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GP 34-00

Machinery

Group Practice

BP GROUP ENGINEERING TECHNICAL PRACTICES

Foreword

This issue of Engineering Technical Practice (ETP) GP 34-00 has been updated to include the validated Shared Learnings and Comments against this ETP within the BP ETP Shared Learning System and to conform to the ETP 5 year review cycle. The major changes introduced at this update are documented below:

- New sections have been added covering machinery maintenance (5.7), machinery repairs (5.8), lubricating oil selection (7.10), and supplier documentation (9.).
- Normative references have been updated to reflect current status, especially for BP ETP documents.
- More information around criticality assessment of machinery and the quality programme for purchase of new equipment has been added.
- Bibliography has been updated, in particular to include the Guidance Notes and Reference Documents that have been added to the ETP Guidance Note system.

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REVISION FOR REVIEW



1. Scope

- a. This GP provides general requirements for machinery, such as pumps, compressors, fans, steam turbines, gas turbines, diesel engines, gears, mixers, centrifuges, and their ancillary systems.
- b. This GP includes requirements for machine type, sparing, sizing, and integration into a system.
- c. This GP does not, in general, cover detailed functional, constructional, or testing requirements but identifies appropriate BP and industry specifications.
- d. This GP applies to equipment used in:
 1. Refineries and chemical works, including offsites and utilities.
 2. Offshore installations and onshore terminals.
 3. Pipelines and pumping stations.
 4. Crude oil and gas gathering and separation plants.
 5. Liquefied natural gas (LNG) plants.
- e. This GP may be applied to other applications similar to those in a. through d. but is not intended for specialised drilling operations.

2. Normative references

The following referenced documents may, to the extent specified in subsequent clauses and normative annexes, be required for full compliance with this GP:

- For dated references, only the edition cited applies.
- For undated references, the latest edition (including any amendments) applies.

BP

GIS 12-201	Low Voltage Induction Motors (IEC).
GIS 12-202	NEMA Low Voltage Induction Motors (PIP ELSMT01D).
GIS 12-203	High Voltage Induction Motors (IEC).
GIS 12-204	Medium Voltage Induction Motors (API 541).
GIS 12-801	Power Generators (IEC).
GIS 12-802	Power Generators (API 546).
GIS 15-011	Noise Control.
GIS 22-101	Fired Heaters (ISO 13705 or API 560).
GIS 24-233	Firewater Pumps and System Design.
GIS 26-106	Steam Surface Condensers.
GIS 34-101	Axial and Centrifugal Compressor and Expander-Compressors (API 617).
GIS 34-102	Integrally Geared Centrifugal Compressors (API 672).
GIS 34-103	Packaged Reciprocating Gas Compressors (ISO 13631).
GIS 34-104	Reciprocating Compressors (ISO 13707 or API 618).
GIS 34-105	Liquid Ring Vacuum Pumps and Compressors (API 681).
GIS 34-106	Rotary Type Positive Displacement Compressors (API 619).
GIS 34-201	Centrifugal Pumps (ISO 13709 or API 610).



GIS 34-202	Horizontal Centrifugal Pumps (ASME B73.1).
GIS 34-203	Vertical Centrifugal Pumps (ASME B73.2M).
GIS 34-204	Centrifugal Pumps (ISO 5199).
GIS 34-205	Centrifugal Pumps (ISO 15783).
GIS 34-211	Positive Displacement Pumps - Reciprocating (API 674).
GIS 34-212	Positive Displacement Pumps - Controlled Volume (API 675).
GIS 34-213	Positive Displacement Pumps - Rotary (API 676).
GIS 34-301	General Purpose Steam Turbines (API 11).
GIS 34-302	Petroleum, petrochemical and natural gas Industries - Steam Turbines - Special-purpose Applications (ISO 10437).
GIS 34-303	Gas Turbines (API 616).
GIS 34-305	Diesel Engines.
GIS 34-306	Natural Gas Engines.
GIS 34-403	Agitators.
GIS 34-501	Special Purpose Gear Units (API 613).
GIS 34-502	General Purpose Gear Units (API 677).
GIS 34-503	Special Purpose Couplings (API 671).
GIS 34-504	General Purpose Couplings (ISO 14691).
GIS 34-701	Lubrication, Shaft-Sealing and Control-Oil Systems and Auxiliaries (ISO 10438 or API 614).
GIS 34-702	Oil Mist Lubrication Systems.
GIS 34-704	Pump Shaft Seal Systems (API 682).
GIS 34-705	Machinery Protection Systems (API 670).
GIS 34-801	Machinery Installation and Installation Design (API 686).
*GS 134-13	Packaging of rotating machinery for offshore use.
GP 35-25	Materials for Sour Service in Exploration and Production Operations.
GP 35-26	Materials for Sour Service in Refining and Marketing Operations.
GP 12-20	Motors.
GP 12-80	Power Generators.
GP 32-10	Integrity Management Requirements for New Materials and Equipment.
GP 32-11	Integrity Management Programme for New Equipment in Manufacture - General Requirements.
GP 32-12	Integrity Management Programme for New Equipment in Manufacture - Rotating Equipment.
GP 44-10	Plant Layout.
GP 44-60	Area Classification (API 500).
GP 44-65	Area Classification (IP 15).
GP 44-70	Overpressure Protection Systems.

American Petroleum Institute (API)

API RP 684	API Standard Paragraphs Rotodynamic Tutorial: Lateral Critical Speeds, Unbalance Response, Stability, Train Torsionals, and Rotor Balancing.
API RP 686	Recommended Practices for Machinery Installation and Installation Design.
API Std 610	Centrifugal Pumps for Petroleum, Petrochemical, and Natural Gas Industries.



API Std 611	General Purpose Steam Turbines for Petroleum, Chemical, and Gas Industry Services.
API Std 612	Petroleum, Petrochemical, and Natural Gas Industries-Steam Turbines-Special-purpose Applications.
API Std 687	Rotor Repair.

International Organization for Standardization (ISO)

ISO 7919 Parts 1 - 5	Mechanical vibration of non-reciprocating machines - Measurements on rotating shafts and evaluation criteria: - Part 1: General guidelines. - Part 2: Large land-based steam turbine generator sets. - Part 3: Coupled industrial machines. - Part 4: Gas turbine set. - Part 5: Machine sets in hydraulic power generating and pumping plants.
ISO 10816 Parts 1 - 7	Mechanical vibration – Evaluation of machine vibration by measurements on non-rotating parts: - Part 1: General guidelines. - Part 2: Land-based steam turbines and generators in excess of 50 MW with normal operating speeds of 1500 r/min, 1800 r/min, 3000 r/min and 3600 r/min. - Part 3: Industrial machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15000 r/min when measured in situ. - Part 4: Gas turbine driven sets excluding aircraft derivatives. - Part 5: Machine sets in hydraulic power generating and pumping plants. - Part 6: Reciprocating machines with power ratings above 100 kW. - Part 7: Rotodynamic pumps.
ISO 15663	Petroleum and natural gas industries - Life cycle costing.
ISO 20815	Petroleum, petrochemical and natural gas industries - Production assurance and reliability management.

National Electrical Manufacturers Association (NEMA)

NEMA SM23	Steam Turbines for Mechanical Drive Service.
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3. Terms and definitions

For the purposes of this GP, the following term and definition applies:

Criticality rating

Rating determined by evaluating combined effect of the likelihood of failure and its consequence, i.e., commercial, safety, environmental, or reputation. “Criticality one” equipment has the most impact.

Nominated manufacturer

The manufacturer with the overall responsibility for the design and installation of the complete machinery package.

4. Symbols and abbreviations

For the purpose of this GP, the following symbols and abbreviations apply:



1001	One out of one.
2002	Two out of two.
2003	Two out of three.
Capex	Capital expenditure.
CMS	Common maintenance strategy.
Cp	Specific heat capacity at constant pressure.
Cv	Specific heat capacity at constant volume.
DCS	Distributed control system.
DLE	Dry low emissions.
E&P	Exploration and Production.
FCCU	Fluidised catalytic cracking unit.
FDFPFLFS	Full density, full pressure, full load, full speed.
FPSO	Floating, production, storage, off-loading (vessel).
GMRC	Gas Machinery Research Council.
HAZOP	Hazard and operability study.
HEPA	High efficiency particulate air (filter).
HP	High pressure.
HSSE	Health, safety, security, and environmental.
LCC	Life cycle cost.
LNG	Liquefied natural gas.
MoC	Management of change.
NPIP	Net positive inlet pressure.
NPSH	Net positive suction head.
NPSHA	Net positive suction head available.
NPSHR	Net positive suction head required.
P&ID	Piping and instrumentation diagram.
OEM	Original equipment manufacturer.
Opex	Operating costs.
OREDA	Offshore reliability data.



ppm	parts per million.
PTC	Performance test code.
R&M	Refining and Marketing.
RE	Rotating equipment.
REI	Rotating equipment initiative.

5. General

5.1. Conflicting requirements

In case of conflict between this GP and other documents, order of precedence shall be:

- National and local regulations in country of installation.
- This GP.
- Other industry codes and standards

5.2. Developing a purchase specification for machinery

5.2.1. Teamwork

- Satisfactory performance of any machinery is founded on its purchase specification, which is the result of the efforts of a multidiscipline team led by a mechanical/machinery engineer and includes process, instrumentation, electrical, control, operations and procurement functions.
- Team members can be drawn from the end user, engineering contractor, and machinery Vendor.

5.2.2. Life cycle costs (LCC)

5.2.2.1. General

- Machinery should be selected on basis of minimum LCC.

Note that there are capital constraints that can cause a selection other than the lowest LCC.

- The principles of the LCC process that should be followed are described in ISO 15663, Parts 1-3. The Hydraulic Institute and European Pump Manufacturers' Association have produced a working guide.

Life cycle costs should as a minimum include the following:

- *Capital equipment costs.*
- *Installation costs.*
- *Operating costs. This includes costs such as fuel gas, electrical power, CO₂ taxes, lube oil, filters etc.*
- *Maintenance costs. To include cost of spares and the cost of overhauls both on and off-site.*
- *Expected lost production due to planned maintenance.*
- *Expected lost production due to unreliability based on experience with similar equipment. For example offshore reliability data (OREDA) data for offshore equipment.*



c. An LCC which corrects Operating Costs (Opex) at a discount rate will result in an unrealistic view of long term operations. Any LCC using this methodology shall also generate a LCC at a 0% discount rate for comparison.

a. Necessity for standby machinery should be considered in the context of LCC analysis that incorporates reliability/availability of individual items of equipment, drivers, and required overall plant availability. The principles for managing reliability and availability are described in ISO 20815.

It is not normal practice to install spares for centrifugal, axial, or rotary positive displacement compressors, except for critical utility systems.

- a. An assessment of each machinery train should be performed and a criticality rating assigned to each equipment item.

- Major projects will define a criticality assessment process including project assessment criteria. The process should define criticality in terms of impact in the areas of Safety, Environment, Production and Reputation with the highest scoring category defining the criticality rating. It is expected that for the majority of rotating equipment packages the production criticality rating will have the highest score and will be the defining category.

1. The Quality Programme for the equipment.
2. The condition and performance monitoring instrumentation required for the equipment.
3. The maintenance regime and activities for the equipment.

d. The Quality Programme for the purchase of each item of rotating equipment shall comply with GP 32-10 Integrity Management Requirements for New Materials and Equipment, GP 32-11 Integrity Management Programme for New Equipment in Manufacture –

General Requirements, and GP 32-12 Integrity Management Programme for New Equipment in Manufacture - Rotating Equipment.

The Quality Programme requirements for new equipment in manufacture are based upon the criticality assessment rating of the equipment being purchased. The scope of the programme defined in these ETP documents includes all factory inspection requirements but not equipment testing requirements.

Equipment is ranked criticality 1 to 4 in these documents with criticality 1 being the highest. GP 32-12 rates all reciprocating and centrifugal compressors and gas turbines as criticality 1 for the purpose of defining the Quality Programme.

Note that at time of writing these documents are available as drafts only and any queries should be referred to the appropriate Rotating Equipment Engineering Technical Authority for resolution.

5.2.3.2. Equipment factory testing

- a. All inspection requirements shall meet the requirements of the section 32 Quality Management ETPs that apply to the purchase of new rotating equipment; GP 32-10, GP 32-11 and GP 32-12. These cover the requirements for hydrotesting, materials testing, PMI and non-destructive examination testing.
- b. For machinery ranked criticality one by either the project criticality assessment or the section 32 Quality Management series of ETPs listed in 5.2.3.2.a. factory testing shall be performed on the machinery and associated systems as detailed in 1 to 8. Any test performed shall meet the requirements defined in the applicable specific equipment GIS document and the base industry standard.

1. A Mechanical run test shall be performed.
2. A Performance test shall be performed.

Centrifugal compressor performance tests are typically performed following American Society of Mechanical Engineers Performance Test Code ASME PTC 10. There is a parallel International Standard, ISO 5389: Turbo compressors - performance test code the second edition of which was published in 2005. The first edition of ISO 5389 was published in 1992 and was used in parallel with ASME PTC 10, a revision was commenced in mid-1990s but was abandoned after the Draft was published but industry started to use the unvalidated draft instead of the 1992 edition. Work on the second edition restarted in 2003.

3. A Balancing test shall be performed. Depending on the equipment type this may be at either operating (high) speed or low speed. Testing for both methods should conclude with a residual unbalance check in accordance with API RP 684.

The purpose of the residual unbalance test is to determine the magnitude and direction of the unbalance in the rotor. For rotors that are operating speed balanced it also provides a baseline measurement at low speed enabling a later balance check at low speed to be performed to confirm that the rotor is within balance tolerance e.g. prior to installation after long-term storage as a spare. It also confirms the calibration of the balancing machine.

Note that API limits for residual unbalance are expressed by the equations $U = 6350W/n$ (in SI units) and $U = 4W/n$ (in US units) whereas ISO limits are expressed as a balance quality grade of ISO 1940-1. The API limit is equivalent to ISO grade G0.7.

4. Overspeed trip system testing shall be performed.



This is not to be confused with the requirements for overspeed testing of individual components, e.g. centrifugal impellers, which are defined in the applicable equipment specific GIS documents and base standards.

5. Functional testing of auxiliary and support systems shall be performed, e.g., oil systems, sealing systems, governor systems, etc.
6. String testing of complete machinery package, including, driver, driven equipment, transmission, gearboxes, lube oil system, seal system, auxiliaries, and control systems is an optional test and its requirement should be assessed on a case-by-case basis.

String testing is designed to reduce the technical risk to a project and can help reduce installation and commissioning time at site. It is normally completed for offshore or remote locations. They may be either a no-load, mechanical test or a full-load mechanical and performance test.

7. Full density, full pressure, full load, full speed (FDFPFLFS) tests is an optional test that should be assessed on a case-by-case basis.

This is a mechanical test under FDFPFLFS to verify mechanical integrity and stability of the compressor or pump. It is normally completed for very high pressure (HP) applications (e.g., HP gas/water injection) or unproven designs to prove stability and leakage flows. It can be completed as part of the performance test or as part of string testing.

In order to maximise the benefit of the test selection of the gas and the test procedure is critical as it is not normally possible to replicate all 4 parameters (density, pressure, load and speed) at once on the test stand. Given that the main purpose of the test is to prove the stability by confirming the predicted rotordynamic behaviour of the seals, particularly balance piston and division wall, the parameters that have the largest effect on seal operation and leakage are more important, i.e., gas density, gas pressure, differential pressure across the seals and operating speed.

8. Rotor dynamic response tests are optional tests that should be assessed on a case-by-case basis.

For sensitive or unproven designs, it is possible to complete a rotor excitation test (shaker test) to validate the rotor response and damping. Rotor unbalance response tests can also be completed.

5.2.3.3. Field testing

- a. Field tests shall be developed and executed to ensure readiness of a machine for commissioning.

Depending on the equipment type, such a program may include:

- Oil flushing.
- Pipework cleaning to meet supplier specification, e.g. steam blowing, chemical cleaning.
- System cleanliness tests.
- Instrumentation functional checks.
- Trip system function tests.
- Control system function tests.

- b. Field tests shall be developed for execution during commissioning runs of the machine.

Depending on the equipment type, such a program may include:

- Baseline condition monitoring runs.
- Overspeed system tests.



- Control system tuning.
 - Surge control system set-up and tuning.
 - Baseline performance tests.
- c. Criticality one rated machinery should be sufficiently instrumented to allow a comparison with the factory tests to be performed once the equipment is installed and commissioned at site.

This allows a baseline performance level to be established for future operational performances to be compared to.

For gas turbines and centrifugal compressors the guidance note [GN 34-003 Field Testing of Gas Turbine and Centrifugal Compressors](#) provides details of the required instrumentation and a methodology for performing site testing. This guidance note is based on a document published by the Gas Machinery Research Council (GMRC).

- d. Vibration acceptance criteria should be defined and specified for all machinery packages. It is recommended that acceptance criteria are based on the evaluation zone limits defined within the appropriate part of the ISO 10816 series of standards for vibration measurements on non-rotating parts or the ISO 7919 series for vibration measurements on rotating shafts.

ISO 10816 consists of the following parts, under the general title Mechanical vibration - Evaluation of machine vibration by measurements on non-rotating parts:

- Part 1: General guidelines.
- Part 2: Land-based steam turbines and generators in excess of 50 MW with normal operating speeds of 1500 r/min, 1800 r/min, 3000 r/min and 3600 r/min.
- Part 3: Industrial machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15000 r/min when measured in situ.
- Part 4: Gas turbine driven sets excluding aircraft derivatives.
- Part 5: Machine sets in hydraulic power generating and pumping plants.
- Part 6: Reciprocating machines with power ratings above 100 kW.
- Part 7: Rotodynamic pumps.

ISO 7919 consists of the following parts, under the general title Mechanical vibration of non-reciprocating machines - Measurements on rotating shafts and evaluation criteria:

- Part 1: General guidelines.
- Part 2: Large land-based steam turbine generator sets.
- Part 3: Coupled industrial machines.
- Part 4: Gas turbine set.
- Part 5: Machine sets in hydraulic power generating and pumping plants.

5.2.4. Plant philosophies

5.2.4.1. General

- a. Machinery and its associated systems shall be specified to integrate with existing philosophies described in 5.2.4.2 through 5.2.4.5 as operated at manufacturing site.
- b. Philosophies not in place (e.g., in green field developments) shall be developed before machinery is ordered.



- c. The philosophies should be linked to the criticality rating of equipment.

5.2.4.2. Condition monitoring

- a. A condition monitoring strategy should be developed based on the criticality of the individual machinery packages. The strategy should define the requirements for:
 - 1. Continuous online systems, offline monitoring systems, or both.
 - 2. Networking of systems.
 - 3. Internet (remote) monitoring capability.
 - 4. Coverage of both mechanical and performance condition monitoring.
 - 5. Vibration, temperatures, tribology.
- b. The condition monitoring strategy should support the defined maintenance strategy.

5.2.4.3. Maintenance

- a. A maintenance strategy should be developed based on criticality of the individual machinery packages. The strategy should define:
 - 1. Equipment that is to be covered by condition based preventative or breakdown maintenance regimes.

The current strategy within BP is to drive towards condition-based maintenance regimes. In order to support this, both equipment condition monitoring and organisational roles and responsibilities need to be sufficiently well defined in order for such a strategy to work.
 - 2. Whether maintenance is to be performed by in house or contracted out labour.
 - 3. Equipment that should have by a Machinery healthcare contracts.

Machinery healthcare contracts may be with the original equipment manufacturer (OEM) or in some cases with a third-party service provider.
 - 4. Site configurations and limitations.
- b. Design of rotating equipment should consider maintenance requirements as inherent part of their design and layout, especially at brownfield locations where standardization would be of benefit.

5.2.4.4. Operation

- a. An operation strategy should be developed: The strategy should consider:
 - 1. The minimum manning levels for the facility.
 - 2. The need for local or remote operation or both.
 - 3. The need for local instrumentation.
 - 4. Tripping policy.

5.2.4.5. Spare parts inventory

The strategy should define:

- a. The spare parts required to meet facility availability requirements taking into consideration the lead times of long lead items.
- b. Whether spare parts should be managed in house or outsourced.
- c. System for adding to stock - covering the availability requirement of the machine, spare part lead time and shelf-life of components.



- d. Critical machinery spare rotor management system - to ensure condition of spare rotors, including:
 - 1. Balance.
 - 2. Probe track runout.
 - 3. Corrosion protection.
 - 4. Documentation.

5.2.5. Use of BP Group Instruction for Supply (GIS) and industry standards

- a. Machinery specifications shall be developed based on applicable BP GIS and associated industry standards.
- b. Data sheets and BP decision points in industry standards shall be completed.

5.2.6. Responsibilities

Rotating machinery is usually a package comprising prime mover and driven equipment normally from different manufacturers. One of these manufacturers needs to be assigned to take overall responsibility for the design of the package, i.e., be the nominated manufacturer.

- a. Overall responsibility
 - 1. Generally, driven equipment manufacturer should be the nominated manufacturer and take overall responsibility for complete package design and installation.
 - 2. For large, complex installations, where cost of the driver represents a significant percentage of total cost (e.g., a gas turbine) either:
 - a) The driver manufacturer may take overall responsibility, or
 - b) The driver may be supplied as free-issue equipment by BP to the driven equipment manufacturer who takes overall responsibility.

“Free issue equipment” is kit supplied to but not procured by the nominated manufacturer. Equipment is not “free” for the user and should be included in any LCC analysis.

- b. Nominated manufacturer should:
 - 1. Be fully responsible for all equipment supplied by other vendors.
 - 2. Ensure that all such equipment and any free issue equipment are properly integrated into the whole installation to comply with applied specifications.
- c. Nominated manufacturer responsibilities should include:
 - 1. Dimensional compatibility.
 - 2. Shaft system critical speeds.
 - 3. Vibration.
 - 4. Noise levels.
 - 5. Acceptability of pipe loads.
 - 6. Arrangement of auxiliary systems.
 - 7. Provision of all data needed for design of support structures or foundations.



5.3. Operating conditions

5.3.1. Process, utilities, and transients

- a. Machinery should be capable of operating unattended. Circumstances for attended operation shall be specified, e.g., start-up, shutdown, abnormal conditions.
- b. Process conditions specified for fluid machinery shall cover the full range of flow, pressure, temperature, molecular weight, viscosity, erosive and corrosive properties, etc. expected throughout all stages of operation, i.e., start-up, shutdown, steady state, transient and alternate process fluid conditions.
- c. If new machinery is to be installed as part of an expansion to existing plant, impact of operational upsets of existing machinery on new machinery (and vice versa) shall be specified or assessed. Both driving and driven equipment systems shall be considered.
- d. Machinery shall be suitable for operation at all specified ambient conditions and controlled ranges of process utilities, including those at start-up and shutdown. Additionally, commissioning which may take place with alternative fluid that results in higher pressure and/or temperatures shall be included on the datasheet and taken into account during design.

Machine operation at the suction pressure relief valve setting is not usually a design case, as it could lead to excessive driver power. The machine and components should be designed to withstand the static relief valve pressure.

For compressors, operation on nitrogen or air could result in higher than normal discharge temperatures due to the increased value of Cp/Cv over that specified for hydrocarbon. Centrifugal pumps specified for hydrocarbon service (specific gravity less than 1) generate higher differential pressures and absorb more power when pumping water e.g. when being factory tested.

- e. If machinery for an E&P application is subject to sour conditions as defined in GP 36-25, materials used shall comply with GP 36-25. If machinery for an R&M application is subject to sour conditions as defined in GP 36-26, materials used shall comply with GP 36-26. For both E&P and R&M this requirement shall apply even if sour conditions only exist for short periods.
- f. Utilities conditions specified should cover:
 1. Full range of pressure, temperature, calorific value, for steam, water, air, gas, together with quality limits on impurities.
 2. Power supplies to be used for auxiliaries and instruments.
 3. Any pressurisation in vents or drains.
 4. Any requirement for units to continue in operation on temporary failure of a utility supply.
- g. For E&P applications, the design shall comply with the additional requirements of EP GP 34-00-1.

Additional requirements for E&P rotating equipment are contained in the Segment STP EP GP 34-00-1 which should be referred to alongside this document for E&P applications.

5.3.2. Machine control methods

- a. Design of process control systems associated with fluid machinery shall take into account need to operate at less than rated conditions.
- b. Operating efficiency at part load should be considered in determining method of machine control.

