

Gas turbine exhaust systems with or without waste heat recovery

National foreword

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Gas turbine exhaust systems with or without waste heat recovery

*Systèmes d'échappement des turbines à gaz avec ou sans récupération
de la chaleur résiduelle*





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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 192, *Gas turbines*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document has been developed in response to the international market need for a specification relating to the exhaust and heat recovery systems for gas turbines. Purchasers and suppliers will benefit from a standard against which equipment can be purchased, designed and constructed - especially given the challenging nature of the turbulent exhaust gas flow and associated complexity of mechanical design. Equipment is frequently installed in remote and challenging locations both onshore and offshore where maintenance and repair can be prohibitively expensive.

A waste heat recovery unit recovers thermal energy from the waste heat available in gas turbine exhaust gases, exchanged into various heat transfer media such as water, water/glycol mixtures, thermal oils and hydrocarbon gases.

The application of heat recovery devices to gas turbines results in significant thermal efficiency gains and resultant environmental benefit from reduction in CO₂ emissions. Gas turbine exhaust is one of many sources of waste heat energy and can be classed as medium grade within a typical temperature range between 400 °C and 600 °C suitable for Rankine cycle applications.

Gas turbine exhaust systems with or without waste heat recovery

1 Scope

This document specifies requirements and gives recommendations for the design, materials of construction, modelling, controlling, fabrication, inspection, testing, installation, start-up and operation of industrial gas turbine (GT) exhaust systems with or without waste heat recovery unit (WHRU). Gas turbines can be on-shore or off-shore for such sectors as oil and gas, chemical and process industries, utilities, or other intensive energy users.

For this document, the exhaust system means all items in the turbine exhaust gas stream between the GT exhaust gas collector outlet flange and the termination/s to the atmosphere.

The following items are not covered by this document:

- heat recovery steam generator equipment (HRSG);
- supplementary fired systems;
- auxiliary fired systems;
- exhaust gas collector (also known as exhaust plenum);
- fire detection and extinguishing systems;
- emissions controls equipment intended to modify the gaseous composition of the exhaust gas;
- WHRUs that are of the firetube type, where the turbine exhaust gas (TEG) passes through the tubes.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 3744, *Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Engineering methods for an essentially free field over a reflecting plane*

ISO 9614, *Acoustics — Determination of sound power levels of noise sources using sound intensity*

ISO 10494, *Turbines and turbine sets — Measurement of emitted airborne noise — Engineering/survey method*

ISO 10474, *Steel and steel products — Inspection documents*

ISO 12241, *Thermal insulation for building equipment and industrial installations — Calculation rules*

ISO 13704, *Petroleum, petrochemical and natural gas industries — Calculation of heater-tube thickness in petroleum refineries*

ISO 13705:2012, *Petroleum, petrochemical and natural gas industries — Fired heaters for general refinery service*

ISO 13916, *Welding — Measurement of preheating temperature, interpass temperature and preheat maintenance temperature*

ISO 14122, *Safety of machinery — Permanent means of access to machinery*

ISO 14555, *Welding — Arc stud welding of metallic materials*

ISO 15612, *Specification and qualification of welding procedures for metallic materials — Qualification by adoption of a standard welding procedure specification*

ISO 15613, *Specification and qualification of welding procedures for metallic materials — Qualification based on pre-production welding test*

ISO 15614-1, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys*

ISO 19902, *Petroleum and natural gas industries — Fixed steel offshore structures*

ASME B16.9, *Wrought steel butt-welding short radius elbows and returns*

ASME B31.3, *Petroleum Refinery Piping*

ASTM C680-10, *Standard Practice for Estimate of the Heat Gain or Loss and the Surface Temperatures of Insulated Flat, Cylindrical, and Spherical Systems by Use of Computer Programs*

EN 287-1, *Qualification test of welders — Fusion welding — Steels*

EN 1011-2, *Welding — Recommendations for welding of metallic materials — Part 2: Arc Welding of Ferritic Steels*

EN 1991-1-4, *Eurocode 1: Actions on structures — Part 1-4: General actions — Wind actions*

EN 10025-2, *Hot rolled products of structural steels — Technical delivery conditions for non-alloy structural steels*

EN 10025-3, *Hot rolled products of structural steels — Technical delivery conditions for normalized/normalized rolled weldable fine grain structural steels*

EN 10253-2, *Butt-welding pipe fittings. Non alloy and ferritic alloy steels with specific inspection requirements*

EN 13445-3:2014, *Unfired pressure vessels — Part 3: Design*

EN 13480, *Metallic Industrial piping*

EN 15614, *Specification and qualification of welding procedures for metallic materials*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1

analogue control signal

control or digital signal that represents a continuous range of values

EXAMPLE A traditional 4-20 mA current loop.

3.2**commissioning**

action whereby dynamic checks and tests where the GT is running, the exhaust system is subject to TEG flow and the WHRU is filled with circulating HTMs, progressively loaded with control systems and functioning

3.3**data sheet**

formal document containing process and/or mechanical data

3.4**insulation**

material applied to either the inside or outside of the exhaust system component casings (e.g. WHRU, ducting, stacks, dampers) in order to reduce the casing material or outer cladding temperature, respectively

3.5**pre-commissioning**

static checks and tests where the exhaust system is cold and the WHRU is not filled with HTM and the controls are energized

3.6**purchaser**

party that enters into contract with the *supplier* (3.8) for the supply of the exhaust system

Note 1 to entry: The purchaser is the party who specifies the technical requirements. The purchaser can also instruct a *contractor* (3.7), an agent or consultant, authorized to act for, and on his behalf. The purchaser can in some cases also be the GT supplier.

3.7**contractor**

party that carries out all or part of the design, engineering, procurement, construction, *commissioning* (3.2) or management of a project or operation of a facility

Note 1 to entry: The *purchaser* (3.6) can choose to undertake all or part of the duties of the contractor

3.8**supplier**

party that manufactures or supplies equipment and services to perform the duties specified by the *purchaser* (3.6)

3.9**WHRU tube bundle**

hairpin tube bundle arrangement contained within a rectangular casing, or a nested helical coiled tube arrangement contained within a cylindrical casing

4 Abbreviated terms

ALS	Absolute limit state
CFD	Computational fluid dynamics
CHT	Conjugate heat transfer
CSCC	Chloride stress corrosion cracking
COTS	Commercial off the shelf
DES	Detached eddy simulation

DFF	Design fatigue factor
DLE	Dry low emission
DNS	Direct numerical simulation
FAT	Factory acceptance test
FEM	Finite element method
FPSO	Floating production storage and offloading
FLS	Fatigue limit state
FSI	Fluid structure interaction
GT	Gas turbine
HART	Highway addressable remote transducer
HCF	High cycle fatigue
HTM	Heat transfer medium
ITP	Inspection and test plan
LES	Large eddy simulation
LCF	Low cycle fatigue
MLD	Multi louvre damper
NDT	Non-destructive test
P&ID	Piping and instrument diagram
PMI	Positive material identification
PQR	Procedure qualification record
PT	Penetrant test
RANS	Reynolds averaged Navier-Stokes CFD modelling (generally referring to modelling steady flow behaviour)
RFQ	Request for quotation
SDRL	Supplier document requirement list
TEG	Turbine exhaust gas
ULS	Ultimate limit state
URANS	Unsteady Reynolds averaged Navier-Stokes CFD modelling
WHRU	Waste heat recovery unit
WPQ	Welding procedure qualification
WPS	Welding procedure specification

5 Proposals

5.1 Purchaser's responsibilities

The purchaser's enquiry should include data sheets, checklist and other applicable information outlined in this document. This information should include any special requirements or exceptions to this document (see [Annex C](#)).

The purchaser is responsible for the correct process specification to enable the supplier to carry out the exhaust system design and manufacture.

The purchaser is responsible to clearly state the supplier's scope of supply.

The purchaser's enquiry should specify the number of copies of drawings, data sheets, specifications, data reports, operating manuals, installation instructions, spare parts lists and other data to be provided by the supplier.

5.2 Supplier's responsibilities

The supplier's proposal should include:

- a) data sheets for each exhaust system and the associated equipment;
- b) an outline drawing showing as a minimum, layout and clearances, arrangement of tube bundles, platforms, ducting, damper systems and stack;
- c) a definition of the extent of shop assembly, including the number, size and weight of prefabricated parts and the number of field welds;
- d) a detailed description of any exceptions to the specified requirements including this document;
- e) a completed noise data sheet if specified by the purchaser;
- f) a time schedule for submission of all required drawings, data and documents;
- g) a program for scheduling the work after receipt of an order; this should include a specified period of time for the purchaser to review and return drawings, procurement of materials, manufacture and the required date of supply;
- h) a list of utilities and quantities required;
- i) if specified by the purchaser, a list of proposed sub-suppliers for major components and items, which can include steel plate, insulation materials, expansion joints, tubes and extended surfaces on tubes, fittings, tube bundle fabrication, dampers, castings, steel fabrication, ladders and platforms and other auxiliary equipment.

The supplier shall identify all parts and components with a shorter estimated lifetime than that specified for the complete system or which will need maintenance and/or removal for service. Expansion joints, damper, actuators and seals are examples of such components.

6 Basic exhaust system design

6.1 General

GT exhaust systems can be with or without a WHRU and damper system which recovers heat from the exhaust of a GT and exchanges this heat into HTM to supplement the thermal requirements of another process. The WHRU enhances the thermal efficiency of the cycle with minimal impact on the operation of the GT itself.

6.2 Exhaust system configuration

Each exhaust system should normally be connected to its own GT. In the event that more than one GT is connected to an exhaust system, then special considerations would apply which are not covered in detail in this document.

6.3 Service life

Unless otherwise stated by the purchaser, the design, selection of equipment and materials and corrosion protection shall be based on a design lifetime of 20 years with 30 starts/stops from cold to full load per year. The supplier should supply the service life and minimum uninterrupted operation interval based on each specific application. The maintenance procedure necessary to achieve these intervals should also be supplied.

NOTE For highly cyclic GT applications, e.g. in single cycle mode, where the start/stop cycles are significantly more frequent, the risk of fatigue on various parts of the WHRU increases.

6.4 Supply responsibility

Supply responsibility for the exhaust system should be either with the GT supplier or contracted directly between the purchaser and the exhaust system supplier.

6.5 GT characteristic data

If the exhaust system is purchased under the GT supplier responsibility then the GT supplier is responsible to provide the required dimensional, acoustic, thermal, flow characteristics (steady state and transient) and mechanical information to the exhaust system supplier as specified in this document.

In the event that the purchaser contracts directly with the exhaust system supplier then it becomes the purchaser's responsibility to obtain this data from the GT supplier and pass it on the exhaust system supplier.

6.6 Required operating envelope

The purchaser is responsible to define the equipment's required operating envelope which should be shown on the data sheets including any dry run requirements as defined in [9.3.2](#).

The supplier is responsible for ensuring that all items of equipment and components provided are designed for the specified operating conditions.

The supplier shall ensure that the equipment takes account of all potential applied loads (typically seismic, transportation, wind loads, etc.).

6.7 Equipment specification

The exhaust system should be proven in practice, robust, reliable, safe, operable and maintainable.

The exhaust system should be based on the least number of factory-built modules consistent with transport and site erection dimensional and weight restrictions.

The exhaust system shall be designed and constructed to meet all operational cases specified in the RFQ.

6.8 WHRU equipment specification

Materials of construction for the tube bundle pressure parts shall be selected from internationally recognized material codes. The supplier's data sheets shall clearly state the location(s) of each material.

The WHRU shall be designed to provide the required performance with no negative tolerance. The design shall consider the selected fouling factor and required degree of over-surface to ensure that these requirements are met.

NOTE The HTM can typically be the following:

- (i) a water/glycol solution;
- (ii) hot oil/thermal oil;
- (iii) water;
- (iv) hydrocarbons, liquid or gaseous.

In the final selection of the HTM, due consideration should be given to operating temperatures and pressures, the degradation limits, surface tension, toxicity, flammability and corrosiveness of the HTM.

6.9 Operating conditions

Each component of the exhaust system (e.g. WHRU tube bundle and supports, casings and linings, ductwork, dampers, etc.) shall be capable of withstanding the most severe temperature specified plus a margin as defined in [Clause 8](#).

6.10 Operating environment

The equipment, including all auxiliaries, shall be designed for operation under the environmental conditions specified by the purchaser. These conditions should include whether the installation is indoors (heated or unheated) or outdoors, maximum and minimum temperatures, unusual humidity, and dusty or corrosive conditions, wind, earthquake and/or sea motions during operation and transport. The unit and its auxiliaries shall be designed for shipment and installation under the specified conditions.

If sub-zero ambient temperatures are specified by the purchaser, then appropriate materials and test procedures should be applied.

6.11 Equipment arrangement

The arrangement of the equipment, including piping and auxiliaries, should be developed jointly by the purchaser and the supplier. It is the purchaser's responsibility to identify dimensional limitations for the location of the exhaust system including space required for tube bundle and/or tube removal as well as any handling weight limitations that apply. The arrangement should be submitted by the supplier to the purchaser for review and agreement during the proposal phase.

The purchaser is responsible for specifying any weight limitations (e.g. maximum total equipment weight, maximum lifted weight). If no such limitations exist, at least the total equipment weight with applicable margin (e.g. $\pm 10\%$) should be included in the supplier's proposal.

6.12 Provision for future addition of WHRU

Where specified by the purchaser, the exhaust system shall include provision for future installation of a WHRU. This should include the bolted panel sized for the full exhaust flow to which a future WHRU can be connected. It should also include bolted duct section which can be replaced with a future damper or diverted system.

6.13 Electrical equipment

Motors, electrical components, and electrical installations shall be certified for the area classification specified (class, group, and division or zone).

6.14 Field assembly and disassembly

The supplier shall state in the proposal the proposed method for the disassembly required for repair or replacement of exhaust system parts such as expansion joints, WHRU, dampers or silencers. While tube failures are rare, if specified by the purchaser, the design shall include provision for tube bundle pressure part repair or replacement.

6.15 Special tools and fixtures

If special tools and fixtures are required to disassemble, assemble or maintain the unit, they shall be included in the supplier's proposal and furnished as part of the initial supply of the equipment. For multi-unit installations, the requirements for quantities of special tools and fixtures should be agreed between the purchaser and the supplier.

6.16 Spare parts

Spare parts supplied with the main equipment delivery shall be identical to the fitted parts.

6.17 Deviations

All proposed deviations of the supplier's equipment from this document shall be listed by the supplier with the bid.

7 Documentation

7.1 General

The supplier should provide all drawings, design details, calculations, and analysis, operation and maintenance manuals, and other information necessary for the design assessment, erection, operation and maintenance of the exhaust system installation. All information should be clear and not open to misinterpretation and shall apply specifically to the installation supplied.

The purchaser should specify which documentation is required to be provided in a local language.

The purchaser should specify the format and number of copies of documentation required from the supplier.

Unless otherwise specified and agreed by the purchaser all documentation should be submitted in electronic format.

All calculations and documentation shall be prepared using the agreed unit system for the project.

7.2 Data sheets

Data sheets should be used for the exchange of specification related information between the purchaser and the supplier. The purchaser is responsible for providing the GT data and corresponding WHRU thermal loads for the required duty envelope. The supplier shall provide completed data sheets with confirmation that performance requirements are met.

The recommended data sheet format for WHRUs is available for download using the link given in [Annex E](#).

7.3 Supplier document requirements

The purchaser should provide a SDRL for the exhaust system.

The supplier shall provide the documents listed in [Table 1](#) for review unless otherwise specified by the purchaser.

The purchaser should specify which documents are subject to his approval.

Table 1 — Documentation to be provided by the supplier and reviewed by the purchaser

Document	Remark
Calculations demonstrating compliance with specification requirements, including any pressure part and structural design codes	
Data sheets	Detailing process design and performance data at all specified operating cases. Mechanical, materials and construction data Key dimensions and weight
Suppliers manufacturing data report	
FAT procedure	
Site performance acceptance test procedure	
General arrangement drawings	Showing locations of all interfaces and major dimensions
Hazardous area and ingress protection certification for all electrical components.	
Welding and NDT data, including — WPS and PQR — WPQ — Weld map — ITP — NDT procedures — NDT personnel qualifications — Procedure for storage and handling of filler metals	
Inspection certificates for all metallic materials of construction.	Material certificates in accordance with ISO 10474 ^a , type 3.1 for all pressure parts and type 2 for materials of exhaust gas ducts/casings. The certificates shall satisfy the applicable code requirements.
Installation, operating and maintenance instructions	
Spare parts list	Commissioning and operational and strategic spare parts lists
Pre-commissioning and commissioning instructions	
Pressure and capacity test certificates for any pressure relief valves	
Pressure test certificates for any fabricated pressure parts	
Quality plan	
Fan and motor curves and data sheets for all fans.	To include: — sound power levels and sound pressure levels — test reports
Sound power levels and sound pressure levels of the equipment.	
P&IDs and controls description including alarm and trip points and cause and effect.	In accordance with appropriate ISO code and shall be complete, comprehensive and consistent
^a Reference can also be made to EN 10204 with regards to material certificates.	

Table 1 (continued)

Document	Remark
Tube bundle vibration and resonance analysis	
Fluid, thermal and structural analysis	See Annexes A and B
Structural dynamic analysis	See Annexes A and B
Instrumentation calibration certificates and data sheet	
3D outside dimensional model	
Packing list and handling instructions	
Foundation loading diagrams and support details	
Cross-sectional drawings	
Electrical/instrument layouts	
Insulation/lining details	
Control philosophy and block diagrams	
Electrical termination and hook-up details	
Interface terminal point list	
Hydrostatic/pneumatic test procedure	
Special tool list	
^a Reference can also be made to EN 10204 with regards to material certificates.	

8 Exhaust system engineering and design

8.1 Overview

Exhaust system components are listed below:

All GT exhaust ducts and transition sections

- a) WHRU(s) (Refer also to [Clause 9](#));
- b) Damper(s) (Refer also to [Clause 10](#));
- c) Stack;
- d) Silencing measures;
- e) Expansion joints;
- f) Structural steel supports.

If WHRU and damper systems are included in the scope of supply refer also to [Clauses 9](#) and [10](#) for WHRU process-design considerations and tube-bundle design requirements.

8.2 Typical WHRU configurations

There are several possible WHRU configurations. These are mainly characterised by different TEG flow directions, and bypass and silencer arrangements.

8.3 General

As the basis of design for the exhaust system the purchaser is responsible to supply the geometry and boundary conditions at battery limits under all specified design and operating conditions and cases, all as detailed in [Annex C](#).

The purchaser should take account of the fact that the exhaust system downstream of the GT can affect the flow conditions at the battery limit.

The purchaser should specify the maintenance philosophy to be applied in the design of the exhaust system components.

The allowable pressure drop across the exhaust side should be agreed by the supplier and the purchaser, and the supplier shall submit calculated pressure drop figures for each part of the system supplied, with necessary backup information for approval.

The purchaser should ensure that the pressure drop over the entire exhaust system does not result in the maximum allowable GT back pressure being exceeded.

NOTE The WHRU back pressure does reduce the shaft power and increase the fuel consumption/CO₂ emission of the GT, hence the specified limits need to balance the desirability of the low back pressure at the GT with the needs to provide a cost-effective exhaust system.

Flow straightening devices are not recommended.

8.4 TEG flow-induced vibrations

For guidance regarding the assessment of flow induced vibration of the exhaust system casings refer to [Annexes A](#) and [B](#).

Supplier shall ensure that TEG vortex shedding frequencies do not coincide with the acoustic frequencies which can cause unacceptable vibration of the WHRU tube bundle and casing or other exhaust system components.

8.5 Exhaust system casing and ducting

8.5.1 General

- a) Components should preferably be cold casing (internally lined). Hot casing designs are subject to approval from the purchaser.
- b) Hot casing designs have greater thermal expansion and transient thermal stress. There should be no change in insulation design principle along the TEG flow path. If unavoidable (e.g. hot casing exhaust collector and cold casing exhaust system), the transition shall be designed by means of an expansion bellow where each flange of the bellow has the same insulation design and material as the flange it is connected to.

NOTE The choice of the insulation principle has significant influence on cost/complexity of routine inspections of the system. While a cold casing system can be inspected from the outside while the GT is running (visual, thermographic), a hot casing system requires inspection from the inside to determine condition and mechanical integrity.

- c) The purchaser is responsible for defining in the RFQ, the extent of CFD or other flow testing of the ducting.
- d) Components should be of circular, square or rectangular construction.
- e) For hot casing design, circular shape is preferable.
- f) In the event of welded attachments inside the TEG path the supplier shall undertake thermal, flow and mechanical analyses which shall be subject to the purchaser's approval.
- g) Transition pieces between duct sections of different cross-sectional areas shall be provided if necessary. Abrupt transitions in cross-section should be avoided.

- h) The flow distribution through any change of flow path (shape and direction) should be taken into consideration for the overall system performance and service life (e.g. performance of WHRU, damper, silencer and GT).

NOTE TEG mal-distribution is a particular feature of exhaust systems which can cause:

- preferential heating of the different passes of the coil;
 - flow detachment from the duct wall and adverse effect to TEG pressure drop;
 - adverse effect to silencer performance and lifetime;
 - adverse effect to damper performance and lifetime.
- i) Expansion joints should be of fabric or metallic construction and shall be provided in the flue gas ducting as necessary (refer to [8.8](#)).
- j) All components (including joints) shall be gas tight to provide zero TEG leakage.
- k) Field joints should be seal-welded insulated and lagged in the field during assembly. If this is not practical due to maintenance philosophy or accessibility, extra attention should be given to the design of the field joint.
- l) For the component design the gas velocity shall be determined with due consideration of the pressure drop and acoustic requirements.
- m) The WHRU casing and ducting walls shall be constructed of steel plate. Plate thickness shall be determined by the overall mechanical design calculations. Plate thickness less than 6 mm for ferritic steel and 5 mm for austenitic steel shall be subject to approval by the purchaser. The material in combination with its corrosion protection should be proposed by the supplier if not stated in the RFQ.
- n) Components shall have a design pressure based on the most severe combination of the wind pressure and 1,5 times the maximum operating TEG pressure in the casing, but not less than 50 mbar. If applicable also explosion loads shall be taken into account.
- o) Components design shall take into consideration all other imposed loads such as:
- (i) lifting and transportation;
 - (ii) installation;
 - (iii) motion, e.g. acceleration from transportation, seismic events or offshore floatation;
 - (iv) snow and ice;
 - (v) wind.
- p) If a combined stack outside the supplier's scope is used, the purchaser is responsible for specifying the maximum positive and negative design pressures taking into account maximum natural draught and maximum back pressure.
- q) The design of stiffeners shall take into account thermal expansion and temperature gradients in normal operation and transient cases such as start-up and shut-down (always required for hot casing designs).
- r) Components shall be designed to prevent vibration, distortion and warping due to temperature, pressure GT pulsations and internal flow. Effective vibration isolation from the GT is particularly essential. Ducting shall be sufficiently rigid to prevent damage from vibration and avoid drumming when exposed to TEG flow over the complete flow range.
- s) Component sections should be suitably stiffened to minimize distortion. Component plate shall be designed to limit the deflections of the span of plate between stiffeners, taking full advantage of multi-span continuity where appropriate, under design conditions.

- t) Horizontal (flat) sections should be avoided to provide a drainage slope. All horizontal stiffeners shall be designed to prevent water accumulation e.g. weep holes.
- u) The exhaust gas system shall be provided with internal drainage connections at low points.
- v) All components shall be designed for the intended lifting or installation procedures.
- w) For hot casing design, welded lifting lugs should be removed after initial installation.
- x) The purchaser is responsible for specifying any requirement for supporting steelwork in the RFQ.
- y) The exhaust system shall be designed to accommodate the calculated thermal expansions, with fixed points local to the WHRU, damper and silencer (where installed) normally providing anchor points.
- z) Component supports shall be designed for all live and static loads, including any uplift due to specified wind and/or other loads. The WHRU hydrostatic test condition shall also be considered.

8.5.2 Hot casing design and materials

- a) It should be noted that this type of design is susceptible to excessive thermal stresses for the casing, associated stiffeners and structural members even for steady state operation. A FEM analysis shall be carried out to optimize the design to minimize the high thermal stresses during transient conditions and verify that the system will withstand the anticipated number of start/stop cycles during the required lifetime.

- b) Hot casing design is inherently unsuitable for units in cyclic operation.

NOTE Design processes can minimise cyclic impacts in steady state conditions but higher thermal stress during transient conditions is unavoidable.

- c) In parts of the exhaust duct with highly pulsating flow (usually close to the GT), the duct walls (especially non-circular) can be exposed to risk of high cycle fatigue due to vibration.
- d) Square corners are particularly susceptible to high stresses. Therefore, sharp corners shall be avoided and welds not be placed in areas with high stress. If square or rectangular design is used, all corners shall be formed with a radius so that all welding is on the sides of the duct.
- e) The casing material selected shall be designed for at least the maximum TEG temperature, as defined in [9.3.2.2 a\)](#).
- f) Supports shall be provided at each end of horizontal ducting sections and at midpoints as required. One support shall be anchored while the others are free to move on sliding pads or small rollers. Sliding supports shall be designed to allow lateral and axial expansion movements of the ducting. If sliding supports are used they shall be of a high temperature bearing material and heat shielded to protect the bearing material and the structural steel.

The material selection falls into one of the following groups:

- (i) Low alloy carbon steel (e.g. 13CrMo4-5, 10CrMo9-10);
- (ii) Stainless steel material, ferritic and austenitic (e.g. AISI 316, AISI 321);
- (iii) High temperature Ni Cr material (e.g. alloy 800).
- g) The following apply to the selected material (type and thickness):
 - (i) Corrosive aspect of the flue gas and required surface protection should be considered.
 - (ii) If low alloy steel is selected, strength values at elevated temperature shall be taken from recognized standard and creep shall be evaluated if operation in creep range is expected.
 - (iii) The temperature limits given in the structural code shall not be exceeded.

- (iv) A surface treatment designed for service life at high temperature should be used on all parts to reduce corrosion rate.
- (v) A corrosion allowance of 1,5 mm shall be included for low alloy material.
- (vi) For ferritic stainless steels a surface coating designed for service life at high temperature shall be used on all parts to reduce corrosion rate.
- (vii) Unless otherwise specified by purchaser, austenitic steels can be left uncoated if not insulated or exposed to marine atmosphere. If exposed to marine atmosphere stress corrosion can be a consideration due to chlorides.

NOTE Low alloy steel materials have good thermal conductivity and low thermal expansion properties, it is therefore a good choice regardless of thermal stress. While they tend to have lower creep stresses, alloy materials have higher thermal conductivity and lower thermal expansion making them less susceptible to thermal stress.

Stainless-steel material have good strength values at high temperatures and reduced corrosion rates. Ferritic steels have better thermal conductivity and lower thermal expansion properties than the austenitic steels. Ferritic Steels have lower corrosion resistance than austenitic.

High temperature Ni Cr materials have improved creep strength at very high temperature as well as very good corrosion properties but are more susceptible to high thermal stress due to lower thermal conductivity and high thermal expansion.

- h) Refer to [8.5.4](#) on flange-bolts system design.

8.5.3 Cold casing design material

Selection of material should be guided by the following considerations:

- a) Carbon steel

As the operating metal temperature is relatively low compared to hot casing design the main concern in material selection is to minimize corrosion. The low temperature increases the risk of condensation on the casing surface underneath the insulation system. This is especially a concern if there are compounds in the fuels which can form acid, such as sulphur.

- b) Stainless-steel material, (e.g. AISI 316, AISI 321)

Where stainless steel is used for marine environment grade SS316 or SS321 shall be used unless otherwise agreed with the purchaser.

For marine environments, stress corrosion is not normally considered to be a problem for material below 60 °C.

- (i) Stainless-steel materials may be used in this type of application due to good corrosion resistance or for cases where operation with insulation failure is a specified design condition.
- (ii) The purchaser is responsible for specifying if “loss of insulation” should be considered as a design case This mode can be critical for the design and give the maximum level of stress. In cases where the purchaser specifies design for loss of insulation then the provisions for hot casing design shall be considered.

NOTE Damage to insulation can remain undiscovered over a considerable length of time and when discovered operational needs might not allow for immediate repair.

8.5.4 Flange bolts

- a) The following factors should be considered in flange bolt design:
 - (i) flange thickness;

- (ii) flange material;
- (iii) local temperature increase over time;
- (iv) ambient conditions;
- (v) gasket type;
- (vi) gasket material;
- (vii) bolt material;
- (viii) bolt manufacturers' procedures.

NOTE For flange-bolt systems, rapid temperature rises in the flanges result in increases in flange thickness due to thermal expansion while the bolt shafts initially remain relatively cold. This can lead, if not addressed properly in the design, to premature (or even immediate) bolt failure, gas leakage and compromised mechanical integrity of the flange connection. If not properly considered, even the first start up cycle can overstretch a wrongly designed bolt resulting in permanent loss of pretension.

- b) Where specified by the purchaser, for cold casing design all evaluations mentioned under a) shall be part of the flange-bolt design to make the system robust and able to maintain mechanical integrity in case of loss of insulation (accidental load).

The additional cost associated with this provision can be justified when taking into account the following aspects:

- (i) Depending on design and insulation method, the insulation and lining system in flange areas can be more vulnerable than in a straight duct.
 - (ii) When insulation is lost, the mechanical integrity of bolts in the affected area can be compromised—even during one start/stop cycle.
 - (iii) Damage to the inside insulation can remain undiscovered over a considerable length of time or when discovered operational needs might not allow for immediate repair.
 - (iv) When insulation damage inside the duct can have compromised the bolts' mechanical integrity, the exchange of the affected bolts can be costly and time consuming if access is difficult.
- c) The supplier shall design flanges, gasket and bolts as one system and ensure that bolts will operate safely within their elastic operational range even when flanges are fully warmed up to expected steady state temperature while the bolt shaft still is at ambient temperature.
 - d) The gasket material shall not be a part of flange pretension system.
 - e) The supplier shall ensure that the bolts under all conditions provide sufficient pretension to ensure gas-tightness and mechanical integrity of the flange connection.
 - f) The flange bolt system shall be designed to the same operating conditions applicable to the exhaust gas system.
 - g) Exhaust systems without internal insulation usually require the use of tension bolts (extended shaft length). For the installation of pretensioned flange bolts the supplier shall develop detailed procedures including the required anti-seizure compound. This shall take account of the effect of torque on the resulting pretension of the final installation.
 - h) Material prone to CSCC is considered unsuitable for exhaust system bolts in a marine environment.
 - i) The method of determining the necessary pretension and ensuring that the specified pretension is provided shall be documented where the flange is designed for greater than 250 °C.
 - j) Acceptable methods of determining the necessary pretension are:
 - FEM analysis (refer to [Annex B](#)).

— Stress strain calculations.

- k) A torque wrench is considered an acceptable method of providing the necessary pretension.

NOTE Experience has shown that it is very difficult to predict what temperatures flange bolts of exhaust systems are exposed to during operation and over the lifetime of a system. Significant contributors to this uncertainty are:

- (i) inconsistent or poor workmanship quality for installation of the internal insulation, especially in flange areas for site-built systems;
 - (ii) deterioration (local or general) of insulation material;
 - (iii) potential complete loss of insulation (accidental);
 - (iv) depending on wind, ambient temperature, precipitation, sunshine and / or orientation the resultant cooling effect can vary hugely.
- l) Unless specified by the purchaser, the bolting system selected shall be maintenance free for the service life and the proposed bolt material shall be presented to purchaser for approval.
- m) The nut shall be of a design that eliminates the risk of loosening due to vibration or thermal effects during the entire life span of the system.

NOTE Bolt systems are typically not easily accessible for maintenance and inspection.

8.5.5 Surface preparation and treatment

8.5.5.1 Functions

Surface treatment can be required for the following functions:

- a) Protection from moisture related corrosion and condensable sulphur contaminants in the TEG. (Note that cold casing designs have potential for condensation of water onto the casing when ambient conditions are such that the casing is below the dew point of the TEG. The dew point is elevated if SO₃ is present in the TEG with resulting condensation of sulphuric acid.)
- b) Protection from corrosion from constituents in the insulation.
- c) Protection from corrosion from weather.
- d) Decorative only.

8.5.5.2 Protection from corrosion

The selection of materials and their associated coating should ensure protection against corrosion from the following:

- a) moisture together with condensable sulphur contaminants in the TEG;
- b) chlorides in the insulation and possible attack on stainless steel;
- c) marine environment (salt) and possible effect on stainless steel;
- d) weather.

8.5.5.3 Treatment specifications

If not specified by the purchaser, the supplier should specify in the proposal the type and application details of coatings (internal and external) envisaged to match the specified operating conditions.

The supplier's specification shall include the following information:

- a) method statement for surface preparation;
- b) method statement for surface treatment;
- c) test procedure;
- d) touch-up and repair procedure;
- e) on-site repair procedure if the surface treatment would be overheated in the event of loss or damage to internal insulation.

8.5.5.4 Requirements for various surface types

8.5.5.4.1 Cold casing, internal surfaces

Where the casing material is susceptible to corrosion due to water or acid dew point it shall be protected by a coating designed for the resulting conditions.

8.5.5.4.2 Cold casing, external surfaces

The treatment shall be suitable for the calculated operating metal temperature plus a margin of at least 100 K to account for solar radiation and hot spots. If the casing is designed to survive loss of internal insulation, the external coating is likely to require repair when the insulation is repaired.

8.5.5.4.3 Hot casing, internal surfaces

It is acceptable that surfaces be left untreated for operational reasons.

A temporary coating should be applied to carbon steel to protect during transportation and storage.

8.5.5.4.4 Hot casing, external surfaces

The treatment shall be designed to withstand the maximum specified TEG temperature and in the case of carbon steel it shall also be designed to protect during transportation and storage.

8.6 Mechanical and thermal analysis

Supplier shall carry out a stress analysis using FEM ([Annex B](#)) or other recognised methods in order to verify that all construction elements and details are within predefined acceptance levels.

- a) The analysis shall cover both static (e.g. normal operation) and transient cases such as start-up and shut-down.
- b) Special attention should be paid to all stress raisers and stress concentration points such as corners, changes in thickness (e.g. flanges), weld undercuts and weld penetrations, equipment mounted to the casing (e.g. lifting lugs, tube hangers, silencer elements), and penetrations.
- c) The resonance frequency should also be confirmed by analysis/testing.
- d) The possibility for combined creep and thermal fatigue interaction shall be considered in material selection and general design. Refer to [Annexes A](#) and [B](#).

8.7 Insulation and refractory

- a) All hot equipment and piping should be insulated for energy conservation, frost protection (if sub-zero ambient temperatures are specified), prevention of hot surface ignition sources in hazardous zoned areas, to protect adjacent equipment or personal protection purposes.

- b) The insulation should consist of bio-soluble fibre. Ceramic fibre may only be used where local regulations permit and with the agreement of the purchaser.

NOTE Bio-soluble fibre is considered less hazardous to health than ceramic fibre.

- c) If energy conservation or prevention of hot surface ignition sources in hazardous zoned areas is not relevant (e.g. stacks) and is not required by the purchaser, alternative means of equipment or personnel protection (e.g. wire screens) can be applied.
- d) The required thickness of insulation shall be determined in accordance with ISO 12241, or ASTM C680-10.
- e) Unless otherwise specified by the purchaser, for personnel protection and/or the avoidance of low temperature chloride corrosion on stainless steel in marine environments, the external casing temperature shall not exceed 60 °C with the maximum expected air temperature at the operating location and a wind speed of 1 m/s. This calculation excludes the effects of direct solar radiation. Unless otherwise specified by purchaser, surface emissivity shall be taken as 0,7. However, it should be recognized that this might not be achievable for higher ambient temperatures (e.g. in excess of 30 °C).
- f) Higher temperatures are permitted at small areas, for example where fasteners, supports or internal attachments are welded to the casing. The hot spot temperature shall not exceed the temperature rating of the hazardous area or the surface coating/paint system.
- g) All access doors, hatches and ports for inspection, viewing and maintenance shall be fitted with an insulation system of equal effectiveness to that of the main surfaces. Particular attention should be given to the design, installation and effectiveness of closing joints such that damage is avoided during opening/closing and any resultant hot spots are within acceptable limits.

8.7.1 Exhaust system casing and ducting external insulation (hot casing design)

- a) It should be noted that this type of design is more susceptible to excessive thermal stresses for the casing, associated stiffeners and structural members.
- b) Care should be taken to apply the external insulation over all the stiffening and structure which is welded to the casing to minimize thermal gradients from occurring in these areas.
- c) Care should be taken to apply external insulation over section flanges to avoid hot spots and to prevent thermal gradients from occurring in these regions during steady state operation.
- d) External insulation shall be covered with stainless steel liner plates installed with adequate allowance for expansion and ensure that the insulation remains dry and free from ingress of water.
- e) Where the risk of hydrocarbon penetration into the insulation cannot be eliminated (e.g. a leakage scenario close to the exhaust system), the insulation shall be fully covered with a hydrocarbon tight membrane under the liner plate. The membrane material shall be able to withstand the TEG temperature.

8.7.2 Exhaust system casing and ducting internal insulation (cold case design)

8.7.2.1 General

- a) The insulation shall consist of multiple staggered layers with a protective, floating lining plate.
- b) In order to prevent voids compression of the insulation under the lining plates shall be applied during installation, according to insulation manufacturer's instructions.
- c) The protective lining plate design shall ensure retention of internal insulation material and should incorporate a separate membrane e.g. pillows, in support of this requirement where required.

- d) Lining fasteners shall allow free expansion of the liner plates in all directions without distortion or bulging and shall avoid generating vibration. Materials shall be selected to resist erosion and oxidation.
- e) Perforated plates can be used to reduce the noise level. In the case of perforated plates, additional measures to prevent loss of insulating material shall be applied, e.g. stainless-steel cloth.
- f) Perforated liner plates shall not be used in areas where the TEG flow pattern represents a significant risk of flow induced damage or premature failure of lining and/or insulation (e.g. for several meters downstream the exhaust collector, bends, transition pieces, duct wall location where the violent flow from turbine compressor bleed impinges).
- g) A floating internal lining plate system design should be used for all internal insulation systems. However normal insulation materials are also acceptable for high temperature low flue gas velocity applications without lining plates, but with additional protection measures in accordance with the supplier's instructions.
- h) The exhaust system consists of zones with high temperature, high flue gas velocity or a combination of both. The design of the internal lining and insulation system shall be such that long-term reliability without loss of insulation effectiveness is achieved.

NOTE The ducting lining downstream from the GT exhaust system interface flange is subject to highly unsteady TEG flow condition which generates high cyclic stresses on the lining system.

- i) The internal insulation system should be designed to withstand the flue gas velocity and temperature.
- j) For the casing and ducting sections (tube bundle arrangement excluded), the hot face design temperature for material selection for the liners shall be as follows:
 - (i) The maximum TEG temperature plus 30 K, or the highest calculated TEG temperature in the subsequent heat transfer sections plus 30 K.
 - (ii) [Table 2](#) provides guidance for the selection of internal lining materials.

Table 2 — Material selection internal lining temperature limitation

Material selection for internal lining	Maximum temperature during continuous operation ^a °C
11 Cr (e.g. SS 409/410)	600
18Cr/8Ni (e.g. 304/316)	700
^a Above 750 °C metal liners are not recommended.	

8.7.2.2 Floating liner plate insulation design

- a) The insulating material shall have a minimum density of 128 kg/m³.
- b) The insulation shall be secured in position by a grid of fasteners which retain a stainless-steel cladding plate which covers and protects the insulation material from the erosion due to the contact with high velocity of the hot exhaust gases.
- c) Alternative systems if proposed by the supplier shall be subject to the purchaser's approval.
- d) The insulation of field-erected connections and module connections require particular design attention. The design of these joints shall ensure that cavities under the steel liner plate are filled with insulation once the joint is completed. All connections between pre-insulated panels and site insulation shall be insulated and designed to avoid discontinuities and insulation loss. Particular attention should be placed on installation for designs where the liner is discontinuous at flanged

connections between sections. Poor installation resulting in gaps between adjacent liner panels, can cause elevated external flange temperatures and ingress of TEG behind the liner, which can lead to degradation of the insulation and corrosion damage beneath the liner due to acidic flue gas condensate.

- e) The insulation shall be multi-layered in all directions and provide consistent coverage in all relevant areas.
- f) Overlapping liner plates shall be appropriate to the flow direction to prevent ingress of TEG behind the liner which can cause distortion and damage to the lining integrity.
- g) Where personnel access is required lining plate floors shall be made of minimum 3 mm thick liner plate, whereas walls and roof shall be a minimum of 2 mm thick.
- h) At the hot face design temperature, the thermal expansion of any plate shall not exceed 20 mm for the extreme diagonal measured between fastener centres.
- i) Where studs type fasteners are used the following minimum requirements shall apply, however the supplier shall remain responsible for the integrity of the design which shall be supported by experience and/or documentation:
 - (i) Studs shall be welded to the casing.
 - (ii) Stud guns shall not be used. Alternative systems can be proposed by the supplier for approval by the purchaser.
 - (iii) Welders shall be individually qualified and test welds shall be subject to destructive testing.

Poor stud to casing welds have been known to result in operation failures and as such particular attention should be paid to this activity.
 - (iv) Stud to casing weld procedures shall be subject to exhaust system supplier and purchaser approval prior to welding and shall include appropriate surface preparation of the weld area.
 - (v) Studs shall be M10 minimum for 2 mm plate and M12 minimum for 3 mm plate.
 - (vi) Unless otherwise agreed with purchaser, studs shall be 316SS material.
 - (vii) At each stud, the sequence of assembly shall be inner nut, washer, plate(s), washer, final nut. The final nut shall be tightened sufficiently to avoid vibration but not so tight as to restrict plate movement; normally half a turn back from finger tight and secured by a tack weld.
 - (viii) Plates shall overlap at least 50 mm and holes shall lie at least 30 mm away from the plate edge. Each hole in the plates shall be at least 3 times stud diameter and allow for the maximum thermal expansion of the plates +25 % plus fabrication and installation tolerances. Such expansion tolerance is not always required in case a central pin is used which becomes a fixed point for the sheet. Tack weld shall not only connect nut/stud, but also fix the washer to the nut to prevent the washer from vibrating and grinding through the stud.
 - (ix) The centre hole (fixed point) should be sized for stud diameter only. Alternatively, the centre location shall be fixed by appropriate tack welds of washer to plate. Studs shall be at least the same grade as the liner plate as a minimum.
 - (x) In high exhaust gas velocity areas studs should be welded to scallop bars which are in turn welded to the casing. These provide additional dimensional stiffness to the cladding. The design of the scalloping needs to consider thermally induced stresses and ensures that the weld detail is designed accordingly.
 - (xi) Alternative stud fixing systems can be proposed by supplier for approval by purchaser. Lining system, including stud spacing and stud to casing weld, can be in accordance with methods demonstrated on units which have been in long-term operation if agreed with purchaser.

Similar grades of stainless steel can gall so dissimilar grades for the washer and cladding sheets should be considered.

- j) If surface treatment is required it shall be applied after welding of the studs.
- k) Cut-out areas for penetrations such as access/inspection doors, observation ports and instruments, as well as corners and module seal details should be designed for minimum risk of hot spots.
- l) All fastener attachments to casings should be designed for minimum risk of hot spots.

8.8 Noise emission and silencing

- a) Where specified by the purchaser, supplier shall include the required silencing measures that are needed as part of the exhaust system in order to meet the overall noise emission requirements specified by the purchaser.

It is recommended that the silencer is supplied as part of the exhaust system scope in order to ensure the overall system is optimised, with respect to silencer location, pressure drop and mechanical design.

The purchaser is responsible for specifying noise emission data at the turbine exhaust.

- b) Where specified by the purchaser silencer elements shall be replaceable without hot work. This should involve oversized access doors and/or silencer panels in bolt-together sections. Access doors shall be installed upstream and downstream of each silencer, to permit the removal/replacement of the silencing panels and/or any other component that needs maintenance.
- c) Site measurement verification shall be in accordance with ISO 3744 or where needed ISO 9614 for duct wall emissions and ISO 10494 for exhaust stack sound power level.
- d) If other noise control measures such as acoustic enclosures are required, they should not in any case obstruct operational or routine maintenance activities.
- e) If acoustic enclosures are proposed, prior approval of the purchaser shall be obtained for their construction, materials and access requirements.
- f) Acoustic insulation of pipes, valves and flanges as necessary to meet the noise level requirements should be agreed with the purchaser.
- g) For cold casing systems, no acoustic insulation shall be fitted on the casing outside to meet the noise requirements.

8.9 Stacks

- a) Self-supported stacks greater than 4 outside diameters long shall be designed according to a recognised stack design standard (such as CICIND, ASME STS-01 or other stack design code). The supplier and purchaser should agree which code is to be applied.
- b) The purchase is responsible for specifying any minimum stack length or discharge height above an agreed datum.
- c) The exhaust gas can reach nearby equipment, working areas or interfere with helicopter traffic. The purchaser is responsible for evaluating the impact of such effects of the exhaust gas plume in determining the required stack height.

NOTE A plume cooling device which induces air to mix with the turbine exhaust gas prior to leaving the stack can be considered to mitigate exhaust gas impingement on adjacent equipment, personnel or helicopter traffic.

- d) Measures should be provided to prevent damage by the ingress of rain or snow. This shall include either means to prevent rain/snow ingress or drainage facilities to remove accumulated water in a

way that doesn't cause damage. Purchaser has the option to specify particular requirements which can include:

- (i) rain hood;
- (ii) internal rims;
- (iii) drainage facilities;
- (iv) damper with built in drain facility.

NOTE Rain hoods have the advantage of protecting against the ingress of rain or snow but the disadvantage of increased pressure drop, disruption of dispersion of exhaust gas and increasing reflected noise to lower elevations.

- e) The purchaser is responsible to identify requirement and details of any stack sampling points including temporary TEG composition measurement, e.g. if required by authorities for emission control.

In that case the purchaser is responsible for the definition of the physical dimensions of the connection (e.g. flange details).

The location should be chosen to accommodate the following:

- (i) easy access from the outside;
 - (ii) sufficient space on the outside for handling and inserting the required probe;
 - (iii) no internals on the inside of the duct (e.g. silencer baffles);
 - (iv) avoidance of parts of the exhaust system with especially severe flow conditions.
- f) Sampling port or ports shall have blind flange bolted covers. Blind flanges shall be fitted with a threaded cap to allow flue gas spot measurements. The blind flange and bolting material shall be the same as the sample port material.
 - g) The use of uninsulated stacks is subject to the purchaser's approval.

In case of an uninsulated stack, personnel protection shall be provided in areas where access can be required during operation and testing, (i.e. ladders, platforms and base).

8.10 Expansion joints

- a) Expansion joint(s) shall be designed for all movements of the exhaust ductwork system and interfacing equipment (axial compression, axial extension, lateral displacements and TEG pulsations).

Supplier shall design each flexible joint to be able to accommodate at least the following within its elastic operational range:

- (i) installation tolerances;
- (ii) global movements of parts supported on different structures;
- (iii) movements due to thermal expansion.

All the above can occur simultaneously in lateral and/or axial direction.

- b) Expansions joints should not be required to accommodate excessive installation tolerances, e.g. in excess of 15 mm.
- c) Expansion joints should be fabric type, or steel-bellows type with inner sleeves, however fabric type is preferred due to higher flexibility and lower rigidity (both for axial and lateral movements).

- d) Fabric expansion joint(s) shall be a flexible multiple layer type and shall be provided with “Bolster Bags” assuring thermal insulation and dampening of flow pulsations. The outer layer shall be fully weather-resistant.
- e) Steel-bellows type expansion joints applied to hot casing designs may be insulated and clad externally, such insulation system shall not inhibit the functionality of the expansion joint and shall, if required, be provided with a rain guard. If the expansion bellows design does not require external insulation and cladding, then personnel protection in the form of a guard and a rain shield shall be provided.
- f) The fabric shall be bolted between the casings flange and strips. Flange and strips shall be rounded in all directions and smoothly connect in corners without sharp edges.
- g) At the outside, where the fabric is pressed and rubbed against the cover strip, an additional protection layer shall be mounted between fabric and strip.
- h) Prior to installation of the fabric, the alignment of the flanges should be verified to be within the design tolerance for the expansion joint.
- i) Each flange of an expansion joint shall be designed to be compatible with the flange of the neighbouring component it is connected to, for example with respect to material choice, thermal expansion, hot- or cold-casing. If not otherwise stated, the expansion joint shall ensure 35 mm axial movement (extension), 50 mm axial movement (compression) and 20 mm lateral movement (in any direction and in combination with axial movement) as a minimum.
- j) Expansion joints shall be designed to accommodate all axial and lateral expansions. These shall consider thermal expansion as well as anticipated deflection of the respective equipment under all specified load conditions (e.g. wind and wave induced motions).
- k) Unless otherwise specified, the expansion joint at the GT discharge point should be provided by the GT supplier and the GT supplier should specify the maximum displacements that can be accommodated at this point.

8.11 Steel structures, stairs, ladders and platforms

- a) Unless otherwise specified by the purchaser, the support structure and access platforms for on-shore installations should be provided by the exhaust system supplier and for offshore by the purchaser. Supporting steel structures, platforms, stairs, ladders and railings shall be in accordance with purchaser's requirements.

Access facilities shall be provided to all inspection/access openings to facilitate the inspection and maintenance requirements specified by the purchaser.

- b) Structural design shall take into account the support requirements for all hydrostatic testing (including during manufacture). In addition, all other load cases expected during the life cycle of the equipment, e.g. transport and erection, wind, snow, seismic and explosion loads shall be covered in the design.
- c) Platforms, stairs or ladders shall not be mounted to pressure parts or hot casing.
- d) The exhaust system including the WHRU package shall be supported independently of the GT package.
- e) The layout of the support system should not restrict any work to be carried out on the GT package (inspection, maintenance, partly or complete exchange).
- f) The purchaser is responsible to specify if the exhaust system and/or its support structure shall include lifting points or beams with appropriate capacity to be used for work on the turbine package.

- g) Such specification should include a material handling strategy describing how components are to be lifted and routed. The steel structure and concept for access ways and platforms shall accommodate such work.
- h) Stairs and platforms should provide access to all valves, gauges, instrument process connections, observation points and access doors, and for all other operational purposes.
- i) Ladders should only be used for creating extra means of escape or to reach instrumentation which require infrequent access for maintenance.
- j) All stairs, platforms and walkways shall comply with the ISO 14122 series.
- k) Unless otherwise specified by the purchaser, all main platforms greater than 8 m long shall be provided with an emergency means of escape leading down to ground or deck level (i.e. in addition to normal access).
- l) No surfaces above 70 °C should be within reach from stairways, ladders, platforms, etc. If this cannot be avoided for technical reasons, then appropriate shielding shall be provided.
- m) Platforms shall have a minimum width of 1m and walkways used only to connect platforms shall have a minimum width of 0,8 m. All locations required for routine operation or access (for example, to dampers, instruments, instrument connections or access doors, etc.) shall be accessible by permanent ladders or platforms. Permanent platform access facilities shall, as a minimum include:
 - (i) Exhaust system bottom gas path access platform - one side of exhaust system, full length of exhaust system.
 - (ii) Actuator(s) systems (e.g. pneumatic/hydraulic equipment) for exhaust bypass control.
 - (iii) Inspection/maintenance platforms for all operational equipment, for example controls, sampling points, control valves, motor operated valves, drain and vent points inaccessible from grade.
 - (iv) Stack emission test platform to the flue gas emission (nozzles) and monitoring equipment.
- n) Access to instruments and instrument connections shall also be accessible by permanent platforms unless otherwise agreed by the purchaser.

8.12 Preservation, handling, packing and storage

8.12.1 Handling and storage of materials

- a) Materials should be handled and stored in accordance with supplier's recommendations.
- b) Materials and components shall be new and unused. Products that have been handled or stored in a way or for a length of time that can have led to significant deterioration should be checked before use to ensure that they still comply with the relevant product standard.
- c) Structural steel components should be packed suitable for handling and transport, so that permanent deformation does not occur and surface damage is minimized.

8.12.2 Handling and storage of construction material and subcomponents at suppliers works

8.12.2.1 General

In the absence of purchaser specifications, the supplier should specify and apply methodologies and measures for preservation and packing to meet the project requirements. The measures should include procedures to protect the equipment during pre-shipment, transportation and storage prior to construction, during construction, before start-up and for prolonged shut-down. Minimum measures pre-dispatch shall include:

- a) thorough cleaning and drying;