Guidelines for safe operation and management of ageing gas turbines on offshore petroleum installations

energy institute

GUIDELINES FOR SAFE OPERATION AND MANAGEMENT OF AGEING GAS TURBINES ON OFFSHORE PETROLEUM INSTALLATIONS

First edition

October 2018

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 20 000 individuals working in or studying energy and 250 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

Andeavor
Apache North Sea
BP Exploration Operating Co Ltd
BP Oil UK Ltd
Centrica
Chevron North Sea Ltd
Chevron Products Company
Chrysaor
CLH
ConocoPhillips Ltd
DCC Energy
EDF Energy
ENI
E. ON UK
Equinor
ExxonMobil International Ltd
Innogy
Kuwait Petroleum International Ltd
Nexen CNOOC
Ørsted
Perenco
Phillips 66
Qatar Petroleum
Repsol Sinopec
RWE npower
Saudi Aramco
Scottish Power
SGS
Shell UK Oil Products Limited
Shell U.K. Exploration and Production Ltd
SSE
TAQA Bratani
Total E&P UK Limited
Total UK Limited
Tullow Oil
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.

ISBN 978 0 85293 882 9

Published by the Energy Institute

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 . . . 7

Acknowledgements . . . 8

1 Introduction . . . 9
1.1 General . . . 9
1.2 Leading commentary . . . 9
1.3 Scope . . . 9
1.4 Application . . . 10
1.5 Legal commentary . . . 10

2 Policy . . . 12
2.1 Company policy and its implementation . . . 13
2.2 Maintenance policy . . . 14
2.3 Inspection policy . . . 16
2.4 Ongoing assessment . . . 16
2.5 ATEX mechanical ignition source assessments . . . 17

3 Management . . . 18
3.1 Policy for addressing ageing . . . 18
3.2 Organisation culture and competency . . . 18
3.2.1 Support engineers . . . 19
3.2.2 Working with specialists . . . 19
3.3 Management of change (MoC) . . . 19

4 Safety and assurance . . . 21
4.1 General . . . 21
4.2 Service bulletins/safety alerts . . . 21
4.3 Hazard identification . . . 21
4.4 Selection of structured review techniques . . . 22
4.5 Assessment of risk . . . 22
4.6 Risk reduction . . . 23
4.6.1 Risk reduction priorities . . . 23
4.7 Performance standards . . . 24

5 Reliability and maintenance analysis . . . 26
5.1 Watch keeping for machinery condition . . . 26
5.2 Collecting information . . . 27
5.2.1 Data input . . . 27
5.2.2 Results . . . 27
5.3 Audit . . . 27
5.3.1 Reviewing performance . . . 27
5.3.2 Site condition report verification of maintenance regimes . . . 27
5.4 Integrity inspections . . . 28
5.5 Inspections of ancillary equipment . . . 28

6 Training, competence and ongoing stewardship . . . 29
6.1 Control of work . . . 29

Contents continued

Page

6.2 Operation and maintenance . . . 29
6.2.1 Competency . . . 30
6.2.2 Operation and troubleshooting . . . 30

7 Assessment for fitness for service . . . 32
7.1 Gas turbine continued service review process. . . . 32

8 Audits and standards . . . 35
8.1 Package audits . . . 35
8.1.1 Safe access . . . 35
8.1.2 Audit best practice . . . 35
8.2 Small Bore Tubing and connections . . . 36
8.3 Flexible Hosing Assemblies. . . . 36

9 Failures and mitigation . . . 37
9.1 Air intakes . . . 37
9.2 Enclosures . . . 48
9.3 Starting system . . . 54
9.4 Ventilation . . . 56
9.5 Exhausts and Waste Heat Recovery Units . . . 58
9.6 Heavy industrial turbines . . . 62
9.7 Light industrial/aero-derivative gas turbines . . . 65
9.8 Free Power Turbines. . . . 67
9.9 Oil systems . . . 70
9.10 Fuel systems . . . 75
9.11 Control systems . . . 78

References . . . 82

Bibliography . . . 84

Annexes

Annex A Guidance for the relevant health and safety regulations applicable to the UK offshore industry. . . . 85

Annex B Boundary definition of a gas turbine for the purpose of this document 86

Annex C Abbreviations . . . 87

Annex D Audit check sheets . . . 89

LIST OF FIGURES AND TABLES

Page

Figures

Figure 1 Application of the guidelines within the maintenance and inspection regime . . . 11
Figure 2 Example of a strategy to develop a company policy for the continued operation of rotating equipment . . . 13
Figure 3 Example of a 5-tier risk assessment matrix . . . 23
Figure 4a Review process flow chart . . . 33
Figure 4b Review process flow chart for retrofit . . . 34
Figure 5 Corrosion of air intake structure . . . 47
Figure 6 Internal corrosion of air intake duct . . . 47
Figure 7 Corrosion failure of inlet turning vanes . . . 47
Figure 8 Manometric drains blocked . . . 47
Figure 9 Duct joints encapsulated – best practice . . . 47
Figure 10 Internal turbine salt deposits (poor intake filtration) . . . 47
Figure 11 Original enclosure design heavy unhinged access panels . . . 53
Figure 12 New package design with hinged doors . . . 53
Figure 13 Water ingress damage . . . 53
Figure 14 Corroded door . . . 53
Figure 15 Damaged door seal . . . 53
Figure 16 Impact damage to damper louvres . . . 53
Figure 17 Corrosion affected fire damper . . . 53
Figure 18 Corrosion affected fire damper replaced . . . 53
Figure 19 Failed hydraulic starter motor . . . 56
Figure 20 Starter drive original design defective OEM upgrade available . . . 56
Figure 21 Typical heavy gas turbine starter package . . . 56
Figure 22 Shows foreign object damage to enclosure ventilation fan . . . 58
Figure 23 Alternative view of enclosure ventilation fan damage . . . 58
Figure 24 Salt build-up on GT casing due to poor enclosure integrity . . . 58
Figure 25 Damaged vent duct bellows . . . 58
Figure 26 Flexible bellows – exhaust corrosion under insulation . . . 61
Figure 27 WHRU duct corrosion under insulation . . . 61
Figure 28 Exhaust Corrosion (bellow area) . . . 61
Figure 29 Pooled water causing – waste heat recovery unit corrosion . . . 61
Figure 30 Exhaust Silencer support link – excessive wear . . . 61
Figure 31 Blown exhaust bellows . . . 61
Figure 32 Exhaust bellows temporary repair . . . 61
Figure 33 Turbine during build roof off . . . 64
Figure 34 Heavy industrial turbine – casing removal *in situ* . . . 64
Figure 35 Compressor casing – surface corrosion . . . 64
Figure 36 Frame 5 heavy industrial general condition . . . 64
Figure 37 Seized IGV lever arms causing damage due to compressor blade failure . . . 67
Figure 38 Compressor blade failure due to high cycle fatigue . . . 67
Figure 39 Damage due to compressor blade failure . . . 67
Figure 40 Aero derivative GT casing fracture due to high cycle fatigue . . . 67
Figure 41 Power turbine outer exhaust diffuser bellows caused by foreign object . . . 70
Figure 42 Further picture of power turbine casing damage . . . 70
Figure 43 Power turbine sheared mount bolts . . . 70
Figure 44 Example of poor housekeeping – residual oil and debris on enclosure floor – potential fire hazard . . . 73

List of figures and tables continued

Page

Figure 45 Oil degradation leading to oil varnish on bearing heavy 73
Figure 46 Cracked plate heat exchanger (lub oil/sea water) 73
Figure 47 Tubing fretting damage From AVIFF guidelines fig T6-4 73
Figure 48 Water/Oil being drained from alternator following cooler failure 74
Figure 49 Typical sludge build up in bottom of lube oil reservoirs. 74
Figure 50 Dual Fuel nozzle minimal contamination 77
Figure 51 Dual Fuel nozzle heavy contamination 77
Figure 52 Aged Fuel System SBT (single ferrule, distorted, poor support etc.). 77
Figure 53 Liquid contamination of gas fuel line 77
Figure 54 Collapsed exhaust due to fuel leakage. 77
Figure 55 Original supply (1985) of control panel 81
Figure 56 Modern (2013) control system (new supply). 81
Figure 57 Original control panel (1978) with vibration protection retrofit 81
Figure 58 Example of original control panel wiring 81
Figure 59 Example of original control panel wiring 81

Table

Table 1 Design considerations within gas turbine packages and/or auxiliaries. 15
Table 2 Air intakes 39
Table 3 Enclosures 49
Table 4 Starting system 55
Table 5 Ventilation. 57
Table 6 Exhausts and waste heat recovery units 59
Table 7 Heavy industrial turbines 63
Table 8 Light industrial/aero-derivative gas turbines 66
Table 9 Free power turbines. 68
Table 10 Oil systems 71
Table 11 Fuel systems 76
Table 12 Control systems. 79

FOREWORD

This document was written and compiled under the direction of North Sea Rotating Equipment Users Network (NSeaREUN) comprising personnel from a cross-section of UK offshore Operators, and PGD Engineering Services. The NSeaREUN members provided input to the development via discussion at meetings, correspondence, individual contributions and with provision of industry experience and other selected information.

The gas turbine (GT) is one of a series of rotating machinery types that operators seek to deploy beyond design life. This document aims to provide those with an involvement in operation and maintenance of such equipment, including managers, designers, equipment manufacturers, and integrity and maintenance engineers, with good practical guidance on how to ensure that the integrity of GTs is retained when operated beyond their designed operation life.

Although instigated by, and produced for, the UK offshore industry, guidance provided herein is regarded as being applicable to similar industries throughout the world. It may also be useful to those involved in related onshore terminal and process plants.

Note:

In several places throughout, examples have been used which have been provided by members of the NSeaREUN. Where these have been cited, it is implicit there are alternative ways and methods that other users may use to meet the same objective that may also constitute good practice. Therefore, these examples are provided for guidance only and should not be regarded as a recommendation or a standard.

This guideline may be reviewed from time to time and it would be of considerable assistance for any future revision if users would send comments or suggestions for improvements to:

The Technical Department, Energy Institute, 61 New Cavendish Street, London, W1G 7AR

E: technical@energyinst.org.uk