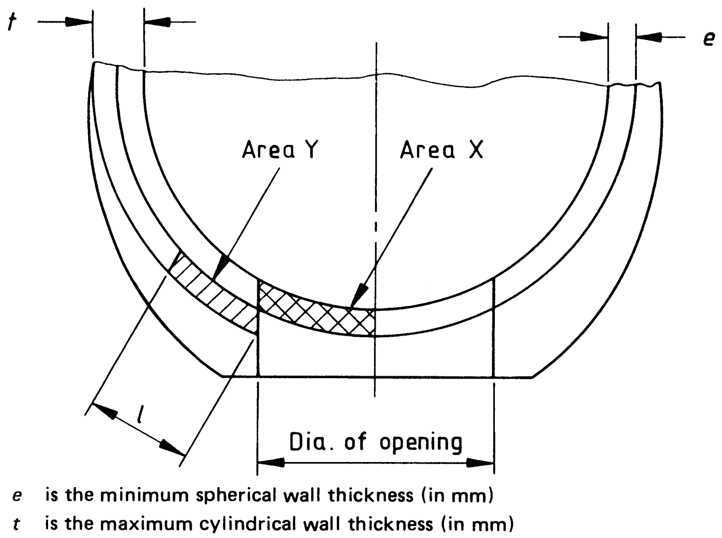


**Figure 3 — Area of reinforcement of spherical formed ends**

Minimum thickness of cylindrical wall, *t*, in mm, according to **10.1**, is calculated from equation (1), i.e. :

$$t = \frac{0.3\,P\,D_i}{7\,f_e - P}$$

where

$P$ = 345 bar

$D_i$ = 202 mm

$f_e$ = 0.5 × 755 N/mm$^2$

= 377.5 N/mm$^2$, or

$f_e$ = 0.38 × 890 N/mm$^2$

= 338.2 N/mm$^2$

thus

$$t = \frac{0.3 \times 345 \times 202}{(7 \times 338.2) - 345}$$

= 10.34 mm.

However, the minimum thickness of the cylindrical wall, *t*, in mm, specified in **10.1**, is not to be less than the value given by equation (2), i.e.:

$$t = 2.48\sqrt{\left(\frac{D_i}{T}\right)}$$

thus

$$t = 2.48\sqrt{\left(\frac{202}{890}\right)} = 1.18 \text{ mm}$$

As this thickness is less than the value calculated from equation (1) the minimum required wall thickness is 10.34 mm.

**B.2.2** ***Example 2. Reinforcement of spherical formed ends***

The minimum thickness of the spherical formed ends, *e*, in mm, according to **10.2**, is calculated from equation (3) i.e.:

$$e = \frac{P D_i}{40 f_e - 1.2 P}$$

$$= \frac{345 \times 202}{(40 \times 338.2) - (1.2 \times 345)}$$

$$= 5.31 \text{ mm min.}$$

The additional reinforcement thickness, *t*, in mm, of area Y in Figure 3 is calculated as follows:

$t - e$

$= 10.34 - 5.31$

$= 5.03$ mm min.

The additional reinforcement length, *l*, in mm, of area Y in Figure 3 is calculated as follows:

area Y = area X

$$5.03\, l = \frac{90\, e}{2}$$

$$= \frac{5.31 \times 45}{5.03}$$

$$= 47.5 \text{ mm min.}$$

## Appendix C Ultrasonic defect detection and thickness measurement

### C.1 Defect detection

**C.1.1** ***General***

Each accumulator body shall be examined ultrasonically using the distance amplitude technique described in BS 4124.

Accumulator bodies less than 375 mm external diameter shall be tested for defects in the parallel walls. Accumulator bodies of 375 mm and larger diameters shall be tested at the ends in addition to the testing of the parallel walls.

**C.1.2** ***Reference reflector***

**C.1.2.1** A reference reflector of a convenient length shall be prepared from an accumulator body of similar diameter and wall thickness, material, surface finish and metallurgical condition to the accumulator body to be inspected. It shall be free from discontinuities which may interfere with the detection of the reference notches.

**C.1.2.2** A longitudinal and a transverse reference notch shall be introduced on the outer and inner surfaces of the reference reflector. If the transverse and longitudinal notches are positioned within 25 mm of each other, the pairs of notches on the inner and outer surfaces shall be separated by at least 50 mm along the axis of the reflector.

The notches shall be 25 ± 0.25 mm long and their width shall be not more than twice the nominal depth. The notches shall be 5 % of the minimum wall thickness.

The tolerance on depth shall be ± 10 % of the nominal notch depth with a minimum depth of 0.025 mm. The cross section of the notch shall be nominally of rectangular section but if spark erosion methods are employed the bottom of the notch may be rounded.

**C.1.3** ***Scanning procedure***

**C.1.3.1** *Parallel walls of accumulator bodies.* The accumulator body to be inspected and the probe shall have a rotating motion and a translation relative to one another such that a helical scan of the accumulator body surface will be described. The speed of rotation and translation shall be constant within ± 10 %. The pitch of the helix shall be less than the probe diameter and shall be related to the effective beam width so as to ensure 100 % coverage at the speeds and feeds used during the calibration procedure.

Inspect the accumulator body wall for longitudinal defects with the ultrasonic energy transmitted in both circumferential directions and for transverse defects in both longitudinal directions.

Periodically check the calibration of the equipment by subjecting the reference reflector to the test procedure. Carry out this check at intervals of not more than 1 h or after 30 accumulator bodies have been tested. If during this check the presence of the appropriate notch is not indicated, then all accumulator bodies tested after the last acceptable calibration shall be retested after recalibration has been accomplished.

**C.1.3.2** *Ends of accumulator body.* Manually examine the entire surface of the ends using a 45° angle probe.

NOTE In order to ensure complete coverage it is recommended that the ends be divided into four segments, each segment being completely examined in turn.

The following scans shall be used:

a) with the probe parallel to the longitudinal axis;

b) with the probe at right angles to the longitudinal axis.

Carry out each scan first with the probe pointing in one direction and then repeat with the probe reversed.

In addition, carry out a scan at the root of the neck with the probe held at an angle of 45° to the longitudinal axis of the accumulator body and then repeat with the probe turned through 90°. The scans shall be made using probes with maximum dimensions between 10 mm and 20 mm.

Scans shall begin or terminate at points 50 mm along the parallel part of the accumulator body and individual scans shall overlap the previous scan by 25 %.

**C.1.4** ***Assessment of results***

Accumulator bodies not showing a defect indication, i.e. one that is equal to or greater than the lesser indication of the notches in the reference reflector, shall be considered as having passed ultrasonic inspection.

If surface defects are removed by grinding, after correction, the accumulator bodies shall be resubmitted to ultrasonic defect detection and thickness measurement described in **C.2**.

### C.2 Thickness measurement

**C.2.1** ***General***

Each accumulator body shall be examined ultrasonically by either a pulse echo or a resonance technique, in accordance with BS 4124, as appropriate, using either contact or immersion methods to ensure that its thickness is not less than the design minimum.

**C.2.2** ***Equipment***

The test equipment shall be capable of indicating a given thickness of material to an accuracy within ± 2.5 % of the set value.

**C.2.3** ***Reference reflector***

Where possible, a reference reflector shall be provided of similar diameter, material, surface finish and metallurgical condition to the accumulator body under test and with a diameter machined or ground to the minimum design thickness (see clause **10**). When it is not possible to provide such a reflector, a flat reference reflector shall be used.

**C.2.4** ***Calibration of equipment***

Using the reference reflector described in **C.2.3**, adjust the equipment to produce a reject signal when the indicated thickness is less than a value equal to 2.5 % greater than the minimum design thickness.

Calibrate the equipment with the reference reflector and/or probe moving in the same manner, in the same direction and at the same speed as specified in **C.1.3.1**.

**C.2.5** ***Procedure***

Helically scan each accumulator body as described in **C.1.3.1** to check that the thickness is nowhere less than the specified minimum.

**C.2.6** ***Assessment of results***

Accumulator bodies that are not acceptable when examined on a go, no-go basis shall be re-examined using equipment capable of giving an actual physical measurement.

## Appendix D Volumetric expansion testing of seamless accumulator bodies

### D.1 General

This appendix gives details of two methods for determining the volumetric expansion of seamless steel accumulator bodies:

a) the water jacket method (preferred method);

b) the non-water jacket method.

The water jacket volumetric expansion test may be carried out on equipment with a levelling burette or with a fixed burette.

Steady temperature conditions shall be maintained and sufficient time shall be allowed to permit the apparatus, the accumulator body and the water to attain a uniform constant temperature.

### D.2 Apparatus

NOTE The test equipment is common to both methods of test.

**D.2.1** *Hydraulic test pressure pipelines,* capable of withstanding pressures twice the maximum test pressure of any accumulator body that may be tested.

**D.2.2** *Glass burettes,* of sufficient length to receive water equivalent to the full volumetric expansion of the accumulator body and of being read to an accuracy of 1 % or 0.1 mL.

**D.2.3** *Pressure gauges,* in accordance with industrial class 1 of BS 1780-2. They shall be tested at regular intervals and in any case not less frequently than once a month.

**D.2.4** *A device* to ensure that the test pressure of the accumulator body is not exceeded by more than 3 % or 10 bar whichever is the lower.

**D.2.5** *Pipework,* preferably utilizing long bends rather than elbow fittings with pressure pipes being as short as possible. Flexible tubing shall be capable of withstanding twice the maximum test pressure of any accumulator body that may be tested and have sufficient wall thickness to prevent kinking.

NOTE Care should be taken to avoid trapping air in the system.

**D.2.6** *Joints* which shall be leaktight.

### D.3 Water jacket method

**D.3.1** ***Principle***

The water-filled accumulator body is enclosed in a jacket which is filled with water. The total volumetric expansion of the accumulator body is measured by the amount of water displaced from the jacket when the accumulator body has been pressurized. The permanent volumetric expansion of the accumulator body is measured by the amount of water that continues to be displaced from the jacket when the pressure has been released.

**D.3.2** ***Apparatus***

**D.3.2.1** *A safety device,* fitted to the water jacket capable of releasing the energy from any accumulator body that may burst at the test pressure.

**D.3.2.2** *An air bleed valve,* fitted to the highest point of the jacket.

**D.3.3** ***Procedure***

**D.3.3.1** *General.* Two methods of performing this test are described in **D.3.3.2** and **D.3.3.3**.

**D.3.3.2** *Levelling burette method*

NOTE 1 Figure 4 shows an example of the required equipment but other types of installation may also be acceptable.

Fill the accumulator body with water and attach the water jacket cover to it. Seal the accumulator body in the jacket and attach the pressure line to the accumulator body. Fill the jacket with water, allowing air to bleed-off through the air-bleed valve. Close the air-bleed valve when water issues freely from it. Adjust the zero level on the burette to the datum mark on the burette support stand. Adjust the height of the water to the burette zero level by manipulation of the jacket filling valve and the drain valve. Raise the pressure in the accumulator body to two-thirds of the test pressure. Close the hydraulic line valve and check that the burette reading remains constant.

NOTE 2 A rising water level indicates a leaking joint between accumulator body and jacket. A falling water level indicates a leaking joint between water jacket and atmosphere.

Open the hydraulic line valve and continue the pressurization of the accumulator body until the test pressure is reached. Close the hydraulic pressure line valve.

Lower the burette until the water level is at the datum mark on the burette support stand. Take the reading of the water level in the burette. Record this reading as the total expansion on the test certificate.

Release the pressure from the accumulator body, raise the burette until the water level is again at the datum line on the burette support stand. Check that the pressure is at zero and that the water level is constant.

Read the water level in the burette. Record this reading as the permanent expansion, $E_p$, if any, on the test certificate.

Check the ratio, $R$, of permanent expansion, $E_p$, to total expansion, $E_t$, does not exceed 5 % as determined by the following:

$$R = \left(\frac{E_p}{E_t}\right) 100$$

**D.3.3.3** *Fixed burette method*

NOTE 1 Figure 5 shows an example of the required equipment but other types of installation may also be acceptable.

Fill the accumulator body with water and attach the water jacket cover to it. Seal the accumulator body in the jacket and attach the pressure line to the accumulator body. Fill the jacket with water, allowing air to bleed-off through the air-bleed valve. Close the air-bleed valve when water issues freely from it. Adjust the water level to zero mark on the burette. Raise the pressure in the accumulator body to two-thirds of the test pressure. Close the hydraulic pressure supply valve and check that the burette reading remains constant.

NOTE 2 A rising water level indicates a leaking joint between accumulator body and jacket. A falling water level indicates a leaking joint between water jacket and atmosphere.

Open the hydraulic pressure line valve and continue the pressurization of the accumulator body until the test pressure is reached. Close the hydraulic pressure line valve.

Read the level of the water in the burette. Record this reading as the total expansion on the test certificate.

Open the hydraulic pressure line drain valve to release pressure from the accumulator body. Check that the pressure is at zero and that the water level is constant.

Read the level of the water in the burette. Record this reading as the permanent expansion, $E_p$, if any, on the test certificate.

Check that the ratio, $R$, of permanent expansion, $E_p$, to total expansion, $E_t$, does not exceed 5 % as determined by the following:

$$R = \left(\frac{E_p}{E_t}\right) 100$$

## D.4 Non-water jacket method

### D.4.1 *Principle*

This method determines the volume of water required to pressurize the filled accumulator body to test pressure. The amount of water passed into the accumulator body under test pressure is measured and, on release of this pressure, the water returned to the manometer is measured. It is necessary to allow for the compressibility of water and the volume of the accumulator body under test to obtain true volumetric expansion. No fall in pressure under this test is permitted.

### D.4.2 *Apparatus*

**D.4.2.1** *General.* The apparatus shall be installed as shown in Figure 6. The water supply pipe shall be connected either to an overhead tank as shown in Figure 6, or to some other supply giving a sufficient head of water. The apparatus shall be arranged so that all air can be removed.

**D.4.2.2** *Glass tube reservoir,* calibrated in millimetres and accurate to 1 % of reading. It shall be arranged so that accurate readings can be determined of the volume of water required to pressurize the filled accumulator body and of the volume expelled from the accumulator body when depressurized. In the case of large accumulator bodies it may be necessary to augment the glass tube with metal tubes arranged in a manifold.

**D.4.2.3** *Two pressure gauges,* in accordance with BS 1780.

**D.4.2.4** *Single-acting hydraulic pump,* if used, the piston shall be in the "back" position when water level is noted.

**D.4.2.5** *Water,* free of air.

NOTE Any leakage from the system or the presence of free air will result in false readings.

### D.4.3 *Procedure*

**D.4.3.1** Completely fill the accumulator body with water and determine the mass of water in it. Connect the container to the hydraulic test pump through flexible pipe A (see Figure 6) and check that all valves are closed. Fill the pump and system with water from tank C by opening valves D, E and H.

**D.4.3.2** To ensure expulsion of air from system, close valve H and raise the system pressure to approximately one-third of the test pressure. Open bleed valve G to release trapped air by reducing the system pressure to zero and reclose valve G. Repeat if necessary.

**D.4.3.3** Continue to fill the system until the level in glass tube M is approximately 300 mm from the top of this tube. Close valve D and mark the water level by pointer P, leaving valves E and H open. Record the level.

**D.4.3.4** Close valve H and raise the pressure in the system until the pressure gauge(s) K indicate the test pressure $P_1$. Stop the pump. After approximately 30 s there should be no change in either water level or pressure.

NOTE A change in level indicates leakage, falling pressure, if there is no leakage, indicates that the accumulator body is still expanding under pressure.

**D.4.3.5** Record the fall of water level in the glass tube.

NOTE Providing there has been no leakage, the water drained from the glass tube will have been pumped into the accumulator body to achieve the test pressure.

Record the difference in water level, corrected for the compressibility of water (see **D.4.4**) as the total volumetric expansion, $E_v$.

**D.4.3.6** Open valve H slowly, to release pressure in the accumulator body, and allow the water released to return to the glass tube. The water level should return to the original level marked by pointer P. If the water level returns to a point below pointer P, the difference in level denotes the amount of permanent volumetric expansion in the container, $E_p$.

**D.4.3.7** Before disconnecting the accumulator body from the test rig, close valve E. This will leave the pump and system full of water for the next test. However, **D.4.3.2** shall be repeated at each subsequent test.

**D.4.3.8** If permanent volumetric expansion has occurred, note the temperature of the water in the accumulator body.

**D.4.3.9** The permanent volumetric expansion, $E_p$, shall not exceed 5 % of the total volumetric expansion, $E_t$.

**D.4.4** ***Calculations***

Calculate the percentage ratio of permanent expansion to total expansion, $R$, in %, as follows.

a) Record the test pressure, $P_1$, in bar.

b) Record the mass of water in the accumulator body at zero gauge pressure, $m_1$, in kg.

c) Record the temperature of the water.

d) Record the amount of water forced into the accumulator body to raise the test pressure, $w_1$, in mL, and calculate its mass, $m_2$, in kg.

e) Determine the total mass of water in the accumulator body, $M$, in kg, as follows:

$$M = m_1 + m_2$$

f) Record the amount of water expelled from the accumulator body to depressurize, $w_2$, in mL.

g) Determine the permanent expansion, $E_p$, in mL, as follows:

$$E_p = w_1 - w_2$$

h) Determine the reduction in volume of water due to compressibility of water, $C$, in mL, as follows:

$$C = MP_1 \left( K - \frac{0.68P_1}{10^5} \right)$$

where

$K$ is the factor for compressibility of water from Table 5;

i) Determine the total volumetric expansion, $E_v$, in mL, as follows:

$$E_v = w_1 - C$$

j) Determine the percentage ratio of permanent expansion to total volumetric expansion, $R$, in %, as follows:

$$R = \frac{E_p}{E_v}$$

**Table 5 — *K* factors for the compressibility of water**

| °C | *K* | °C | *K* | °C | *K* |
|---|---|---|---|---|---|
| 6 | 0.049 15 | 13 | 0.047 59 | 20 | 0.046 54 |
| 7 | 0.048 86 | 14 | 0.047 42 | 21 | 0.046 43 |
| 8 | 0.048 60 | 15 | 0.047 25 | 22 | 0.046 33 |
| 9 | 0.048 34 | 16 | 0.047 10 | 23 | 0.046 23 |
| 10 | 0.048 12 | 17 | 0.046 95 | 24 | 0.046 13 |
| 11 | 0.047 92 | 18 | 0.046 80 | 25 | 0.046 04 |
| 12 | 0.047 75 | 19 | 0.046 68 | 26 | 0.045 94 |

*Example.* In the following example, allowance for pipe stretch has been neglected.

| | |
|---|---|
| Test pressure, $P_1$ | = 232 bar gauge |
| Mass of water in accumulator body at zero gauge pressure, $m_1$ | = 113.8 kg |
| Temperature of water | = 15 °C |
| Water forced into accumulator body to raise pressure to 232 bar, $w_1$ | = 1 745 mL or 1.745 kg |
| Total mass of water, $M$, in accumulator body at 232 bar, i.e. 113.8 + 1.745 | = 115.545 kg |
| Water expelled from accumulator body to depressurize, $w_2$ | = 1 742 mL |
| Permanent expansion, $E_p$ = 1 745 – 1 742 | = 3 mL |
| From Table 5, $K$ factor for 15 °C water temperature | = 0.047 25 |

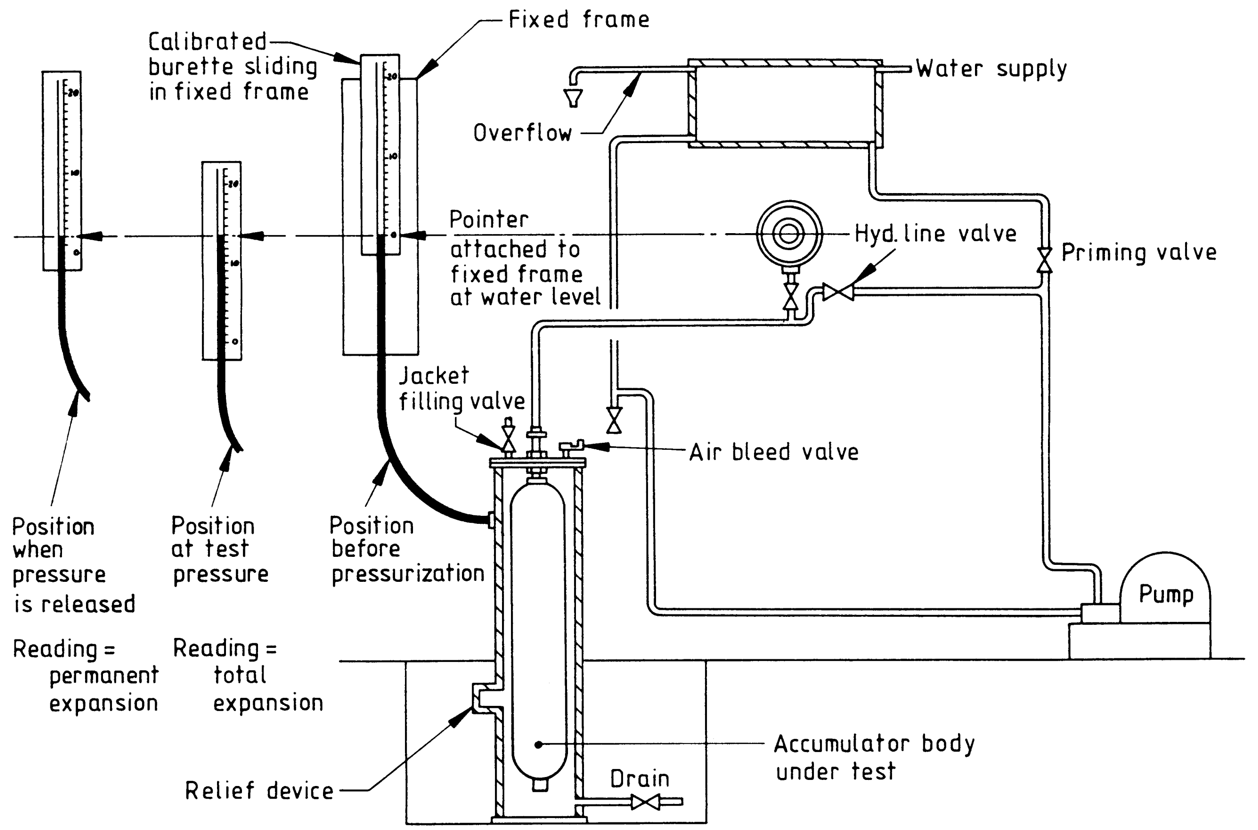


**Figure 4 — Example of apparatus for water jacket method (levelling burette)**

Reduction in volume of water due to compressibility, $C$, at 232 bar and 15 °C =

$$115.545 \times 232 \left(0.04725 - \frac{0.68 \times 232}{10^5}\right)$$

$$= 1224.25 \text{ mL}$$

Total volumetric expansion,
$E_v = 1\ 745 - 1224.25$ = 520.75 mL

Percentage ratio of permanent expansion to total volumetric expansion, $R = \frac{3 \times 100}{520.75}$ = 0.58 %

## Appendix E Proof pressure test

### E.1 Apparatus

All rigid pipework flexible tubing, valves, fittings and components forming the pressure system of the test equipment shall be capable of withstanding a pressure twice the maximum test pressure of any accumulator body to be tested.

Pressure gauges shall comply with the requirements for industrial class gauges specified in BS 1780. They shall be tested at regular intervals, and in any case not less frequently than once a month.

The design and installation of the pressure system and the accumulator bodies connected to it shall be such as to avoid trapping air in the system.

### E.2 Procedure

NOTE More than one accumulator body may be tested at a time provided that they all have the same test pressure and that each individual test point is capable of being isolated.

When applied to the accumulator body the test pressure shall not be exceeded by more than 3 % or 10 bar, whichever is the lower.

On attaining the test pressure, isolate the accumulator body from the pump and hold the pressure for a minimum of 1 min, during which period the pressure, as registered on the test gauge, shall remain constant.

If there is a leakage in the pressure system it shall be repaired and the accumulator body retested.

Thoroughly dry the interior of each accumulator body immediately after testing. Accumulator bodies shall not be heated above 350 °C.

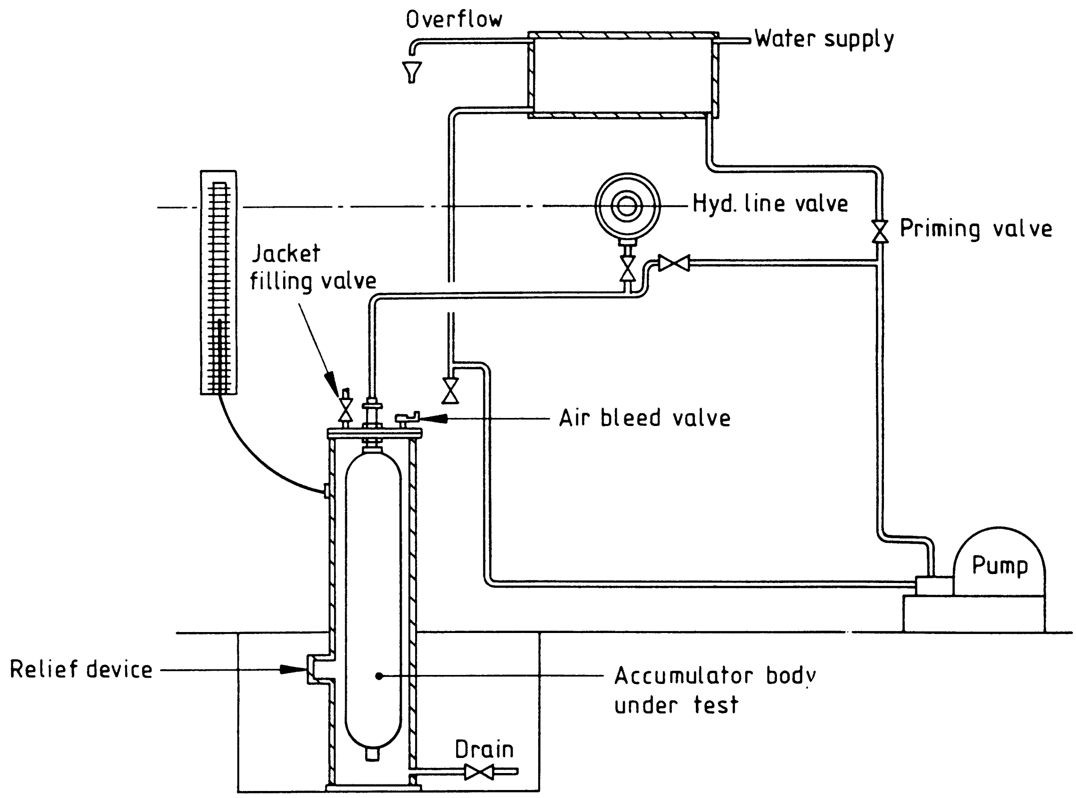


**Figure 5 — Example of apparatus for water jacket method (fixed burette)**

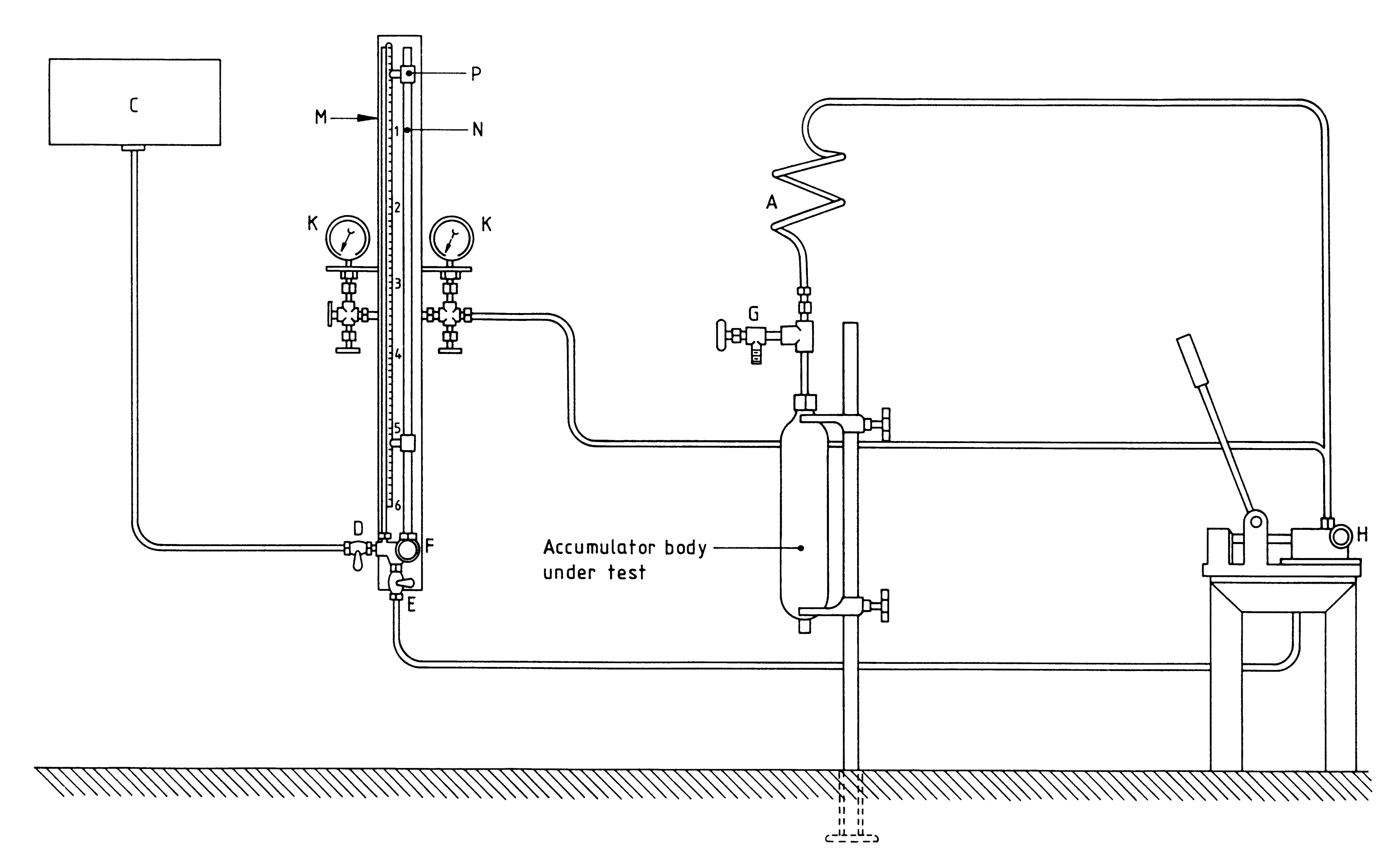


Figure 6 — Non-water jacket method

# Appendix F Specimen certificates

## F.1 Specimen acceptance certificate

Certificate No. . . . . . . . . . . . . . Serial Nos. . . . . . . . . . . . . . . . . . . . . . . . . .

Manufacturer . . . . . . . . . . . . . . Specification BS 7201 : Part 1 : 1989

Customer . . . . . . . . . . . . . . . . Inspection . . . . . . . . . . . . . . . . . . . . . . . . .

Capacity . . . . . . . . . . . . . . . . Manufacturer's Order No. . . . . . . . . . . . . . . . . . . .

Design or working pressure bar Customer's Order No. . . . . . . . . . . . . . . . . . . . .

**Minimum wall thickness.** The parallel wall and spherical end thickness have been measured and found to be satisfactory.

**Hardness range.** All accumulator bodies have been controlled within the following hardness values.

Minimum . . . . . . . . HB
Maximum . . . . . . . . HB

**Heat treatment.** All accumulator bodies have been heat treated at the following temperatures.

*Oil quench from . . . . °C
*Normalize at . . . . . . °C
*Temperature at. . . . . °C

**Hydraulic pressure test**

(a) Volumetric expansion test (see separate test certificate **F.2**), or

(b) Proof pressure test and ultrasonic test.

(1) *Proof pressure test.* Each accumulator body has been proof tested to a pressure of . . . . . . . . . bar and found to be satisfactory.

(2) *Ultrasonic test.* Each accumulator body has been ultrasonically examined on the parallel wall to a 5 % reference standard and found to be satisfactory.

(c) Date of pressure test . . . . . . . . . .

## F.2 Specimen hydraulic volumetric expansion test certificate

| Serial No. | Cast No. | Total expansion | Permanent expansion | Permanent/total expansion ratio $R$ | Water capacity |
|---|---|---|---|---|---|
| | | mL | mL | % | L |

For and on behalf of
the manufacturer. . . . . . . . . . . . . . . . . . . . . . . Date . . . . . . .

For and on behalf of
the Independent Inspecting Authority. . . . . . . . . . . . Date . . . . . . .

* Delete as appropriate.

## F.3 Specimen steel test certificate

**Material**

**Steelmaker** . . . . . . . . . . . . . . . . . . . . .

**Tubemaker** . . . . . . . . . . . . . . . . . . . . .

| Cast | C | Si | Mn | Cr | Mo | Ni | P | S |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |

## Mechanical tests

| Cast | Test piece dimensions | Upper yield stress or 0.2 % proof stress | Tensile strength | dimensions |
|---|---|---|---|---|
| | | N/mm$^2$ | N/mm$^2$ | % |

**Bend test results** . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

**For and on behalf of**
**the manufacturer** . . . . . . . . . . . . . . . . . . . . . . . . **Date** . . . . .

**For and on behalf of**
**the Independent Inspecting Authority** . . . . . . . . . . . . . **Date** . . . . .

# Publications referred to

BS 18, *Methods for tensile testing of metals (including aerospace materials).*
BS 240, *Method for Brinell hardness test and for verification of Brinell hardness testing machines.*
BS 891, *Method for Rockwell hardness test.*
BS 891-1, *Testing of metals.*
BS 1610, *Materials testing machines and force verification equipment.*
BS 1780, *Specification for bourdon tube pressure and vacuum gauges.*
BS 1837, *Methods for the sampling of iron, steel, permanent magnet alloys and ferro-alloys.*
BS 3894, *Method for converting elongation values for steel.*
BS 3894-1, *Carbon and low alloy steels.*
BS 4124, *Methods for ultrasonic detection of imperfections in steel forgings.*
BS 4500, *ISO limits and fits.*
BS 4500-1, *General, tolerances and deviations.*
BS 5045, *Transportable gas containers*[2)].
BS 5045-1, *Specification for seamless steel gas containers above 0.5 litre water capacity.*

[2)] Referred to in the foreword only.

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