



**RP 42-2**

# **BOLTING FOR FLANGED JOINTS**

**March 1997**

**Copyright © The British Petroleum Company p.l.c.**

All rights reserved. The information contained in this document is subject to the terms and conditions of the agreement or contract under which the document was supplied to the recipient's organisation. None of the information contained in this document shall be disclosed outside the recipient's own organisation without the prior written permission of Manager, Standards, BP International Limited, unless the terms of such agreement or contract expressly allow.

| <b>BP GROUP RECOMMENDED PRACTICES AND SPECIFICATIONS FOR ENGINEERING</b>                                                                                                                                                                                   |                      |                              |      |         |             |       |  |  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|------------------------------|------|---------|-------------|-------|--|--|
| Doc. No. <b>RP 42-2</b>                                                                                                                                                                                                                                    |                      | Issue Date <b>March 1997</b> |      |         |             |       |  |  |
|                                                                                                                                                                                                                                                            |                      | Latest Amendment Date        |      |         |             |       |  |  |
| Document Title<br><b>BOLTING FOR FLANGED JOINTS</b>                                                                                                                                                                                                        |                      |                              |      |         |             |       |  |  |
| <b>APPLICABILITY</b>                                                                                                                                                                                                                                       | <b>BP Chemicals</b>  |                              |      |         |             |       |  |  |
| Regional Applicability:                                                                                                                                                                                                                                    | <b>International</b> |                              |      |         |             |       |  |  |
| <b>SCOPE AND PURPOSE</b><br><br>This Recommended Practice gives guidelines on the bolting and jointing of flanges used on piping and pressurised equipment (up to 2500#).                                                                                  |                      |                              |      |         |             |       |  |  |
| <b>AMENDMENTS</b><br><table border="0"> <thead> <tr> <th>Date</th> <th>Page(s)</th> <th>Description</th> </tr> </thead> <tbody> <tr> <td colspan="3"><hr/></td> </tr> </tbody> </table>                                                                    |                      |                              | Date | Page(s) | Description | <hr/> |  |  |
| Date                                                                                                                                                                                                                                                       | Page(s)              | Description                  |      |         |             |       |  |  |
| <hr/>                                                                                                                                                                                                                                                      |                      |                              |      |         |             |       |  |  |
| <b>CUSTODIAN</b> (See Quarterly Status List for Contact)<br><b>Chemical Engineering</b>                                                                                                                                                                    |                      |                              |      |         |             |       |  |  |
| <b>Issued by:-</b><br>Engineering Practices Group, BP International Limited, Research & Engineering Centre<br>Chertsey Road, Sunbury-on-Thames, Middlesex, TW16 7LN, UNITED KINGDOM<br>Tel: +44 1932 76 4067      Fax: +44 1932 76 4077      Telex: 296041 |                      |                              |      |         |             |       |  |  |

## CONTENTS

| Section                                                   | Page       |
|-----------------------------------------------------------|------------|
| <b>FOREWORD .....</b>                                     | <b>iii</b> |
| <b>1. SCOPE AND PURPOSE .....</b>                         | <b>1</b>   |
| 1.1 Scope .....                                           | 1          |
| 1.2 Document Basis.....                                   | 1          |
| <b>2. GENERAL GUIDELINES .....</b>                        | <b>1</b>   |
| 2.1 Flange System .....                                   | 1          |
| 2.2 Flange Elements .....                                 | 1          |
| <b>3. BOLT CHARACTERISTICS .....</b>                      | <b>2</b>   |
| 3.1 Materials .....                                       | 2          |
| 3.2 Dimensions.....                                       | 2          |
| 3.3 Bolt Protection .....                                 | 3          |
| <b>4. REQUIRED BOLT LOAD .....</b>                        | <b>4</b>   |
| 4.1 Code Checks .....                                     | 4          |
| 4.2 Basic Considerations.....                             | 4          |
| 4.3 Guidelines .....                                      | 4          |
| <b>5. APPLIED BOLT LOAD .....</b>                         | <b>5</b>   |
| 5.1 Hand Wrenching.....                                   | 6          |
| 5.2 Turn of Nut Method .....                              | 6          |
| 5.3 Torque Wrenching.....                                 | 6          |
| 5.4 Stud Heaters.....                                     | 7          |
| 5.5 Hydraulic Tensioners .....                            | 7          |
| <b>6. LOAD MEASUREMENT .....</b>                          | <b>8</b>   |
| 6.1 Torque Measurement.....                               | 8          |
| 6.2 Bolt Elongation .....                                 | 8          |
| 6.3 Ultrasonic Stress Monitoring .....                    | 8          |
| <b>7. FLANGE INTEGRITY.....</b>                           | <b>9</b>   |
| <b>FIGURES 1 TO 4 - BOLT LENGTHS AND EXTENSIONS .....</b> | <b>10</b>  |
| <b>FIGURE 5 - HYDRAULIC TENSIONER.....</b>                | <b>11</b>  |
| <b>FIGURE 6 - STUD AND NUT NUMBERING .....</b>            | <b>12</b>  |



|                                     |           |
|-------------------------------------|-----------|
| <b>APPENDIX A.....</b>              | <b>13</b> |
| DEFINITIONS AND ABBREVIATIONS ..... | 13        |
| <b>APPENDIX B.....</b>              | <b>14</b> |
| LIST OF REFERENCED DOCUMENTS.....   | 14        |
| <b>APPENDIX C.....</b>              | <b>16</b> |
| TORQUING PROCEDURE.....             | 16        |



## **FOREWORD**

### **Introduction to BP Group Recommended Practices and Specifications for Engineering**

The Introductory Volume contains a series of documents that provide an introduction to the BP Group Recommended Practices and Specifications for Engineering (RPSEs). In particular, the 'General Foreword' sets out the philosophy of the RPSEs. Other documents in the Introductory Volume provide general guidance on using the RPSEs and background information to Engineering Standards in BP. There are also recommendations for specific definitions and requirements.

### **Value of this Guidance for Specification**

This Recommended Practice gives guidelines on the bolting and jointing of flanges used on piping and pressurised equipment (up to 2500#).

### **Application**

This document may refer to certain local, national and international regulations but the responsibility to ensure compliance with legislation and any other statutory requirements lies with the user. The user should adapt or supplement this document to ensure compliance for the specific application.

### **Qualification to Applicability**

This Recommended Practice although a BP Group Document has been prepared and developed by BP Chemicals and is specifically intended for use in chemical plants.

### **Feedback and Further Information**

Users are invited to feed back any comments and to detail experiences in the application of BP RPSE's, to assist in the process of their continuous improvement.

For feedback and further information, please contact Standards Group, BP Engineering or the Custodian. See Quarterly Status List for contacts.



## **1. SCOPE AND PURPOSE**

### **1.1 Scope**

This Recommended Practice gives guidelines on the bolting and jointing of flanges used on piping and pressurised equipment (up to 2500#).

### **1.2 Document Basis**

This Recommended Practice is a guidance document and refers to a number of external references which give additional guidance on particular aspects of flange bolting. This document has been widely based upon Technical Reference 1 (Appendix B) and does not attempt to review the theoretical behaviour of bolts, but instead considers some of the practical aspects of bolting. There have been many papers and books written on bolted joints, Technical Reference 1 (Appendix B) being one of the most comprehensive. There appears to be agreement that bolting is complex, Technical Reference 2 (Appendix B) refers to a survey by the Bolting Technology Council, which compiled a list of more than 100 variables believed to influence the behaviour of a bolted joint.

## **2. GENERAL GUIDELINES**

### **2.1 Flange System**

Structurally, the bolts in a flange system can be considered as heavy springs clamping the rings together in order to maintain a gasket seal. The design for bolted flange connections considers the proportioning of the bolting, ie. the number and size of bolts, as one of the most important factors. In assembling flanged joints, the gasket shall be uniformly compressed to the proper design loading. Special care shall be used in assembling flanged joints in which flanges have widely differing mechanical properties.

The combination of temperatures and thermal expansion coefficients of the flanges and bolts during service may provide a leaking joint as a result of bolts loosening or creep.

### **2.2 Flange Elements**

The three elements of the system, ie. gasket, bolting and flange rings, are equally important as any one can cause a failure ie. leakage: for example:-



- a) Choose the wrong gasket and you may never be able to get a tight joint.
- b) Overstrength bolts on an incorrect tightening procedure could lead to excessive flange rotation and thus leakage. The understrength bolts can easily be yielded without seating the gasket.
- c) An incorrectly proportioned flange ring can give excessive rotation which even a change of gasket may not be able to accommodate.

### 3. BOLT CHARACTERISTICS

#### 3.1 Materials

Whilst carbon steel bolts are used for some low grade flange applications, it is rare that they are used above Class 150 rating or with gaskets other than compressed asbestos fibre. The most common bolting material is 1% chrome, 0.2% molybdenum (eg [ASTM A193 B7](#) or [BS 4882 B7](#)) which, although design codes gives stress values up to 500°C (932°F), is most commonly used up to 300°C (572°F).

Above 300/400°C (572/752°F 1% chrome, 0.6% molybdenum, 0.25% vanadium (eg [ASTM A 193](#) or [B16](#) or [BS 4882 B16](#)) can be used with a maximum practical temperature of 550°C (1022°F). The most common range of materials for high temperature are the austenitic stainless steels (Type 304, 316, 321 and 347). Comparable material grades are available for nuts with a slight change of metallurgy to avoid galling between the bolts and nuts.

For material limitations refer to relevant pressure vessel and piping codes.

High alloy and non-ferrous bolting materials are available for special applications.

#### 3.2 Dimensions

Where bolt or studbolt lengths are not specified by the flange standard, they may be calculated by the formulae below:-

For stud bolts (Fig 1)  $LSB = 2(C + t + M) + G + X$

For bolts (Fig 2)  $LB = 2(C + t) + M + G + X$



Where

|   |   |                                                                                                                                                                           |
|---|---|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| C | = | Nominal flange thickness including height of raised face or thickness of backing flange in the case of lap flanges.                                                       |
| T | = | Plus tolerance for flange thickness and raised face.                                                                                                                      |
| M | = | Maximum thickness of heavy series nut to <a href="#">BS 4882</a> .                                                                                                        |
| G | = | 0.12 inches (minimum) gaskets thickness for raised face, male/female and tongued/grooved flanged or the approximate distance between flanges for solid metal ring joints. |
| X | = | Maximum difference between depth of tongue and groove or, in the case of lap flanges, twice the maximum thickness of the lap stub end.                                    |

The length of bolt should be rounded up to the nearest ¼ in. The above formulae make no allowance for end points or rounded ends and for negative tolerance on bolt length. The length of points should comply with [BS 4882](#).

The above formulae are based on the requirements of [ANSI B16.5](#).

When hydraulic bolt tensioning devices are used the bolt lengths should have additional length equivalent to depth of one nut or as dictated by the device user.

### 3.3

#### **Bolt Protection**

Bolt protection against environmental corrosion during storage or operation is available with the specification of zinc, cadmium or PTFE coating. Aluminised bolts are employed to reduce seizure problems due to oxidation at higher operating temperatures. It should be noted that in some coating processes, heat treatment is used which could reduce the tensile properties of the bolt.



## **4. REQUIRED BOLT LOAD**

### **4.1 Code Checks**

Many important aspects in considering the required bolt load are discussed in Appendix S of ASME VIII division 1. These aspects are summarised and further discussed below.

The required bolt load has to be greater than all of the following:

- a) The minimum gasket seating load.
- b) The design pressure load plus gasket pressure sealing load.
- c) The design pressure load plus gasket pressure sealing load plus fatigue preload.
- d) The test pressure end load.

Note that Cyclic loading will require additional bolt preload.

A discussion of fatigue in bolts and selection of preload is given in Technical Reference 1 (Appendix B).

### **4.2 Basic Considerations**

The required bolt load should be checked so that:

- a) There is a reasonable margin on yield stress.
- b) Attention is given to bolt relaxation for high temperature joints.
- c) Attention is given to any differential thermal loads between flanges and bolts.

### **4.3 Guidelines**

In considering 4.2, the following should be borne in mind:-

- a) For simple flanges, a bolt stress between 0.5 and 0.75 of bolt yield stress at design temperature would be considered adequate.
- b) At high temperatures, creep of the flange and/or bolts will result in relaxation and, dependent on the elasticity of the gasket, may result in leakage. Common practice would be to retighten which, if infrequent, may be sufficient to solve the problem.



Excessive retightening, however, may lead to "ratcheting" and subsequent bolt failure. [BS 4882](#), and other references, give data on typical stress relaxation behaviour of bolting materials at temperature up to 800°C for 1000 hrs (a mere six weeks of operation!). These stress relaxation considerations lead to the temperature limits discussed in 3.1.

- c) If high temperature flanges are fully insulated and the flange and bolting expansion coefficients are similar, it is unlikely that appreciable differential thermal loads will occur. However, to avoid using high temperature bolting, it is common to leave the flange uninsulated. The bolting will in those circumstances be cooler than the flange ring, which in turn will be cooler than the fluid temperature. [ANSI B31.3](#) recommends bolt temperatures for uninsulated flanges are considered at 80% of the fluid temperature.
- d) Thermocouple tests on actual flanges have found bolts nearly 100°C (180°F) cooler than the fluid temperature of 400°C (752°F). It would be pessimistic to assume this temperature difference existed between flange and bolts, and again very pessimistic to calculate a fully restrained stress resulting from this temperature difference. Nevertheless, a cooler bolt in a hot flange will increase the bolt load, with the risk of gasket crushing, bolt yielding or flange rotation. Evaluation would probably require a reasonable thermal analysis associated with an interaction analysis for the total flange assembly, not a task to be entered lightly.

Devices may need to be fitted to absorb differential thermal expansion between flanges and bolts. Figures 3 & 4 illustrate the use of bolt extension sleeves and spring washers which would require special consideration for the particular application.

## 5. APPLIED BOLT LOAD

As equipment sizes become larger, or as process pressures increase, or with increasing emphasis to reduce hazard, it becomes more important to be able to tighten bolted flanges evenly and with a predictable load.

The methods depend either on using torque to produce the bolt end load, or a stretching technique. The accuracy of the torquing techniques depend largely upon the operator's experience and are more susceptible to the quality of the stud and nut surfaces, and the degree of lubrication. Having carried out a review of the required bolt load, as described in 4.1 the next decision should be which bolt tightening method to use. The rest of this section discusses features of each common method. Whilst



there will inevitably be variation in load between individual bolts, it has been estimated that the typical load variations for different bolting methods are as follows:

| Method               | Load variation  |
|----------------------|-----------------|
| Hand wrench          | indeterminate   |
| Turn of nut method   | +/- 30%         |
| Torque wrench        | +/- 20%         |
| Stud heaters         | better than 10% |
| Hydraulic tensioning | better than 10% |

Whatever method of tightening is used, lubrication with a compound such as molybdenum disulphide is essential. This can reduce a dry coefficient of friction of 0.2 to 0.04 or less.

There are some proprietary brands such as "Rotabolt" which can be utilised with any tightening method to provide accuracy of  $\pm 5\%$ .

### 5.1 Hand Wrenching

Although being the commonest method for tightening small diameter bolts, the results are very dependant upon the skill and experience of the operators and are thus variable. [ASME VIII](#), Division 1 Appendix S discusses the result of tests which indicated that the expected stress level could be approximately  $45,000/d^{1/2}$  psi where (d) is the bolt diameter in inches. ( $1564/d^{1/2}$  N/mm<sup>2</sup> where (d) is in mm).

This formula demonstrates that bolts  $\frac{1}{2}$  inch in diameter or less can be easily overstressed, whilst bolts 1 inch in diameter and larger will probably be understressed. For these larger bolts, hand wrenching is often supplemented by "flogging spanner" and hammering.

### 5.2 Turn of Nut Method

This method is more commonly used in the structural industry and consists of "bedding down" the nut and then turning the nut a calculated number of degrees. The method is described in Technical References 1 and 5 (Appendix B) and would appear to be dependant upon dimensions, thread and nut strength as well as ability to rotate the nut to close limits.

### 5.3 Torque Wrenching

Better control of bolt stress and prevention of overtightening would appear possible with torque wrenches. Depending on bolt size and space available several techniques can be applied:



- a) Manual torque wrenches are available up to 550 kg m (4000 lbft) and theoretically could tighten 1 to 2 inch bolts, but in practice may be difficult to use above 1½ inches. Appendix I shows a typical procedure for use with manual torque wrenches.
- b) Manual impact torque wrenches operate by converting spring power into torque impact. They are particularly useful for releasing "frozen nuts" and the largest can deliver nearly 1000 kg m (7000 lbft) with a capacity of 2½ inch bolts.
- c) Manual torque multipliers use planetary or spur gear trains to generate up to 6000 kg m (43000 lbft). These units obviously have a large capacity, but much of the input torque is lost in mechanical efficiency of the multiplier gears and accuracy becomes more difficult to guarantee.
- d) Impact wrenches have been used for many years for a wide range of bolt diameters. They are available with various methods of output torque control and are discussed in detail in Technical Reference 1 (Appendix B).
- e) Hydraulic torque wrenches are popular because of the small space required. A hydraulic piston drives a short stubby ratchet wrench through as many cycles as necessary to tighten the bolt. Portable units are available up to 2000 kg m (14500 lbft) and larger units up to 13800 kg m (100000 lbft).

#### **5.4 Stud Heaters**

The simplest method available is to heat the bolts, incorporate into the flange assembly, screw down the nuts and wait for the assembly to cool. However, the results are variable and time to cool can be excessive. The more usual method for large bolts is to gun drill a central hole for a full length electrical stud heater. Nuts are screwed down metal to metal and heaters switched on.

The nuts are rotated as the bolt elongates until a calculated nut rotation, and thus bolt extension, is achieved. This method is still time consuming even with a heater in every bolt, and the use of electrical heating in the field can be hazardous.

#### **5.5 Hydraulic Tensioners**

As seen from the section shown in figure 5, the tensioner locates over an extended bolt which is loaded by a hydraulic cylinder. The nut socket has a turning mechanism or tommy bar holes enabling the nut to be easily rotated when the bolt is stretched. The recommended bolt



extension above the permanent nut equals the bolt diameter. Ideally, alternate bolts are fitted with tensioners (minimum of four) which are then hydraulically connected to a single power unit. When the predetermined hydraulic load is achieved, the nuts are rotated to contact the flange and then the tensioner moved to the other bolts.

For larger flanges, a three pass cycle is common, one pass at 60 percent, next at 80 percent and the final pass at full load. Note that some loss of load occurs when transferring from hydraulic load to bolt mechanical load, and the final pass may have to be higher than the final required load.

"Standard" hydraulic tensioners are available for the popular bolt diameter range of 1½ to 4 inches and special tensioners above 4 inches up to 12 inches diameter. The dimensions of the standard tensioners allow normal bolt spacing to be used with standard nuts. High pressure flanges may require closer bolt spacing and cylindrical barrel nuts, these can be drilled with tommy bar holes and tensioned by this method.

After tensioning, the protruding threads of the bolts should be protected with cap, ideally fitted with grease nipples.

## **6. LOAD MEASUREMENT**

### **6.1 Torque Measurement**

Monitoring of the applied torque will give an indication of bolt load and thus stress. Independent measurement will give a check on bolt stress (See: Appendix C).

### **6.2 Bolt Elongation**

Ideally, the elongation of each bolt should be checked to confirm uniform and specified bolt tension. In practice several bolts are chosen and marked as reference bolts. The reference length is the distance between the centre of the nuts and a bolt elongation micrometer used over the length of the bolt to measure change in length. To give accurate seating for the micrometer the most practical method is to cement a ball bearing into centre punch holes on each end face of the bolt.

### **6.3 Ultrasonic Stress Monitoring**

Experience has been gained using ultrasonics to predict bolt load.

A transducer is placed at one of the bolt during tightening and a microprocessor is used to measure the change in time for the ultrasonic



wave to bounce back from the far end of the bolt as the bolt stretches. Alternatively, it may be used to measure the change in bolt resonant frequency as the stress level increases.

A detailed discussion on these methods is given in Technical Reference 1 (Appendix B).

## **7. FLANGE INTEGRITY**

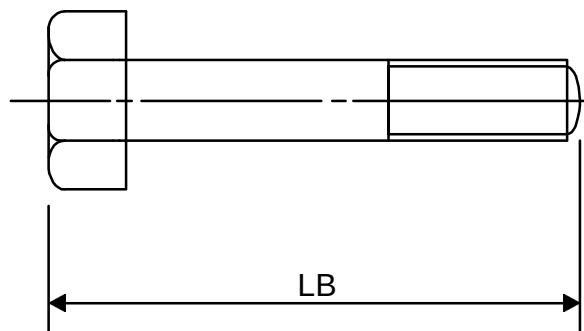
The resultant flange system should consist of compatible flange ring, gaskets and bolting. The success of the flange to seal across the operating and test range is however very dependant on the skill used to bolt up the flange. If a parallel is drawn with a main shell butt weld, it is found that as well as the necessary design of the weld shape and specification of the weld metal, the weld procedure is then qualified as well as the welder himself. For critical flange joints, consideration should be given to the qualification of the bolting procedure and bolting operators.

If hydraulic tensioners are used, it is common for a specialist company to be used who have developed procedures and trained operators. If torquing procedures are used, sample load measurements would need to be made, as discussed in 6.1, to qualify the procedure and the operators.

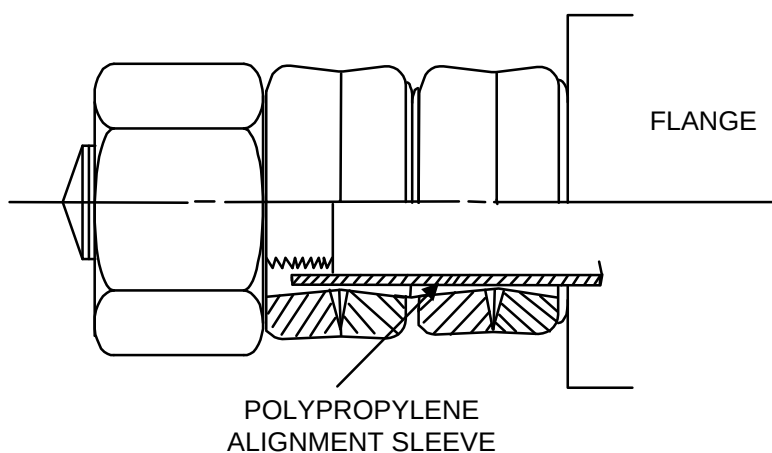




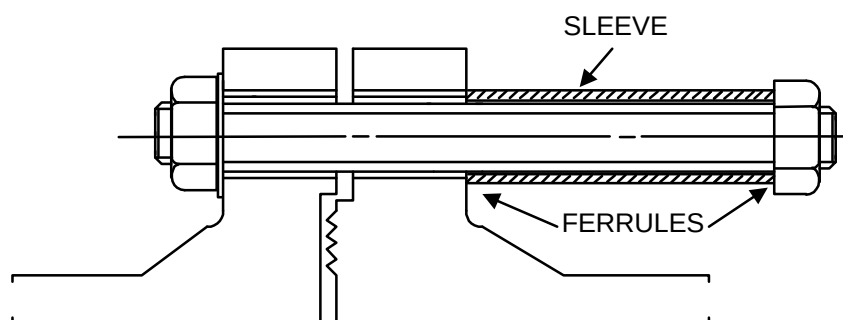
**FIGURE 1  
LENGTH OF STUDBOLT**



**FIGURE 2  
LENGTH OF BOLT**

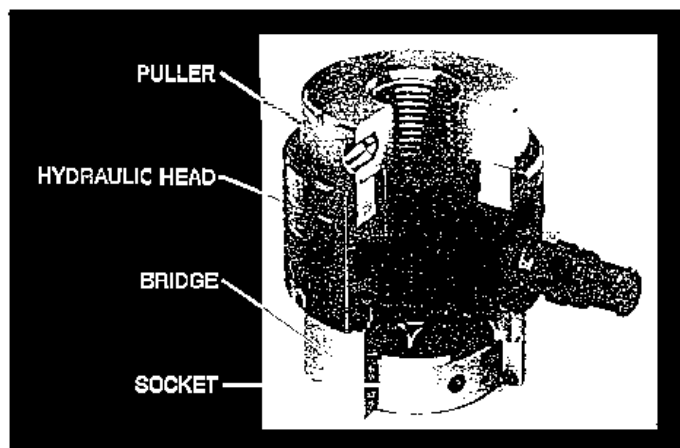


**FIGURE 3 - SPRING WASHERS**

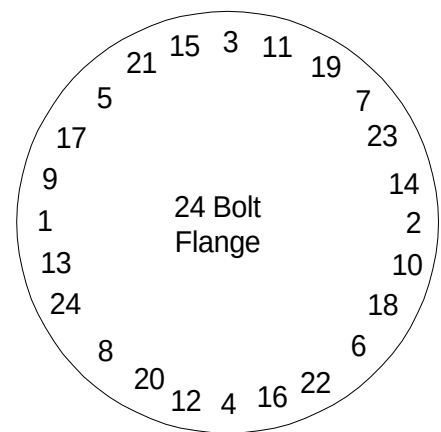
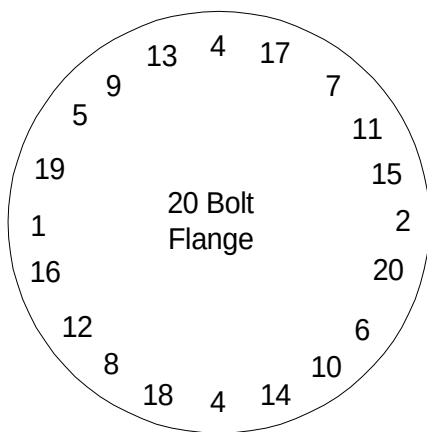
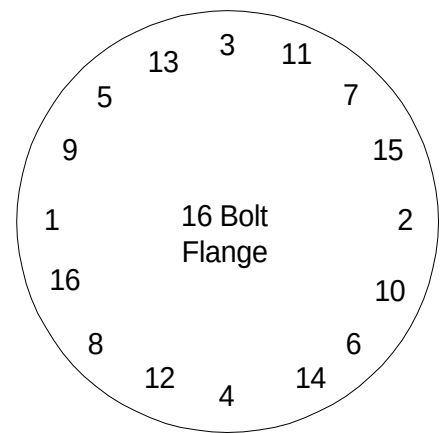
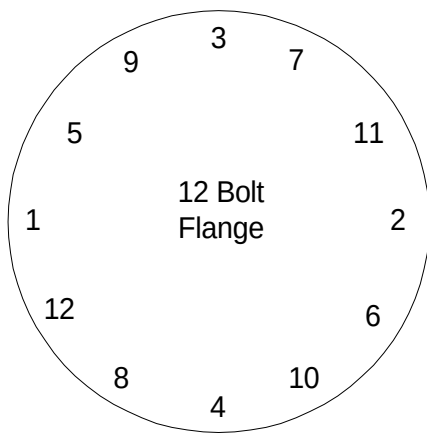
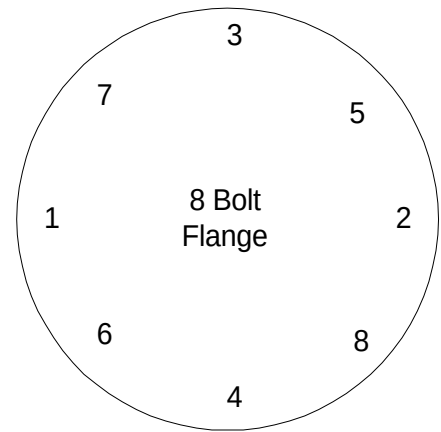
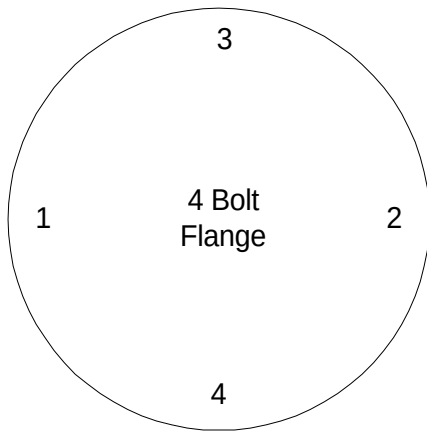


**FIGURE 4 - BOLT EXTENSION SLEEVE**

**FIGURES 1 TO 4 - BOLT LENGTHS AND EXTENSIONS**



**FIGURE 5 - HYDRAULIC TENSIONER**



**FIGURE 6 - STUD AND NUT NUMBERING**



**DEFINITIONS AND ABBREVIATIONS****Definitions**

Standardised definitions may be found in the BP Group RPSEs Introductory volume.

**Abbreviations**

|      |                                                                                |
|------|--------------------------------------------------------------------------------|
| ANSI | American National Standards Institute                                          |
| ASME | American Society of Mechanical Engineers                                       |
| ASTM | American Society of Testing and Materials                                      |
| BS   | British Standard                                                               |
| HAZ  | Heat Affected Zone                                                             |
| HV   | Vickers Hardness                                                               |
| ISO  | International Standards Organisation                                           |
| MSS  | Manufacturers Standardization Society of the Valve and Fittings Industry, Inc. |
| NDT  | Non-Destructive Testing                                                        |
| SI   | Système International d'Unités                                                 |



**LIST OF REFERENCED DOCUMENTS**

A reference invokes the latest published issue or amendment issue unless stated otherwise.

Referenced standards may be replaced by equivalent standards that are internationally or otherwise recognised provided that it can be shown to the satisfaction of the purchaser's professional engineer that they meet or exceed the requirements of the referenced standards.

**Technical References:**

Copies of the following Technical References are available from the custodian of this Recommended Practice.

1. Mechanical Design of Heat Exchangers Vol 4. Heat Exchanger Design Handbook, Hemisphere Pub. Corp.
- 2.. Bickford J.H., An Introduction to the Design and Behaviour of Bolted Joints. M. Decker, New York.
3. Bickford J.H., The Bolting Technology Council and the search for more accurate preload. Advances in Bolted Joint Technology, ASME PVP Vol. 158.
4. Rossheim D.B. and Markl A.R.C., Gasket Loading Constants, Pressure Vessel and Piping Design, Collected Papers. 1927-1959, ASME p.87 (1960).
5. Payne J.R., Bazergui A., Leon G.F., New Gasket Factors - A Proposed Procedure:, Proc. 1985 Pressure Vessel and Piping Conference, ASME, PVP - Vol. 98.2, pp.85-93.
6. Vosbrinck W.J.H., Nuts - How do you tighten them? Hydrocarbon Processing, Jan 1973, p.89.

**National Documents**

- [BS 4882](#) Specification for Bolting for Flanges and Pressure Containing Purposes
- [ANSI/ASME B16.5](#) Pipe Flanges and Flange Fittings
- [ANSI/ASME B31.3](#) Code for Pressure Piping Section 3



## Industry Documents

[ASTM A 193](#) Specification for Alloy-Steel and Stainless Steel Bolting Materials for High-Temperature Service

[ASME VIII](#) Pressure Vessel and Boiler Code, section VIII - Rules for Construction of Pressure Vessels.



**TORQUING PROCEDURE****Torquing Procedure**

Unless friction conditions are known accurately, there is no benefit in assuming a complex relationship between torque and bolt tension. Simplified formulae have been used to generate predicted torque levels and Table 1 is typical of torque/bolt diameter relationships which are used in practice. This table is at the conservative end of a range of tables available.

**Preparation**

1. Thoroughly clean the flange faces. The seating surfaces must be free from imperfections and true. The flanges must be free from grease, as the degree of friction between the gasket and flange face is critical.
2. Check studs and nuts for proper size, conformance with piping material specifications, cleanliness and absence of burrs.
3. Gaskets shall be checked for size and conformance to specifications, Metal gaskets shall have grease, rust and burrs completely removed. The filler material on spiral wound gaskets must be proud of windings.
4. Check flange alignment. pipework flanges are often limited to a maximum out-of-alignment of 0.75mm (0.03 in).
5. Number the studs and nuts (per Figure 6) to aid in identification and facilitate applying criss-cross bolt-up procedure.
6. Coat stud and nut thread, and nut and flange bearing surfaces with liberal amount of the selected bolt thread compound.

**Torque Wrench**

Impact type torque wrenches are available and may be used.

They must be considered a labour saving device since they are not entirely reliable as a mean of achieving even bolt tension. However, evenness of bolt load can be considered to be at least as good as that achieved with a spanner and hammer. Therefore only an experienced and qualified crew should be employed.



1. "Hand" tighten bolts with a short wrench using the "criss-cross" pattern shown in Figure 6. Apply load evenly to all bolts. Note that Figure 6 is also applicable to pipework flanges.
2. Apply the torque wrench (set at initial torque) in the "criss-cross" pattern. Table 1 has been prepared to provide **total** torque loads and incremented loads for each "criss-cross" round of tightening. **These loads assume lubrication** of the bolt threads and the contact surface between the nut and flange.
3. Set torque wrench for the next increment and continue tightening and resetting until the final torque load has been reached.
4. Go around once again at the final torque load using the "criss-cross" pattern.

## Notes

- 1 **Never** draw up tight on one or two bolts only. This will cause local gasket crushing or pinching, which will result in leaks. Always tighten up gradually, using the "criss-cross" pattern. After each round of tightening, the alignment may be checked by measuring the distance between the flange faces.
2. Table C1 is intended as a guide. Many unknowns including the amount and type of lubrication will affect the torque required to attain 345 N/mm<sup>2</sup> (50,000 psi) bolt stress. The only reliable way to determine bolt stress is to measure bolt elongation, or to use a bolt tensioning device. If bolt elongation measurements indicate that torque loads given in Table C1 below are higher or lower than necessary to achieve 345 N/mm<sup>2</sup> (50,000 psi) bolt stress, adjustment should be made.



**TABLE C1****BOLT TORQUE TO DEVELOP 50,000 PSI BOLT STRESS<sup>(1)</sup>**

| Normal bolt |          | Torque kg-m (ft-lbs) |                      |
|-------------|----------|----------------------|----------------------|
| Dia in      | Initial  | Increment            | Final <sup>(2)</sup> |
| 1/2         | 2 (15)   | 2 (15)               | 8 (60)               |
| 5/8         | 3 (20)   | 5 (33)               | 17 (120)             |
| 3/4         | 5 (35)   | 8 (55)               | 28 (200)             |
| 7/8         | 7 (50)   | 12 (90)              | 44 (320)             |
| 1           | 11 (80)  | 18 (130)             | 65 (470)             |
| 1 1/8       | 14 (100) | 26 (190)             | 93 (670)             |
| 1 1/4       | 16 (120) | 36 (260)             | 125 (900)            |
| 1 3/8       | 21 (150) | 48 (350)             | 165 (1200)           |
| 1 1/2       | 22 (160) | 66 (480)             | 220 (1600)           |
| 1 5/8       | 25 (180) | 88 (640)             | 290 (2100)           |
| 1 3/4       | 25 (180) | 115 (840)            | 370 (2700)           |
| 1 7/8       | 25 (180) | 145 (1040)           | 450 (3300)           |
| 2           | 35 (250) | 175 (1250)           | 550 (4000)           |

- (1) Table assumes bolts are lubricated with an oil-graphite mixture.
- (2) Final torque based on 3 equal increments after initial tightening.

