EFRC Report

Scope of Standards and Guidelines for Reciprocating Compressor Systems

First Edition, April 2019

Foreword

The EFRC is the European Forum for Reciprocating Compressors and has been founded in 1999 by Neuman & Esser, Leobersdorfer Maschinenfabrik, Hoerbiger Ventilwerke, TNO Science & Industry, TU Dresden, Thomassen Compression Systems, Wärtsilä Compression Systems and Burckhardt Compression. The target of the EFRC is to serve as a platform to facilitate exchange of information between vendors, operators and scientists working in the field of reciprocating compressors.
This is achieved by knowledge transfer (conferences, internet, student workshops, training and seminars), standardization work (e.g. API 618, ISO 13707, ISO 10816) and by joint pre-competitive research projects, aiming at improving the performance and the image of the reciprocating compressor.

In the R&D projects the forces are combined of all interested parties to solve or investigate problems which are beyond the scope of a single player. The basic research and pre-competitive research projects are carried out at research institutes or universities. In this way, the R&D group of the EFRC will serve as the scientific arm of the reciprocating compressor community.
The R&D group is open to all EFRC members and the annual budget is funded by participating members. The results are owned by the EFRC and the research results are disclosed to EFRC research group members only.

Vibrations are an important criterion to judge the safety, integrity and efficiency of compressor installations. For that purpose, several international standards have been developed. The existing standards are unspecific and do not make a distinction in vibration levels for different parts of the reciprocating compressor system, e.g. foundation, frame, cylinder, pulsation dampers and piping. For that reason, the “EFRC Guidelines for Vibrations in Reciprocating Compressor Systems” were developed.

The vibration levels from the guidelines are intended to be used during a field survey to judge the long-term safety, reliability and efficiency. The guidelines are not intended for condition monitoring purposes.

Disclaimer

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1 Introduction

Many different standards and guidelines have been developed by different standardisation organisations and research institutes. The advantage of having standards and guidelines is that it provides in many cases a purchase specification to facilitate the manufacturer and procurement of systems and guidance on common practice and points of attention. Besides that, these standards aim to achieve installations with optimum integrity, safety and reliability, and to minimise maintenance and downtime costs.
Most standards are revised after a certain time to cover the latest field experiences and results of research projects in achieving more efficient, reliable, safe and economic systems.

There is a continuous development of standards and guidelines and it has been recognised that it is sometimes very difficult for designers and users not to get lost on the number of available standards and guidelines and their applications.
This report has been prepared for that reason which summarises the scope and application of the most applied standards and guidelines for the design, installation and operation of reciprocating compressor systems.
It shall be noted that this only a snapshot and the reader shall make sure that he is using the latest revision of the documents.

A summary of available standards of leading international standardisation organisations can be found on the following websites (keep in mind these links may change in time):

- API: https://www.api.org/Standards
- ASME: https://www.asme.org/about-asme/standards
- ISO: https://www.iso.org/standards.html
- NORSOK: https://www.standard.no/en/sectors/energi-og-klima/petroleum/norsok-standards/#.XI44w0xFyUk
- VDI: https://www.vdi.eu/engineering/vdi-standards
- IEC: https://www.iec.ch/standardsdev/publications
- TEMA: http://www.tema.org/index.html

The website of the European Forum for Reciprocating Compressors and the Gas Machinery Research Council are as follows:

- EFRC: www.recip.org
- GMRC: https://library.gmrc.org/

The API is focussing on refinery applications and the available API standards are summarised in the API catalogue which is available via: https://www.api.org/products-and-services/standards/purchase#tab-catalog
The 2016 edition lists API standards, recommended practices, equipment specifications, other technical documents, and reports and studies is there to help the oil and natural gas industry safely, efficiently, and responsibly supply energy to billions of people around the world. Each year API distributes more than 300,000 copies of its publications.
For upstream, API publications cover offshore structures and floating production systems, tubular goods, valves and wellhead equipment, and drilling and production equipment.
In the downstream arena, API publications address marketing and pipeline operations and refinery equipment, including storage tanks, pressure-relieving systems, compressors, turbines, and pumps.
API also has publications that cut across industry sectors, covering fire and safety protection and

petroleum measurement. API information technology standards cover EDI, e-business, telecommunications, and information technology applications for the oil and natural gas industry. Other API publications catalogued here include economic analysis, toxicological test results, opinion research reports, and educational materials that provide basic information about the oil and natural gas industry and how technology is transforming it. The publications in the catalogue are intended for API members and non-members.

The standards and guidelines as summarised in this report are grouped as follows:

- Chapter 2: General design of reciprocating compressors.
- Chapter 3: Field vibration measurements and acceptance criteria.
- Chapter 4: Safety.
- Chapter 5: Condition monitoring.
- Chapter 6: Installation.
- Chapter 7: Inspection of repair of refinery equipment.

It shall be emphasized that standards and guidelines are sometimes focussed on specific applications, regions of the world or other variables. The contents may not always be fully applicable or mandatory for a specific system due to the wide range of applications, compressor types and models, operating speeds, rated loads, power, etc.

Many of the standards and guidelines summarised in this report are not always used or may even be superseded by other standards. However, together with available handbooks they can be used as a source for information and reference when no specifications are applicable.

2 Design

2.1 Reciprocating compressor design

2.1.1 API Specification 11P

Packaged Reciprocating Compressors for Oil and Gas Production Services (Historical Standard) | 2nd edition 1989

This Standard has been superseded by the ISO 13631.

This standard covers the minimum requirements for a packager supplied, designed and fabricated, skid-mounted, reciprocating, separable or integral compressor with lubricated cylinders and its prime movers used in oil and gas production services. It also includes all necessary auxiliary equipment such as water and gas coolers, exhaust silencer, emission control equipment, inlet air filter, scrubbers, control panel, piping, etc. Required to install an operable unit in compliance with the purchase specifications and with a minimum of field construction and field purchased equipment.

Compressors intended for refinery, chemical or petrochemical services as covered in API 618 - Reciprocating Compressors for General Refinery Services, compressors that are block-mounted, compressors that are non-lubricated, compressors with single-acting, trunk-type (automotive-type) pistons that also serve as cross-heads, and either utility or instrument air compressors that discharge at 8.6 barg or below are specifically excluded from this specification. Diesel engine, gas turbine and steam turbine prime movers are also specifically excluded.

2.1.2 API Standard 618

Reciprocating Compressors for Petroleum, Chemical and Gas Industry Services | 5th edition 2010

Covers the minimum requirements for reciprocating compressors and their drivers used in petroleum, chemical, and gas industry services for handling process air or gas with either lubricated or nonlubricated cylinders. Compressors covered by this standard are of low to moderate speed and in critical services. Also covered are related lubricating systems, controls, instrumentation, intercoolers, aftercoolers, pulsation suppression devices, and other auxiliary equipment.

2.1.3 ISO 8012

Compressors for the process industry -- Reciprocating types -- Specifications and data sheets for their design and construction | 1988

Specifies the technical requirements for the design and construction of compressors; it also details the documentation requirements. Annex A, which contains instructions subject agreements in the contract, is given for information only. Annex B, which contains the data sheets, forms an integral part of this Standard.

2.1.4 ISO 13707

Petroleum and natural gas industries -- Reciprocating compressors | 1st edition 2000

This International Standard is based upon the accumulated knowledge and experience of manufacturers and users of reciprocating compressors. The objective of this International Standard is to provide a purchase specification to facilitate the manufacture and procurement of reciprocating compressors for general petroleum and natural gas industry services, but its use is not limited to these services.

This International Standard covers the minimum requirements for reciprocating compressors and their drivers used in the petroleum and natural gas industries with either lubricated or nonlubricated cylinders. This International Standard may be used for other services or in other industries by agreement. Compressors covered by this International Standard are moderate to low-speed and in critical services. Also included are related lubricating systems, controls, instrumentation, intercoolers, aftercoolers, pulsation suppression devices and other auxiliary equipment. Excluded are integral gas-engine driven compressors, packaged high-speed separable engine-driven reciprocating gas compressors, compressors with single-acting trunk-type (automotive-type) pistons that also serve as crossheads and either plant or instrument air compressors that discharge at gauge pressures of 9 bar or below. Also excluded are gas engine and steam engine driver.

Note:
This International Standard is based on API standard 618, 4th edition, 1995. Since the 5th edition is the latest version of the API 618, the ISO 13707 can be considered obsolete. It is expected that the ISO 13707 will not be updated and for that reason it is recommended to use the latest API 618 version.

2.1.5 ISO 13631
Petroleum and natural gas industries -- Packaged reciprocating gas compressors | 2002

This International Standard is based on API specification 11P second edition, November 1989.

It gives requirements and recommendations for the design, materials, fabrication, inspection, testing and preparation for shipment of packaged skid-mounted, reciprocating, separable or integral compressors with lubricated cylinders and their prime movers, for use in the petroleum and natural gas industries for the compression of hydrocarbon gas.
It is also applicable to all necessary auxiliary equipment, such as water and gas coolers, silencers, emission control equipment, filters, separators, control panel, piping, etc., required to install an operable unit in compliance with the purchase specifications and with the intent of minimizing field construction and field-purchased equipment. ISO 13631:2002 is not applicable to the following:

- reciprocating compressors for petroleum and natural gas industries covered by ISO 13707;
- column-mounted compressors;
- non-lubricated compressors;
- compressors having trunk-type (automotive-type) pistons that also serve as crossheads;
- utility or instrument air compressors with a discharge gauge pressure of 0,9 MPa (9 bar) or less;
- compressors driven by diesel engine, gas turbine and steam turbine prime movers.

2.1.6 GMRC Guideline Power Loss
Calculation of Power Loss of Compressor Manifolds | 1st edition 2015

This guideline describes the analytical approach for calculating power loss in compressor manifolds. Analysis and testing were also done to verify the analytical work. The main goal was to create a concise document explaining how to apply the developed approach for calculating power loss referred to as the Flow Energy Method. Examples demonstrating the application and significance of the power

loss due to mean and fluctuating flows will be presented. Simplified approaches for estimating the pressure drop and power loss due to fluctuating flow will also be presented.
A secondary goal of this project is that the guideline will provide the basis for ensuring a consistent approach is used for calculating power loss in reciprocating compressors. This guideline can be a reference for GMRC members as well as other guidelines and industry specifications such as the Packaged High-Speed Reciprocating Compressor Design Guideline for Gas Transmission & Storage Applications, API 618, API 688 and ISO 10816.

2.1.7 GMRC Guideline High-speed compressors natural gas transmission

High-speed reciprocating compressor packages for natural gas transmission & storage (downstream) applications | 2nd edition 2017

High-speed reciprocating compressors, driven by natural gas engines or electric motors, provide the advantages of lower capital cost, shorter installation time and compactness. They have become the most common equipment type applied in the upstream and much of the midstream natural gas compression markets. However, as larger horsepower (≥1472 HP), high-speed (≥700 rpm) reciprocating compressor packages have been applied, especially in low ratio, high-flow, highly flexible pipeline transmission applications, concerns regarding efficiency, vibration, pulsation, controls, ancillary components and systems, pipeline throughput and diagnostics have increased. Higher speed compressors naturally create a broader spectrum of pulsation frequencies that must be addressed, and the lighter frames and I-beam skid mounting, typical of high-speed compressor packages, tend to be more flexible and reactive than traditional heavier, slow-speed compressors that are block mounted. Pulsation dampening, and piping system pressure losses can also be more of a concern because of the higher frequency pulsation generated by high-speed compressors.
This has driven the need for better and more sophisticated methods of pulsation and vibration modelling and analysis as well as additional pulsation control “tools” and suggested practices for damping, de-tuning, and/or cancelling pulsations.

Another important consideration is that for centrifugal and traditional slower speed (<700 rpm) reciprocating compressors, the compressor OEM often takes full responsibility for the systems integration and its performance. In contrast, high-speed compressor packages are typically not offered by the compressor OEM directly. Instead, for high-speed compressor systems, a packager purchases the compressor, the driver and other high-value content from individual manufacturers and integrates/assembles them on a fabricated skid with pulsation bottles, scrubbers, gas piping, utility piping, instrumentation, controls, auxiliaries, etc. The vast majority of the compressor units that are designed and manufactured by packagers are for upstream applications, which are smaller size units that are typically not highly engineered and for which high efficiency is not a primary consideration. Some of the practices that are common and reliable for smaller high-speed upstream compressor packages are not necessarily adequate for applications with larger, heavier, high-flow, low ratio, or highly flexible reciprocating compressors.

The former API 11P (no longer in print) and the current ISO 13631, intended primarily for field gas compressors, provide no in-depth guidance in many of the areas of concern.
The GMRC guidelines gives specifications for the purposes of procuring, designing and applying large, high-speed compressor packages.
It is intended to provide the end user and operator with more reliable procedures and references for selecting, specifying, procuring, applying and operating high-speed units with more predictable and reliable results, and it provides packagers with a more comprehensive and detailed guideline for

designing and building high-speed compressor packagers that meet customer and equipment OEM expectations.

While portions of this document may be applicable to gathering and midstream applications, the principal use is targeted for higher horsepower (≥1472 kW), high-speed (≥700 rpm), highly flexible, low ratio gas transmission compressor applications and versatile gas storage and withdrawal applications.
A significant part of this document provides a tutorial on how to handle specific aspects of large compressor package specification, procurement and design.

For guidance on field gas compressor packages, that are generally under 1472 kW, refer to "GMRC High-Speed Compressor Package Guideline for Field Gas (upstream) Applications.

2.1.8 GMRC Guideline High-Speed Compressor Field Gas
High-Speed Compressor Package Guideline for Field Gas (upstream) Applications" | 1st edition 2017

High-speed reciprocating compressors, driven by natural gas engines or electric motors, provide the advantages of lower capital cost, shorter installation time and compactness. They have become the most common equipment type applied in the upstream and much of the midstream natural gas compression markets.
However, as high-speed (≥700 rpm) engine and electric motor-driven reciprocating compressor packages have been applied, concerns often arose regarding efficiency, vibration, pulsation, controls, ancillary components and systems, pipeline throughput and diagnostics.
Existing industry specifications are of limited value for the purposes of procuring, designing and applying high-speed compressor packages. API 618, intended for low-speed process compressors, is generally too complex, much of it is not applicable to high- speed compressors, and it lacks enough detail in some important areas.

Its pulsation and vibration standard only applies to low-speed compressors, leaving confusion in the marketplace about what standard should be applied to high-speed units. In the absence of a standard, many units are fabricated without a proper analysis. In particular, the range of potential operating conditions is typically not adequately explored during the selection, procurement or manufacturing processes. The former API 11P (no longer in print) and the current ISO 13631, intended primarily for field gas compressors, provide no in-depth guidance in many of the areas of concern. Neither fully provides the more comprehensive direction required.
These issues are addressed in the 2017 version of the "GMRC Guideline for High-Speed Compressor Packages for Natural Gas Transmission & Storage Applications" which are applicable for large horsepower (≥1472 kW), high-speed (≥700 rpm) engine and electric motor-driven reciprocating compressor packages.

The aforementioned GMRC Guidelines are useful for field gas or upstream compression applications, however they do not address a number of key application issues. The upstream compression sector applies higher-speed (up to 1800 rpm) reciprocating compressor packages that are generally under 1472 kW.
Field gas applications have several characteristics that are not covered in the aforementioned GMRC Guidelines for downstream applications.
Material on how to handle wet gas, dirty gas, and wider variations in gas analysis including sour, CO_2 and N_2 content; on-skid fuel gas conditioning; high pressure ratios requiring multiple stages with intercooling; engine accessory end drives for auxiliary equipment; portability; outdoor packages; and

integrated enclosures for cold weather packages are included in the "*GMRC High-Speed Compressor Package Guideline for Field Gas (Upstream) Applications"*
This guideline gives a summary of recommended practices for high-speed reciprocating and screw compressor package selection, integration, design, installation, commissioning, and operation. While portions of the guidelines may be applicable to other applications, the principal use is targeted for field gas and upstream gas processing compressor applications. The document provides the end user with more reliable procedures and references for selecting, specifying, procuring, applying and operating high-speed units with more predictable and reliable results. It also provides packagers with a more comprehensive and detailed specification for designing and building high-speed compressor packagers that meet customer and equipment OEM expectations.

It is noted that it is the intention that the material from these guidelines will be used as a reference for the development of a new API-11P specification.

2.1.9 EFRC Liquid Guidelines
How to avoid Liquid Problems in Reciprocating Compressor Systems| 3rd edition 2018

Reciprocating compressors are positive displacement machines which are unable to handle substantial amounts of liquids. Significant amounts of liquids entering reciprocating compressors are known to cause reliability problems or even catastrophic failures such as:

- Loss of primary containment due to incompressibility of liquids.
- Damaged compressor parts. A slug as a result of liquid carry-over from a process or from interstage coolers is particularly hard on compressor valves which can damage compressor parts such as valves (especially at the suction side), piston rings piston, piston rod, crosshead, and bearings, due to increased forces caused by increased pressure fluctuations (exceeding design limits). The valves can also be damaged by stiction and pressure spikes.
- Reduction in reliability of the compressor due to unpredictable wear of cylinder wearing parts, dilution of the lubricating oil film or washing away PTFE transfer films. Insufficient lubricating will result in accelerated wear of the rider and piston rings and an increase in piston rod drop in such a way that piston will touch the cylinder wall or liner.

These EFRC guidelines establish procedures and guidelines for the design and operation of a reciprocating compressor system with respect to liquid handling. The goal of these guidelines is to ensure the reliable operation of reciprocating compressor systems by avoiding liquid related problems. In general, these guidelines are not intended to be the only reference for designing and operation of reciprocating compressor systems. Using the API Standard 618 together with these guidelines is indispensable. In other words, these guidelines can be used as a complementary document to the available guidelines and engineering practices. These guidelines are intended for OEM's, end-users and engineering companies.
The presence of liquid in reciprocating compressors can lead to serious damages and or unscheduled shut down of compressors. Liquid related problem however mainly originates from other components in systems rather than the compressor cylinder. Thus, in this document, the compressor system is divided into different components. Each component in the system is being investigated to decrease the chance of liquid related problems. Engineering rules are given to increase the awareness on the design and operation of different compressor system's components.

The system components which are covered by these guidelines are:

- Separators and their auxiliaries, such as demisters, level control, etc.
- Pulsation dampers.
- Upstream, downstream and interstage piping.

- Drains.
- Miscellaneous.

In the section of separators, engineering rules on the pre-selection, design check and operation of separators are given. For the design of separators, this document needs to be used in conjunction with the more detailed guidelines which are specifically developed for separators. The rules on how to check the separator vendor's design are valid for pressures up to 105 barg. For pressure above 105 barg, the capacity of separators will be further de-rated, and the design procedure should be done in consultation with a separator expert.

It is a common practice that the layout (system (piping, skids, etc.) is worked out prior to detailing the scrubber/ separator sizing, resulting in constraints for separator design to minimize liquid carry-over. For that reason, it is important that the design of the separator shall be done in a very early stage of the project. It is also very important in this that the different disciplines for plant layout, mechanical and process work together for designing and fabrication of the most robust system that is also cost efficient.

Even though the scope of the document does not include any vibration related issues, engineering guidelines are given for the separator design to avoid vibration problems. Fatigue failures due to vibration are a significant cause of downtime and safety concerns and shall be avoided. If the design of the separator for "liquid removal" does contradict the design to avoid vibration problems, a decision shall be made by the vendor and purchaser about the preferred design.

In addition to the component description of the system, guidelines on the operation of reciprocating compressor systems at different operational stages are given.

Examples of reciprocating compressor systems covered in these guidelines are:

- Horizontal, vertical, V-, W- and L-type compressor systems.
- Constant and variable speed compressors.
- Compressors driven by electric motors, gas and diesel engines, steam turbines, with or without a gearbox, flexible or rigid coupling.
- Dry running and lubricated reciprocating compressors.
- Compressor systems for all types of gases.
- Diaphragm compressors.
- Labyrinth compressors.

For hyper compressor systems which consist of one or more booster compressors and a hyper compressor, the guidelines are not applicable for the hyper compressor part.

2.2 Pulsation and Vibration Control

2.2.1 Pulsation and vibration control (design) requirements of compressors and piping

2.2.1.1 API Specification 11P:

Packaged Reciprocating Compressors for Oil and Gas Production Services (Historical Standard) | 2nd edition 1989

It shall be noted that this standard has been superseded by the ISO 13631.

This standard covers the minimum requirements for a packager supplied, designed and fabricated, skid-mounted, reciprocating, separable or integral compressor with lubricated cylinders and its prime movers used in oil and gas production services. It also includes all necessary auxiliary equipment such as water and gas coolers, exhaust silencer, emission control equipment, inlet air filter, scrubbers, control panel, piping, etc. Required to install an operable unit in compliance with the purchase specifications and with a minimum of field construction and field purchased equipment.

Compressors intended for refinery, chemical or petrochemical services as covered in API 618 (and in ISO 13707) "Reciprocating compressors for petroleum and natural gas industries), compressors that are block-mounted, compressors that are non-lubricated, compressors with single-acting, trunk-type (automotive-type) pistons that also serve as cross-heads, and either utility or instrument air compressors that discharge at 8.6 barg or below are specifically excluded from this specification. Diesel engine, gas turbine and steam turbine prime movers are also specifically excluded.

Section 10.3 covers the pulsation and vibration control.

2.2.2 *API Specification 618*
Reciprocating Compressors for Petroleum, Chemical, and Gas Industry Services" |5th Edition, *(includes Errata 1 dated November 2009 and Errata 2 dated July 2010)*

Covers the minimum requirements for reciprocating compressors and their drivers used in petroleum, chemical, and gas industry services for handling process air or gas with either lubricated or nonlubricated cylinders.
Compressors covered by this standard are of low to moderate speed and in critical services. Also covered are related lubricating systems, controls, instrumentation, intercoolers, aftercoolers, pulsation suppression devices, and other auxiliary equipment.

Clause 7.9 and Annex M, N, O and P, cover the pulsation and vibration control.

2.2.2.1 *API RP 688*
Pulsation and Vibration Control in Positive Displacement Machinery Systems for Petroleum, Petrochemical, and Natural Gas Industry Services | 1st edition 2012

Provides guidance on the application of pulsation and vibration control requirements found in the API purchasing specifications for positive displacement machinery. The fundamentals of pulsation and piping system analysis are presented in Part 1. Part 2 deals specifically with reciprocating compressors and provides commentary regarding each paragraph of Section 7.9 of API Std 618, 5th Edition.

2.2.2.2 *API Standard 688*
Pulsation and Vibration Control for Positive Displacement Machinery Systems for Petroleum, Chemical, and Natural Gas Industry Service| 2nd edition (not yet published)

Despite the fact that the second revision is not released yet, it is good to mention some fact and the scope this document. The 1st edition is a Recommended Practice (RP) but the 2nd edition has been changed into a Standard (Std).

This standard covers the minimum requirements for pulsation and vibration control for positive displacement machinery systems used in the petroleum, chemical, and natural gas industry services. All Clauses on pulsation and vibration control of positive displacement machinery systems will be removed from the applicable standards. The specific machinery addressed in the 2nd edition of the API 688 includes:

- Reciprocating compressors (ref. API 618).
- Rotary-type positive displacement compressors (ref. API 619).
- Positive displacement pumps – Reciprocating (ref. API 674).
- Positive displacement pumps – Controlled Volume (ref. API 675).
- Positive displacement pumps – Rotary (ref. API 676).

Separate clauses for each type of machinery with its own specifications applicable for that machine: e.g. high frequency issues for screw compressors, cavitation for pumps etc. Further on, all material from the 1st edition of the API RP 688 will be placed into an informative Annex of the API 688.

2.2.2.3 Energy Institute
Guidelines for the avoidance of vibration induced fatigue failure in process pipework | 2008

These guidelines assess all those concerned with minimising the risk of incurring loss of containment from vibration induced fatigue failures of process plant pipework.
The document is an enhanced and expanded version of the former MTD Guidelines document which was first issued in 1999 which has been a key element in maintaining integrity in the design and maintenance of process pipework within the oil, gas and petro-chemical industries.
Since the first issue, years of practical experience have been gained in its use which has now been incorporated to good effect. The opportunity has also been taken to widen the document's technical scope, remove ambiguities and make its use more user-friendly and more accessible to a wider range of operation and maintenance personnel.
These guidelines are designed to provide guidance, assessment methods and advice on control and mitigation measures when a new process system is being designed, when undertaking an assessment of an existing plant or process system, when changes to an existing plant or process system are being considered (such as operational, process or equipment changes), and when a vibration issue is identified on an existing plant.
An erratum has been issued for this document referring to pages 61 and 68, which is freely available in the sample pages. These changes have been incorporated into the main PDF and are sent out as a loose-leaf sheet with any hard copy purchased.

2.2.2.4 ISO 13707
Petroleum and natural gas industries — Reciprocating compressors | 1st edition 2000

This International Standard covers the minimum requirements for reciprocating compressors and their drivers used in the petroleum and natural gas industries with either lubricated or nonlubricated cylinders.

<u>Section 12 and Annex M, N and O cover the pulsation and vibration control</u>.

This International Standard is based on API standard 618, 4th edition, 1995. Since the 5th edition is the latest version of the API 618, the ISO 13707 can be considered obsolete.

Remark:
This International Standard is based on API standard 618, 4th edition, 1995. Since the 5th edition is the latest version of the API 618, the ISO 13707 can be considered obsolete. It is expected that there will not be an update of the ISO 13707 in the near future and for that reason it is recommended to use the latest API 618 version.

2.2.2.5 ISO 20154
Ships and marine technology -- Guidelines on vibration isolation design methods for shipboard auxiliary machinery | 2017

The purpose is to provide general guidelines on the design of ship vibration isolation based on the basic methodology of vibration isolation for shipboard machinery, for example, auxiliary engine, compressor, fan, pump, etc. A well-designed vibration isolation system can significantly reduce the vibration transmission from shipboard machinery to ship structures lowering the noise level onboard the ship or the underwater noise radiated from the ship.

2.2.3 Torsional and lateral vibration design requirements

2.2.3.1 API RP 684
API Standard Paragraphs Rotordynamic Tutorial: Lateral Critical Speeds, Unbalance Response, Stability, Train Torsionals, and Rotor Balancing | 2nd Edition, August 2005

Describes, discusses, and clarifies the section of the API Standard Paragraphs that outline the complete lateral and torsional rotor dynamics and rotor balancing acceptance program designed by API to ensure equipment mechanical reliability. Background material on the fundamentals of these subjects (including terminology) along with rotor modelling utilized in this analysis is presented for those unfamiliar with the subject. This document is an introduction to the major aspects of rotating equipment vibrations that are addressed during a typical lateral dynamics analysis.

2.2.3.2 GMRC Control of Torsional Vibrations Reciprocating Compressors
Guideline and Recommended Practice for Control of Torsional Vibrations in Direct Driven Separable Reciprocating Compressors | 2015 5th revision

The purpose of this document is to define a recommended practice for helping to ensure the integrity of separable reciprocating compressor applications with respect to torsional vibration. Its focus is on the practice of torsional vibration analysis and the associated assessment criteria. As required, discussions of other items related to torsional vibration inclusive of drive train design, configuration, fabrication, and assembly are also presented.

Despite the presence of more sophisticated design and analysis tools, torsional vibration-related problems continue to be a recurring issue for reciprocating compressor installations. Most of problems have occurred with motor-driven compressors. However, engine-driven systems are also not immune from experiencing torsional vibration issues. Reported problems have included crankshaft failures, coupling failures, motor shaft failures, failures of welded joints on motor spiders, auxiliary drive failures and cooler fan shaft failures. These issues often require the need to add dampers, change flywheels, change speed range, or improve tolerance of a component to the torque and the resulting stress.

This document seeks to introduce some uniformity to the process of torsional vibration analysis and testing. In addition, its intent is also to provide information to those who are responsible for a compressor installation as to what to expect from a torsional vibration analysis, as well as the significance of the different elements of such an analysis.

The document's sections are targeted as follows:

- Section 1, Scope & Introduction, provides an overview of the Guideline and its purpose.
- Section 2, General Requirements for Torsional Analysis, is most directly oriented toward those with responsibility for initiating the torsional analysis and interpreting its results.
- Section 3, Detailed Requirements for Torsional Analysis, is directed at those responsible for executing the analysis.
- Section 4, Torsional Validation Testing, provides guidelines for experimental verification of torsional behaviour in the as-built equipment.
- Section 5, Installation, Operation and Maintenance Considerations, provides guidelines for maintaining the integrity of torsionally tuned machinery systems.
- Appendix A: Data Required for Torsional Analysis, provides checklists of data required from equipment manufactures for the execution of a torsional analysis.
- Appendix B: Recommended Computational Procedures, provides specific computational procedures that have been identified as best practices for use where no other procedure has been validated for developed various subject areas referenced in the Sections 2, 3 or 4.

2.2.3.3 ISO 3046-5
Reciprocating internal combustion engines -- Performance -- Part 5: Torsional vibrations | 2001

This part of the ISO 3046 establishes general requirements and definitions for torsional vibrations in shaft systems, of sets driven by reciprocating internal combustion (RIC) engines. Where necessary, individual requirements can be given for particular engine applications.
This part of the ISO covers sets driven by reciprocating internal combustion engines for land, rail-traction, and marine use, excluding sets used to propel road construction and earthmoving tractors, industrial type of tractors, automobiles, and trucks, and aircraft.

This second edition cancels and replaces the first edition (ISO 3046-5:1978), which has been technically revised.

ISO 3046 consists of the following parts, under the general title Reciprocating internal combustion engines --Performance:

- Part 1: Declarations of power, fuel and lubricating oil consumptions and test methods--Additional requirements.
- Part 2: Test methods.
- Part 3: Test measurements.
- Part 4: Speed governing.
- Part 5: Torsional vibrations.
- Part 6: Overspeed protection.
- Part 7: Codes for engine power.

2.2.3.4 VDI 2039

Torsional vibration of drivelines calculation, measurement, reduction", 2016

The standard contains descriptions of linear and nonlinear vibration systems and the impact of and components with frequency-dependent properties. It presents a plurality of drive train components. For the user, the torsional vibration calculations with calculation modelling, set-up and solving of the movement equations as well as assessment of the results are presented. Finally, the standard presents torsional vibration measurements, non-linearities, parameter excitations and special aspects of torsional vibration in drive trains, measures to reduce torsional vibrations and the generation of torsional vibrations.

2.3 Noise (Acoustics)

2.3.1 Pipe systems and valves

2.3.1.1 GMRC Report Compressor station piping noise

Compressor station piping noise: noise mechanisms and prediction method | 2011

The intention of this report is to provide a more thorough understanding of the mechanisms which create audible noise from within the compressor station piping and available methods of predicting pipe flow noise apart from the machinery produced noise at a station.
This report provides several noise prediction methods for flow-induced noise due to turbulent flow, noise related to pulsations, and excitation of piping resonances and noise due to the pipe wall motion from related vibrations and structure borne noise. These methods can help to better control noise from station piping and avoid operational problems through proper piping design.
At present, noise measurements and analysis of the compressor station is an "after the fact" scenario. Acoustic barriers, piping insulation, buried piping, diffusers, and silencers are used to reduce noise. Often, the noise issue is addressed by the operating company after start-up, although this could be part of the compressor station design effort. Engine and compressor original equipment manufacturers are held to a certain design specification (such as 85 dBA at a 1 meter distance) but the combined station noise levels are significantly higher than the OEM specification due to the additional contributions from the station piping and accessory machinery. As part of a station design project, it should be possible to avoid major noise issues through resonance avoidance, design mitigation for reducing turbulent, flow-induced excitation, and vibration controls in specific areas.
Field experience indicates that many noise issues are caused by a single source point within the piping (apart from the well characterized machinery level noise). The source point creates noise through one of the mechanisms described herein and leads to excessively high observed noise levels. Often, pinpointing and reducing the dominant cause of the observed noise can help to reduce noise to operationally acceptable levels.

This report is written as a general handbook for understanding and diagnosing compressor station piping noise issues. Its focus is solely on the mechanisms which can create noise within a piping system. It is limited to flow-induced noise, pulsation-related noise, and piping wall vibration noise (either from the flow or structure-borne) and provides a methodology for predicting noise levels related to these specific noise mechanisms. The report does not provide a design methodology or requirements for machinery, control valves, or noise controls (such as insulation, acoustic barriers, and silencers).

In addition, the methods presented herein will predict audible noise due to the sources within the pipe and the piping wall itself. External noise (outside the pipe) at the compressor station will be a combination of other noise sources at the compressor station and not composed solely of station piping noise. Noise will travel externally based on the location of reflection sources (buildings, walls, and other structures) and the buried and unburied pipe. Any methodology for station noise predictions should be applied within this framework.

2.3.1.2 VDI 3733
Noise at pipes | 1996

The purpose of this Guideline is to impart the important knowledge concerning the correct application of sound regulations in the planning, design and laying of pipes with mostly round cross-section in industrial plants; it is broken down according to the criteria generation of sound, sound transmission, sound radiation and sound reduction.
Firstly, the noise mechanisms are explained, and advice given on the determination or use of sound Parameters; the following, for example, may be important:

- the sound power produced by the flow in the pipe;
- the sound power introduced into the fluid and the pipe wall by external sound sources;
- the sound velocities in the fluid and the pipe wall;
- attenuation of the sound transmission in the fluid and in the pipe wall;
- attenuation of the sound transmission in the fluid by deflectors, branches, sudden changes in cross-section and fittings;
- the diminishing sound power in the pipe with increasing pipe length;
- the natural, limit, circumferential expansion and pass frequencies of the pipe;
- the radiation efficiency (or logarithmic radiation efficiency) of the pipe;
- the sound reduction index of the pipe wall.

2.3.2 Working environment

2.3.2.1 ISO 2631
Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration

Part 1: General requirements | 2nd edition 1997
This part of IS0 2631 defines methods for the measurement of periodic, random and transient whole-body vibration. It indicates the principal factors that combine to determine the degree to which a vibration exposure will be acceptable. Informative annexes indicate current opinion and provide guidance on the possible effects of
vibration on health, comfort and perception and motion sickness. The frequency range considered is:

- 0.5 Hz to 80 Hz for health, comfort and perception, and
- 0.l Hz to 0.5 Hz for motion sickness.

Although the potential effects on human performance are not covered, most of the guidance on whole-body vibration measurement also applies to this area. This part of IS0 2631 also defines the principles of preferred methods of mounting transducers for determining human exposure. It does not apply to the evaluation of extreme magnitude single shocks such as occur in vehicle accidents.
This part of IS0 2631 is applicable to motions transmitted to the human body as a whole through the supporting surfaces: the feet of a standing person, the buttocks, back and feet of a seated person or the

supporting area of a recumbent person. This type of vibration is found in vehicles, in machinery, in buildings and in the vicinity of working machinery.

Part 2: Vibration in buildings (1 Hz to 80 Hz) | 2003

Structural vibration to which human beings are exposed in buildings can be detected by the occupants and can affect them in many ways. More particularly, their comfort and quality of life may be reduced. For the evaluation of vibration in buildings with respect to comfort and annoyance, overall weighted values of the vibration are preferred. The value obtained with the appropriate frequency weighting characterizes the place or site within the building where people may be present, by giving an indication of the suitability of that place.

This part of ISO 2631 concerns human exposure to whole-body vibration and shock in buildings with respect to the comfort and annoyance of the occupants. It specifies a method for measurement and evaluation, comprising the determination of the measurement direction and measurement location. It defines the frequency weighting W_m which is applicable in the frequency range 1 Hz to 80 Hz where the posture of an occupant does not need to be defined.

Whilst it is often the case that a building will be available for experimental investigation, many of the concepts contained within ISO 2631-2 would apply equally to a building in the design process or where it will not be possible to gain access to an existing building. In these cases, reliance will have to be placed on the prediction of the building response by some means.

ISO 2631-2 does not provide guidance on the likelihood of structural damage, which is discussed in ISO 4866. Further, it is not applicable to the evaluation of effects on human health and safety.

Acceptable magnitudes of vibration are not stated in ISO 2631-2.

The mathematical definition of the frequency weighting W_m is given in Annex A. Guidelines for collecting data concerning complaints about building vibration are given in Annex B.

2.3.2.2 NORSOK standard S-002
Working Environment | 2014

This NORSOK standard applies to the design of new installations and modification or upgrading of existing installations for offshore drilling, production, and utilisation and pipeline transportation of petroleum, including accommodation units for such activities.
This NORSOK standard stipulates design requirements related to the working environment of petroleum installations as well as requirements regarding systematic management of working environment issues in project development and the design process.
The purpose of this NORSOK standard is to ensure that the design of the installation promotes the quality of the working environment during the operational phase.

Section 5.5 “Noise and Vibration” gives guidelines on the installation of noisy equipment and allowable noise limits. Vibration limits are based on boundaries given in ISO 2631-1 “Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration – Part 1: General requirements, 2nd edition 1997”.
The limits are derived from the acceptability of the exposure of human beings to vibrations and are based on a 12 h working day.

2.3.3 Machines

2.3.3.1 IEC 60034-9

Rotating electrical machines--Part 9: Noise limits | 2007

This part of IEC 60034:

- specifies test methods for the determination of sound power level of rotating electrical machines;
- specifies the maximum A-weighted sound power levels for factory acceptance testing of network-supplied, rotating electrical machines in accordance with lEC 60034-1, having methods of cooling according to lEC 60034-6 and degrees of protection according to lEC 60034-5, and having the following characteristics:
  - standard design, either a.c. or d.c., without additional special electrical, mechanical, or acoustical modifications intended to reduce the sound power level;
  - rated output from 1 kW (or kVA) up to and including 5500 kW (or kVA);
  - rated speed not greater than 3750 min–1
- provides guidance for the determination of noise levels for a.c. cage induction motors supplied by converters. Excluded are a.c. motors supplied by converters. For these conditions see IEC 60034-17 for guidance.

The object of this standard is to determine maximum A-weighted sound power levels, LWA in decibels, dB, for airborne noise emitted by rotating electrical machines of standard design, as a function of power, speed and load, and to specify the method of measurement and the test conditions appropriate for the determination of the sound power level of the machines to provide a standardized evaluation of machine noise up to the maximum specified sound power levels. This standard does not provide correction for the existence of tonal characteristics.

Sound pressure levels at a distance from the machine may be required in some applications, such as hearing protection programs. Information is provided on such a procedure in Clause 8 based on a standardized test environment.

NOTE 1 This standard recognizes the economic reason for the availability of standard noise-level machines for use in non-critical areas or for use with supplementary means of noise attenuation.

NOTE 2 Where sound power levels lower than those specified in Tables 1 or 2 are required, these should be agreed between the manufacturer and the purchaser, as special electrical, mechanical, or acoustical design may involve additional measures.

2.3.3.2 ISO 2151

Acoustics Noise test code for compressors and vacuum pumps -- Engineering method (Grade 2) | 2004

ISO 2151:2004 specifies methods for the measurement, determination and declaration of the noise emission from portable and stationary compressors and vacuum pumps. It prescribes the mounting, loading and working conditions under which measurements are to be made, and includes measurement or determination of the noise emission expressed as the sound power level under specified load conditions and the emission sound pressure level at the work station under specified load conditions. It is applicable to compressors for various types of gases, oil-lubricated air compressors, oil-flooded air compressors, water injected air compressors, oil-free air compressors, compressors for handling hazardous gases (gas compressors), compressors for handling oxygen, compressors for handling acetylene, high pressure compressors (over 40 bar/4 MPa), compressors for application at low inlet temperatures (i.e. below 0 °C), large compressors (over 1 000 kW input power), portable and skid-mounted air compressors, and rotary positive displacement blowers and centrifugal blowers and exhausters in applications of 2 bar/0,2 MPa or less. It is not applicable to compressors for gases other than acetylene having a maximum allowable working pressure of less than 0,5 bar/0,05 MPa, refrigerant compressors used in refrigerating systems or heat pumps, nor to hand-held portable compressors.

2.3.3.3 ISO 3740
Acoustics — Determination of sound power levels of noise sources — Guidelines for the use of basic standards | 2000

The series of International Standards, for which this International Standard serves as a guideline for use, comprises ISO 3741, ISO 3743-1, ISO 3743-2, ISO 3744, ISO 3745, ISO 3746, ISO 3747, ISO 9614-1 and ISO 9614-2. In principle, the methods of determining sound power levels described in ISO 3741 to ISO 3747 and ISO 9614-1 and ISO 9614-2 cover all types of machinery and equipment.

ISO 3741 to ISO 3747, ISO 9614-1 and ISO 9614-2 make up a set of basic International Standards which specify the acoustical conditions and instrumentation to be used, describe the procedures to be followed, and give general information on the mounting and operation of the machine under test in order to determine sound power levels.
The selection of standards for the determination of sound power levels can, for practical reasons, have consequences for the selection of standards for the determination of the emission sound pressure levels (see ISO 11200) and vice versa. It is beneficial to make the choice of standards concurrently with respect to the two noise emission quantities.

Relationships to other standards
This International Standard is one of a series which specifies various methods for determining the noise emission of a piece of machinery or equipment, or a sub-assembly of such equipment (referred to throughout this International Standard as the "machine under test"). Standards in this series are grouped in three categories as follows:
a) Methods for the determination of sound power levels
This category includes the following standards (see Table 1):

- ISO 3741 to ISO 3747 give methods with precision grade, engineering grade or survey grade of accuracy for determining sound power levels of machinery and equipment using sound pressure level measurements in different types of environments;
- ISO 9614-1 and ISO 9614-2 describe methods for determining the sound power levels of machinery and equipment using sound intensity level measurements.

b) Methods for the determination of emission sound pressure levels at work stations and at other specified positions.
This category includes the following standards:

- ISO 11200 gives guidelines for the choice of the method to be used;
- ISO 11201, ISO 11202 and ISO 11204 give methods for determining emission sound pressure levels of machinery and equipment from measured sound pressure levels;
- ISO 11203 gives methods for determining the emission sound pressure levels of machinery and equipment from the sound power levels.

c) Noise test codes

For a particular family of machinery or equipment, a noise test code specifies the following:

- the methods and instruments to be used for the determination of the sound power level;
- the method to be used for the determination of emission sound pressure levels at work stations and/or at other specified positions;
- the positions of the work stations;
- the mounting and operating conditions of the machine under test for the purpose of determining the noise emission quantities;
- the method to be used for verifying declared noise emission quantities.
- ISO 12001 gives rules for the drafting and presentation of a noise test code.

2.3.3.4 ISO 3741

Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Precision methods for reverberation test rooms | 2010

ISO 3741:2010 specifies methods for determining the sound power level or sound energy level of a noise source from sound pressure levels measured in a reverberation test room. The sound power level (or, in the case of noise bursts or transient noise emission, the sound energy level) produced by the noise source, in frequency bands of width one-third-octave, is calculated using those measurements, including corrections to allow for any differences between the meteorological conditions at the time and place of the test and those corresponding to a reference characteristic impedance. Measurement and calculation procedures are given for both a direct method and a comparison method of determining the sound power level and the sound energy level.

In general, the frequency range of interest includes the one-third-octave bands with mid-band frequencies from 100 Hz to 10 000 Hz. Guidelines for the application of the specified methods over an extended frequency range in respect to lower frequencies are given in an annex. ISO 3741:2010 is not applicable to frequency ranges above the 10 000 Hz one-third-octave band.

The methods specified in ISO 3741:2010 are suitable for all types of noise (steady, non-steady, fluctuating, isolated bursts of sound energy, etc.) defined in ISO 12001.

The noise source under test can be a device, machine, component or sub-assembly. ISO 3741:2010 is applicable to noise sources with a volume not greater than 2 % of the volume of the reverberation test room. For a source with a volume greater than 2 % of the volume of the test room, it is possible that the achievement of results as defined in ISO 12001:1996, accuracy grade 1 (precision grade) is not feasible.

The test rooms that are applicable for measurements made in accordance with ISO 3741:2010 are reverberation test rooms meeting specified requirements.

Information is given on the uncertainty of the sound power levels and sound energy levels determined in accordance with ISO 3741:2010, for measurements made in limited bands of frequency and for A-weighted frequency calculations from them. The uncertainty conforms to ISO 12001:1996, accuracy grade 1 (precision grade).

2.3.3.5 ISO 3747

Acoustics — Determination of sound power levels and sound energy levels of noise sources using sound pressure — Engineering/survey methods for use in situ in a reverberant environment | 2010

ISO 3747:2010 specifies a method for determining the sound power level or sound energy level of a noise source by comparing measured sound pressure levels emitted by a noise source (machinery or

equipment) mounted *in situ* in a reverberant environment, with those from a calibrated reference sound source. The sound power level (or, in the case of noise bursts or transient noise emission, the sound energy level) produced by the noise source, in frequency bands of width one octave, is calculated using those measurements. The sound power level or sound energy level with frequency A-weighting applied is calculated using the octave-band levels.
The method specified in ISO 3747:2010 is suitable for all types of noise (steady, non-steady, fluctuating, isolated bursts of sound energy, etc.) defined in ISO 12001. The method is primarily applicable to sources which emit broad-band noise. It can, however, also be used for sources which emit narrow-band noise or discrete tones, although there is a possibility that the measurement reproducibility is then degraded.
The noise source under test can be a device, machine, component or sub-assembly, especially one which is non-movable.
The test environment that is applicable for measurements made in accordance with ISO 3747:2010 is a room where the sound pressure level at the microphone positions depends mainly on reflections from the room surfaces. In measurements of ISO 12001:1996, accuracy grade 2 (engineering grade), background noise in the test environment is low compared to that of the noise source or reference sound source.
Information is given on the uncertainty of the sound power levels and sound energy levels determined in accordance with ISO 3747:2010, for measurements made in octave bands and for A-weighted frequency calculations performed on them. The reproducibility conforms with that of either ISO 12001:1996, accuracy grade 2 (engineering grade) or ISO 12001:1996, accuracy grade 3 (survey grade), depending on the extent to which the requirements concerning the test environment are met.

2.3.3.6 ISO 9614
Acoustics - Determination of sound power levels of noise sources using sound intensity

Part 1: Measurement at discrete points | 1993
This part of ISO 9614 specifies a method for measuring the component of sound intensity normal to a measurement surface which is chosen to enclose the noise source(s) of which the sound power level is to be determined. The one-octave, one-third-octave or band-limited weighted sound power level is calculated from the measured value. The method is applicable in situ or in special purpose test environments to any source for which a physically stationary measurement surface can be defined, and on which the noise generated by the source is stationary in time.

This standard was last reviewed and confirmed in 2018. Therefore, this version remains current.

Part 2: Measurement by scanning | 1996
This part of ISO 9614 specifies a method for measuring the component of sound intensity normal to a measurement surface which is chosen so as to enclose the noise source(s) of which the sound power level is to be determined.
Surface integration of the intensity component normal to the measurement surface is approximated by sub-dividing the measurement surface into contiguous segments and scanning the intensity probe over each segment along a continuous path which covers the extent of the segment. The measurement instrument determines the average normal intensity component and averaged squared sound pressure over the duration of each scan. The scanning operation may be performed either manually or by means of a mechanical system.
Band-limited weighted sound power level is calculated from the measured octave or one-third-octave band values. The method is applicable to any source for which a physically stationary measurement

surface can be defined, and on which the noises generated by the source under test and by other significant extraneous sources are stationary in time, as defined in 3.13. The source is defined by the choice of measurement surface. The method is applicable *in situ*, or in special-purpose test environments.
This part of ISO 9614 specifies certain ancillary procedures, described in annex B, to be followed in conjunction with the sound power determination. The results are used to indicate the quality of the determination, and hence the grade of accuracy. If the indicated quality of the determination does not meet the requirements of this part of ISO 9614, the test procedure is to be modified in the manner indicated.
This part of ISO 9614 does not apply in any frequency band in which the sound power of the source is found to be negative on measurement.

2.3.3.7 ISO 9614-3:
Acoustics - Determination of sound power levels of noise sources using sound intensity - Part 3: Precision method for measurement by scanning | 2002

ISO 9614-3:2002 specifies a method for measuring the component of sound intensity normal to a measurement surface which is chosen to enclose the sound source(s) of which the sound power level is to be determined. Surface integration of the intensity component normal to the measurement surface is approximated by subdividing the measurement surface into contiguous partial surfaces and scanning the intensity probe over each partial surface along a continuous path which covers the extent of the partial surface.
The measurement instrument determines the averaged normal intensity component and averaged squared sound pressure over the duration of each scan. The scanning operation can be performed either manually or by means of a mechanical system. The octave band or band-limited weighted sound power level is calculated from the measured one-third-octave- band values.
The method is applicable to any source for which a physically stationary measurement surface can be defined, and on which the sound generated by the source under test and by other significant extraneous sources are stationary in time. The source is defined by the choice of measurement surface. The method is applicable in specific test environments fulfilling all relevant requirements of ISO 9614-3.

ISO 9614-3 specifies certain ancillary procedures, described in annex C, to be followed in conjunction with the sound power determination. The results are used to indicate the quality of the determination, and hence the grade of accuracy. If the quality of the determination does not meet the requirements of ISO 9614-3, the test procedure shall be modified in the manner indicated. ISO 9614-3 is not applicable to any frequency band in which the sound power of the source is found to be negative on measurement.
It is applicable to sources situated in any environment which is neither so variable over time as to reduce the accuracy of the measurement of sound intensity to an unacceptable degree, nor subjects the intensity measurement probe to gas flows of unacceptable speed or unsteadiness. In some cases, it will be found that the test conditions are too adverse to allow the requirements of ISO 9614-3 to be met. For example, extraneous noise levels can exceed the dynamic capability of the measuring instrument or can vary to an excessive degree during the test. In such cases the method given in ISO 9614-3 is not suitable for the determination of the sound power level of the source.

2.3.3.8 ISO 8528-10

Reciprocating internal combustion engine driven alternating current generating sets | 2014

This part of ISO 8528 was prepared by ISO Technical Committee ISO/TC 70, Internal combustion engines.

ISO 8528 consists of the following parts under the general title "Reciprocating internal combustion engine driven alternating current generating sets":

- Part 1: Application, ratings and performance | 2018
- Part 2: Engines | 2018
- Part 3: Alternating current generators for generating sets | 2005
- Part 4: Control gear and switchgear | 2005
- Part 5: Generating sets | 2018
- Part 6: Test methods | 2005
- Part 7: Technical declarations for specification and design | 2017
- Part 8: Requirements and tests for low-power generating sets | 2016
- Part 9: Measurement and evaluation of mechanical vibrations | 2017
- Part 10: Measurement of airborne noise by the enveloping surface method | 2014
- Part 11: Dynamic, uninterrupted power supply systems.
- Part 12: Emergency power supply to safety services |2014

Part 10: Measurement of airborne noise by the enveloping surface method | 2014

This part of ISO 8528 defines measurement methods for the determination of airborne noise emitted by reciprocating internal combustion engine driven generating sets in such a way that the total of relevant noise emissions, e.g. exhaust and cooling system noise, together with all other sources of engine noise, are evaluated on a similar basis to yield comparable results. However, when the exhaust and cooling systems are ducted to a remote site their noise contribution is not to be included in this part of ISO 8528.

The essential noise emission characteristic value is the sound power level.

The results of measurement taken in accordance with this part of ISO 8528 are classified as either accuracy grade 2 or grade 3 depending on which acoustic measurement conditions are complied with. Accuracy grade 2 (i. e., engineering method in accordance with ISO 3744) requires the measuring area to be a substantially acoustic-free field over a reflecting plane (with an environmental correction K_{2A} < 2 dB) and with negligible background noise level (background noise correction K_{1A} < 1,3 dB). Accuracy grade 3 (i. e. survey method in accordance with ISO 3746) requires the environmental correction K_{2A} to be less or equal than 7 dB, and the background noise correction K_{1A} to be less or equal than 3 dB.

For the operation of a generating set under steady conditions this part of ISO 8528 allows for the calculation of the A-weighted sound power level as well as appropriate octave or one third octave sound power level for the appropriate accuracy grade.

This part of ISO 8528 applies to RIC engine driven AC generating sets for fixed and mobile applications with rigid or flexible mountings. It is applicable for land and marine use, excluding generating sets used on aircraft or to propel land vehicles and locomotives.

NOTE 1 This part of ISO 8528 has been developed for RIC engine driven AC generating sets, but it can also be applied to RIC engine driven DC generating sets.

NOTE 2 For some specific applications (e. g. essential hospital supplies, high rise buildings, etc.) supplementary requirements may be necessary. The provisions of this part of ISO 8528 should be regarded as a basis.

NOTE 3 True comparisons can only be made between generating sets when the measurement are classified in the same accuracy grade.

2.3.3.9 ISO 13332:
Reciprocating internal combustion engines -- Test code for the measurement of structure-borne noise emitted from high-speed and medium-speed reciprocating internal combustion engines measured at the engine feet | 2000

This International Standard defines the procedure for measuring the capacity of a high-speed or medium-speed engine to generate vibration and the determination of the frequency limits of validity of the information quoted. The method described in this International Standard is not suitable for low-speed engines. This International Standard describes an engineering and not a precision method. Whether the tests are carried out on the test bed or on site shall be agreed between the user and the manufacturer.
This International Standard applies to high-speed and medium-speed reciprocating internal combustion engines for land, rail traction and marine use, excluding engines used to propel agricultural tractors, road vehicles and aircraft. This International Standard may be applied to engines used to propel road-construction and earth-moving machines, industrial trucks and for other applications where no suitable International Standard for these engines exists.

2.3.3.10 VDI 3753
Characteristic noise emission values of technical sound sources - Reciprocating internal combustion (RIC) engines | October 1997

This Guideline applies to reciprocating internal combustion (RIC) engines in accordance with DIN ISO 3046-1, hereinafter called reciprocating internal combustion (RIC) engines, working after the two- or four-cycle principle with diesel engine combustion. Such kind of reciprocating internal combustion (RIC) engines are used, for example:

- in industry (e.g. as stationary engines) and
- to drive equipment, machines, watercraft, rail bound and road vehicles.

This Guideline describes the state of the art of the abovementioned engines with respect to their airborne sound radiation. The indicated noise emission values have been determined in accordance with a standardised measurement method. The characteristic emission values defined in clause 4 and presented in clause 5 are used to describe the noise emission.
Furthermore, Annex A of this Guideline gives Information regarding methods for the reduction of airborne sound and structure-borne sound of reciprocating internal combustion (RIC) engines.
This Guideline presents an aid to its users (designers, manufacturers, operators and institutions dealing with the evaluation, checking or monitoring of the noise emission of reciprocating internal combustion [RIC] engines) in assessing the acoustic aspects.

This document references to the following standards:
DIN 45635-1; DIN 45635-11; DIN EN ISO 11689; DIN EN ISO 14163; DIN EN ISO 4871; DIN ISO 3046-1; ISO 11689; ISO 14163 : ISO 6798; VDI 2062 BLATT 1; VDI 2567; VDI 2711

2.3.3.11 VDI-Standard 3731 Blatt 1
Characteristic noise emission values of technical sound sources; compressors | 1982

2.4 Foundation, machine bolts, grouting, soil& piles, skids, mounting systems

2.4.1 BS CP 2012-1
Code of practice for foundations for machinery. Foundations for reciprocating machines | 1974

This Code of Practice (CP) covers machinery normally rotating in the low (up to 5 Hz) and medium (5 Hz to 25 Hz) frequency ranges and of a size for which a rigid block type foundation is normally used. Information to assemble and steps to take to realise a satisfactory design and adequate control of construction work on site.

The subject which are discussed are: Foundations, Structural systems, Structural design, Design, Site investigations, Vibration, Vibration control, Concretes, Dimensions, Fixing, Reinforced concrete, Pile foundations, Vibration dampers, Vibration measurement, Design calculations, Seatings, Construction operations, Grouting, Bibliography, Reciprocating parts

Appendices include step by step design procedure.

2.4.2 EFRC Report Foundations, Anchor Bolts, Grouting of Reciprocating Compressors
Summary of international guidelines, standards and best practices of foundations, anchor bolts and grouting of reciprocating compressor systems | 1st edition 2016

Reciprocating compressors generate dynamic loads which require a support system that can resist dynamic loads and the resulting vibrations. When excessive, such vibrations may be detrimental to the machinery and its support system.
Foundations shall be designed to be able to withstand the static and dynamic loads to prevent excessive foundation settlement and vibration problems of the compressor system.
Besides an adequate foundation structure, the compressor must be mounted in a correct and sufficient way with anchor bolts to the foundation structure to ensure frame and coupling alignment and providing energy paths for dissipation of dynamic loads.

Many engineers with varying backgrounds are engaged in the analysis, design, construction, maintenance, and repair of machine foundations and mountings.
Therefore, it is important that the owner/operator, geotechnical engineer, structural engineer, and equipment supplier collaborate during the design process.
Each of them has inputs and concerns that are important and shall be effectively communicated with each other, especially considering that machine foundation and mounting design procedures and criteria are not covered in standards and guidelines used in civil engineering.
Many firms and individuals have developed their own standards and specifications as a result of research and development activities, field studies, or many years of successful engineering or construction practices.
Besides that, there are many documents, procedures, papers, and guidelines available on foundations and mounting methods for reciprocating compressors, all highlighting particular segments of the total procedure.

The Gas Machinery Research Council (GMRC) has carried out extensive research projects on foundations and mountings of reciprocating compressors. The results of these research projects have been summarized in several reports and contain many relevant information, of which much are still up-to-date.
Besides the GMRC reports, many other documents, guidelines, standards, papers etc. are available which contain valuable information which has been used in this project. Unfortunately, most of this material is not available for everybody, is too extended or not directly applicable.
This EFRC report is a comprehensive document, consisting of a summary of up-to-date best practices and engineering rules on foundations and mounting methods for reciprocating compressor systems.

Different guidelines and standards have been developed for different items as summarised and discussed in this document. This results in different values for item such as for example the bolt preload. A particular value can be prescribed in a standard and can be different per country. For that reason, only a summary of those particular values has been given instead of a recommendation.
Due to the fact that these guidelines and standards contain already very useful information, many parts have been copied or referenced in this EFRC report.

It was not the scope of the EFRC project to develop detailed design and construction rules for all applicable items. Where relevant, a reference is given to the document containing the detailed design procedure for a certain topic.
However, several guidelines have been derived from existing standards and guidelines which can be used in the design of the anchorage system for the actual foundation system of interest. Examples are pocket size, edge and anchor bolt distance, etc. It shall be noted that the examples as given are based on certain material properties, dimensions, anchor preloads etc. If the values for the foundation system of interest deviate from those of the examples as given in this report, the values shall be adjusted accordingly.

Finally, it shall be noted that many companies have developed their own guidelines and best practices which have been applied for many years without having major problems. These company guidelines may differ from the summary of the guidelines as given in this report, but this does not necessarily mean that the company guidelines are not suitable to use.

2.4.3 GMRC Guidelines Foundation, Machine bolts, Grouting, Soil& Piles, Skids, Mounting

The following GMRC guidelines give very valuable information for the foundation, machine bolts, grouting, soil& piles, skids and mounting systems for reciprocating compressors:

- GMRC Guideline "High-speed reciprocating compressor packages for natural gas transmission & storage (downstream) applications", 2st edition 2017
- GMRC Guideline "High-Speed Compressor Package Guideline for Field Gas (upstream) Applications", 1st edition 2017)

2.4.4 PIP REIE686A
Recommended Practice (RP) for Machinery Installation and Installation Design (Supplement to PIP REIE686/API RP686) | 2012

This Practice supplements PIP REIE686/API RP686, Recommended Practice for Machinery Installation and Installation Design.

Together, this Practice and PIP REIE686/API RP686 provide requirements for installation recommended procedures, practices, and checklists for the installation and pre-commissioning of new, existing, and reapplied machinery and to assist with the installation design of such machinery.
The scope of this RP describes additions, changes, and deletions that have been made to PIP REIE686/API RP686. In addition, decisions that have been made regarding options offered by PIP REIE686/API RP686 are also described.

2.5 Separators

2.5.1 API Specification 12J
Specification for oil and gas separators | 8th edition 2008

This specification covers minimum requirements for the design, fabrication, and shop testing of oil-field type oil and gas separators and/or oil-gas-water separators used in the production of oil and/or gas, and usually located but not limited to some point on the producing flowline between the wellhead and pipeline. Separators covered by this specification may be vertical, spherical, or single or double barrel horizontal.
Unless otherwise agreed upon between the purchaser and the manufacturer, the jurisdiction of this specification terminates with the pressure vessel as defined in the Scope of Section VIII, Division 1 of the ASME Boiler and Pressure Vessel Code, hereinafter referred to as the ASME Code. Pressure vessels covered by this specification are normally classified as natural resource vessels by API 510, Pressure Vessel Inspection Code. Separators outside the scope of this specification include centrifugal separators, filter separators, and de-sanding separators.

2.5.2 EFRC Liquid Guidelines
How to Avoid Liquid Problems in Reciprocating Compressor Systems | 3rd edition 2018

These EFRC guidelines establish procedures and guidelines for the design and operation of a reciprocating compressor system with respect to liquid handling. The goal of these guidelines is to ensure the reliable operation of reciprocating compressor systems by avoiding liquid related problems. In general, these guidelines are not intended to be the only reference for designing and operation of reciprocating compressor systems. Using the API Standard 618 [1] together with these guidelines is indispensable. In other words, these guidelines can be used as a complementary document to the available guidelines and engineering practices. These guidelines are intended for OEM’s, end-users and engineering companies.
The presence of liquid in reciprocating compressors can lead to serious damages and or unscheduled shut down of compressors. Liquid related problem however mainly originates from other components in systems rather than the compressor cylinder. Thus, in this document, the compressor system is divided into different components. Each component in the system is being investigated to decrease the chance of liquid related problems. Engineering rules are given to increase the awareness on the design and operation of different compressor system’s components.
The system components which are covered by these guidelines are:

- Separators and their auxiliaries, such as demisters, level control, etc.
- Pulsation dampers.
- Upstream, downstream and interstage piping.
- Drains.
- Miscellaneous.

In the section of separators, engineering rules on the pre-selection, design check and operation of separators are given. For the design of separators, this document needs to be used in conjunction with the more detailed guidelines which are specifically developed for separators. The rules on how to check the separator vendor’s design are valid for pressures up to 105 barg. For pressure above 105 barg, the capacity of separators will be further de-rated and the design procedure should be done in consultation with a separator expert.
In addition to the component description of the system, guidelines on the operation of reciprocating compressor systems at different operational stages are given.

2.5.3 NORSOK-P-100
Process Systems | 2010

This NORSOK standard defines the minimum functional requirements for process systems on an offshore installation. In addition, the standard includes a number of recommendations to give additional guidance for the system design.
Section 5.1 gives rules for the Horizontal separator design. Section 5.2 gives design rules for vertical scrubbers which are used for separation of liquid from streams with high gas-to-liquid ratios to protect downstream equipment from liquid carry-over. For elimination of very fine mist (droplet size < 3 microns) filter separators are required. Filter separators are not covered in this NORSOK standard.

2.5.4 SHELL DEP 31.22.05.11:
Gas/liquid separators - type selection and design rules | 2007

This DEP specifies requirements and gives recommendations for the selection and design of gas/liquid separators.
Design rules for the following types of separators are given in (Section 3):

- Knock-out drum (vertical and horizontal separator).
- Wire mesh demister (vertical and horizontal separator).
- Vane-type demister (vertical and horizontal separator).
- Separators of the SMS family (SMS, SVS, SMSM).
- Cyclone with tangential inlet (conventional cyclone).
- Cyclone with straight inlet and swirler ("Gasunie" cyclone).
- Vertical multicyclone separator with reversed-flow multicyclone bundle (conventional multicyclone separator).
- Filter separator.

The design of gas/liquid/liquid three-phase separators is excluded from the scope of this DEP; for this subject, DEP 31.22.05.12-Gen. should be consulted. Users of this DEP should first consult Section 2 ("Selection Criteria for Gas/Liquid Separators") to familiarise themselves with the general design philosophy and the characteristics of the various separators. After selection of the desired separator the design rules can be obtained from Section 3. Further guidance for debottlenecking of existing separators is given in Appendix XI. This is a revision of the DEP of the same number dated September 2002; a summary of the main changes is given in (1.6).

2.6 Pressure Vessels

2.6.1 ASME Boiler & Pressure Vessel Code (BPVC) Section VIII Pressure Vessels

Division 1 provides requirements applicable to the design, fabrication, inspection, testing, and certification of pressure vessels operating at either internal or external pressures exceeding 15 psig. Such vessels may be fired or unfired. This pressure may be obtained from an external source or by the application of heat from a direct or indirect source, or any combination thereof. Specific requirements apply to several classes of material used in pressure vessel construction, and also to fabrication methods such as welding, forging and brazing. Division 1 contains mandatory and non-mandatory appendices detailing supplementary design criteria, non-destructive examination and inspection acceptance standards. Rules pertaining to the use of the single ASME certification mark with the U, UM and UV designators are also included.

Division 2 provides requirements on materials, design, and non-destructive examination are more rigorous than in Division 1; however, higher design stress intensity values are permitted. These rules may also apply to human occupancy pressure vessels typically in the diving industry. Rules pertaining to the use of the single ASME certification mark with the U2 and UV designators are also included.

Division 3 provides requirements are applicable to pressure vessels operating at either internal or external pressures generally above 10,000 psi. It does not establish maximum pressure limits for either Section VIII, Divisions 1 or 2, nor minimum pressure limits for this Division. Rules pertaining to the use of the single ASME certification mark with the U3, UV3 and UD3 designator are also included.

Referenced BPVC sections BPVC-II, A, B, C, D Section II, Materials, Parts A through D.
- BPVC-V Section V, Non-destructive Examination.
- BPVC-IX Section IX, Welding, Brazing, and Fusing Qualifications.

Is an American Society of Mechanical Engineers (ASME) standard that regulates the design and construction of boilers and pressure vessels. The American Society of Mechanical Engineers works as an Accreditation Body and entitles independent third parties such as verification, testing and certification agencies. The different sections and divisions are:
- ASME BPVC Section II – A, B, C Materials specification.
- ASME BPVC Section II – D Materials properties.
- ASME BPVC Section III - Rules for Construction of Nuclear Facility Components.
- ASME BPVC Section V - Non-destructive Examination.
- ASME BPVC Section VIII:
  - Division 1- Rules for Construction of Pressure Vessels
    This division provides requirements applicable to the design, fabrication, inspection, testing, and certification of pressure vessels operating at either internal or external pressures exceeding 15 psig (1.034 barg). Such vessels may be fired or unfired. This pressure may be obtained from an external source or by the application of heat from a direct or indirect source, or any combination thereof. Specific requirements apply to several classes of material used in pressure vessel construction, and also to fabrication methods such as welding, forging and brazing. Division 1 contains mandatory and non-mandatory appendices detailing supplementary design criteria, non-destructive examination and inspection acceptance standards. Rules pertaining to

the use of the single ASME certification mark with the U, UM and UV designators are also included.

  - Division 2 - Alternative Rules
    The requirements of this division on materials, design, and non-destructive examination are more rigorous than in Division 1; however, higher design stress intensity values are permitted. These rules may also apply to human occupancy pressure vessels typically in the diving industry. Rules pertaining to the use of the single ASME certification mark with the U2 and UV designators are also included.
  - Division 3 - Alternative Rules for Construction of High Pressure Vessels
    The requirements of this division are applicable to pressure vessels operating at either internal or external pressures generally above 10,000 psi. It does not establish maximum pressure limits for either Section VIII, Divisions 1 or 2, nor minimum pressure limits for this Division. Rules pertaining to the use of the single ASME certification mark with the U3, UV3 and UD3 designator are also included.
- ASME SECTION IX, Welding, brazing, and fusing procedures; welders; brazers; and welding, brazing and fusing operators, July 2017

2.6.2 BS PD 5500
Specification for unfired fusion welded pressure vessels | 2018

The PD 5500 "Specification for unfired, fusion welded pressure vessels" is a code of practice that provides rules for the design, fabrication, and inspection of pressure vessels.
PD 5500 was formerly a widely used British Standard known as BS 5500, but was withdrawn from the list of British Standards because it was not harmonized with the European *Pressure Equipment Directive* (97/23/EC). In the United Kingdom it was replaced by EN 13445. It is currently published as a "Published Document" (PD) by the British Standards (BS) Institution.

BS PD 5500:2018 specifies requirements for the design, construction, inspection, testing and verification of compliance of new unfired fusion welded pressure vessels. The materials of construction are specified in Section 2. The term "pressure vessel" as used in this specification includes branches up to the point of connection to the connecting piping by bolting, screwing or welding, and supports, brackets or other attachments directly welded to the pressure containing shell. The term "unfired" excludes vessels that are subject to direct generated heat or flame impingement from a fired process. It does not exclude vessels subject to electrical heating or heated process streams.

It has the following sections:

- Section1- General.
- Section2 – Materials.
- Section3 – Design.
- Section4 - Manufacture and workmanship.
- Section5 - Inspection and testing.
- Annexes A through Z.

It is noted that BS PD 5500 is not the same as EN13445 because the EN13445 is mainly comprised of PD 5500 and AD-Merkblätter.

2.6.3 EN 13445
Unfired pressure vessels | 5th edition 2018

The EN 13445 series of standards applies to unfired pressure vessels subject to a pressure greater than 0,5 bar gauge but may be used for vessels operating at lower pressures, including vacuum.
Compliance with the EN 13445 series can be used to demonstrate compliance with the Pressure Equipment Directive.
EN 13445 specifies the requirements for design, construction, inspection and testing of unfired pressure vessels. It defines terms, definitions and symbols applicable to unfired pressure vessels. EN 13445 comprises the following Parts:

- Part 1: General
- Part 2: Materials
- Part 3: Design
- Part 4: Fabrication
- Part 5: Inspection and testing
- Part 6: Requirements for the design and fabrication of pressure vessels and pressure parts constructed from spheroidal graphite cast iron
- PD CR 13445-7, Unfired pressure vessels — Part 7: Guidance on the use of conformity assessment procedures
- Part 8: Additional requirements for pressure vessels of aluminium and aluminium alloys
- CEN/TR 13445-9, Unfired pressure vessels — Part 9: Conformance of EN 13445 series to ISO 16528.

It is noted that EN13445 is comprised of mainly BS PD5500 and AD-Merkblätter.

2.6.4 ISO 16528-1 & 2:
Boilers and pressure vessels |2007

ISO 16528 consists of the following parts, under the general title *Boilers and pressure vessels*:

- Part 1: Performance requirements.
- Part 2: Procedures for fulfilling the requirements of ISO 16528-1.

Part 1: Performance requirements
This part of ISO 16528 specifies performance requirements for boilers and pressure vessels, to ensure the integrity of the pressure boundary.
An important safety requirement is the suitable provision of technical requirements considering the various modes of failure that can occur in boilers and pressure vessels. Guidance is given on these modes together with the criteria for satisfying these.

There are significant differences among countries in regulating the supply and operation of boilers and pressure vessels. These differences include compliance with specific standard(s) limiting source or specification of materials, use of specific inspection bodies and discriminatory certification systems or import licenses. However, these standards have a proven history of supporting public safety and good commercial operating experience.

This part of ISO 16528, which is performance-based, enables these standards to co-exist, providing an approach that can accommodate technical innovations, existing regulatory frameworks and market needs. Compliance with the requirements of this part of ISO 16528 does not relieve parties from obligations under local, national or international laws or regulations.

This part of ISO 16528 defines the performance requirements for the construction of boilers and pressure vessels.
It is not the intent of this part of ISO 16528 to address operation, maintenance and in-service inspection of boilers and pressure vessels.
In relation to the geometry of the pressure-containing parts for pressure vessels, the scope of this part of ISO 16528 includes the following:

a) welding end connection for the first circumferential joint for welded connections;
b) first threaded joint for screwed connections;
c) face of the first flange for bolted, flanged connections;
d) first sealing surface for proprietary connections or fittings;
e) safety accessories, where necessary

In relation to the geometry of pressure-containing parts for boilers, the scope of this part of ISO 16528 covers the following:

f) feedwater inlet (including the inlet valve) to steam outlet (including the outlet valve), including all inter-connecting tubing that can be exposed to a risk of overheating and cannot be isolated from the main system;
g) associated safety accessories;
h) connections to the boilers involved in services, such as draining, venting, desuperheating, etc.

This part of ISO 16528 does not apply for nuclear components, railway and marine boilers, gas cylinders or piping systems or mechanical equipment, e.g. turbine and machinery casings.

Part 2: Procedures for fulfilling the requirements of ISO 16528-1
There are commonly used national/regional standards that have a proven history of supporting public safety and have good commercial operating experience. It is the intention of this part of ISO 16528 to provide a process to identify national/regional standards that satisfy the performance requirements of ISO 16528-1.

2.7 Heat Exchangers

2.7.1 API Std 660/ ISO 16812
Shell-and-Tube Heat Exchangers |9th edition 2015

Specifies requirements and gives recommendations for the mechanical design, material selection, fabrication, inspection, testing, and preparation for shipment of shell-and-tube heat exchangers for the petroleum, petrochemical, and natural gas industries. This standard is applicable to the following types of shell-and-tube heat exchangers: heaters, condensers, coolers, and reboilers.
This standard is not applicable to vacuum-operated steam surface condensers and feed-water heaters.

2.7.2 API Std 661
Petroleum, Petrochemical, and Natural Gas Industries—Air-Cooled Heat Exchangers for General Refinery Service | 7th edition 2013

Gives requirements and recommendations for the design, materials, fabrication, inspection, testing, and preparation for shipment of air-cooled heat exchangers for use in the petroleum, petrochemical, and natural gas industries. This standard is applicable to air-cooled heat exchangers with horizontal bundles, but the basic concepts can also be applied to other configurations.

2.7.3 API Std 662, Part 1/ISO 15547-1
Plate Heat Exchangers for General Refinery Services

Part 1—Plate-and-Frame Heat Exchangers (ANSI/API Std 662, Part 1) |2005
Gives requirements and recommendations for the mechanical design, materials selection, fabrication, inspection, testing, and preparation for shipment of plate-and-frame heat exchangers for use in petroleum, petrochemical and natural gas industries. It is applicable to gasketed, semi welded and welded plate-and-frame heat exchangers. This edition of API Std 662-1 is an identical national adoption of ISO 15547-1:2005, 1st Edition February 2006 | Reaffirmed: February 2011

Part 2—Brazed Aluminium Plate-Fin Heat Exchangers (ANSI/API 662, Part 2). This edition of API Std 662-2 is an identical national adoption of ISO 15547-2, 2005
Gives requirements and recommendations for the mechanical design, materials selection, fabrication, inspection, testing, and preparation for shipment of brazed aluminium plate-fin heat exchangers for use in petroleum, petrochemical and natural gas industries.

2.7.4 API Std 663
Hairpin-Type Heat Exchangers | 1st edition 2014

Specifies requirements and gives recommendations for the mechanical design, materials selection, fabrication, inspection, testing, and preparation for shipment of hairpin heat exchangers for use in the petroleum, petrochemical, and natural gas industries. Hairpin heat exchangers include double-pipe and multi-tube type heat exchangers.

2.7.5 API Std 664
Spiral Plate Heat Exchangers | 1st edition2014

Specifies the requirements and gives recommendations for the mechanical design, materials selection, fabrication, inspection, testing, and preparation for shipment of spiral plate heat exchangers for the petroleum, petrochemical, and natural gas industries. It is applicable to standalone spiral plate heat exchangers and those integral with a pressure vessel.

2.7.6 ISO 13706

Petroleum and natural gas industries — Air-cooled heat exchangers | 2011

Gives requirements and recommendations for the design, materials, fabrication, inspection, testing and preparation for shipment of air-cooled heat exchangers for use in the petroleum, petrochemical and natural gas industries.
ISO 13706:2011 is applicable to air-cooled heat exchangers with horizontal bundles, but the basic concepts can also be applied to other configurations.

2.7.7 ISO 16812

Petroleum and natural gas industries — Shell and tube heat exchangers

ISO 16812:2007 specifies requirements and gives recommendations for the mechanical design, material selection, fabrication, inspection, testing and preparation for shipment of shell-and-tube heat exchangers for the petroleum, petrochemical and natural gas industries.

ISO 16812:2007 is applicable to the following types of shell-and-tube heat exchangers: heaters, condensers, coolers and reboilers.

2.7.8 ISO 15547-1

Petroleum, petrochemical and natural gas industries -- Plate-type heat exchangers -- Part 1: Plate-and-frame heat exchangers | 2005

ISO 15547-1:2005 gives requirements and recommendations for the mechanical design, materials selection, fabrication, inspection, testing, and preparation for shipment of plate-and-frame heat exchangers for use in petroleum, petrochemical and natural gas industries. It is applicable to gasketed, semi-welded and welded plate-and-frame heat exchangers.

TEMA stands for “Tubular Exchangers Manufacturers Association” and is a trade association of leading manufacturers of shell and tube heat exchangers, who have pioneered the research and development of heat exchangers for over sixty years. TEMA is recommended standards, based upon sound engineering principles, research and field experience in the manufacturing, design, installation and use of Tubular Exchangers.
There are three classes of mechanical standards in TEMA: “R”, “C”, and “B” which suggest acceptable designs for various service applications.

- TEMA Class “R” designation is for the generally severe requirements of petroleum and related processing applications.
- TEMA Class “B” designation is for chemical process service.
- TEMA Class “C” designation if for the generally moderate requirements of commercial and general process applications, is the least restrictive and most widely used.

While all three classes share good engineering practices, TEMA “R” Class has some noticeable differences.

2.8 Drive train

2.8.1 Electric motor

2.8.1.1 API Std 541

Form-wound squirrel cage induction motors 375 kW and larger, | 5th edition, December 2014

Covers the minimum requirements for all form-wound squirrel-cage induction motors 375 kW and larger for use in petroleum industry services. This standard may be applied to adjustable speed motors and induction generators with appropriate attention to the specific requirements of such applications.

2.8.1.2 API Std 546

Brushless Synchronous Machines—500 kVA and Larger

Covers the minimum requirements for form- and bar-wound brushless synchronous machines in petroleum-related industry service. The standard has been updated to include both synchronous motors and generators with two different rotor designs:

- the conventional salient-pole rotor with solid or laminated poles, and
- the cylindrical rotor with solid or laminated construction.

Also included are new datasheet guides to help clarify the datasheet requirements.

2.8.1.3 API Std 547

General-Purpose Form-Wound Squirrel Cage Induction Motors—250 Horsepower and Larger | 1st edition 2005

Covers the requirements for form-wound induction motors for use in general purpose petroleum, chemical, and other industrial severe duty applications. These motors:

- are rated 250 hp (185 kW) through 3000 hp (2250 kW) for 4, 6, and 8 pole speeds,
- are rated less than 800 hp (600 kW) for two-pole (3000 or 3600 RPM) motors of totally-enclosed construction
- are rated less than 1250 hp (930 kW) for two-pole motors of WP-II type enclosures,
- drive centrifugal loads, drive loads having inertia values within those listed in NEMA MG 1 Part 20,
- are not induction generators.

2.8.1.4 GMRC Guideline electric motor drive equipment

Application guideline for electric motor drive equipment for natural gas compressors | 4th edition 2009

The following guideline addresses the need for practical guidance on electric motor drives for gas compressors. The guideline is directed to issues which are not addressed in detail by the existing Institute of Electrical and Electronics Engineers (IEEE) electric motor standards or American Petroleum Institute(API) compressor standards.

The guideline does not discuss specific electric motor designs because the intent was not to specify how motors should be designed as design standards already exist. The authors intended the following document to be used to educate the users of gas compression equipment who need to know how to specify the electric motor drive system and assure that the system design can support the power and speed range for the application. In the last ten years, electric motor driven compression has become more common in the natural gas industry.

Many of the components of an electric motor drive system have undergone technological changes to meet the needs of gas compressor applications. While many electric drive systems are currently operating successfully, electric motor technologies, variable frequency drives, variable speed gear systems and advanced bearing technologies are still evolving to provide a more efficient drive system with a larger and more flexible operating envelope.
This guideline focuses on the mainstream electric motor technology currently employed for gas compressor applications. Among the most challenging issues for electric driven gas compression are system start-up and method of meeting capacity demands of the pipeline through speed variation. This guideline addresses these issues by providing a description of the various drive train configurations available for variable speed, and the multiple starting methods available to the operator.

The important parameters involved in assessing the motor power and torque curves for the gas compressor operation are also covered. Other influential drivetrain components (bearings, couplings, and shaft design) are discussed. In some areas, it is appropriate to refer the reader to the relevant standards which cover some of these topics more extensively. The guideline also provides guidance on factors affecting motor performance in terms of life, maintenance, reliability and efficiency. In Appendix A-1, basic electric motor definitions and formulas are provided as a reference. The appendix also provides a checklist of the common issues that should be reviewed when designing an electric motor driven compressor station.

2.8.1.5 IEC 60034-1

Rotating electrical machines" — Part 1: Rating and performance | 13th edition 2017

This part of IEC 60034 is applicable to all rotating electrical machines except those covered by other IEC standards, for example, IEC 60349.
Machines within the scope of this document may also be subject to superseding, modifying or additional requirements in other standards, for example, IEC 60079 and IEC 60092.

2.8.1.6 IEC 60079

The International Electrotechnical Commission (IEC) 60079 series (consists of 35 parts) of explosive atmosphere standards covers a wide array of important considerations when it comes to potentially explosive atmospheres. Dealing with general equipment requirements, gas detectors, intrinsically safe equipment, a variety of different methods of equipment protection, and moving on to the classification of areas, material characteristics, and some industry specific standards, the IEC 60079 series is truly expansive.

2.8.1.7 EC 60529

Degrees of protection provided by enclosures IP Code | edition 2.2 2013

IEC 60529 1989 A1 1999 A2 2013 Applies to the classification of degrees of protection provided by enclosures for electrical equipment with a rated voltage not exceeding 72 5 kV.
The object of this standard is to give:

a) Definitions for degrees of protection provided by enclosures of electrical equipment as regards:
   - protection of persons against access to hazardous parts inside the enclosure;
   - protection of the equipment inside the enclosure against ingress of solid foreign objects;
   - protection of the equipment inside the enclosure against harmful effects due to the ingress of water.
b) Designations for these degrees of protection.
c) Requirements for each designation.
d) Tests to be performed to verify that the enclosure meets the requirements of this standard.

It will remain the responsibility of individual technical committees to decide on the extent and manner in which, the classification is used in their standards and to define "enclosure" as it applies to their equipment. However, it is recommended that for a given classification the tests do not differ from those specified in this standard. If necessary, complementary requirements may be included in the relevant product standard. A guide for the details to be specified in relevant product standards is given in annex B.

For a particular type of equipment, a technical committee may specify different requirements provided that at least the same level of safety is ensured.

This standard deals only with enclosures that are in all other respects suitable for their intended use as specified in the relevant product standard and which from the point of view of materials and workmanship ensure that the claimed degrees of protection are maintained under the normal conditions of use.

This standard is also applicable to empty enclosures provided that the general test requirements are met and that the selected degree of protection is suitable for the type of equipment to be protected.

Measures to protect both the enclosure and the equipment inside the enclosure against external influences or conditions such as:

- mechanical impacts;
- corrosion;
- corrosive solvents (for example, cutting liquids);
- fungus;
- vermin;
- solar radiation ;
- icing;
- moisture (for example, produced by condensation);

- explosive atmospheres and the protection against contact with hazardous moving parts external to the enclosure (such as fans), are matters for the relevant product standard to be protected.

2.8.1.8 NFPA 70
National Electrical Code |2017 Edition

The National Electrical Code (NEC), or NFPA 70, is a regionally adoptable standard for the safe installation of electrical wiring and equipment in the United States. It is part of the National Fire Codes series published by the National Fire Protection Association (NFPA), a private trade association. Despite the use of the term "national", it is not a federal law. It is typically adopted by states and municipalities in an effort to standardize their enforcement of safe electrical practices.[2] In some cases, the NEC is amended, altered and may even be rejected in lieu of regional regulations as voted on by local governing bodies.

2.8.1.9 NEMA (National Electrical Manufacturers Association) MG 1-2016
Motors and Generators

The MG 1-2016 is an information Guide for General Purpose Industrial AC Small and Medium Squirrel-Cage Induction Motor Standards.

It assists users in the proper selection and application of motors and generators. Contains practical information concerning performance, safety, testing, and construction and manufacture of ac and dc motors and generators.
The 2016 now includes Part 34: Air-Over Motor Efficiency Test Method. This part is for air over (AO) motors, to operate in and be cooled by the airstream of a fan or blower that is not supplied with the motor and whose primary purpose is providing airflow to an application rather than the primary purpose of cooling the motor.

The standards appearing in this publication have been developed by the Motor and Generator Section and approved for publication as standards of the National Electrical Manufacturers Association. They are intended to assist users in the proper selection and application of motors and generators.

Practical information concerning performance, safety, test, construction, and manufacture of alternating- current and direct-current motors and generators within the product scopes defined in the applicable section or sections of this publication is provided in these standards. Although some definite-purpose motors and generators are included, the standards do not apply to machines such as generators and traction motors for railroads, motors for mining locomotives, arc-welding generators, automotive accessory and toy motors and generators, machines mounted on airborne craft, etc.

2.8.2 Combustion engines

2.8.2.1 ISO 3046-1

Reciprocating internal combustion engines -- Performance -- Part 1: Declarations of power, fuel and lubricating oil consumptions, and test methods -- Additional requirements for engines for general use | 2002

It specifies the requirements for the declaration of power, fuel consumption, lubricating oil consumption and the test method in addition to the basic requirements defined in ISO 15550.

It defines codes for engine brake power in accordance with ISO 15550, in order, where necessary, to simplify the application of the statements of power and to facilitate communication. This applies, e.g., to statements of power used on engine data plates.

It applies to reciprocating internal combustion (RIC) engines for land, rail-traction and marine use and may be applied to engines used to propel road construction and earth-moving machines, industrial trucks as well as for other applications where no suitable International Standard for these engines exists.

2.8.2.2 ISO 15550

Internal combustion engines–Determination and method for the measurement of engine power-- General requirements |2016

It establishes the framework for ISO engine power measurement standards. It specifies standard reference conditions and methods of declaring the power, fuel consumption, lubricating oil consumption and test methods for internal combustion engines in commercial production using liquid or gaseous fuels.
It applies to reciprocating internal combustion engines (spark-ignition or compression-ignition engines) but excluding free piston engines rotary piston engines. These engines may be naturally aspirated or pressure-charged either using a mechanical pressure-charger or turbocharger.
It applies to engines used for land, rail-traction and marine use; the propulsion of automotive vehicles; motorcycles; the propulsion of agricultural tractors and machines; the propulsion of earth-moving machinery; the propulsion of recreational craft or other small marine craft up to 24 m hull length.
It may be applied to engines used to propel road construction machines, industrial trucks and for other applications where no suitable International Standard for these engines exists. It may also be applied to tests performed both on a test bed at a manufacturer's works as well as on site.

2.8.3 Steam turbines

2.8.3.1 API Std 611

General Purpose Steam Turbines for Petroleum, Chemical, and Gas Industry Services |5th edition 2008, reaffirmed in 2014

Covers the minimum requirements for general-purpose steam turbines. These requirements include basic design, materials, related lubrication systems, controls, auxiliary equipment, and accessories.

General-purpose turbines are horizontal or vertical turbines used to drive equipment that is usually spared, is relatively small in size or is in non-critical service.
They are generally used where steam conditions will not exceed a pressure of 48 bar (700 psig) and a temperature of 400C (750F) or where speed will not exceed 6000 rpm. This standard does not cover special-purpose turbines.

2.8.3.2 API Std 612/ISO 10437
Petroleum Petrochemical and Natural Gas Industries—Steam Turbines—Special-Purpose Applications |7th Edition | August 2014

It specifies the minimum requirements for steam turbines for special-purpose applications for use in the petroleum, petrochemical, and natural gas industries. These requirements include basic design, materials, fabrication, inspection testing, and preparation for shipment. It also covers the related lube oil systems, instrumentation, control systems, and auxiliary equipment. It is not applicable to general-purpose steam turbines, which are covered in API Std 611.

2.8.3.3 ISO 10437
Petroleum, petrochemical and natural gas industries – Steam turbines – Special-purpose applications |2003

This standard specifies requirements and gives recommendations for the design, materials, fabrication, inspection, testing and preparation for shipment of special-purpose steam turbines. It also covers the related lube-oil systems, instrumentation, control systems and auxiliary equipment. It is not applicable to general-purpose steam turbines, which are covered in ISO 10436.

2.8.4 Belt drives

2.8.4.1 ISO 1081
Belt Drives - V-Belts and V-Ribbed Belts, and Corresponding Grooved Pulleys - Vocabulary | 3rd edition 1995

This International Standard defines terms relating to V-belt drives, V-belts, hexagonal belts, joined V-belts and the corresponding V-grooved pulleys, V-ribbed belt drives, V-ribbed belts and V-ribbed pulleys, as well as the corresponding symbols.

2.8.4.2 ISO 1813
Belt drives - V-ribbed belts, joined V-belts and V-belts including wide section belts and hexagonal belts - Electrical conductivity of antistatic belts: Characteristics and methods of test | 4th edition 2014

It specifies the maximum electrical resistance of antistatic endless V-ribbed belts, joined V-belts, and single V-belts including wide section belts and hexagonal belts, as well as corresponding production control and individual proof methods of measurements.
The application is limited to new belts intended to be used in an explosive atmosphere or in situations where there is a fire risk. The test is intended to ensure that the belt is sufficiently conductive to dissipate charges of electricity which can form on it in service.

2.8.5 Reduction Gears

2.8.5.1 API Std 613
Special Purpose Gear Units for Petroleum, Chemical and Gas Industry Services (ANSI/API Std 613) | 5th edition 2003, reaffirmed 2007

Covers the minimum requirements for special-purpose, enclosed, precision single- and double-helical one-and two-stage speed increasers and reducers of parallel-shaft design for refinery services. Primarily intended for gear units that are in continuous service without installed spare equipment.

2.8.5.2 API Std 677
General-Purpose Gear Units for Petroleum, Chemical and Gas Industry Services (3rd edition 2006, reaffirmed 2010, includes Errata 1 of 2012)

Covers the minimum requirements for general-purpose, enclosed, single, and multistage gear units incorporating parallel shaft helical and right angle spiral bevel gears for the petroleum, chemical, and gas industries. Gears manufactured according to this standard shall be limited to the following pitch line velocities. Helical gears shall not exceed 60 meters per second (12,000 feet per minute), and spiral bevels shall not exceed 40 meters per second (8,000 feet per minute). Typical applications for which this standard is intended are cooling tower water pump systems, forced and induced draft fan systems, and other general-purpose equipment trains.

2.8.5.3 ISO 13691
Gears —High-speed special-purpose gear units for the petroleum, chemical and gas industries.

This International Standard specifies the minimum requirements for enclosed, precision, single and double helical, one- and two-stage speed increasers and reducers of parallel shaft design with pinion speeds of 3000 min^{-1} or greater, or pitch line velocities of 25 m/s or greater, for special purpose applications. Such applications will typically be required to operate continuously for extended periods, without installed spare equipment and are critical to the continued operation of the installation. By agreement this International Standard may be used for other services.

2.8.6 Couplings

2.8.6.1 API Std 671/ ISO 10441
Special Purpose Couplings for Petroleum, Chemical and Gas Industry Services | 4th edition 2007

This edition of API Std 671 is the identical national adoption of ISO 10441:2007
Special Purpose Couplings for Petroleum, Chemical and Gas Industry Services Specifies the requirements for couplings for the transmission of power between the rotating shafts of two machines in special-purpose applications in the petroleum, petrochemical and natural gas industries. Such applications are typically in large and/or high-speed machines, in services that can be required to operate continuously for extended periods, are often unspared and are critical to the continued operation of the installation. By agreement, it can be used for other applications or services.
Couplings covered are designed to accommodate parallel (or lateral) offset, angular misalignment and axial displacement of the shafts without imposing unacceptable mechanical loading on the coupled machines. It is applicable to gear, metallic flexible element, quill shaft and torsionally resilient type

couplings. Torsional damping and resilient type couplings are detailed in Annex A; gear-type couplings are detailed in Annex B and quill shaft style coupling are detailed in Annex C. Also covers the design, materials of construction, manufacturing quality, inspection and testing special purpose couplings.

2.8.6.2 *ISO 10441*

Petroleum, petrochemical and natural gas industries -- Flexible couplings for mechanical power transmission--Special-purpose applications |2007

ISO 10441-2007 specifies the requirements for couplings for the transmission of power between the rotating shafts of two machines in special-purpose applications in the petroleum, petrochemical and natural gas industries. Such applications are typically in large and/or high-speed machines, in services that can be required to operate continuously for extended periods, are often unspared and are critical to the continued operation of the installation. By agreement, it can be used for other applications or services.

Couplings covered by the standard are designed to accommodate parallel (or lateral) offset, angular misalignment and axial displacement of the shafts without imposing unacceptable mechanical loading on the coupled machines. It is applicable to gear, metallic flexible element, quill shaft and torsionally resilient type couplings.

ISO 10441-2007 covers the design, materials of construction, manufacturing quality, inspection and testing of special-purpose couplings.

ISO 10441-2007 does not define criteria for the selection of coupling types for specific applications.

ISO 10441-2007 is not applicable to other types of couplings, such as clutch, hydraulic, eddy-current, rigid, radial spline, chain and bellows types.

2.8.6.3 *ISO 14691*

Petroleum and natural gas industries — Flexible couplings for mechanical power transmission — General purpose applications | 2008

ISO 14691:2008 specifies the requirements for couplings for the transmission of power between the rotating shafts of two machines for general-purpose applications in the petroleum, petrochemical and natural gas industries. Such applications typically require couplings to transmit power at speeds not exceeding 4000 r/min, between machines in which the first lateral critical speed is above the running speed range (stiff-shaft machines). ISO 14691:2008 can, by agreement, be used for applications outside these limits.

ISO 14691:2008 is applicable to couplings designed to accommodate parallel (or lateral) offset, angular misalignment and axial displacement of the shafts without imposing excessive mechanical loading on the coupled machines. Couplings covered by ISO 14691:2008 include gear (and other mechanical contact types), metallic flexible-element and various elastomeric types. Such couplings can be of all metal construction or can include components of non-metallic materials, such as composites.

ISO 14691:2008 covers design, materials of construction, inspection and testing of couplings and methods of attachment of the coupling to the shafts (including tapered sleeve and other proprietary devices).

ISO 14691:2008 does not apply to special types of couplings, such as clutch, hydraulic, eddy-current, rigid and radial-spline types.

ISO 14691:2008 does not define criteria for the selection of coupling types for specific applications.

2.9 Lubrication

2.9.1 API Std 614, 5th edition 2008 /ISO 10438-1
Lubrication, Shaft-Sealing and Oil-Control Systems and Auxiliaries (ANSI/API Std 614) | 2007 includes Errata 1 of 2008

Covers the minimum requirements for General Purpose and Special Purpose Oil Systems. The standard also includes requirements for Self-acting Gas Seal Support Systems. The standard includes the systems' components, along with the required controls and instrumentation. Chapters included in Std 614 are: 1. General Requirements; 2. Special-purpose Oil Systems; 3. General purpose Oil Systems; and 4. Self-acting Gas Seal Support Systems. This edition of API Std 614 is the identical national adoption of ISO 10438:2007.

2.9.2 ISO 10438-1
Petroleum, petrochemical and natural gas industries -- Lubrication, shaft-sealing and control-oil systems and auxiliaries | 2007

Part 1: General requirements
ISO 10438-1:2007 specifies general requirements for lubrication systems, oil-type shaft-sealing systems, dry-gas face-type shaft-sealing systems and control-oil systems for general- or special-purpose applications. General-purpose applications are limited to lubrication systems. These systems can serve equipment such as compressors, gears, pumps and drivers.
ISO 10438-1:2007 is intended to be used in conjunction with ISO 10438-2, ISO 10438-3 or ISO 10438-4, as appropriate

Part 2: Special-purpose oil systems
ISO 10438-2:2007, in conjunction with ISO 10438-1, specifies requirements for oil systems for special-purpose applications. These oil systems can provide lubrication oil, seal oil or both. These systems can serve equipment such as compressors, gears, pumps and drivers.

Part 3: General-purpose oil systems
ISO 10438-3:2007, in conjunction with ISO 10438-1, specifies requirements for oil systems for general-purpose applications. These oil systems can provide lubrication oil, but not seal oil and can serve equipment such as compressors, gears, pumps and drivers.

Part 4: Self-acting gas seal support systems
ISO 10438-4:2007 in conjunction with ISO 10438-1 specifies requirements for support systems for self-acting gas seals (dry gas seals), for example as described in ISO 10439 and ISO 10440-1. These systems can serve equipment such as compressors, gears, pumps and drivers.

2.10 Operation, Controls and Instrumentation

2.10.1 API RP 1110

Pressure testing of steel pipelines for the transportation of gas, petroleum gas, hazardous liquids, highly volatile or carbon dioxide | 6th edition 2013, reaffirmed: July 2018

Recommended Practice for the Pressure Testing of Steel Pipelines for the Transportation of Gas, Petroleum Gas, Hazardous Liquids, Highly Volatile Liquids, or Carbon Dioxide.
It applies to all parts of a pipeline or pipeline facility including line pipe, pump station piping, terminal piping, compressor station piping, metering station piping, delivery station piping, regulator station piping, appurtenances connected to line pipe, appurtenances connected to facility piping, fabricated assemblies, valves, tees, elbows, reducers, flanges, and any other pipeline equipment or appurtenances. This RP does not apply to pumping units, compressor units, breakout tanks, pressure vessels, control piping, sample piping, instrument piping/tubing, or any component or piping system for which other codes specify pressure testing requirements (i.e. ASME *Boiler and Pressure Vessel Code*, piping systems covered by building codes, etc.). Although this recommended practice (RP) contains guidelines that are based on sound engineering judgment, it is important to note that certain governmental requirements may differ from the guidelines presented
in this document. Nothing in this RP is intended to inhibit the use of engineering solutions that are not covered in this document. This may be particularly applicable where there is innovative developing technology.
Where an alternative is offered, the RP may be used, provided any and all variations from the document are identified and documented. This RP does not address piping systems that are pressure tested with natural gas, nitrogen, or air.

2.10.2 ISO 3511

Industrial process measurement control functions and instrumentation -- Symbolic representation | 1985

Part 1: Basic requirements
Forms one part of four which provide a universal means of communication between the various interests involved in the design, manufacture, installation and operation of measurement and control equipment used in the process industries. This part establishes a symbols system for use in depicting the basic functions. The system has been limited to the identification of instrument functions and does not provide means of illustrating specific instruments. The definitions are used solely for the purpose of application and understanding of the symbol system.

Part 2: Extension of basic requirements
Forms and extension of part 1 which is limited to identification of instrument functions. Includes additional symbols and is intended for the communication of measurement and control functions among instrument specialists and other engineers involved in vessels, piping, layout design and operation. The definitions given in ISO 3511-1 apply equally to this part.

Part 3: Detailed symbols for instruments interconnection diagrams
Forms one part of four and specifies symbols which show, by detailing the components, the external connections between units of equipment. These symbols are not intended to replace the graphic symbols contained in IEC Publication 117. the diagrams may employ single line or multi-line

representation and be combined with, or replaced ty tables, provided clarity is maintained. For further assistance see IEC Publication 113 Part 5, Preparation of interconnection diagrams and tables.

Part 4: Basic symbols for process computer, interface, and shared display/control functions
The symbols in this part shall be considered a supplement to the symbols given in ISO 3511/1 and ISO 3511/2 and used in conjunction with them. The letter code for function identification shall be taken from table 1 of these two parts. The symbols are limited to identification on process flow diagrams, piping and instrument diagrams, etc. and do not provide means of illustrating specific instruments or parts thereof. The application methods are shown in the examples.

2.11 Piping and pipe components

2.11.1 Piping

2.11.1.1 ASME B31 Pressure Piping

B31 Code for pressure piping, developed by American Society of Mechanical Engineers - ASME, covers Power Piping, Fuel Gas Piping, Process Piping, Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids, Refrigeration Piping and Heat Transfer Components and Building Services Piping. ASME B31 was earlier known as ANSI B31. The various parts of the ASM B31 are:

B31.1 Power Piping | 2018
It prescribes minimum requirements for the design, materials, fabrication, erection, test, inspection, operation, and maintenance of piping systems typically found in electric power generating stations, industrial and institutional plants, geothermal heating systems, and central and district heating and cooling systems.
It also covers boiler-external piping for power boilers and high-temperature, high pressure water boilers in which steam or vapor is generated at a pressure of more than 15 psig; and high temperature water is generated at pressures exceeding 160 psig and/or temperatures exceeding 250 degrees F.

ASME B31.1 is one of ASME's most requested codes, widely adopted by jurisdictions worldwide. It is prominently referenced in ASME's Boiler and Pressure Vessel Code, Section I.

This Code serves as a companion to ASME's B31.3 Code on Process Piping as well as to the other codes in ASME's B31 series. Together, they remain essential references for anyone engaged with piping.
Intended for manufacturers, designers, operators and owners of piping systems including, but not limited to, steam, water, oil, gas, and air services, plus all potential governing entities.

B31.2 Fuel Gas Piping |1968
This has been withdrawn as a National Standard and replaced by ANSI/NFPA Z223.1, but B31.2 is still available from ASME and is a good reference for the design of gas piping systems (from the meter to the appliance).

This Code covers the design, fabrication, installation, and testing of piping systems for fuel gases such as natural gas, manufactured gas, liquefied petroleum gas (LPG)-air mixtures above the upper combustible limit, liquefied petroleum gas (LPG) in the gaseous phase, or mixtures of these gases.

Included within the scope of this Code are fuel gas piping systems both in buildings and between buildings, from the outlet of the consumer's meter set assembly (or point of delivery) to and including the first pressure containing valve upstream of the gas utilization device. (See Figure B-1 in Appendix B).

Piping systems within the scope of this Code include all components such as pipe, valves, fittings, flanges (except inlet and outlet flanges that are a part of equipment or apparatus described in Par. 200.1.4), bolting and gaskets. Also included are the pressure containing parts of other components such as expansion joints, strainers and metering devices and piping supporting fixtures and structural attachments.

Piping systems covered by this Code may be used only at pressures permitted by the various limitations contained in this Code. Vacuum piping systems are not covered by this Code. See Subdivision 222.5.

This Code does not apply to:

a) Fuel gas piping systems with metal temperature above 450°F or below −2°F.
b) Fuel gas piping systems in petroleum refineries, loading terminals, natural gas processing plants, bulk plants, compounding plants, or refinery tank farms, etc. within the scope of USAS B31.3.
c) Fuel gas piping in power and atomic energy plants, within the scope of USAS B31.1.
d) Gas gathering, transmission, and distribution piping systems (including compressor stations, metering stations, pressure regulating stations, etc.) for natural, manufactured, or diluted liquefied petroleum gases within the scope of USAS B31.8.
e) Fuel gas piping systems within the scope of USAS Z21.30. (For the convenience of the Code user, the scope of USAS Z21.30-1964 is included in Appendix C.).
f) Piping systems for conveying liquefied petroleum gas (LPG) in the liquid phase nor to containers or storage system for liquefied petroleum gases within the scope of USAS Z106.1.
g) Proprietary items of equipment, apparatus, or instruments, such as compressors, gas generating sets and calorimeters.
h) Design and fabrication of pressure vessels covered by the ASME Boiler and Pressure Vessel Code.
i) Support structures and equipment such a s stanchions, towers, building frames, pressure vessels, mechanical equipment, and foundations.
j) Piping systems for conveying premixed fuel gas-air mixtures which are in the combustible or inflammable limits or range.

B31.3 - Process Piping |2016

ASME B31.3 contains requirements for piping typically found in petroleum refineries; chemical, pharmaceutical, textile, paper, semiconductor, and cryogenic plants; and related processing plants and terminals. It covers materials and components, design, fabrication, assembly, erection, examination, inspection, and testing of piping.

This Code applies to piping for all fluids including:

1) raw, intermediate, and finished chemicals;
2) petroleum products;
3) gas, steam, air and water;
4) fluidized solids;
5) refrigerants; and
6) cryogenic fluids.

Also included is piping that interconnects pieces or stages within a packaged equipment assembly.
Key changes to this revision include:

- Severe Cyclic Conditions.
- MPa Allowable Stresses.
- Expansion Joints.
- Flange Joint Assembly.
- Ultrasonic Examination Acceptance Criteria.
- Category M Fluid Service Examination.
- Leak Testing of Instrument Connections.
- Leak Testing of Vacuum Systems.
- Leak Testing of Insulated Systems.
- Leak Testing of Assembled Piping.

B31.3 is one of ASME's most requested codes. It serves as a companion to ASME's B31.1 Code on Power Piping as well as to the other codes in ASME's B31 series. Together, they remain essential references for anyone engaged with piping.
Careful application of these B31 codes will help users to comply with applicable regulations within their jurisdictions, while achieving the operational, cost and safety benefits to be gained from the many industry best-practices detailed within these volumes.
Intended for manufacturers, users, constructors, designers, and others concerned with the design, fabrication, assembly, erection, examination, inspection, and testing of piping, plus all potential governing entities.

B31.4 Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids |2016
This Code prescribes requirements for the design, materials, construction, assembly, inspection, and testing of piping transporting liquids such as crude oil, condensate, natural gasoline, natural gas liquids, liquefied petroleum gas, carbon dioxide, liquid alcohol, liquid anhydrous ammonia and liquid petroleum products between producers' lease facilities, tank farms, natural gas processing plants, refineries, stations, ammonia plants, terminals (marine, rail and truck) and other delivery and receiving points.
Piping consists of pipe, flanges, bolting, gaskets, valves, relief devices, fittings and the pressure containing parts of other piping components. It also includes hangers and supports, and other equipment items necessary to prevent overstressing the pressure containing parts. It does not include support structures such as frames of buildings, buildings stanchions or foundations.
Requirements for offshore pipelines are found in Chapter IX. Also included within the scope of this Code are:

a) Primary and associated auxiliary liquid petroleum and liquid anhydrous ammonia piping at pipeline terminals (marine, rail and truck), tank farms, pump stations, pressure reducing stations and metering stations, including scraper traps, strainers, and prover loop;
b) Storage and working tanks including pipe-type storage fabricated from pipe and fittings, and piping interconnecting these facilities;
c) Liquid petroleum and liquid anhydrous ammonia piping located on property which has been set aside for such piping within petroleum refinery, natural gasoline, gas processing, ammonia, and bulk plants;
d) Those aspects of operation and maintenance of liquid pipeline systems relating to the safety and protection of the general public, operating company personnel, environment, property and the piping systems.

B31.5 Refrigeration Piping and Heat Transfer Components |2016

This Code prescribes requirements for the materials, design, fabrication, assembly, erection, test, and inspection of refrigerant, heat transfer components, and secondary coolant piping for temperatures as low as -320 deg F (-196 deg C), whether erected on the premises or factory assembled, except as specifically excluded in the following paragraphs.

Users are advised that other piping Code Sections may provide requirements for refrigeration piping in their respective jurisdictions.

This Code shall not apply to:

a) any self- contained or unit systems subject to the requirements of Underwriters Laboratories or other nationally recognized testing laboratory:
b) water piping;
c) piping designed for external or internal gage pressure not exceeding 15 psi (105 kPa) regardless of size; or
d) pressure vessels, compressors, or pumps, but does include all connecting refrigerant and secondary coolant piping starting at the first joint adjacent to such apparatus.

B31.8 Gas Transmission and Distribution Piping Systems |2018

This Code covers the design, fabrication, installation, inspection, and testing of pipeline facilities used for the transportation of gas. This Code also covers safety aspects of the operation and maintenance of those facilities.

This Code is concerned only with certain safety aspects of liquefied petroleum gases when they are vaporized and used as gaseous fuels. All the requirements of NFPA 58 and NFPA 59 and of this Code concerning design, construction, and operation and maintenance of piping facilities shall apply to piping systems handling butane, propane, or mixtures of these gases.

B31.8S Managing System Integrity of Gas Pipelines | 2018

This Standard applies to on-shore pipeline systems constructed with ferrous materials and that transport gas.

Pipeline system means all parts of physical facilities through which gas is transported, including pipe, valves, appurtenances attached to pipe, compressor units, metering stations, regulator stations, delivery stations, holders and fabricated assemblies.

The principles and processes embodied in integrity management are applicable to all pipeline systems. This Standard is specifically designed to provide the operator (as defined in section 13) with the information necessary to develop and implement an effective integrity management program utilizing proven industry practices and processes. The processes and approaches within this Standard are applicable to the entire pipeline system.

B31.9 Building Services Piping | 2017

ASME B31.9 contains rules for the piping in industrial, institutional, commercial, and public buildings, and multi-unit residences, which does not require the range of sizes, pressures, and temperatures covered in B31.1.

ASME B31.9 prescribes requirements for the design, materials, fabrication, installation, inspection, examination, and testing of piping systems for building services. It includes piping systems in the building or within the property limits.

It joins with ASME's many other safety standards governing the building and construction industry, including the A17 series on elevators and escalators; the B30 series on cranes, hoists and lifts; and the A112 series on plumbing.

B31.9 also serves as a companion to ASME's other B31 codes on piping systems. Together, they remain essential references for anyone engaged with piping.
Key changes to this revision include the addition of allowable stresses for (austenitic) stainless steels to TableI-1, and revisions to references in Mandatory Appendix III.
Careful application of these B31 codes will help users to comply with applicable regulations within their jurisdictions, while achieving the operational, cost and safety benefits to be gained from the many industry best-practices detailed within these volumes.
It is intended for designers, owners, regulators, inspectors, and manufacturers of industrial, institutional, commercial, and public building pipelines.

B31.11 Slurry Transportation Piping Systems |2008
Rules for this Code section have been developed considering the needs for applications, which include piping transporting aqueous slurries between plants and terminals, pumping and regulating stations. This Code prescribes requirements for the design, materials, construction, assembly, inspection, testing, operation, and maintenance of piping transporting aqueous slurries of non-hazardous materials, such as coal, mineral ores, concentrates, and other solid materials.

There is a newer edition of this standard available. It is ASME B31.4-2012, Pipeline Transportation Systems for Liquids and Slurries. It is a consolidation and revision of ASME B31.4-2009 and ASME B31.11-2002(R2008).

B31.12 Hydrogen Piping and Pipelines |2014
ASME B31.12 Standard on Hydrogen Piping and Pipelines contains requirements for piping in gaseous and liquid hydrogen service and pipelines in gaseous hydrogen service. The general requirements section covers materials, brazing, welding, heat treating, forming, testing, inspection, examination, operating, and maintenance. The industrial piping section covers requirements for components, design, fabrication, assembly, erection, inspection, examination, and testing of piping. This Code is applicable to piping in gaseous and liquid hydrogen service and to pipelines in gaseous hydrogen service. B31.12 is applicable up to and including the joint connecting the piping to associated pressure vessels and equipment but not to the vessels and equipment themselves. It is also applicable to the location and type of support elements, but not to the structure to which the support elements are attached.
B31.12 is presented in the following parts:

a) Part GR — General Requirements. This part contains definitions and requirements for materials, welding, brazing, heat treating, forming, testing, inspection, examination, operation, and maintenance.
b) Part IP — Industrial Piping. This part includes requirements for components, design, fabrication, assembly, erection, inspection, examination, and testing of piping.
c) Part PL — Pipelines. This part sets forth requirements for components, design, installation, and testing of hydrogen pipelines.

It is required that each part be used in conjunction with the General Requirements section but independent of the other parts. It is not intended that this edition of this Code be applied retroactively to existing hydrogen systems.

2.11.1.2 NFPA 54/ANSI Z223.1
National Fuel Gas Code | 2018

NFPA 54, National Fuel Gas Code provides industry-accepted guidance for the safe installation and operation of fuel gas piping systems, appliances, equipment, and accessories. The 2018 edition includes updates based on recognized risks, recent research, and the techniques, materials, developments, and construction practices in use today. From design to installation, maintenance, and inspection -- no matter what aspect of fuel gas safety your job involves, the latest edition of the National Fuel Gas Code is essential.

2.11.1.3 ISO 15649
Petroleum and natural gas industries – Piping | 2001

This International Standard specifies the requirements for design and construction of piping for the petroleum and natural gas industries, including associated inspection and testing.
This International Standard is applicable to all piping within facilities engaged in the processing or handling of chemical, petroleum, natural gas or related products.
EXAMPLE Petroleum refinery, loading terminal, natural gas processing plant (including liquefied natural gas facilities), offshore oil and gas production platforms, chemical plant, bulk plant, compounding plant, tank farm.
This International Standard is also applicable to packaged equipment piping which interconnects individual pieces or stages of equipment within a packaged equipment assembly for use within facilities engaged in the processing or handling of chemical, petroleum, natural gas or related products.
This International Standard is not applicable to transportation pipelines and associated plant.
EXAMPLE Pipeline pump station, pipeline compressor station, pipeline tank farm, offshore platform risers up to and including pig launching facility.

2.11.1.4 NORSOK L-001
Piping and valves | 2017

This standard was adopted as a NORSOK Standard in January 2017. It replaces the 1999 edition. This standard should be seen in conjunction with other NORSOK standards for design, construction and installation of piping and systems. This fourth edition has, to a large extent, been simplified compared to previous edition. Projects shall develop pipe class sheets and valve data sheets to suit actual conditions, based on guidelines and requirements in this standard. The focus is to establish simple, robust and cost-efficient solutions.
The most frequently used piping classes are given as example sheets in Annex A. Material master sheets are included in Annex B and element datasheets are found in Annex C. Active links to complementary documents such as the NORSOK weldolet guidelines in Annex D and the 2014/68/EU (PED) verification of revision 4 (2017) in Annex E are only available in the electronic version of the standard.

2.11.1.5 NORSOK L-003
Piping details |2017

The piping details was adopted as a NORSOK standard in January 2017. It replaces the 1996 edition of L-CR-003.
The new edition reflects the current industry practices for piping details.
During the revision of the existing document and available industry documents, all details were discussed. Some of the old piping details were combined. Those no longer in use were deleted. Based on present needs, seven new piping details were added.

2.11.1.6 NORSOK P-002
Process system design, Edition 1, August 2014 (the new NORSOK P-002 replaces P-001 and P-100)

This NORSOK (Norwegian Standard) standard provides requirements for the following aspects of topside process piping and equipment design on offshore production facilities:

- design pressure and temperature.
- safety instrumented secondary pressure protection systems line sizing.
- system and equipment isolation insulation and heat tracing.

These criteria are applicable for all processes, process support and utility systems.
Additionally, this NORSOK standard defines the minimum functional requirements for process systems on an offshore installation. The standard includes several recommendations to give additional guidance for the system design.

The following changes have been made to this NORSOK standard:
P-001 and P-100 have been combined into a single document to improve accessibility and remove redundancy. Content has been simplified and some superfluous text has been deleted.
The document has been updated to reflect current industry practice and relevant international standards.
In clause 21.2, the sizing of knock out drum with respect to liquid accumulation, has been made more consistent with international standards. The use of instrumented protection functions to allow for reduced liquid accumulation capacity requires more stringent documentation.

API Std 521, sixth edition issued January 2014 covers acoustic fatigue in piping, sizing of flare knock-out drums, choke valve failure, water hammer and allowance for non-return valves in some depth, so these sections have been removed or edited from this Norsok Standard.

ISO 23251 and ISO 28300 have been classed as Informative in this document as they are similar to API Std 251 (Pressure-Relieving and Depressuring Systems) and API Std 2000 (Venting Atmospheric and Low-Pressure Storage Tanks), which have been recently updated and better reflect current thinking.

For HAZOP studies, the recommendation to use full reporting has been removed. This is seen as being up to the individual company’s standards.
The system numbers used in this NORSOK standard are those defined in NORSOK Z-DP-002.

2.11.2 *Flanges*

2.11.2.1 *ASME B16*
Valves, Flanges, Fittings, and Gaskets

ASME B16 is intended for manufacturers, owners, employers, users and others concerned with the specification, buying, maintenance, training and safe use of valves, flanges, fittings and gaskets with pressure equipment, plus all potential governing entities. Careful application of certain B16 standards can help users comply with important regulations within their jurisdictions, while achieving operational, cost and safety benefits gained from the many industry best-practices covered in these B16 Standards.
ASME B16 has many different parts on valves, flanges, fittings, and gaskets. Even though several of them are not used for reciprocating compressor systems a complete summary of the B16 parts is as follows:

Valves

- B16.10**:** Face-to-Face and End-to-End Dimensions **of** Valves.
- B16.33: Manually Operated Metallic Gas Valves **for** Use in Gas Piping Systems up to **175** psi (Sizes NPS 1/2 through NPS 2).
- B16.34:Valves Flanged, Threaded, and Welding End.
- B16.38: Large Metallic Valves for Gas Distribution: Manually Operated, NPS 2 1/2 (DN 65) to NPS 12 (DN 300), 125 psig (8.6 barg) Maximum.
- B16.40: Manually Operated Thermoplastic Gas Shutoffs and Valves in Gas Distribution Systems.
- B16.44: Manually Operated Metallic Gas Valves for Use in Above Ground Piping Systems up to 5 psi.

Flanges

- B16.5: Pipe Flanges and Flanged Fittings: NPS 1/2 through NPS 24 Metric/Inch Standard.
- B16.36: Orifice Flanges.
- B16.47: Large Diameter Steel Flanges: NPS 26 through NPS 60 Metric/Inch Standard.
- B16.48: Line Blanks.

The most applied part for flanges of reciprocating compressor systems is the ASME B16.5 (Pipe Flanges and Flanged Fittings: NPS 1/2 through NPS 24 Metric/Inch Standard) of which the scope is as follows:

This Standard covers pressure–temperature ratings, materials, dimensions, tolerances, marking, testing, and methods of designating openings for pipe flanges and flanged fittings. Included are:

1. flanges with rating class designations 150, 300, 400, 600, 900, and 1500 in sizes NPS 1/2 through NPS 24 and flanges with rating class designation 2500 in sizes NPS 1/2 through NPS 12, with requirements given in both metric and U.S. Customary units with diameter of bolts and flange bolt holes expressed in inch units
2. flanged fittings with rating class designation 150 and 300 in sizes NPS 1/2 through NPS 24, with requirements given in both metric and U.S. Customary units with diameter of bolts and flange bolt holes expressed in inch units (3) flanged fittings with rating class designation 400, 600, 900, and 1500 in sizes NPS 1/2 through NPS 24 and flanged fittings with rating class designation 2500 in sizes 1/2 through NPS 12 that are acknowledged in Nonmandatory Appendix E in which only U.S. Customary units are provided.

This Standard is to be used in conjunction with equipment described in other volumes of the ASME B16 Series of Standards as well as with other ASME standards, such as the Boiler and Pressure Vessel Code and the B31 Piping Code

Fittings

- B16.1: Grey Iron Pipe Flanges and Flanged Fittings: Classes 25, 125, and 250**.**
- B16.3: Malleable Iron Threaded Fittings: Classes 150 and 300.
- B16.4: Grey Iron Threaded Fittings: Classes 125 and 250.
- B16.9: Factory Made Wrought Buttwelding Fittings.
- B16.11: Forged Fittings, Socket-Welding and Threaded.
- B16.12: Cast Iron Threaded Drainage Fittings.
- B16.14: Ferrous Pipe Plugs, Bushings, and Locknuts with Pipe Threads.
- B16.15: Cast Copper Alloy Threaded Fittings: Classes 125 and 250.
- B16.18: Cast Copper Alloy Solder Joint Pressure Fittings.
- B16.22: Wrought Copper and Copper Alloy Solder- Joint Pressure Fittings.
- B16.23: Cast Copper Alloy Solder Joint Drainage Fittings: DWV.
- B16.24: Cast Copper Alloy Pipe Flanges, Flanged Fittings, and Valves: Classes 150, 300, 600, 900, 1500, and 2500.
- B16.25: Buttwelding Ends.
- B16.26: Cast Copper Alloy Fittings for Flared Copper Tubes.
- B16.29: Wrought Copper and Wrought Copper Alloy Solder-Joint Drainage Fittings-DWV.
- B16.39: Malleable Iron Threaded Pipe Unions: Classes 150, 250, and 300.
- B16.42: Ductile Iron Pipe Flanges and Flanged Fittings: Classes 150 and 300.
- B16.49: Factory-Made, Wrought Steel, Buttwelding Induction Bends for Transportation and Distribution Systems.
- B16.50: Wrought Copper and Copper Alloy Braze- Joint Pressure Fittings.
- B16.51: Copper and Copper Alloy Press-Connect Pressure Fittings.

Gaskets

- B16.20 Metallic Gaskets for Pipe Flanges.
- B16.21 Non-metallic Flat Gaskets for Pipe Flanges.

2.11.2.2 ISO 7005
Pipe flanges

This standards consists of three parts as follows:

Part 1: Steel flanges for industrial and general service piping systems (2011 (this standard was last reviewed and confirmed in 2017, therefore this version remains current)
This part establishes a base specification for pipe flanges suitable for general purpose and industrial applications including, but not limited to, chemical process industries, electric power generating industries, petroleum and natural gas industries. It places responsibility for the selection of a flange series with the purchaser.

It is applicable to flanges within facilities engaged in the processing or handling of a wide variety of fluids, including steam, pressurized water and chemical, petroleum, natural gas or related products.

ISO 7005-1:2011 is also applicable to packaged equipment piping, which interconnects individual pieces or stages of equipment within a packaged equipment assembly for use within facilities engaged in the processing or handling of a variety of fluids, including steam and chemical, petroleum, natural gas or related products.

Part 2: Cast iron flanges: 1998 (this standard was last reviewed and confirmed in 2018 Therefore this version remains current.)
This part, together with parts 1 and 3, cancels and replaces ISO 2084:1974, ISO 2229:1973 and ISO 2441:1975. Specifies requirements for circular grey, malleable and ductile cast iron flanges of series 1 and 2. Annex A (guidance on tolerances on dimensions) and B (bibliography) are for information only.

Part 3: Copper alloy and composite flanges: 1998 (this standard was last reviewed and confirmed in 2014, therefore this version remains current)
This part specifies requirements for circular flanges of series 1 and 2. It also specifies the types of flanges and their facings, dimensions, tolerances, bolt sizes (including copper alloy), flange face surface finish, marking, testing, inspection and materials. An annex includes application and installation.

2.11.3 Valves

2.11.3.1 API RP 553

Refinery Valves and Accessories for Control and Safety Instrumented Systems | 2nd edition 2012

Addresses the special needs of automated valves in refinery services. The knowledge and experience of the industry has been captured to provide proven solutions to well-known problems. This document provides recommended criteria for the selection, specification, and application of piston (i.e. double-acting and spring-return) and diaphragm-actuated (spring-return) control valves. Control valve design considerations are outlined such as valve selection, material selection, flow characteristic evaluation, and valve accessories. It also discusses control valve sizing, fugitive emissions, and consideration of the effects of flashing, cavitation,
and noise. Recommendations for emergency block and vent valves, on/off
valves intended for safety instrumented systems, and special design valves for refinery services, such as Fluid Catalytic Cracking Unit (FCCU) slide valves and vapor depressurizing systems, are also included in this recommended practice.

Page 98-100 from gives the following summary:

- Std 594 Check valves.
- Std 598 Valve inspection and testing.
- Std 599 Metal plug valves.
- Std 600 Steel gates valves.
- Std 602 Gate, globe, and check valves DN 100 and smaller for the Petroleum and natural gas industries.
- Std 603 Corrosion resistant bolted bonnet gate valves.
- Std 608 Metal ball valves-flanged, threaded and welding ends.
- Std 609 Butterfly valves: double-flanged, lug and wafer type.
- Std 615 Valve selection guide.
- Std, 623 Steel globe valves -flanged and butt-welding ends, bolted bonnets.
- Std 624 Type testing of rising steam valves equipped with flexible graphite packing for fugitive emissions.

2.11.3.2 API 594
Check Valves: Flanged, Lug, Wafer, and Butt-Welding | 7th edition 2010

This standards covers design, materials, face-to-face dimensions, pressure-temperature ratings, and examination, inspection, and test requirements for two types of check valves:

Type "A" check valves
These are short face-to-face and can be: wafer, lug, or double flanged; single plate or dual plate; grey iron, ductile iron, steel, nickel alloy, or other alloy designed for installation as follows:

- between Classes 125 and 250 cast iron flanges as specified in ASME B16.1;
- between Classes 150 and 300; ductile iron flanges as specified in ASME B16.42;
- between Classes 150 and 2500 steel flanges as specified in ASME B16.5, and
- between Classes 150 and 600 steel pipeline flanges as specified in MSS SP-44 or steel flanges as specified in ASME B16.47.

Type "B" bolted cover swing check valves
These are long face-to-face and can be: flanged or buttwelding ends of steel, nickel alloy, or other alloy material. End flanges shall be as specified in ASME B16.5 or ends shall be butt-welding as specified in ASME B16.25.

2.11.3.3 API Std 520
Sizing, Selection, and Installation of Pressure-Relieving Devices

Part I—Sizing and Selection
Applies to the sizing and selection of pressure relief devices used in refineries and related industries for equipment that has a maximum allowable working pressure of 15 psig (103 kPag) or greater. The pressure relief devices covered in this standard are intended to protect unfired pressure vessels and related equipment against overpressure from operating and fire contingencies.
This standard includes basic definitions and information about the operational characteristics and applications of various pressure relief devices. It also includes sizing procedures and methods based on steady state flow of Newtonian fluids. Atmospheric and low-pressure storage tanks covered in API Std 2000 and pressure vessels used for the transportation of products in bulk or shipping containers are not within the scope of this standard. See API Std 521 for information about appropriate ways of reducing pressure and restricting heat input. The rules for overpressure protection of fired vessels are provided in ASME Section I and ASME B31.1 and are not within the scope of this standard.

Part II—Installation
Covers the methods of installation for pressure relief devices for equipment
that has a maximum allowable working pressure (MAWP) of 15 psig (1.03 bar g) or greater. Pressure relief valves or rupture disks may be used independently or in combination with each other to provide the required protection against excessive pressure accumulation. The term "pressure relief valve" includes safety relief valves used in either compressible or incompressible fluid service, and relief valves used in incompressible fluid service. Covers gas, vapor, steam, and incompressible fluid service.

2.11.3.4 API Std 521
Pressure-Relieving and Depressuring Systems | 6th edition 2014

Applies to pressure relieving and vapor depressuring systems. Although intended for use primarily in oil refineries, it is also applicable to petrochemical facilities, gas plants, liquefied natural gas (LNG) facilities, and oil and gas production facilities. The information provided is designed to aid in the selection of the system that is most appropriate for the risks and circumstances involved in various installations. This standard specifies requirements and gives guidelines for the following:

- examining the principal causes of overpressure;
- determining individual relieving rates;
- selecting and designing disposal systems, including such component parts as piping, vessels, flares, and vent stacks.

This standard does not apply to direct-fired steam boilers.

2.11.4 Pressure relief and flare systems

2.11.4.1 API Std 520
Sizing, Selection, and Installation of Pressure-Relieving Devices

Part I—Sizing and Selection, 9th Edition, July 2014
Applies to the sizing and selection of pressure relief devices used in refineries and related industries for equipment that has a maximum allowable working pressure of 15 psig (103 kPag) or greater. The pressure relief devices covered in this standard are intended to protect unfired pressure vessels and related equipment against overpressure from operating and fire contingencies.
This standard includes basic definitions and information about the operational characteristics and applications of various pressure relief devices. It also includes sizing procedures and methods based on steady state flow of Newtonian fluids. Atmospheric and low-pressure storage tanks covered in API Std 2000 and pressure vessels used for the transportation of products in bulk or shipping containers are not within the scope of this standard. See Std 521 for information about appropriate ways of reducing pressure and restricting heat input. The rules for overpressure protection of fired vessels are provided in ASME Section I and ASME B31.1 and are not within the scope of this standard.

Part II—Installation, 6th Edition, March 2015
Covers the methods of installation for pressure relief devices for equipment that has a maximum allowable working pressure (MAWP) of 15 psig (1.03 bar g) or greater. Pressure relief valves or rupture disks may be used independently or in combination with each other to provide the required protection against excessive pressure accumulation. The term “pressure relief valve” includes safety relief valves used in either compressible or incompressible fluid service, and relief valves used in incompressible fluid service. Covers gas, vapor, steam, and incompressible fluid service.

2.11.4.2 API standard 521
Pressure-relieving and Depressuring Systems | sixth edition, January 2014

The portions of this standard dealing with flares and flare systems are an adjunct to API Standard 537, which addresses mechanical design, operation, and maintenance of flare equipment. It is important for all parties involved in the design and use of a flare system to have an effective means of

communicating and preserving design information about the flare system. To this end, API has developed a set of flare datasheets, which can be found in API 537, Appendix E. The use of these datasheets is both recommended and encouraged as a concise, uniform means of recording and communicating design information.
The Bibliography lists the documents that are referenced informatively in this standard, as well as other documents not cited in this standard, but which contain additional useful information. Some of the content of the documents listed might not be suitable for all applications and therefore needs to be assessed for each application before use.

This standard is applicable to pressure-relieving and vapor depressuring systems. Although intended for use primarily in oil refineries, it is also applicable to petrochemical facilities, gas plants, liquefied natural gas (LNG) facilities, and oil and gas production facilities. The information provided is designed to aid in the selection of the system that is most appropriate for the risks and circumstances involved in various installations.
This standard specifies requirements and gives guidelines for the following:

- examining the principal causes of overpressure;
- determining individual relieving rates;
- selecting and designing disposal systems, including such component parts as piping, vessels, flares, and vent stacks.

This standard does not apply to direct-fired steam boilers.

2.11.4.3 API Std 526
Flanged Steel Pressure-Relief Valves | 6th edition 2009 (includes Errata 1 dated 2009 and Errata 2 dated 2012)

Purchase specification for flanged steel pressure-relief valves. Basic requirements are given for direct spring-loaded pressure-relief valves and pilot-operated pressure-relief valves as follows:

- orifice designation and area;
- valve size and pressure rating, inlet and outlet;
- materials;
- pressure-temperature limits;
- center-to-face dimensions, inlet and outlet.

2.11.4.4 API Std 527
Seat Tightness of Pressure Relief Valves | 4th edition 2014

Describes methods of determining the seat tightness of metal- and soft seated pressure relief valves, including those of conventional, bellows, and pilot-operated designs.
The maximum acceptable leakage rates are defined for pressure relief valves with set pressures from 103 kPa gauge (15 psig) to 41,379 kPa gauge (6,000 psig). If greater seat tightness is required, the purchaser shall specify it in the purchase order.
The test medium for determining the seat tightness—air, steam, or water— shall be the same as that used for determining the set pressure of the valve.
For dual-service valves, the test medium—air, steam, or water—shall be the same as the primary relieving medium.
To ensure safety, the procedures outlined in this standard shall be performed by persons experienced in the use and functions of pressure relief valves.

2.11.4.5 API Std 537/ISO 25457

Flare Details for General Refinery and Petrochemical Service | 2008 (This edition of API Std 537 is the identical national adoption of ISO 25457:2)

It specifies requirements and provides guidance for the selection, design, specification, operation and maintenance of flares and related combustion and mechanical components used in pressure-relieving and vapor depressurizing systems for the petroleum, petrochemical, and natural gas industries. Although this standard is primarily intended for new flares and related equipment, it is also possible to use it to evaluate existing flare facilities.

2.11.4.6 ISO 23251

Petroleum, petrochemical and natural gas industries -- Pressure-relieving and depressuring systems | 2006

Is applicable to pressure-relieving and vapour depressuring systems. Although intended for use primarily in oil refineries, it is also applicable to petrochemical facilities, gas plants, liquefied natural gas (LNG) facilities and oil and gas production facilities. The information provided is designed to aid in the selection of the system that is most appropriate for the risks and circumstances involved in various installations.
It is intended to supplement the practices set forth in ISO 4126 or API RP 520-1 for establishing a basis of design.
It specifies requirements and gives guidelines for examining the principal causes of overpressure; and determining individual relieving rates; and selecting and designing disposal systems, including such component parts as piping, vessels, flares, and vent stacks.
It does not apply to direct-fired steam boilers.

2.11.4.7 ISO 28300

Petroleum, petrochemical and natural gas industries -- Venting of atmospheric and low-pressure storage tanks |2008

This standard was last reviewed and confirmed in 2018. Therefore, this version remains current.
It covers the normal and emergency vapour venting requirements for aboveground liquid petroleum or petroleum products storage tanks and aboveground and underground refrigerated storage tanks designed as atmospheric storage tanks or low-pressure storage tanks. Discussed in ISO 28300:2008 are the causes of overpressure and vacuum; determination of venting requirements; means of venting; selection, and installation of venting devices; and testing and marking of relief devices.
It is intended for tanks containing petroleum and petroleum products, but it can also be applied to tanks containing other liquids; however, it is necessary to use sound engineering analysis and judgment whenever this standard is applied to other liquids.
ISO 28300:2008 does not apply to external floating-roof tanks.

2.11.5 Material & coatings

2.11.5.1 *API RP 578*

Material Verification Program for New and Existing Alloy Piping Systems | 2nd edition 2010

Provides the guidelines for a material and quality assurance system to verify that the nominal composition of alloy components within the pressure envelope of a piping system is consistent with the selected or specified construction materials to minimize the potential for catastrophic release of toxic or hazardous liquids or vapours.
This RP provides the guidelines for material control and material verification programs on ferrous and nonferrous alloys during the construction, installation, maintenance, and inspection of new and existing process piping systems covered by the ASME B31.3 and API 570 piping codes. This RP applies to metallic alloy materials purchased for use either directly by the owner/user or indirectly through vendors, fabricators, or contractors and includes the supply, fabrication, and erection of these materials. Carbon steel components specified in new or existing piping systems are not specifically covered under the scope of this document unless minor/trace alloying elements are critical to component corrosion resistance or similar degradation.

2.11.5.2 *EN 13480-3*

Metallic industrial piping | 2017

It specifies the requirements for materials (including metallic clad materials) for industrial piping and supports covered by EN 13480-1 manufactured from of metallic materials. It is currently limited to steels with sufficient ductility. This Part of this European Standard is not applicable to materials in the creep range.
This is a multi-part document divided into the following parts:

- Part 1 Metallic industrial piping. General.
- Part 2 Metallic industrial piping. Materials.
- Part 3 Metallic industrial piping. Design and calculation.
- Part 4 Metallic industrial piping. Fabrication and installation.
- Part 5 Metallic industrial piping. Inspection and testing.
- Part 6 Metallic industrial piping. Additional requirements for buried piping.
- Part 8 Metallic industrial piping. Additional requirements for aluminium and aluminium alloy piping.

2.11.5.3 *ISO 15156-1*

Petroleum and natural gas industries -- Materials for use in H2S-containing environments in oil and gas production |2015

Part 1: General principles for selection of cracking-resistant materials
It describes general principles and gives requirements and recommendations for the selection and qualification of metallic materials for service in equipment used in oil and gas production and in natural-gas sweetening plants in H2S-containing environments, where the failure of such equipment can pose a risk to the health and safety of the public and personnel or to the environment. It can be

applied to help to avoid costly corrosion damage to the equipment itself. It supplements, but does not replace, the materials requirements given in the appropriate design codes, standards, or regulations.

It addresses all mechanisms of cracking that can be caused by H2S, including sulphide stress cracking, stress corrosion cracking, hydrogen-induced cracking and stepwise cracking, stress-oriented hydrogen-induced cracking, soft zone cracking, and galvanically induced hydrogen stress cracking.

Table 1 provides a non-exhaustive list of equipment to which this part of ISO 15156 is applicable, including permitted exclusions.

It applies to the qualification and selection of materials for equipment designed and constructed using load-controlled design methods. For design utilizing strain-based design methods, see Clause 5.

Is not necessarily applicable to equipment used in refining or downstream processes and equipment.

Part 2: Cracking-resistant carbon and low-alloy steels, and the use of cast irons
This part gives requirements and recommendations for the selection and qualification of carbon and low-alloy steels for service in equipment used in oil and natural gas production and natural gas treatment plants in H2S-containing environments, whose failure can pose a risk to the health and safety of the public and personnel or to the environment. It can be applied to help to avoid costly corrosion damage to the equipment itself. It supplements, but does not replace, the materials requirements of the appropriate design codes, standards or regulations.
It addresses the resistance of these steels to damage that can be caused by sulphide stress-cracking (SSC) and the related phenomena of stress-oriented hydrogen-induced cracking (SOHIC) and soft-zone cracking (SZC).
It also addresses the resistance of these steels to hydrogen-induced cracking (HIC) and its possible development into stepwise cracking (SWC).
This part is concerned only with cracking. Loss of material by general (mass loss) or localized corrosion is not addressed.
Table 1 provides a non-exhaustive list of equipment to which this part of ISO 15156 is applicable, including permitted exclusions.
It applies to the qualification and selection of materials for equipment designed and constructed using load-controlled design methods. For design utilizing strain-based design methods, see ISO 15156-1:2015, Clause 5.
Annex A lists SSC-resistant carbon and low alloy steels, and A.2.4 includes requirements for the use of cast irons.
This part is not necessarily suitable for application to equipment used in refining or downstream processes and equipment.

Part 3: Cracking-resistant CRAs (corrosion-resistant alloys) and other alloys
This part gives requirements and recommendations for the selection and qualification of CRAs (corrosion-resistant alloys) and other alloys for service in equipment used in oil and natural gas production and natural gas treatment plants in H2S-containing environments whose failure can pose a risk to the health and safety of the public and personnel or to the environment. It can be applied to help avoid costly corrosion damage to the equipment itself. It supplements, but does not replace, the materials requirements of the appropriate design codes, standards, or regulations.
It addresses the resistance of these materials to damage that can be caused by sulphide stress-cracking (SSC), stress-corrosion cracking (SCC), and galvanically induced hydrogen stress cracking (GHSC).

It is concerned only with cracking. Loss of material by general (mass loss) or localized corrosion is not addressed.

Table 1 provides a non-exhaustive list of equipment to which this part of ISO 15156 is applicable, including permitted exclusions.
It applies to the qualification and selection of materials for equipment designed and constructed using load-controlled design methods. For design utilizing strain-based design methods, see ISO 15156-1:2015, Clause 5.
It is not necessarily suitable for application to equipment used in refining or downstream processes and equipment.

2.11.5.4 NORSOK M-501
Surface preparation and protective coating | 6th edition 2012

This NORSOK standard gives the requirements for the selection of coating materials, surface preparation, application procedures and inspection for protective coatings to be applied during the construction and installation of offshore installations and associated facilities.
This NORSOK standard cover paints, metallic coatings and application of spray-on passive fire protective coatings.
The aim of this NORSOK standard is to obtain a coating system, which ensures optimal protection of the installation with a minimum need for maintenance that the coating system is maintenance friendly that the coating system is application friendly that health, safety and environmental impacts are evaluated and documented.
This NORSOK standard is not applicable to pipelines and pipeline risers.
The main changes included in this edition are that the content of a paint report and an example of such is included additional requirements for surface protection of valves actuators, gearboxes, pumps and motors are implemented requirements for reinforcement and anchoring of sprayed fire protecting with fibre mesh are given requirements for subsea coatings at higher temperature than 50 °C is given IMO MSC215(82) classification testing has been accepted as an alternative qualification method for ballast water tank coatings (coating system no. 3B) more detailed specification of what to include in the coating procedure specification is given a time limit for the validity of the coating procedure test is specified coating system numbering is made more detailed for system no. 6 and system no. 7 polyester based powder coating is included as an alternative on top of hot dipped galvanized steel and aluminium based structure coating system for subsea is split into three categories.

2.11.5.5 NORSOK R-004
Piping and equipment insulation | 3rd edition 2006

This NORSOK standard covers the minimum requirements for thermal, acoustic, personnel protection, fire protection and pipe penetration insulation of pipe work, equipment, vessels, tanks, valves, flanges etc. for offshore/onshore installations and not for sub-sea installation. It does not cover refractory or insulation of heating, ventilation and air conditioning (HVAC) related items.
This edition is updated and partly rewritten based on industry experience over the last years. A new clause is added on piping penetrations and qualification of new products. Test requirements for acoustic insulation have been updated in accordance with ISO 15665. Thickness tables for insulation classes have been deleted in this edition.

2.11.6 Welding

2.11.6.1 API RP 577
Welding Processes, Inspection, and Metallurgy | 2nd edition 2013

It provides guidance to the API authorized inspector on welding inspection as encountered with fabrication and repair of refinery and chemical plant equipment and piping. Common welding processes, welding procedures, welder qualifications, metallurgical effects from welding, and inspection techniques are described to aid the inspector in fulfilling their role implementing API 510, API 570, Std 653 and RP 582. The level of learning and training obtained from this document is not a replacement for the training and experience required to be an American Welding Society (AWS) Certified Welding Inspector (CWI).

2.11.6.2 API RP 582
Welding Guidelines for the Chemical, Oil, and Gas Industries | 2nd edition 2009

It provides supplementary guidelines and practices for welding and welding related topics for shop and field fabrication, repair, and modification of the following:

- pressure-containing equipment, such as pressure vessels, heat exchangers, piping, heater tubes, and pressure boundaries of rotating equipment and attachments welded thereto;
- tanks and attachments welded thereto;
- non- removable internals for process equipment;
- structural items attached and related to process equipment;
- other equipment or component items, when referenced by an applicable purchase document.

This document is general in nature and augments the welding requirements of ASME *BPVC* Section IX and similar codes, standards, specifications, and practices, such as those listed in Section 2. The intent of this document is to be inclusive of chemical, oil, and gas industry standards, although there are many areas not covered herein, e.g. pipeline welding and offshore structural welding are intentionally not covered. This document is based on industry experience and any restrictions or limitations may be waived or augmented by the purchaser.

2.11.6.3 ASME IX
ASME Boiler and Pressure Vessel Code, Section IX: Welding and Brazing Qualifications | 2019

This Section contains rules relating to the qualification of welding, brazing, and fusing procedures as required by other BPVC Sections for component manufacture. It also covers rules relating to the qualification and requalification of welders, brazers, and welding, brazing and fusing machine operators in order that they may perform welding, brazing, or plastic fusing as required by other BPVC Sections in the manufacture of components. Welding, brazing, and fusing data cover essential and nonessential variables specific to the joining process used.

Careful application of this Section will help users to comply with applicable regulations within their jurisdictions, while achieving the operational, cost and safety benefits to be gained from the many industry best-practices detailed within these volumes.

It is intended for manufacturers, users, constructors, designers and others concerned with the design, fabrication, assembly, erection, examination, inspection and testing of pressure vessels, plus all potential governing entities.

2.11.6.4 API RP 582
Welding Guidelines for the Chemical, Oil, and Gas Industries | 2009

Provides supplementary guidelines and practices for welding and welding related topics for shop and field fabrication, repair, and modification of the following:
pressure-containing equipment, such as pressure vessels, heat exchangers, piping, heater tubes, and pressure boundaries of rotating equipment and attachments welded thereto;

- tanks and attachments welded thereto;
- nonremovable internals for process equipment;
- structural items attached and related to process equipment; other equipment or component items, when referenced by an applicable purchase document.

This document is general in nature and augments the welding requirements of ASME *BPVC* Section IX and similar codes, standards, specifications, and practices, such as those listed in Section 2. The intent of this document is to be inclusive of chemical, oil, and gas industry standards, although there are many areas not covered herein, e.g. pipeline welding and offshore structural welding are intentionally not covered. This document is based on industry experience and any restrictions or limitations may be waived or augmented by the purchaser.

2.11.6.5 API 1104
Welding of Pipelines and Related Facilities| 21st edition 2013 (Includes Errata 1 through 5 and addendum 1 (2014) and addendum 2 (2016)

This standard covers the gas and arc welding of butt, fillet, and socket welds in carbon and low-alloy steel piping used in the compression, pumping, and transmission of crude petroleum, petroleum products, fuel gases, carbon dioxide, and nitrogen and, where applicable, covers welding on distribution systems. It applies to both new construction and in-service welding.
The welding may be done by a shielded metal-arc welding, submerged arc welding, gas tungsten-arc welding, gas metal-arc welding, flux-cored arc welding, plasma arc welding, oxyacetylene welding, or flash butt welding process or by a combination of these processes using a manual, semiautomatic, or automatic welding technique or a combination of these techniques. The welds may be produced by position or roll welding or by a combination of position and roll welding.

This standard also covers the procedures for radiographic, magnetic particle, liquid penetrant, and ultrasonic testing as well as the acceptance standards to be applied to production welds tested to destruction or inspected by radiographic, magnetic particle, liquid penetrant, ultrasonic, and visual testing methods. The values stated in either inch-pound units or SI units are to be regarded separately as standard. Each system is to be used independently of the other, without combining values in any way.
Processes other than those described above will be considered for inclusion in this standard. Persons who wish to have other processes included shall submit, as a minimum, the following information for the committee's consideration:

- A description of the welding process.
- A proposal on the essential variables.
- A welding procedure specification.
- Weld inspection methods.

- Types of weld imperfections and their proposed acceptance limits.
- Repair procedures.

It is intended that all work performed in accordance with this standard shall meet or exceed the requirements of this standard.

2.11.6.6 The American Welding Society (AWS)

This society has published over 241 AWS-developed codes, recommended practices and guides which are written in accordance with American National Standards Institute (ANSI) practices. The following parts may be of interest for the reciprocating industry:

AWS A2.4	Standard symbols for welding, brazing, and non-destructive examination
AWS A3.0	Standard welding terms and definitions
AWS A5.1	Specification for carbon steel electrodes for shielded metal arc welding
AWS A5.18	Specification for carbon steel electrodes and rods for gas shielded arc welding
AWS B2.1	Specification for Welding Procedure and Performance Qualification
AWS B1.10	Guide for the non-destructive examination of welds
AWS D1.1	Structural welding (steel)
AWS D1.2	Structural welding (aluminium)
AWS D1.3	Structural welding (sheet steel)
AWS D1.4	Structural welding (reinforcing steel)
AWS D1.6	Structural welding (stainless steel)
AWS D1.7	Structural welding (strengthening and repair)
AWS D1.9	Structural welding (titanium)
AWS D10.10	Heating practices for pipe and tube
AWS D10.11	Root pass welding for pipe
AWS D10.12	Pipe welding (mild steel)
AWS D10.13	Tube brazing (copper)
AWS D10.18	Pipe welding (stainless steel)
AWS D11.2	Welding (cast iron)
AWS D14.4	Machinery joint welding

2.11.6.7 NORSOK M-601
Welding and Inspection of piping | 2016

This standard covers additional and optional technical requirements to ASME B31.3 for welding and weld inspection of piping systems in material types carbon steel with SMYS $\leq$ 360 MPa, SS type 316, type 6Mo, type 565, type 22Cr duplex and type 25Cr duplex, titanium grade 2 and copper-nickel alloys. This NORSOK standard supersedes M-601 from 2008.

The materials shall be selected and specified in accordance with piping class sheets included in NORSOK L-001. That means that this standard covers piping systems with nominal outside diameter greater than 20 mm and wall thickness ranging from 2,5 mm and above.
The standard applies to all welding and weld inspection of piping fabrication at all stages from prefabrication, through module or skid mounted unit assembly, site and field installation and modification work during operation.

2.11.6.8 NEN-EN-ISO 17637
Non-destructive testing of welds. Visual testing of fusion-welded joints | 2017

NEN-EN-ISO 17637 specifies the visual testing of fusion welds in metallic materials. It may also be applied to visual testing of the joint prior to welding.
The subjects which are discussed are: welded joints, Fusion welding, Welding, Repair, Visual inspection (testing), Non-destructive testing, Inspection, Test equipment, Gauges, Working range, Accuracy, Angles (geometry), Testing conditions

2.11.7 Small Bore Connections and Thermowells

2.11.7.1 AVIFF Energy Institute
Guidelines for the avoidance of vibration induced fatigue failure | 2008

This document provides a public domain methodology to help minimise the risk of vibration induced fatigue of process piping. It is intended for use by engineers with nu prerequisite knowledge of vibration. Pipework vibration is only superficially covered buy standard design codes, and hence awareness of the problem among plant designers and operators is limited. (e.g. B31.1).
These guidelines can be used to asses (i) a new design, (ii) an existing plant, (iii) a change to an existing plant and (iv) and a potential problem that has been identified on an operating systems. They therefore offer a proactive approach to pipework vibration issues. This is in contrast to the highly reactive approach traditionally employed when vibration problems arise, e.g. during the commissioning or when operational changes are made.

These guidelines provide a staged approach. Initially, a qualitative assessment is undertaken to (i) identify the potential excitation mechanisms that may exists and (ii) provide a means of rank ordering a number of process systems or units in order to prioritise the subsequent assessment. A quantitative assessment is than undertaken on the higher risk areas to determine the likelihood of a vibration induced piping failure.
Details of on-site inspection and measurements survey techniques are provided to help refine the quantitative assessment for an as-built system. To reduce the risk to an acceptable level, example corrective actions are outlined.

It is recognised that there will always be some cases where the type of excitation or complexity response is outside the scope of these guidelines. In such cases specialist advice should be sought.

2.11.7.2 *GMRC Guideline Small Diameter Branch Connections*

Design guideline for small diameter branch connections | 1st edition, 2011

Vibration of piping due to mechanical excitation is present in nearly any environment where small diameter branch connections (BCs) are used. In initial piping designs, small diameter connections are often overlooked and not considered. However, these smaller connections are just as susceptible to fatigue failures as the larger piping which is carefully designed.
Several industry standards mention high level considerations for BCs, but there is a lack of recommendations for the smaller diameter connections, especially related to the length of the connection and allowable weight. This guideline addresses the design of small diameter BCs in order to minimize the likelihood of failures due to fatigue.
The guideline is laid out for selection of branches based on operational frequency (speed) and configuration type.

The design philosophy of this guideline is to reduce risk by placing the lowest mechanical natural frequency of the branch connection above the frequencies of most significant excitation occurring at the base of the branch line. The guideline does not attempt to predict actual vibration amplitudes. In addition to the frequency-based criteria, a secondary non-resonant stress criterion was also included. It is possible to generate dynamic stress (and strain) in the branch connection if there is significant vibration in the mainline even if the mechanical response of the branch line is not excited.

This guideline provides recommendations on the allowable weight and length for various unique configurations of small diameter BCs. The BCs covered are connections with pipe diameter less than two inches where the nominal branch diameter to main pipe diameter ratio is less than 25%. Six different connection configurations are covered:

- Two cantilever configurations.
- Pressure Safety Valve (PSV) configuration.
- Double connection at the source configuration, and
- Two connections with external restraints.

Sections are provided which address ten different excitation or design frequencies (related to operational speed). The determination of the frequency for the connection selection will be discussed in a later section. Ten different operational frequencies are included: 15, 24, 30, 40, 48, 60, 80, 96, 144, and 200 Hz. Under each of these frequencies, recommendations for the branch geometries are provided for each of the six BC configurations. Each of the recommended geometries covers multiple nominal branch diameters (½”, ¾”, 1”, 1 ½”, and 2”) and indicates the maximum acceptable lengths of the branch based on the weight which is mounted on the branch.

2.11.7.3 *ASME PTC 19.3 TW-2016*

Thermowells Performance test codes (revision of ASME PTC 19.3 TW-2010)

The object of this Standard is to establish a mechanical design standard for reliable service of tapered, straight, and stepped-shank thermowells in a broad range of applications. This includes an evaluation of the forces caused by external pressure, and the combination of static and dynamic forces resulting from fluid impingement.

This Standard applies to thermowells machined from bar stock and includes those welded to or threaded into a flange as well as those welded into a process vessel or pipe with or without a weld adaptor. Thermowells manufactured from pipe are outside the scope of this Standard.
Thermowells with specially designed surface structures (e.g., a knurled surface or a surface with spiral ridges) are beyond the scope of this Standard, due to the difficulty of providing design rules with broad applicability for these types of thermowells.
Thermowell attachment methods, standard dimensions, parasitic vibration of a sensor mounted inside the thermowell, and thermal equilibrium of the sensor relative to the process stream are beyond the scope of this Standard. In addition, thermowells fabricated by welding, including flame spray or weld overlays, at any place along the length of the shank or at the tip are outside the scope of this Standard. The application of the overlay to a bar-stock thermowell may affect any number of critical attributes such as natural) frequency, damping, material properties, or surface finish. These changes are difficult to account for in the calculations, therefore, there is risk that an inappropriately designed thermowell could be installed.

3 Field vibration measurements and acceptance criteria

3.1 Definitions of terms and expressions

3.1.1 ISO 2041: Mechanical vibration, shock and condition monitoring -Vocabulary | 2018

This document defines terms and expressions unique to the areas of mechanical vibration, shock and condition monitoring.

3.2 Reciprocating Compressor and Piping

3.2.1 EFRC Vibration Guidelines

Guidelines for Vibrations in reciprocating compressors: | 4th edition 2017

This guideline establishes procedures and guidelines for the measurement and classification of mechanical vibration of reciprocating compressor systems. The vibration values are defined primarily to classify the vibration of the compressor system and to avoid fatigue problems with parts in the reciprocating compressor system, i.e. foundation, compressor, dampers, piping and auxiliary equipment mounted on the compressor system.
These guidelines apply to reciprocating compressor systems mounted rigidly with typical rotational speed ratings greater than 120 r/min and up to and including 1800 r/min. The general evaluation criteria which are presented relate to operational measurements. The criteria are also used to ensure that machine vibration does not adversely affect the equipment directly mounted on the machine, e.g. pulsation dampers and the pipe system.
The machinery driving the reciprocating compressor, however, is evaluated in accordance with other appropriate guidelines or standards, e.g. ISO 10816-3.
It is recognized that the evaluation criteria might only have limited application when considering the effects of internal machine components, e.g. problems associated with valves, pistons, and piston rings might be unlikely to be detected in the measurements. Identification of such problems can require investigative diagnostic techniques which are outside the scope of this document.

Examples of reciprocating compressor systems covered by these guidelines are:

- horizontal, vertical, V-, W- and L-type compressor systems;
- constant and variable speed compressors;
- compressors driven by electric motors, gas and diesel engines, steam turbines, with or without a gearbox, flexible or rigid coupling;
- dry running and lubricated reciprocating compressors.

These guidelines do not apply to hyper compressors.

It should be emphasized that these guidelines are not intended for condition monitoring purposes. Noise is also outside the scope of the guidelines.

3.2.2 *ISO 10816-1*

Mechanical vibration -- Evaluation of machine vibration by measurements on non-rotating parts -- Part 1: General guidelines | 1995

It stablishes the general conditions and procedures for the measurement and evaluation of vibration, using measurements made on the non-rotating parts of machines. The general evaluation criteria relate to both operational monitoring and acceptance testing and have been established primarily with regard to securing reliable long-term operation of the machine. Replaces ISO 2372 and ISO 3945, which have been technically revised.

3.2.3 *ISO 10816-3*

Mechanical vibration -- Evaluation of machine vibration by measurements on non-rotating parts -- 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 | 2009

ISO 10816-3:2009 gives criteria for assessing vibration measurements when made *in situ*. The criteria specified apply to machine sets having a power above 15 kW and operating speeds between 120 r/min and 15 000 r/min.

3.2.4 *ISO 10816-8*

Mechanical vibration — Measurement and evaluation of machine vibration —Part 8: Reciprocating compressor systems | 1st edition 2018

ISO 10816-8:2014 establishes procedures and guidelines for the measurement and classification of mechanical vibration of reciprocating compressor systems. The vibration values are defined primarily to classify the vibration of the compressor system and to avoid fatigue problems with parts in the reciprocating compressor system, i.e. foundation, compressor, dampers, piping, and auxiliary equipment mounted on the compressor system.

ISO 10816-8:2014 applies to reciprocating compressors mounted on rigid foundations with typical rotational speed ratings in the range 120 r/min up to and including 1 800 r/min. The general evaluation criteria which are presented relate to operational measurements. The criteria are also used to ensure that machine vibration does not adversely affect the equipment directly mounted on the machine, e.g. pulsation dampers and the pipe system.

NOTE: The general guidelines presented in ISO 10816-8:2014 can also be applied to reciprocating compressors outside the specified speed range but different evaluation criteria might be appropriate in this case.

The machinery driving the reciprocating compressor, however, is evaluated in accordance with the appropriate part of ISO 10816 or other relevant standards and classification for the intended duty.

It is recognized that the evaluation criteria might only have limited application when considering the effects of internal machine components, e.g. problems associated with valves, pistons, and piston rings might be unlikely to be detected in the measurements. Identification of such problems can require investigative diagnostic techniques which are outside the scope of ISO 10816-8:2014.

Examples of reciprocating compressor systems covered by ISO 10816-8:2014 are

- horizontal, vertical, V-, W-, and L-type compressor systems;
- constant and variable speed compressors;
- compressors driven by electric motors, gas, and diesel engines, steam turbines, with or without a gearbox, flexible or rigid coupling, and dry running and lubricated reciprocating compressors.

ISO 10816-8:2014 does not apply to hyper compressors.

Drivers are not included in ISO 10816-8:2014.

The guidelines are not intended for condition monitoring purposes. Noise is also outside the scope of ISO 10816-8:2014.

Note: ISO will convert all parts from the ISO 7919 and ISO 10816 series into ISO 20816 series. This took place already for parts 1, 2, 4, 5

3.2.5 ISO 20816-1
Mechanical vibration -- Measurement and evaluation of machine vibration – Part 1: General guideline | 1st edition 2016

This first edition of ISO 20816-1 cancels and replaces ISO 7919-1:1996, ISO 10816-1:1995 and ISO 10816-1:1995/Amd 1:2009 which have been merged and editorially revised.

This standard establishes general conditions and procedures for the measurement and evaluation of vibration using measurements made on rotating, non-rotating and non-reciprocating parts of complete machines. It is applicable to measurements of both absolute and relative radial shaft vibration regarding the monitoring of radial clearances but excludes axial shaft vibration. The general evaluation criteria, which are presented in terms of both vibration magnitude and change of vibration, relate to both operational monitoring and acceptance testing. They have been provided primarily regarding securing reliable, safe, long-term operation of the machine while minimizing adverse effects on associated equipment. Guidelines are also presented for setting operational limits.

The evaluation criteria for different classes of machinery will be included in other parts of ISO 20816 when they become available. In the meantime, guidelines are given in Clause 6.

The term "shaft vibration" is used throughout ISO 20816 because, in most cases, measurements are made on machine shafts. However, the ISO 20816 series is also applicable to measurements made on other rotating elements if such elements are found to be more suitable, provided that the guidelines are respected.

For the purposes of ISO 20816, operational monitoring is those vibration measurements made during the normal operation of a machine. The ISO 20816 series permits the use of different measurement quantities and methods, provided that they are well-defined, and their limitations are set out, so that the interpretation of the measurements is well-understood.

The evaluation criteria relate only to the vibration produced by the machine itself and not the vibration transmitted to it from outside.

ISO 20816-1:2016 does not include consideration of torsional vibration. For torsional vibration, see, for example, ISO 3046-5, ISO 22266-1 or VDI 2039.

3.2.6 ISO 20816-8

Mechanical vibration — Measurement and evaluation of machine vibration —Part 8: Reciprocating compressor systems| 1st edition 2018 (merge of ISO 10816-8 and ISO 7919)

Introduction

This standard gives general guidelines for the evaluation of machine vibration by measurements on both non-rotating parts and rotating shafts. The present document, however, establishes special procedures and guidelines for the measurement and classification of mechanical vibration of reciprocating compressors. Since, in general, it is not common to measure shaft vibration, this document refers to vibration of the main structure of the compressor, including the foundation, pulsation dampers and attached pipe system. The guidance values given for these vibrations are defined primarily to classify the vibration and to avoid problems with auxiliary equipment mounted on these structures. Recommendations for measurements and evaluation criteria are provided in this document.

Typical features of reciprocating compressors are the oscillating masses, the cyclically varying torques, cylinder stretch and the pulsating forces in the cylinders, pulsation dampers and the pipe system. All these features cause alternating loads on the main supports and vibration of the compressor system. The vibration values of reciprocating compressor systems are generally larger than for rotating compressors but, since they are largely determined by the design features of the compressor, they tend to remain more constant over the life of the system than for rotating machinery.

In the case of reciprocating compressor systems, the vibration measured on the main structure of the compressor (including the foundation, pulsation dampers and piping) and quantified according to this document can only give a rough idea of the vibratory states of the components within the machine itself.

The damage which can occur when exceeding the guidance values based on experience with similar compressor systems is sustained predominantly by machine-mounted components (e.g. instrumentation, heat exchangers, filters, pumps), connecting elements of the compressor with its peripheral parts (e.g. pipelines) or monitoring instruments (e.g. pressure gauges, thermometers).

The question as above which vibration values damage is to be expected largely depends on the design of these components and their fastenings. In some cases, special measurements on certain compressor system components can be required to ascertain that the vibration values do not cause damage. It also happens that, even if measured values are within the guidance values of this document, problems occur owing to the great variety of components which can be attached.

Local vibration problems as described above can be rectified by specific “local measures” (e.g. by elimination of resonances). Experience has shown, however, that it is possible in the majority of cases to state measurable quantities characterizing the vibratory state and to give guidance values for these. This shows that the measurable variables and the guidance values for acceptable vibration in most cases permit a reliable evaluation.

If the measured vibration values as given in this document do not exceed the guidance values, abnormal wear of internal compressor components caused by vibration is unlikely to occur.

The vibration values of reciprocating compressor systems are not only affected by the properties of the compressor itself but also, to a large degree, by the foundation. Since a reciprocating compressor can act as a vibration generator, vibration isolation between the compressor and its foundation can be necessary. The vibration response of the foundation and the vibration from adjacent equipment can have considerable effect on the vibration of the compressor system.

Scope
This document establishes procedures and guidelines for the measurement and classification of mechanical vibration of reciprocating compressor systems. The vibration values are defined primarily to classify the vibration of the compressor system and to avoid fatigue problems with parts in the reciprocating compressor system, i.e. foundation, compressor, dampers, piping and auxiliary equipment mounted on the compressor system. Shaft vibration is not considered.

This document applies to reciprocating compressors mounted on rigid foundations with typical rotational speed ratings in the range 120 r/min up to and including 1 800 r/min. The general evaluation criteria which are presented relate to operational measurements. The criteria are also used to ensure that machine vibration does not adversely affect the equipment directly mounted on the machine, e.g. pulsation dampers and the pipe system.

NOTE The general guidelines presented in this document can also be applied to reciprocating compressors outside the specified speed range but different evaluation criteria might be appropriate in this case.

The machinery driving the reciprocating compressor, however, is evaluated in accordance with the appropriate part of ISO 10816, ISO 20816 or other relevant standards and classification for the intended duty. Drivers are not included in this document.

It is recognized that the evaluation criteria might only have limited application when considering the effects of internal machine components, e.g. problems associated with valves, pistons and piston rings might be unlikely to be detected in the measurements. Identification of such problems can require investigative diagnostic techniques which are outside the scope of this document.

Examples of reciprocating compressor systems covered by this document are:
- horizontal, vertical, V-, W- and L-type compressor systems;
- constant and variable speed compressors;
- compressors driven by electric motors, gas and diesel engines, steam turbines, with or without a gearbox, flexible or rigid coupling, and
- dry running and lubricated reciprocating compressors.

This document does not apply to hyper compressors. The guidelines are not intended for condition monitoring purposes. Noise is also outside the scope of this document.

3.2.7 VDI 3842
Vibrations in piping systems | 2004 (identical to BS EN ISP 286-1-2010)

The objective of guideline VDI 3842 is to deal with vibrations in pipework systems, and in particular:
- to describe vibration phenomena and the associated kinds of excitation.
- to describe and explain calculation methods which allow comprehension of loads and which are used for checking the pipework systems;
- to describe and explain measuring procedures for analysing pipe vibrations;
- to describe methods for evaluating vibrations and vibration-induced stresses;
- to specify remedial measures to apply in the event of vibration problems.

As far as strength checks of pipes are concerned, this VDI guideline primarily provides an overview, referencing the relevant codes of practise applicable to the various branches of industry. The prime objective here is to make it easier to begin working with the special codes of practise.
The air vibrations excited by the vibrating pipes (secondary air-borne sound) are classified under the field of engineering acoustics and will not be dealt with here and are described in VDI 3733 (see section 2.3 of this report).
The scope of application covers pipework systems in all branches of industrial plant construction:

- Power engineering.
- Chemicals, petrochemicals, process engineering.
- Shipbuilding.
- Buildings technology.
- Water supply systems.

Process-specific vibration phenomena are found in the individual industries here.

3.3 Electric drivers

3.3.1 IEC-60034-14

Rotating electrical machines — Part 14: Mechanical vibration of certain machines with shaft heights 56 mm and higher — Measurement, evaluation and limits of vibration severity | 3rd edition 2003 (consolidated with amendment 1 of 2007)

This part of IEC 60034 specifies the factory acceptance vibration test procedures and vibration limits for certain electrical machines under specified conditions, when uncoupled from any load or prime mover.

It is applicable to DC and three-phase AC machines, with shaft heights 56 mm and higher and a rated output up to 50 MW, at operational speeds from 120 min^{-1} up to and including 15 000 min^{-1}.

This document is not applicable to machines mounted *in situ* (on site), three-phase commutator motors, single-phase machines, three-phase machines operated on single-phase systems, vertical waterpower generators, turbine generators greater than 20 MW and machines with magnetic bearings or series-wound machines.

NOTE For machines measured *in situ*, refer to applicable parts of ISO 20816, ISO 10816 and ISO 7919. It is noted that ISO will convert all parts from the ISO 7919 and ISO 10816 series into ISO 20816 series. This took place already for parts 1, 2, 4, 5.

3.3.1.1 VDI 3839-5

Instructions on measuring and interpreting the vibration of machines - typical vibration patterns with electrical machines | 2005

The document gives an overview of the typical vibration patterns encountered in electrical machines with outputs between 10 kW and a few hundreds of MW. These machines may be three-phase alternating current generators or direct-current generators installed in thermal power stations, or small hydro-electric power plants, in vehicles or aboard ship.

3.4 Gas motors and diesel engines

3.4.1 ISO 10816-6

Mechanical vibration — Evaluation of machine vibration by measurements on non-rotating parts — Part 6: Reciprocating machines with power ratings above 100 kW | Amendment 1: 2015

This part of IS0 10816 specifies the general conditions and procedures for the measurement and evaluation of vibration, using measurements made on the non-rotating and non-reciprocating parts of complete machines. Shaft vibration, including torsional vibration, is beyond the scope of this part of IS0 10816.

It generally applies to reciprocating piston machines mounted either rigidly or resiliently with power ratings of above 100 kW. Typical examples of application are:
marine propulsion engines, marine auxiliary engines, engines operating in diesel generator sets, gas compressors and engines for diesel locomotives.

The general evaluation criteria which are presented relate to both operational monitoring and acceptance testing. They are also used to ensure that the machine vibration does not adversely affect the equipment directly mounted on the machine.

Consideration should also be given to the machinery driven by or driving the reciprocating machine. These should be evaluated in accordance with relevant standards and classification for the intended duty.

It is recognized that the evaluation criteria may only have limited application when considering the effects of internal machine components; for example, problems associated with valves, loose pistons, piston rings, etc. are unlikely to be reflected in the measurements.
Identification of such problems requires investigative techniques which are outside the scope of this part of ISO 10816.
Noise is also outside the scope of this part of This part of IS0 10816 does not apply to machines installed in road vehicles (e.g. trucks, passenger cars, self-propelling construction machinery and tractors).

It is recommended to use ISO 10816-8 or the ISO 20816-8 for reciprocating compressors instead of ISO 10816-6.

3.4.2 VDI 3838

Measurement and evaluation of mechanical vibration of reciprocating piston engines and piston compressors with power ratings above 100 kW – (Addition to DIN ISO 10816-6)

Guideline VDI 3838 essentially applies to rigidly or flexibly mounted reciprocating piston engines and piston compressors with power ratings above 100 kW and speeds between 120 rpm and 3000 rpm. Typical examples of applications include: drive engines for ships, engines for auxiliary equipment in ships, engines for diesel generator sets and for diesel locomotives, and gas compressors. This guideline provides practical instructions on measuring and evaluating vibration when measurements are taken at the non-rotating and non-reciprocating parts of complete machines. Guide values for the permissible vibration of mounted components such as pumps, intercoolers or turbochargers are not provided in this guideline. Nor does it deal with torsional vibration, axial vibration or benching vibration of the crankshafts.

Guideline VDI 3838 does not apply to all large two-stroke engines with speeds below 120 rpm. When assessing the vibration of these engines it will be necessary to refer to the experience of the corresponding manufacturer.
Guideline VDI 3838 does not apply to generating sets with reciprocating internal combustion engines of the block type: in these cases, standards ISO 8528-9 or DIN ISO 8528-9 apply. Also excluded are machines installed in road vehicles (for example, in trucks, passenger cars, self-propelled construction equipment and tractors) and machines with rotary pistons.
Guideline VDI 3838 does not apply to machines which drive or are driven by the reciprocating piston machine unless the machine in question is also a reciprocating piston machine. They should be assessed on the basis of the standards which apply to them and in accordance with the intended service conditions.

The general evaluation criteria presented here apply not only to acceptance measurements and operational monitoring at the place of installation but also to acceptance procedures in testing facilities. They should ensure that the vibration of the machine do not have any negative influence on the environment, on the operating personnel or on components mounted directly on the machine. Further detailed information about measuring and evaluating the vibration of reciprocating piston engines and compressors is provided in guideline VDI 3839 Part 8.
It should be noted that the evaluation criteria are applicable only with qualifications if the effects of internal machine parts are to be covered; you should not necessarily expect problems, for example, with valves, piston play, piston rings and so on to be revealed or be detectable in the measurement signals. Detection of such problems calls for the use of special investigation methods which are not the subject of this guideline. Noise generation is not covered either.

3.4.3 VDI 3839
Instructions on measuring and interpreting the vibrations of machines

Part 1: General principles | 2001
Guidelines in the VDI 3839 series provide descriptions of the methods and equipment used for measuring the vibration of machines. They explain the basic criteria which apply to evaluation of measurement results and specify which guidelines and standards this evaluation should be based on. Furthermore, instructions are given regarding the analysis and interpretation of measured vibration with a view to ascertaining their causes in the event of complaints, faults or damage, thereby enabling remedial measures to be initiated.
To this end examples of typical causes of vibration and the associated vibration patterns are given in Parts 2 to 8. The guidelines in the VDI 3839 series are not intended to replace specialist works on vibration theory. They are predominantly intended to be used as guides for engineers and technicians in development, testing or engineering departments who are not specifically qualified or trained in the field of vibration
measurement and interpretation. They should also provide an overview for people who only occasionally have to deal with vibration-related problems –for example, when damage or malfunctions occur.

Last but not least, the reader of these guidelines should find information on when it is advisable to call in experts who can apply their specialised knowledge of the design, working principles and vibration related problems of certain machine types.

Part 2: Instructions on measuring and interpreting the vibrations of machines - vibration patterns for excitation arising from unbalance, incorrect assembly, bearing faults and damage to rotating
Gives descriptions of the methods and equipment used for measuring the vibration of machines.

Part 8: Typical vibration patterns with reciprocating compressors | 2004
Guideline VDI 3839 Part 8 provides information about vibration excitation and vibration patterns which, arising from the excitation forces of reciprocating
piston engines, can occur in these engines themselves or in machines driving or driven by them.
This part is applicable to reciprocating machines with power ratings in excess of 100 kW as engines in stationary systems for the purpose of generating energy, as drives for compressors, pumps and other machines in process technology, in ships and in rail track vehicles.
It is also applicable to reciprocating compressors in this power output range. Reciprocating machines dealt with in this guideline are without exception reciprocating piston machines. The guideline does not apply to rotary piston machines. Information about the terminology from the field measurement and analysis used here, about measurement and analysis equipment mentioned or recommended, and about special analytical methods may be found in VDI 3839 Part 1.

Reference should still be made to VDI 3839 Part 2 which provides an overview of vibration patterns for excitation arising from unbalance, incorrect assembly, bearing faults and damage to rotating components – in other words, from excitations which can occur with all kinds of machines with rotating parts, irrespective of their size, power rating and speed. With reciprocating machines, however, these vibrations are in most cases only of secondary importance compared with those which are caused by their typical, design-determined excitation forces.

3.4.4 ISO 8528-9

Reciprocating internal combustion engine driven alternating current generating sets – Part 9: Measurement and evaluation of mechanical vibrations | 2017

ISO 8528-9:2017 describes a procedure for measuring and evaluating the external mechanical vibration behaviour of generating sets at the measuring points stated in this document.

It applies to Reciprocating internal combustion (RIC) engine driven a.c. generating sets for fixed and mobile installations with rigid and/or resilient mountings. It is applicable for land and marine use, excluding generating sets used on aircraft or those used to propel land vehicles and locomotives.

For some specific applications (essential hospital supplies, high rise buildings, etc.) supplementary requirements may be necessary. The provisions of this document are intended to be regarded as a basis for such applications.

For generating sets driven by other reciprocating-type prime movers (e.g. sewage gas engines, steam engines), the provisions of this document are intended to be regarded as a basis for such applications.

4 Safety

4.1 Compressors

4.1.1 BS EN 1012-3

Compressors and vacuum pumps. Safety requirements. Process compressors | 2013

This European Standard is applicable to process gas compressors and process gas compressor units having an operating pressure greater than 0,5 bar (gauge), an input shaft power greater than 0,5 kW and designed to compress all gases other than air, nitrogen or inert gases which are covered in Part 1. This document deals with all significant hazards, hazardous situations and events relevant to the design, installation, operation, maintenance, dismantling and disposal of process gas compressors and process gas compressor units, when they are used as intended and under conditions of misuse which are reasonably foreseeable by the manufacture.
This part of EN 1012 includes under the general term compressor units those machines which comprise: - the compressor; - a drive system including the prime mover; - any component or device supplied which is necessary for operation. This part of EN 1012 is not applicable to compressors which are manufactured before the date of publication of this document by CEN. The requirements of this European Standard do not take into account the interaction between the compressor/compressor unit and other processes carried out on site.
Excluded are: - refrigerant compressors used in refrigerating systems or heat pumps for which the safety requirements are given in EN 60335-2-34 or EN 12693; - the specification of performance levels and/or safety integrity levels for safety related parts of control systems.
Performance levels and/or safety integrity levels are an important aspect of compressor design and should be determined by the manufacturer and the user based on a risk assessment (see Introduction). This European Standard does not cover those safety aspects of road transport dealt with by EC legislation for trailers.

4.2 Drivers

4.2.1 IEC 60079-0

Explosive atmospheres- Part 0: Electrical equipment – General requirements | 2012

This part of IEC 60079 specifies the general requirements for construction, testing and marking of electrical equipment and Ex Components intended for use in explosive atmospheres. The standard atmospheric conditions (relating to the explosion characteristics of the atmosphere) under which it may be assumed that electrical equipment can be operated are: - temperature -20 °C to +60 °C; - pressure 80 kPa (0,8 bar) to 110 kPa (1,1 bar); and - air with normal oxygen content, typically 21 % v/v. This standard and other standards supplementing this standard specify additional test requirements for equipment operating outside the standard temperature range, but further additional consideration and additional testing may be required for equipment operating outside the standard atmospheric pressure range and standard oxygen content, particularly with respect to types of protection that depend on quenching of a flame such as ‘flameproof enclosure “d”’ (IEC 60079-1) or limitation of energy, ‘intrinsic safety “i”’ (IEC 60079-11).

4.2.2 *IEC 60079 Electrical apparatus for explosive gas atmospheres*

Part 14: Electrical installations in hazardous areas (other than mines) | 2012

This part of IEC 60079 contains the specific requirements for the design, selection and erection of electrical installations in explosive gas atmospheres.
These requirements are in addition to the requirements for installations in non-hazardous areas.
This standard applies to all electrical equipment and installations in hazardous areas whether permanent, temporary, portable, transportable or hand-held.
It applies to installations at all voltages.
This standard does not apply to electrical installations in mines susceptible to firedamp.

NOTE This standard may apply to electrical installations in mines where explosive gas atmospheres other than firedamp may be formed and to electrical installations in the surface installation of mines:

- electrical installations in areas where the hazard is due to combustible dusts or fibres;
- inherently explosive situations, for example explosives manufacturing and processing; – rooms used for medical purposes

Part 17: Inspection and maintenance of electrical installations in hazardous areas (other than mines) | 2002

This part of IEC 60079 is intended to be applied by users, and covers factors directly related to the inspection and maintenance of electrical installations within hazardous areas only. It does not include conventional requirements for electrical installations, nor the testing and certification of electrical apparatus. It does not cover Group I apparatus (applications for mines susceptible to firedamp).

This standard supplements the requirements laid down in IEC 60364-6-61.

4.2.3 *NEN-EN-IEC 60204-1*

Safety of machinery - Electrical equipment of machines - Part 1: General requirements | 2018

NEN-EN-IEC 60204-1 applies to electrical, electronic and programmable electronic equipment and systems to machines not portable by hand while working, including a group of machines working together in a co-ordinated manner. The equipment covered by this part of IEC 60204 commences at the point of connection of the supply to the electrical equipment of the machine (see 5.1).
This part of IEC 60204 is applicable to the electrical equipment or parts of the electrical equipment that operate with nominal supply voltages not exceeding 1000 V for alternating current (AC) and not exceeding 1500 V for direct current (DC), and with nominal supply frequencies not exceeding 200 Hz. This part of IEC 60204 does not cover all the requirements (for example guarding, interlocking, or control) that are needed or required by other standards or regulations in order to protect persons from hazards other than electrical hazards. Each type of machine has unique requirements to be accommodated to provide adequate safety. This part of IEC 60204 specifically includes, but is not limited to, the electrical equipment of machines as defined in 3.1.40.

This part of IEC 60204 does not specify additional and special requirements that can apply to the electrical equipment of machines that, for example:

- are intended for use in open air (i.e. outside buildings or other protective structures);
- use, process, or produce potentially explosive material (for example paint or sawdust);
- are intended for use in potentially explosive and/or flammable atmospheres;

- have special risks when producing or using certain materials; - are intended for use in mines;
- are sewing machines, units, and systems (which are covered by IEC 60204-31);
- are hoisting machines (which are covered by IEC 60204-32); - are semiconductor fabrication equipment (which are covered by IEC 60204-33). Power circuits where electrical energy is directly used as a working tool are excluded from this part of IEC 60204.

5 Condition Monitoring

5.1 API 670

Machine Protection | 5th edition 2014
Provides a purchase specification to facilitate the manufacture, procurement, installation, and testing of vibration, axial-position, and bearing temperature monitoring systems for petroleum, chemical, and gas industry services. Covers the minimum requirements for monitoring radial shaft vibration, casing vibration, shaft axial position, and bearing temperatures. It outlines a standardized monitoring system and covers requirements for hardware (sensors and instruments), installation, testing, and arrangement.

Annex P is the informative Annex for Reciprocating Compressor Monitoring.

5.2 ISO 22096

Condition monitoring and diagnostics of machines -- Acoustic emission | 2007
It specifies the general principles required for the application of acoustic emission to condition monitoring and diagnostics of machinery operating under a range of conditions and environments. It is applicable to all machinery and associated components and covers structure-borne measurements only.

5.3 ISO 13374

Condition monitoring and diagnostics of machines -- Data processing, communication and presentation

Part 1: General guidelines | 2003
This part establishes general guidelines for software specifications related to data processing, communication, and presentation of machine condition monitoring and diagnostic information.

Part 2: Data processing | 2007
This part details the requirements for a reference information model and a reference processing model to which an open condition monitoring and diagnostics (CM&D) architecture needs to conform. Software design professionals require both an information model and a processing model to adequately describe all data processing requirements. ISO 13374-2:2007 facilitates the interoperability of CM&D systems.

Part 3: Communication | 2012
This part of ISO 13374 specifies requirements for data communication for an open condition monitoring and diagnostics (CM&D) reference information architecture and for a reference processing architecture. Software design professionals require communications to be defined for exchange of CM&D information between software systems. This part of ISO 13374 facilitates the interoperability of CM&D systems.

Part 4: Presentation | 2015

This part details the requirements for presentation of information for technical analysis and decision support in an open architecture for condition monitoring and diagnostics. Software design professionals need to present diagnostic/prognostic data, health information, advisories, and recommendations on computer displays and in written report formats to end-users. This part of ISO 13374 provides standards for the display of this information in CM&D systems.

6 Installation

6.1 Machinery installation

6.1.1 API RP 686 Machine installation

API RP 686 for Machinery Installation Recommended Practice RP686 for Machinery Installation and Installation Design | 2nd edition 2009

Provides recommended procedures, practices, and checklists for the installation and pre-commissioning of new, existing, and reapplied machinery and to assist with the installation design of such machinery for petroleum, chemical, and gas industry services facilities. In general, this RP is intended to supplement vendor instructions and the instructions provided by the original equipment manufacturer (OEM) should be carefully followed with regard to equipment installation and checkout. Most major topics of this RP are subdivided into sections of “Installation Design” and “Installation” with the intent being that each section can be removed and used as needed by the appropriate design or installation personnel.

6.2 Field testing and acceptance tests

6.2.1 GMRC Guideline for field testing

Guideline for field testing of reciprocating compressor performance | 1st edition 2009

This guideline is intended to serve as a reference for field testing of reciprocating compressor performance. It applies to any party conducting a field test of a reciprocating compressor or compressor package (manufacturer, user company, or third- party). It is intended to provide a technically sound, yet practical procedure for all aspects of conducting field performance tests of reciprocating compressors.
Specific requirements of a particular test may dictate that the test procedure deviates from this guideline or the ideal installation described. However, when a particular test deviates from the installation requirements or other test procedures, the deviation will affect the uncertainty of the test and should be accounted for in the uncertainty analysis, as recommended in this guideline.
The development of this guideline was initiated by the ever-growing presence of high-speed reciprocating compressors in the industry. However, there are several low -speed reciprocating compressors operating that also need performance tests. This guideline addresses items that should be considered for both high- and low-speed compressors when conducting performance tests.
The standards that are used as references for this guideline are ASME PTC 10-1997, “Performance Test Code on Compressors and Exhausters,” and API 618, “Reciprocating Compressors for Petroleum, Chemical, and Gas Industry Service” and ISO 1217, “Displacement Compressors – Acceptance Tests.”

6.2.2 ISO 1217

Displacement compressors — Acceptance tests |2009

This International Standard specifies methods for acceptance tests regarding volume rate of flow and power requirements of displacement compressors. It also specifies methods for testing liquid-ring type compressors (see Annex A).

This International Standard specifies the operating and testing conditions which apply when a full performance test is specified.
For compressors manufactured in batches or in continuous production quantities and supplied against specified data, the tests described in Annexes B, C and D are considered equivalent alternatives.
Annex E, which is normative, applies to any electrically driven compressor manufactured in batches or in continuous production quantities and supplied against specified data having variable speed drive (e.g. variable frequency drive, direct current drive and switched reluctance), which incorporates a displacement compressor of any type driven by an electric motor.
Detailed instructions are given for a full performance test, including the measurement of volume flow rate and power requirement, the correction of measured values to specified conditions and means of comparing the corrected values with the guarantee conditions. This International Standard specifies methods for determining the value of the tolerances to be applied to the measurement of flow, power and specific power.

NOTE The tolerances to be applied to the measurement of flow, power, specific power, etc. for all acceptance tests carried out in accordance with this International Standard are agreed on by the manufacturer and the purchaser at the contractual stage or prior to the execution of the tests.

Annex F specifies standard inlet conditions for reference purposes. Annex G, which is normative, indicates the uncertainty of measurement.
This International Standard is not applicable to noise statements, which are identified in ISO 2151.

7 Inspection and repair of refinery equipment

7.1 Pressure vessels, boilers and heaters

7.1.1 API 510

Pressure Vessel Inspection Code: In-Service Inspection, Rating, Repair, and Alteration | 10th Edition | May 2014

It covers the in-service inspection, repair, alteration, and rerating activities for pressure vessels and the pressure-relieving devices protecting these vessels.
This inspection code applies to most refining and chemical process vessels that have been placed in service. This includes:

- vessels constructed in accordance with an applicable construction code;
- vessels constructed without a construction code (non-code)—a vessel not
- fabricated to a recognized construction code and meeting no known
- recognized standard;
- vessels constructed and approved as jurisdictional special based upon
- jurisdiction acceptance of particular design, fabrication, inspection,
- testing, and installation;
- non-standard vessels—a vessel fabricated to a recognized construction code but has lost its nameplate or stamping.

7.1.2 API RP 572

Inspection practices for pressure vessels | 4th edition 2016

API RP 572 is a recommended practice developed and published by the American Petroleum Institute (API) that covers the inspection of pressure vessels, including those with a design pressure under 2 bara, and the standards for their construction and maintenance.

It is more a technical guide document rather than a code, as such, but it does perform a useful function in supporting the content of API 510.

In addition, RP 572 also discusses, with relation to pressure vessels, the reasons for inspection, causes of deterioration, the frequency and methods of inspection, methods of repair, and preparation of records and reports.
This recommended practice covers a large variety of topics related to the inspection of pressure vessels including safety precautions, thickness measurements, both internal and external inspections, and special methods of detecting mechanical damage. The first edition of the recommended practice was originally published in January of 1992, with the most recent 4th Edition published in December of 2016.
To be most effective, this recommended practice requires knowledge of other API standards and practices. Some of these standards include, but are not limited to:

- API 510, Pressure Vessel Inspection Code,
- API RP 571, Damage Mechanisms Affecting Fixed Equipment in the Refining Industry, and
- API RP 574, Inspection Practices for Piping System Components.

It is also helpful to have a general familiarity with the ASME Boiler and Pressure Vessel Code**,** Section VIII (Pressure Vessels**)** when using API RP 572.

7.1.2.1 API RP 572
Inspection Practices for Pressure Vessels, Covers the inspection of pressure vessels | 3rd edition 2009

It includes a description of the various types of pressure vessels (including pressure vessels with a design pressure below 15 psig) and the standards for their construction and maintenance. RP 572 also includes reasons for inspection, causes of deterioration, frequency and methods of inspection, methods of repair, and preparation of records and reports.

7.1.2.2 API RP 573
Inspection of Fired Boilers and Heaters | 3rd edition 2013

Covers the inspection practices for fired boilers and process heaters (furnaces) used in petroleum refineries and petrochemical plants. The practices described in this document are focused to improve equipment reliability and plant safety by describing the operating variables which impact reliability and to ensure that inspection practices obtain the appropriate data, both on-stream and off-stream, to assess current and future performance of the equipment.

7.2 Piping

7.2.1 API 570
Piping Inspection Code: In-service Inspection, Rating, Repair, and Alteration of Piping Systems | 3rd edition 2009

Covers the inspection, rating, repair, and alteration procedures for metallic and fiberglass reinforced plastic piping systems and their associated pressure relieving devices that have been in-service. The intent of this code is to specify the in-service inspection and condition monitoring program that is needed to determine the integrity of piping. That program should provide reasonably accurate and timely assessments to determine if any changes in the condition of piping could possibly compromise continued safe operation.
API 570 was developed for the petroleum refining and chemical process industries but may be used, where practical, for any piping system. It is intended for use by organizations that maintain or have access to an authorized inspection agency, a repair organization, and technically qualified piping engineers, inspectors, and examiners. Intended for use by organizations that maintain or have access to an authorized inspection agency, repair organization, and technically qualified personnel. May be used, where practical, for any piping system. Piping inspectors are to be certified as stated in this inspection code.

7.2.1.1 API RP 574
Inspection Practices for Piping System Components | 3rd edition 2009

Supplements API 570 by providing piping inspectors with information that can improve skill and increase basic knowledge and practices. This RP describes inspection practices for piping, tubing, valves (other than control valves), and fittings used in petroleum refineries and chemical plants.

Common piping components, valve types, pipe joining methods, inspection planning processes, inspection intervals and techniques, and types of records are described to aid the inspector in fulfilling their role implementing API 570. This publication does not cover inspection of specialty items, including instrumentation and control valves.

7.2.1.2 *API RP 576*
Inspection of Pressure-Relieving Devices | 3rd edition | 2013

Describes the inspection and repair practices for automatic pressure-relieving devices commonly used in the oil and petrochemical industries. As a guide to the inspection and repair of these devices in the user's plant, it is intended to ensure their proper performance. This publication covers such automatic devices as pressure-relief valves, pilot-operated pressure-relief valves, rupture disks, and weight-loaded pressure-vacuum vents.
The scope of this RP includes the inspection and repair of automatic pressure relieving devices commonly used in the oil and petrochemical industry. This publication does not cover weak seams or sections in tanks, explosion doors, fusible plugs, control valves, and other devices that either depend on an external source of power for operation or are manually operated. Inspections and tests made at manufacturers' plants, which are usually covered by codes or purchase specifications, are not covered by this publication.
This publication does not cover training requirements for mechanics involved in the inspection and repair of pressure-relieving devices. Those seeking these requirements should see API 510, which gives the requirements for a quality control system and specifies that the repair organization maintain and document a training program ensuring that personnel are qualified.

7.3 Risk based inspection

7.3.1 *API RP 580*
Risk-Based Inspection | 2nd edition 2009

Provides users with the basic elements for developing and implementing a risk-based inspection (RBI) program for fixed equipment and piping in the hydrocarbon and chemical process industries. RP 580 is intended to supplement API 510, API 570, and Std 653. These API inspection codes and standards allow an owner/user latitude to plan an inspection strategy and increase or decrease the code designated inspection frequencies based on the results of a RBI assessment.

7.3.2 *API Risk-Based Inspection Software*
API RBI software, created by petroleum refinery and chemical plant owner/ users for owner/users, finds its basis in API Publication 581, *Base Resource Document—Risk-Based Inspection.* Practical, valuable features are built into the technology, which is based on recognized and generally accepted good engineering practices.
The purposes of the Risk-Based Inspection Program are:

- screen operating units within a plant to identify areas of high risk;
- estimate a risk value associated with the operation of each equipment item in a refinery or chemical process plant based on a consistent methodology;
- prioritize the equipment based on the measured risk;
- design a highly effective inspection program; and

- systematically manage the risks associated with equipment failures.

The RBI method defines the risk of operating equipment as the combination of two separate terms: the consequence of failure and the likelihood of failure.

7.3.2.1 API RP 581
Risk-Based Inspection Technology | 2nd edition 2008

API has researched and developed an approach to risk-based inspection (RBI). This document details the procedures and methodology of RBI. RBI is an integrated methodology that uses risk as a basis for prioritizing and managing an in-service equipment inspection program by combining both the likelihood of failure and the consequence of failure. Utilizing the output of the RBI, the user can design an inspection program that manages or maintains the risk of equipment failures. The following are three major goals of the RBI program.

- Provide the capability to define and quantify the risk of process equipment failure, creating an effective tool for managing many of the important elements of a process plant
- Allow management to review safety, environmental, and business interruption risks in an integrated, cost effective manner.
- Systematically reduce the likelihood and consequence of failure by allocating inspection resources to high risk equipment.

The RBI methodology provides the basis for managing risk by making informed decisions on the inspection method, coverage required, and frequency of inspections. In most plants, a large percentage of the total unit risk will be concentrated in a relatively small proportion of the equipment items. These potential high risk components may require greater attention, perhaps through a revised inspection plan. With a RBI program in place, inspections will continue to be conducted as defined in existing working documents, but priorities and frequencies will be guided by the RBI procedure. The RBI analysis looks not only at inspection, equipment design, and maintenance records, but also at numerous process safety management issues and all other significant issues that can affect the overall mechanical integrity and safety of a process unit.