Guidelines for management of integrity of bolted joints in pressurised systems

Third edition

energy institute

GUIDELINES FOR MANAGEMENT OF INTEGRITY OF BOLTED JOINTS IN PRESSURISED SYSTEMS

Third edition

October 2021

Published by
Energy Institute, London
The Energy Institute is a professional membership body incorporated by Royal Charter 2003
Registered charity number 1097899

The Energy Institute (EI) is the chartered professional membership body for the energy industry, supporting over 23 000 individuals working in or studying energy and 200 energy companies worldwide. The EI provides learning and networking opportunities to support professional development, as well as professional recognition and technical and scientific knowledge resources on energy in all its forms and applications.

The EI's purpose is to develop and disseminate knowledge, skills and good practice towards a safe, secure and sustainable energy system. In fulfilling this mission, the EI addresses the depth and breadth of the energy sector, from fuels and fuels distribution to health and safety, sustainability and the environment. It also informs policy by providing a platform for debate and scientifically-sound information on energy issues.

The EI is licensed by:
- the Engineering Council to award Chartered, Incorporated and Engineering Technician status, and
- the Society for the Environment to award Chartered Environmentalist status.

It also offers its own Chartered Energy Engineer, Chartered Petroleum Engineer, and Chartered Energy Manager titles.

A registered charity, the EI serves society with independence, professionalism and a wealth of expertise in all energy matters.

This publication has been produced as a result of work carried out within the Technical Team of the EI, funded by the EI's Technical Partners. The EI's Technical Work Programme provides industry with cost-effective, value-adding knowledge on key current and future issues affecting those operating in the energy sector, both in the UK and internationally.

For further information, please visit **http://www.energyinst.org**

The EI gratefully acknowledges the financial contributions towards the scientific and technical programme from the following companies:

ADNOC
BP Exploration Operating Co Ltd
BP Oil UK Ltd
Chevron North Sea Ltd
Chevron Products Company
Chrysaor
CLH
CNOOC
ConocoPhillips Ltd
DCC Energy
Drax Group
EDF Energy
EDPR
ENI
E. ON UK
Equinor
ExxonMobil International Ltd
Innogy
Ithaca Energy
Intertek
Kuwait Petroleum International Ltd
Neptune Energy
Ørsted
Phillips 66
Prax
Qatar Petroleum
Repsol Sinopec
RWE npower
Saudi Aramco
Scottish Power
SGS
Shell UK Oil Products Limited
Shell U.K. Exploration and Production Ltd
Siemens Gamesa Renewables
Spirit Energy
SSE
TAQA Bratani
TotalEnergies
Uniper
Valero
Vattenfall
Vitol Energy
Woodside
World Fuel Services

However, it should be noted that the above organisations have not all been directly involved in the development of this publication, nor do they necessarily endorse its content.

Copyright © 2021 by the Energy Institute, London.
The Energy Institute is a professional membership body incorporated by Royal Charter 2003.
Registered charity number 1097899, England
All rights reserved

No part of this book may be reproduced by any means, or transmitted or translated into a machine language without the written permission of the publisher.

ISBN 978 1 78725 274 5

Published by the Energy Institute

The information contained in this publication is provided for general information purposes only. Whilst the Energy Institute and the contributors have applied reasonable care in developing this publication, no representations or warranties, express or implied, are made by the Energy Institute or any of the contributors concerning the applicability, suitability, accuracy or completeness of the information contained herein and the Energy Institute and the contributors accept no responsibility whatsoever for the use of this information. Neither the Energy Institute nor any of the contributors shall be liable in any way for any liability, loss, cost or damage incurred as a result of the receipt or use of the information contained herein.

Hard copy and electronic access to EI and IP publications is available via our website, **https://publishing.energyinst.org**.
Documents can be purchased online as downloadable pdfs or on an annual subscription for single users and companies.
For more information, contact the EI Publications Team.
e: **pubs@energyinst.org**

CONTENTS

Page

Foreword **8**

Acknowledgements **9**

Dedication **11**

Introduction **12**

1 Ownership, support and integration **17**
1.1 Ownership 17
1.2 Support 17
1.3 Integration 17

2 Management process **18**
2.1 Overview and safety 18
2.2 Process elements 18

3 Bolted joint technology and practice **19**
3.1 Overview 19
3.2 Flanged joint principles 19
3.3 Types of bolted joints 20
3.3.1 Flanged piping joints 20
3.3.2 Compact flanges 21
3.3.3 Clamp connectors 22
3.3.4 Non-standard flanges 23
3.4 Bolted pipe joint components – care and attention 23
3.4.1 Flanges and clamp connectors 23
3.4.2 Gaskets and seal rings 25
3.4.3 Insulation/isolation gaskets/sets 30
3.4.4 Bolting 31
3.5 Principles of joint assembly and disassembly 34
3.5.1 Identification of joint and selection of correct components 34
3.5.2 Inspect the components and flange faces 35
3.5.3 Assemble the components 35
3.5.4 Alignment 35
3.5.5 Break-out 36
3.6 Controlled tightening of joints 37
3.6.1 Bolt load calculations 37
3.6.2 Paint or coatings under the nut face and on the joint interface 38
3.6.3 Torquing-specific considerations 38
3.6.4 Tensioning-specific considerations 40
3.7 Bolted joint reliability 41
3.7.1 Reliability factors 41
3.7.2 Bolt load calculations 41
3.7.3 Bolt tightening 41
3.7.4 Hydraulic tensioners 42
3.7.5 Tensioning process 43
3.7.6 Equipment and tools 43
3.7.7 Load control systems – assured bolt load 44

Contents continued

Page

4 Criticality assessment 46
4.1 Assessing the risks with bolted joints 46
4.2 Service fluid/gas 47
4.3 Leak potential 47
4.4 Loss potential 48
4.5 Local factors 48
4.6 Joint criticality rating 48

5 Training and competence 50
5.1 Introduction 50
5.2 Training 50
5.3 Competence 51
5.4 Competence assurance management system 51
5.5 Standards, guidelines and codes of practice 53
5.5.1 EN 1591 Part 4:2013 53
5.5.2 ASME-PCC-1-2013 Appendix A – training and qualification of bolted joint personnel 53
5.5.3 OLF 118 (Norwegian oil industry association) approved training course 54
5.5.4 Engineering Construction Industry Training Board (ECITB)/Step Change in Safety –Mechanical Joint Integrity 4 stage model 54
5.6 Third-party certification 56

6 Records, data management and tagging 57
6.1 Introduction 57
6.2 Unique joint identification 57
6.3 Records and data management 60
6.3.1 Recommended data 60

7 In-service inspection 65
7.1 Introduction 65
7.2 Risk assessment 65
7.3 Degradation mechanisms 65
7.4 Inspection techniques 69
7.4.1 Non-destructive testing 69
7.4.2 Destructive testing 71
7.5 Defect mitigation measures 71

8 Management of leaks 72
8.1 Introduction 72
8.2 Engineering risk assessment of leaks 72
8.3 Stages at which leaks occur 72
8.4 Corrective actions 75
8.5 Managing leaks and repairs 76
8.6 Learning from leaks 77

9 Analysis and review 80

Contents continued

Page

10 Integrity testing 81
10.1 Code compliant pressure testing vs. Post construction integrity leak testing 81
10.2 Integrity leak testing methods 82
10.2.1 'Gross air' (audible) leak testing 82
10.2.2 'Soapy bubble' leak testing 83
10.2.3 Helium leak testing 85
10.2.4 Hydrostatic leak testing 87
10.2.5 Hydrostatic – pneumatic leak testing 87
10.3 Factors to consider when selecting a leak testing method 89
10.4 Integrity leak testing documentation 90
10.5 Test medium specification 90
10.6 HSE risks and control measures 91
10.7 Training and competency. 93

11 Hot bolting (single stud/odd bolting) bolt replacement 95
11.1 Introduction 95
11.2 Hot bolting practices 95
11.2.1 Hot bolting (single stud replacement.) 95
11.2.2 Odd bolting 96
11.2.3 Hot start-up re-torque 96
11.3 Engineering review and risk assessment. 96
11.3.1 Maximum working pressure for hot bolting (single stud replacement.). 97
11.3.2 Maximum working pressure for odd bolting 98
11.4 Four bolt flanges 98
11.5 Records of hot bolting 99

12 Lessons learned 100
12.1 Training and competence reduces hydrocarbon leakage. 100
12.2 Clamp connector leakage causes explosion 101
12.3 Leak testing tape causes joint failure 102
12.4 Examples of effective tagging and joint ID 102
12.4.1 Joint missed 102
12.4.2 Duplicate joints 102
12.5 Interference with joints post flange management causes leakage 103
12.6 Loss of containment on onshore asset due to leakage from pressure vessel flange 103
12.7 Use of incorrect lubricant. 104
12.8 Fatality during clamp connector break-out. 104
12.9 Injuries during flange break-out. 105
12.10 Leakage due to use of alternative manufacturer seal rings in compact flanges and clamp connectors 105
12.11 High hardness and or contact stress of RTJ rings causes groove damage 105
12.12 Fitting of earthing tags to joints causing risk to joint integrity 105

LIST OF FIGURES AND TABLES

Page

Figures

Figure 1 Essential elements of a management system . . . 13
Figure 2 Image of raised face flange with spiral wound gasket and studded bolts showing forces on the gasket bolts and flange . . . 20
Figure 3 Image of flat face flange with full face gasket and studded bolts showing forces on the gasket bolts and flange . . . 21
Figure 4 Image of RTJ with studded bolts showing forces on ring, bolts and flange . . . 21
Figure 5 Operation of a Norsok L005 (ISO 27509) compact flange . . . 22
Figure 6 Clamp connector showing preferred orientation . . . 23
Figure 7 Sealing faces showing surface finish on raised face, flat face and RTJ, clamp connector and compact flange . . . 24
Figure 8 Nut seating area on a flange and clamp. . . . 24
Figure 9 Raised face flange connected to a flat face flange . . . 24
Figure 10 Flange identification markings . . . 24
Figure 11 Spiral wound and kammprofile gasket marking . . . 25
Figure 12 Spiral wound gasket with inner ring buckling . . . 26
Figure 13 Image of metal clad gasket . . . 27
Figure 14 Image of pipe flange kammprofile . . . 27
Figure 15 Image of heat exchanger kammprofile. . . . 28
Figure 16 Image of CMG gasket . . . 28
Figure 17 Image of graphite tanged gasket . . . 28
Figure 18 Image showing octagonal ring and oval ring . . . 29
Figure 19 Image showing different types of octagonal ring . . . 29
Figure 20 Image of nuts and bolts correctly installed with grade markings showing. . . . 31
Figure 21 Common bolt and nut grade markings . . . 33
Figure 22 Flange alignment tolerances ASME B31.3 and PCC-1-2013 . . . 36
Figure 23 Cross bolt torque tightening sequence. . . . 39
Figure 24 New image of tension passes. . . . 40
Figure 25 Examples of a multi part tag . . . 60
Figure 26 Sample JIR/JCC . . . 64
Figure 27 Badly corroded flange . . . 66
Figure 28 Dissimilar flanges corroding . . . 66
Figure 29 Different bolt material . . . 66
Figure 30 Badly wasted bolt . . . 67
Figure 31 Crevice corrosion . . . 67
Figure 32 Fatigued bolt . . . 67
Figure 33 Image of SCC . . . 68
Figure 34 Hydrogen embrittlement . . . 68
Figure 35 Flange face corrosion. . . . 68
Figure 36 Seal ring . . . 69
Figure 37 Phased array ultrasonics. . . . 70
Figure 38 Example leak decision and analysis process . . . 78
Figure 39 Flange with gasket seating face pitting . . . 79
Figure 40 Encasement clamp repair on a 24 in. seawater line to stop leak on stub of composite flange. . . . 79
Figure 41 Stages of mechanical joint integrity competence . . . 97
Figure 42 Root cause example. . . . 103

Tables

Table 1 Joint criticality – typical criteria used and controls applied 49
Table 2 Gross air leak testing advantages and disadvantages 83
Table 3 Soapy bubble leak testing advantages and disadvantages 85
Table 4 Helium leak testing typical acceptance criteria 86
Table 5 Helium leak testing advantages and disadvantages 86
Table 6 Hydrostatic leak testing advantages and disadvantages 87

FOREWORD

This publication intends to provide a fully updated and much expanded third edition of the guidance for the *Management of Bolted Joints in Pressurised Systems* in order to facilitate good practice throughout the industry.

This document describes the principles and good practice for the establishment of a management system for bolted joints in pressurised systems. Individually, the sections of this document provide details of what is considered good practice in the key areas of ensuring joint integrity. Together, they provide the framework and principles of a management system. It should be noted that this document is not intended as a design guide for bolted joints, but as a guide to how to manage joints during construction and commissioning phases and throughout their operational life.

Although it is anticipated that following this publication will assist those involved in the management of bolted joints, the information contained in this publication is provided as guidance only. While every reasonable care has been taken to ensure the accuracy of its contents, the EI, and the technical representatives listed in the acknowledgements, cannot accept any responsibility for any action taken, or not taken, on the basis of this information. The EI shall not be liable to any person for any loss or damage which may arise from the use of any of the information contained in any of its publications.

The above disclaimer is not intended to restrict or exclude liability for death or personal injury caused by own negligence.

Suggested revisions are invited and should be submitted to the Technical Department, Energy Institute, 61 New Cavendish Street, London, W1G 7AR.

ACKNOWLEDGEMENTS

The Institute wishes to record its appreciation of the work carried out by the following individuals over the project duration:

Steering group members:

Roubik Allahverdi	Lloyds Register
Ismenia Alvarez	Apache
Henrik Anderson	Shell
Louise Atkin	HSE
Stephen Bage	Maersk Oil
Blair Barclay	ECITB
Matthew Barnett	CNOOC International
Kevin Beaumont	HYTORC
Anthony Bokas	Baker Hughes
Gary Briggs	Lamons
Stuart Brooks	BP
Richard Carroll	BG Group
Fran Chalmers	Centrica
Rod Corbett	Rotabolt
Terrance Dixon	Independent
Glen Eaton	Grayloc
Dr Bill Eccles	Bolt Science
Andrew Ferguson	Baker Hughes
Sean Fraser	Grayloc
Derek Gall	Conocophillips
Colin Gibson	James Walker
Neil Gledhill	Chevron
Scott Grieve	Chevron
Jim Hewson	Lamons
Gary Johnson	Maersk Oil
Martin Lawson	SPX
Phil Ligertwood	Chevron
Les Linklater	Step Change in Safety
Wayne Longden	Chevron
Gary Longhurst	BP
Syd Lyth	Lamons
John Macdonald	Chevron
Paul Magill	Pamargan
Gary Milne	Flexitallic
Roddy Milne	PIM Ltd
Robert Noble (Chair)	Asset 55
Michael Riach	Stork
Philip Roberts	Strongwork.co.uk
Karen Robertson	Total
Martin Roughton	Grayloc
Ibrahim Shahin	BG Group
Mike Shearer	Lloyds Register
Gavin Sim	Alba Gaskets Ltd
Mike Skellett	HSE

Gavin Smith	Phoenix Sealing
Roy Smith	HYTORC
Andy Stephens	BG Group
G Todd	Well Services group

Technical editing: Robert Noble (Chair) and then Kevin Beaumont (HYTORC) with thanks to the team at Asset 55 for closing out the work that Robert began.

This new third edition guidance was coordinated and managed by Dr Cameron Stewart, Energy Institute, Upstream Technical Manager.