



DPC: 25/30464517 DC

BSI Group Headquarters

389 Chiswick High Road London W4 4AL

Tel: +44 (0)20 8996 9000

Fax: +44 (0)20 8996 7400

www.bsigroup.com

Date: 11 February 2025

Origin: International

Latest date for receipt of comments: 06 April 2025

Project No. 2022/02485

Responsible committee: GME/21/7 Mechanical vibration, shock and condition monitoring - Condition monitoring

Interested committees:

Title: Draft BS ISO 17934 Condition monitoring and diagnostics of machines - Reciprocating compressors.

Please notify admin.start@bsigroup.com if you are aware of any keywords that might assist in clarifying or identifying the standard or of the content of this standard:

- i) has any issues related to 3rd party IPR, patent or copyright
- ii) affects other national standard(s)
- iii) requires additional national guidance or information

WARNING: THIS IS A DRAFT AND MUST NOT BE REGARDED OR USED AS A BRITISH STANDARD. THIS DRAFT IS NOT CURRENT BEYOND 06 April 2025

This draft is issued to allow comments from interested parties; all comments will be given consideration prior to publication. No acknowledgement will normally be sent. **See overleaf for information on the submission of comments.**

No copying is allowed, in any form, without prior written permission from BSI except as permitted under the Copyright, Designs and Patent Act 1988 or for circulation within a nominating organization for briefing purposes. Electronic circulation is limited to dissemination by e-mail within such an organization by committee members.

Further copies of this draft may be purchased from BSI Shop <http://shop.bsigroup.com> or from BSI Customer Services, Tel: +44(0) 20 8996 9001 or email cservices@bsigroup.com. British, International and foreign standards are also available from BSI Customer Services.

Information on the co-operating organizations represented on the committees referenced above may be obtained from <https://standardsdevelopment.bsigroup.com/>.

E-mail: admin.start@bsigroup.com

Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

For national standards, comments will be reviewed by the relevant UK national committee and the resulting standards published as a British Standard.

UK Vote

Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

Submission of Comments

- **Annotated drafts are not acceptable and will be rejected.**
- All comments should be submitted online at <https://standardsdevelopment.bsigroup.com/>. You will need to register in order to comment.

Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
------------------	------------------------

1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/ Figure/Table/Note	Type of comment	Comment (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	



DRAFT International Standard

ISO/DIS 17934

Condition monitoring and diagnostics of machines — Reciprocating compressors

*Surveillance et diagnostic d'état des machines — Compresseurs
alternatifs*

ICS: 23.140

ISO/TC 108/SC 5

Secretariat: **SA**

Voting begins on:
2025-02-11

Voting terminates on:
2025-05-06

This document is circulated as received from the committee secretariat.

THIS DOCUMENT IS A DRAFT CIRCULATED FOR COMMENTS AND APPROVAL. IT IS THEREFORE SUBJECT TO CHANGE AND MAY NOT BE REFERRED TO AS AN INTERNATIONAL STANDARD UNTIL PUBLISHED AS SUCH.

IN ADDITION TO THEIR EVALUATION AS BEING ACCEPTABLE FOR INDUSTRIAL, TECHNOLOGICAL, COMMERCIAL AND USER PURPOSES, DRAFT INTERNATIONAL STANDARDS MAY ON OCCASION HAVE TO BE CONSIDERED IN THE LIGHT OF THEIR POTENTIAL TO BECOME STANDARDS TO WHICH REFERENCE MAY BE MADE IN NATIONAL REGULATIONS.

RECIPIENTS OF THIS DRAFT ARE INVITED TO SUBMIT, WITH THEIR COMMENTS, NOTIFICATION OF ANY RELEVANT PATENT RIGHTS OF WHICH THEY ARE AWARE AND TO PROVIDE SUPPORTING DOCUMENTATION.

Reference number
ISO/DIS 17934:2025(en)

Full document details: 25/30464517 DC

© ISO 2025  **Documents**
Document Sharing Hub



COPYRIGHT PROTECTED DOCUMENT

© ISO 2025

All rights reserved. Unless otherwise specified, or required in the context of its implementation, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

Page

Foreword	iv
Introduction	v
1 Scope	1
2 Normative references	2
3 Terms and definitions	2
4 Symbols and abbreviated terms	5
5 Initial preparations for condition monitoring	7
6 Failure modes of reciprocating compressors	7
6.1 General	7
6.2 Reciprocating compressor components	8
6.3 Potential failure mode identification and prioritization	8
7 Monitoring and diagnostic techniques	9
7.1 General	9
7.2 Condition monitoring techniques overview	9
7.3 Primary descriptors and plots	11
7.4 Correlation measurements	14
7.5 Adaptive monitoring strategy	15
7.6 Monitoring and diagnostic technique selection and evaluation	16
7.7 Automatic diagnostic decision support and artificial intelligence (AI)	16
8 Implementing, operating and maintaining a monitoring solution	17
8.1 General	17
8.2 Sensor selection and installation	17
8.3 Subclause title (first level)	18
8.4 Daily operation of the monitoring system	20
Annex A (informative) Machine components and failure modes	21
Annex B (informative) Monitoring techniques for reciprocating compressor components and failure modes	25
Annex C (informative) Primary monitoring and diagnostic techniques	28
Annex D (informative) Evaluation of monitoring techniques	79
Bibliography	81

Foreword

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

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

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO [had/had not] received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at www.iso.org/patents. ISO shall not be held responsible for identifying any or all such patent rights.

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

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

This document was prepared by Technical Committee ISO/TC 108, *Mechanical vibration, shock and condition monitoring*, Subcommittee SC 5, *Condition monitoring and diagnostics of machine systems*.

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

Introduction

Reciprocating compressors have been used in industry long before centrifugal, axial and other types of compressors were even invented, and they are still being used today. In fact, reciprocating compressors have a special niche in the industry that cannot be matched by other compressors. These are applications where precise, efficient high-pressure gas delivery is needed with low flow rates in comparison with turbo-compressors. This is made possible by the positive displacement compression action of these machines. The compressor's efficient flexibility is essential for variable process conditions such as for multiple-stream compression, and for gases that vary in molecular weight. They are able to generate a high-pressure ratio independent of the density of the gas and are very flexible to control the capacity. In the hydrocarbon processing industry, the reciprocating compressor is especially ideal for low molecular weight gases such as hydrogen (H_2).

Reciprocating compressors are increasingly important in refinery processes such as for hydrotreating, hydrocracking, isomerisation and catalytic reforming, much of which is intended for producing more clean fuels. There are many industrial applications today that require this type of compression, and this requirement will continue well into the future. This is especially true in future energy transition processes such as midstream transport and storage, where pure hydrogen or a blend of hydrogen with natural gas will become an important energy carrier.

The reciprocating compressor successfully fulfils those process requirements for which it is intended, but there is a challenge from the maintenance side for these machines. As a result of the many moving parts (rotation and translation) and the high-dynamic forces and moments caused by the reciprocating movement of these parts (including pulsation-induced forces and cylinder gas forces, also called cylinder stretch forces), there is a higher incidence of wear, leakage and breakage, compared to the centrifugal compressor. The extra maintenance and downtime incurred by reciprocating compressors, both planned and unplanned, can represent a critical bottleneck to process production, if not properly managed.

Because of the inherent design of the reciprocating compressor, it will always require more maintenance (e.g., replacing compressor valves, piston rings and rider bands, and packing), than a comparable turbo-compressor. Therefore, for this reason, an effective condition monitoring and diagnostics strategy plays an extremely important role for reducing downtime and life cycle costs of these machines while increasing reliability, safety, integrity and efficiency.

Traditionally, however, the reciprocating compressor is often less monitored or incorrectly monitored compared to other critical plant machinery. This is partly due to the difficulty of detecting and diagnosing the unique potential failure modes associated with the machine's reciprocating action, caused by the dynamic loads described before. From a vibration perspective, many machine faults manifest themselves as impacts, i.e. short duration non-stationary peaks or peaks that occur only at approximate specific crank angles. Consumable component wear is difficult to monitor directly and therefore requires specialized measurement techniques. The same for cylinder trim leak detection and diagnostics. Pressure and flow-induced pulsations due to the reciprocating action can distort the raw signals. Therefore, not only are specialized measurement techniques required, but also expertise for interpreting the results.

In general, there is less understanding of the condition monitoring and diagnostics requirements of reciprocating compressors compared to other machines, and there has been a lack of standards to fulfil this void. Existing standards such as ISO 13631, ISO 20816-8, API 618 and API 670 deal with design, procurement, installation and protection of the machines but very few of them address condition monitoring and diagnostics.

Condition monitoring and diagnostics of machines — Reciprocating compressors

1 Scope

This document focuses on recommended condition monitoring techniques for detecting and diagnosing developing machine faults associated with the most common potential failure modes for reciprocating compressors.

This document is intended to improve the reliability of implementing an effective condition monitoring approach for the reciprocating compressors.

This document is also intended to help create a mutual understanding of the criteria for successful reciprocating compressor condition monitoring and to foster cooperation between the various application stakeholders.

This document is intended for end-users, contractors, consultants, service providers, machine and parts manufacturers and instrument suppliers.

The condition monitoring and diagnostics strategy and techniques described in this document technically apply to reciprocating compressors with many different machine configurations (e.g. vertical/horizontal/L-type/V-type/W-type cylinder orientation, number of stages, speed range, cylinder lubrication, capacity control, cylinder cooling) and used in many different industrial applications.

From a cost benefits perspective, however, this document is most relevant for critical, possibly single-line units vs. standby units and/or medium to large sized units that are over 1 000 kW.

The vast majority of these types of reciprocating compressors are used primarily in hydrocarbon and chemical processing industries and natural gas transport and storage facilities. As these machines are used extensively in the upstream, midstream and downstream oil & gas industries, the focus will be on these applications but this by no means excludes critical applications in other industries.

Some of the applicable reciprocating compressors covered by this document include:

- a) Slow (under 600 r/min) and moderate speed (600-1 000 r/min) units manufactured and procured according to ISO 13707/API 618 (whichever is most up-to-date);
- b) High-speed and pre-packaged units (over 1 000 r/min) on a skid that are manufactured and procured according to ISO 13631/API 11P (whichever is most up-to-date);
- c) Hyper compressors used for secondary ethylene compression in low density polyethylene (LDPE) production;
- d) Lubricated and non-lubricated machines;
- e) Water-cooled and gas-cooled machines;
- f) Horizontal, vertical V-type, L-type and W-type machines;
- g) Horizontal, vertical machines with piston rings and those with labyrinth seal pistons (vertical machines only);
- h) Single-acting and double acting compression;
- i) With tandem cylinder configuration;

- j) Single and multi-stage compression;
- k) With and without capacity control;
- l) Ring, poppet, reed and plate valve types;
- m) Compressors mounted on flexible and rigid structures;
- n) Compressors driven by electric motors, gas and diesel engines, turbines (with or without a gearbox), all with a flexible or rigid coupling;
- o) Integral gas-engine-driven compressors (engine portion out of scope);
- p) Offshore applications, such as platforms, FPSOs, FLNGs, FPU and fixed installations.

NOTE

FPSO - Floating Production Storage and Offloading

FLNG - Floating Liquefied Natural Gas

Reciprocating compressors not covered are:

- 1) Diaphragm compressors;
- 2) Compressors with single-acting trunk-type (automotive-type) pistons that are connected directly with the crankshaft by a connecting rod (there is no piston rod or crosshead);
- 3) Plant or instrument-air compressors with a discharge pressure of 9 barg (125 psig) or less.

This document focuses on the compressor itself (cylinders, distance pieces, crosshead, frame and all internal parts) and not on the prime mover or the external systems such as piping, scrubbers, pulsation vessels, and pulsation control devices. Only brief mention is made for monitoring the foundation/skid/pedestal.

The scope does not include monitoring the auxiliary systems such as for lubrication, cylinder cooling, intercoolers and gas purging, but process parameters from these systems are often monitored.

The scope does not cover installation analyses of systems either, such as pulsation and mechanical response analysis of the piping, thermal analysis of piping.

Emissions regulations have recently become more stringent, therefore monitoring leak gas to the atmosphere is briefly mentioned in this document.

This document covers online (permanently installed) and portable instrument condition monitoring and diagnostic techniques for operating reciprocating compressors.

Machine testing, which is only done during shutdown, although very important, is not part of the scope of this document. Nor is one-time acceptance and performance testing within the scope.

The condition monitoring techniques presented in this document cover a wide range of continuous and interval-based monitoring techniques under generalized conditions for a wide range of applications.

The actual monitoring approach required, however, can be different from one application to another.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

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

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

API 618 has a description of terms used for reciprocating compressors that are also applicable here. Some terms that have not been completely defined are defined here:

3.1

machine state

operational process or duty cycle of the reciprocating compressor

EXAMPLE Stopped, unloaded, loaded, capacity control (variable frequency drive, valve unloading, clearance pockets, recycling), change of speed, change of suction and/or discharge conditions and change of gas properties.

3.2

Descriptor

A sensor measurement signal that is processed for detecting and/or diagnosing one or more machine fault symptoms, such as a calculated performance value

3.3

Prime mover

The engine, motor or turbine that drives the reciprocating compressor

3.4

wire drawing effect

pressure drop of gas as it passes through the suction valve (effective flow area). This reduces volumetric efficiency

3.5

monitoring technique

measurement or set of descriptors used to detect a potential failure mode [3.10](#) or provide diagnostic information on the type of fault and its location and severity

3.6

throw (crank throw)

portion of crankshaft that connects to a single cylinder or a tandem cylinder. Also refers to the entire cylinder and distance piece assembly connected to the crankshaft

3.7

stroke

the distance travelled by the piston from top dead center (TDC) to bottom dead center (BDC), or vice versa. It is also the crank rotation diameter or crank radius x 2

3.8

rod reversal

a change in direction of force in the piston rod/crosshead pin loading (tension to compression or vice-versa), which results in a load reversal at the crosshead pin during each revolution (API 618)

3.9

tail rod

rod extension from piston on head end to ensure equal volume displacement on both sides of piston for more equal rod reversal

3.10

tandem cylinder

two stages of compression on a single throw, where two pistons with different diameters (the smaller for high pressure, the larger for low pressure), are mounted on a single rod. The order of the large and small piston on the rod depends on the application.

3.11

crosshead

converts rotary motion of crankshaft into reciprocating motion for the piston and piston rod with minimal friction. It also prevents :

- prevents piston side loads in order to maximize cylinder liner wear and avoid damage to the piston and cylinder liner
- protects piston rod from connecting rod sideways forces
- allows the connecting rods to move freely

3.12

potential failure mode

change of condition of a reciprocating compressor component that can be detected by measurements that indicate an incipient fault is developing, which will eventually lead to failure

3.13

crank angle reference sensor

also called a reference/speed and phase sensor or a crankshaft position sensor, it generates at least one pulse per crank revolution. This is used for determining machine speed and for synchronizing one or more descriptor to crank angles. There are different types of sensors used for this purpose (displacement sensors, inductive sensors and optical sensors) with different types of output. API 670 specifies displacement sensors for protection systems.

3.14

power, indicated

this is the brake power times the mechanical efficiency. It also represents the total area enclosed by a PV diagram times the speed

3.15

power, brake

this is the power delivered by the prime mover to supply the indicated power for the cylinder and compensate for frictional losses (indicated power + friction power). It is also the ratio of the indicated power to mechanical efficiency

Note 1 to entry: Brake horsepower of a reciprocating compressor is the power measured using a brake type (load) dynamometer on the crankshaft.

3.16

power, adiabatic

this is the power required for isentropic compression and expansion within the cylinder chamber

3.17

power, friction

this is the power lost due to rider band and piston ring friction on liner, packing friction, crosshead pin friction, and the connecting rod bearing and the main bearing friction

3.18

prognostics

predicting when a machine or component has to be serviced, repaired or replaced long before a fault symptom is even detected. This can be a data-driven or model-based prediction model where loading conditions are continuously monitored

3.19

volumetric efficiency

there are two values for this; for discharge and suction. It is the ratio of the actual volume of gas displaced by the piston for suction and discharge to the design swept volume of gas. Another definition is the ratio of the stroke distance the suction and discharge valves are open to the total piston displacement-stroke

3.20

compressor efficiency

this is a measure in how effectively a compressor converts energy into work. It gives an indication of the combined thermodynamic losses due to all the valves during the gas compression and expansion work. It also includes losses due to gas friction and mechanical losses

4 Symbols and abbreviated terms

For the purposes of this document, the following symbols and abbreviated terms apply:

Table 1 — Example

Symbol	Description	SUI Unit	Reference
BDC	Bottom dead center position of the piston in the cylinder on the crank end side	-	Figure C.3
CE	Crank end side of cylinder	-	Figure C.4
CM	Condition monitoring (i.e., detecting and diagnosing a machine fault at an early stage of development)	-	Table 2 , 8 , Clause 6.3 , 7.2 , 8.2 , 8.4
CMS	Condition monitoring system	-	Clause C.5.1 a)
DCS	Distributed control system	-	Table C.2 , C.14 , Clause /2 , 8.3 f)
d_{cyl}	Cylinder diameter	mm	Figure C.4
d_{rod}	Piston rod or tail rod diameter	mm	Figure C.4
F	Force	N	Figure C.9
FB	Flow balance between suction capacity and discharge capacity	-	Eqn C.11
GF	Geometric factor for calculating rider band wear	-	Eqn C.32
HE	Head end side of cylinder	-	Figure C.4
k	Isentropic exponent (also known as the ratio of specific heats, C_p / C_v)	-	Eqn C.4 , C.15 , C.17
l	Connecting rod length	mm	Figure C.4
m	Mass of running components, such as piston, piston rod, crosshead	kg	Figure C.9
MACCPL	Maximum allowable continuous combined pin load (similar to MACCRL, except focus is on crosshead pin and must include part of piston rod mass for calculating inertia)	N	Clause C.10.1 a)
MACCRL	Maximum allowable continuous combined rod load (traditional terminology, superseded by MACCPL)	N	Clause C.10.1 a)
MACCGL	Maximum allowable continuous combined gas load	N	Clause C.10.1 b)
n	Polytropic exponent that depends on gas properties	-	Eqn C.3 , C.4 , C.15 , C.17 , Clause C.11
OEM	Original equipment manufacturer	-	Clause 8.4 , C.2.1 f) , C.5.1 a) , C.7.2 , C.12 , Table D.2
P_D	Discharge pressure	Pa, bar	Figure C.3
P_{CE}	Pressure in CE compression chamber	Pa, bar	Figure C.9
P_{HE}	Pressure in HE compression chamber	Pa, bar	Figure C.9
P_S	Suction pressure	Pa, bar	Figure C.3
P_{std}	Pressure at standard conditions	Pa, bar	Eqn C.8
PV	Pressure versus volume	-	Figure C.3
PWR_{adiab}	Adiabatic power	W	Figure C.8
PWR_{brake}	Brake power	W	Clause C.8.1 g)

Table 1 (continued)

Symbol	Description	SUI Unit	Reference
PWR_{ind}	Indicated power	W	Figure C.8
PWR_{isen}	Isentropic power	W	Eqn C.17
PWR_{suct}	Suction valve power loss power	W	Figure C.8
PWR_{disch}	Discharge valve power loss power	W	Figure C.8
Q	Capacity, volumetric flow	m^3/s	Eqn C.10
Q_d	Capacity at discharge conditions (see Q_s)	m^3/s	Eqn C.7, C.8, C.9
Q_m	Capacity, mass flow	kg/s	Clause C.6.1 d)
Q_s	Capacity at inlet conditions	m^3/s	Eqn C.7, C.8, C.9
r	Crank radius (stroke/2)	mm	Figure C.4
R_{compr}	Compression ratio	%	Eqn C.22
RPM	Revolutions Per minute (crank rotational speed)	r/min	Eqn C.7, C.17
T_d	Discharge temperature	K, C	-Eqn C.15, C.16, Clause C.13
T_{d-act}	Actual gas discharge temperature (measured, not calculated)	C	Eqn C.16, Clause C.13
TDC	Top dead center position of the piston in the cylinder on the head end side	-	Figure C.3
T_{d-theo}	Theoretical gas discharge temperature	K, C	Eqn C.15, C.16
T_{pp}	Temperature of pressure packing	C	Clause C.14.1
T_s	Suction temperature	K, C	Eqn C.8, C.15
T_{std}	Temperature at standard conditions	K, C	Eqn C.8
TWF	Time waveform signal, such as raw vibration or dynamic pressure	-	Clause C.16.4, C.17.4
VE_D	Volumetric efficiency at discharge valves	%	Eqn C.6
VE, VE_S	Volumetric efficiency at suction valves (sometimes suction volumetric efficiency is written simply as VE)	%	Eqn C.5
V_{Swept}	Swept volume displacement in the cylinder (crank end or head end)	m^3	Figure C.3
V_{Cl}, V_3	Clearance volume in the cylinder (crank end or head end)	m^3	Figure C.4
V_D	Discharge volume (V_2-V_3)	m^3	Figure C.3
V_S	Suction volume (V_1-V_4)	m^3	Figure C.3
V_1	Total cylinder chamber volume (V_3+V_{Swept})	m^3	Figure C.3
V_2	Volume at start of discharge	m^3	Figure C.3
V_3, V_{Cl}	Clearance volume in the cylinder (crank end or head end, fixed or variable)	m^3	Figure C.3
V_4	Volume at start of suction	m^3	Figure C.3
Z_s	Compressibility factor for gas at suction conditions	-	Eqn C.9
Z_{std}	Compressibility factor for gas at standard conditions	-	Eqn C.9
ΔT_d	Difference between actual and theoretical gas discharge temperature	K, C	Eqn C.16
η_{compr}	Compressor efficiency	%	Eqn C.18
η_{mech}	Mechanical efficiency	%	Eqn C.21

5 Initial preparations for condition monitoring

Implementing an optimal machine condition-based monitoring strategy for reciprocating compressors involves several steps, all of which should be considered in order to maximize machine production, reliability, safety, integrity and efficiency, and minimize the life cycle costs of the machine.

- a) These initial steps, which are beyond the scope of this document, are generalized in ISO 17359 and include evaluating:
 - 1) cost benefit analysis of the machine for monitoring;
 - 2) machine maintenance history and potential failure modes;
 - 3) reliability requirements and criticality audit;
 - 4) lead-time-to-maintenance requirements.
- b) After the condition monitoring strategy has been implemented, it should be periodically reviewed and refined as experience is gained and monitoring technology improves;
- c) If a condition monitoring system is already in use, the monitoring and diagnostic functionality of that system may have to be re-evaluated from time to time in order to fulfil current condition monitoring strategy requirements, as described in a).
- d) The entire process of implementing a condition-based monitoring strategy is summarized in [Table 2](#), which is in part based on ISO 13379 1:2012, Figure 1.

Table 2 — Implementation of a condition-based monitoring solution for reciprocating compressors

CM implementation	Activity	Remarks
CM strategy	CM implementation overview	Described in ISO 17359
	Cost benefits and risk analysis	Partly described in IEC 60300-3-3, IEC 60812, ISO 13379
CM application	Failure modes, monitoring techniques, descriptors	See Tables 3 to 7 of this document for a list of standards for specific reciprocating compressor monitoring techniques
CM system	Data processing, measurement systems, data management	Partly described in ISO 13374 1, ISO 13374-2, ISO 13374-3
	Data security, cyber security	ISO/IEC 27032
	Sensors	y Common types described in this document
CM operations	Detection, diagnostics	General diagnostics described in this document
	Root cause analysis, prognostics	Standards currently under development
NOTE Condition monitoring implementation activities not covered in this document are shaded in grey.		

6 Failure modes of reciprocating compressors

6.1 General

The implementation of an effective condition monitoring and diagnostics approach for reciprocating compressors is directly related to the relevant potential failure modes that can occur on specific machine components.

Failure means the component is no longer able to serve its intended function.

A condition monitoring solution shall offer enough functionality to detect the prioritized potential failure modes, while conversely, unneeded functionality that is not planned for the future should be avoided since this would only add to cost in terms of investment, training, operation and upkeep.

Failure modes for the basic components of the reciprocating compressor are described in more detail as follows:

- a) Cylinders – [Table A.1](#);
- b) Distance piece and frame – [Table A.2](#).

Failure modes that are detected by specific monitoring techniques are summarized in [Table B.1](#).

6.2 Reciprocating compressor components

The potential failure modes considered in this document are grouped in the following primary component categories (see [Figures A.1](#) and [A.2](#) for an illustration):

- a) **Cylinders** - Compressor valves, valve unloading mechanism, piston, cylinder liner, variable clearance volume mechanism, tail rod, piston rings, cylinder liner, piston nut, rider bands;
- b) **Distance piece** (single and double) – primary and low-pressure piston rod pressure packing¹⁾, piston rod, oil wipers, packing vent piping, crosshead (guide, shoe, pin and pin bushing);
- c) **Frame and foundation** - Main bearings, big-end bearings, small-end crankshaft, connecting rod, small-end bearings, foundation/skid, anchor bolts;
- d) **Gas properties**²⁾
- e) **Auxiliary and other external systems**³⁾ - Cooling system, main lubrication system, cylinder and packing lubrication system, nitrogen buffer gas purge/vent system, knock-out drums;

6.3 Potential failure mode identification and prioritization

The condition monitoring solution implemented for a specific application depends on identifying the relevant potential failure modes that are expected to occur on the machine, and then prioritizing them. Although not covered by this document, this is done by

reliability and risk analysis methods such as failure mode effects analysis (FMEA), failure modes effects and criticality analysis (FMECA), fault tree analysis (FTA) and other methods (these are partly covered by the standards summarized under CM Strategy in [Table 2](#)).

The actual method that is most suitable for identifying and prioritizing potential failure modes depends on the user application and requirements.

Regardless of the method employed, there are a number of factors that should be considered for identifying potential failure modes:

- a) original machine design and construction;
- b) machine refurbishment and modifications;
- c) compressor mounting type and design, such as foundation, skid, pedestal;
- d) compressor piping and vessel restraints;

-
- 1) The packing can also be part of the cylinder for some reciprocating compressors.
 - 2) Gas properties are not in their strict definition a component of the reciprocating compressor, but they play an important role in calculating performance parameters that monitor the compressor.
 - 3) The failure modes for these components are normally already monitored by manufacturer installed sensors and instrumentation, but this data, nevertheless is important for correlating with reciprocating compressor condition monitoring data for more reliable and accurate diagnostics, as described in [Clause 7.4](#).

- e) pulsation control systems;
- f) maintenance, monitoring and operational history (including off-design operation);
- g) ambient conditions;
- h) single-line machines versus standby units;
- i) operating parameters such as type of gas, pressure, temperature, flow, capacity control.

Prioritization of the potential failure modes depends on their criticality in a cost benefits analysis, which is influenced by:

- 1) cost for production downtime;
- 2) current and operation maintenance strategy;
- 3) life cycle costs of the machine;
- 4) availability of spare production capacity;
- 5) process has only a single-line unit or there are also standby units
- 6) availability of maintenance expertise;
- 7) availability of condition monitoring and diagnostic expertise;
- 8) availability and procurement period for spare parts.

There exist many potential failure modes for reciprocating compressors, some of which can be detected and diagnosed relatively easily, and some with more difficulty.

This document focuses on the potential failure modes listed in Annex [A.3](#), which are generalized for a wide range of applications and machine types, and which can be monitored and diagnosed using the techniques described in [Annex C](#). The potential failure modes presented in this document are not prioritized for any specific application.

As the reciprocating compressor design and its operation and maintenance regime can be very different from one application to the next, it is important to highlight that the failure modes described in this document can be different from those of the actual user's application.

7 Monitoring and diagnostic techniques

7.1 General

Monitoring techniques have been developed and refined over the years to detect, identify and evaluate the severity of one or more symptoms of specific potential failure modes before they occur and with sufficient lead-time such that maintenance can be planned ahead of time, so production is minimally interrupted.

7.2 Condition monitoring techniques overview

A monitoring technique can consist of one or more of the following:

- a) **primary measurements** (also called primary descriptors) - Detecting and/or diagnosing a fault condition in the machine ([Clause 7.3](#)).
- b) **correlation values** - Process values and other measurements are used for correlating with the primary descriptors to improve reliability and accuracy of the monitoring technique detection and diagnosis ([Clause 7.4](#)), as well as to define specific machine states for monitoring under different operating conditions with individual alarm limits ([Clause 7.5](#))

- c) **automatic decision support algorithms** - These utilize the primary descriptors together with correlation values and other data to optimize diagnostics ([Clause 7.7](#))

A summary of the most common monitoring techniques is listed in [Tables 3](#) to [5](#), which includes a reference to relevant standards for these techniques.

More detailed information on the machine components typically monitored, their failure modes and the monitoring techniques used to detect and diagnose these failure modes is given in the [Annexes A, B](#) and [C](#):

- [Annex A](#) – Provides a detailed overview of reciprocating machine components and their potential failure modes. This also provides terminology used in this standard for the machine components. [Table A.1](#) generically lists the typical failure modes for the machine components, but the actual way the components fail depends on the application, machine design and how it is operated and maintained;
- [Annex B](#) – Provides a detailed overview of the typical monitoring techniques used for monitoring the reciprocating compressor components and the potential failure modes addressed by these techniques. Sensor installation for typical monitoring techniques is graphically summarized in [Figure B.1](#), and [Table B.1](#) lists the failure modes typically detected and diagnosed by the monitoring techniques;
- [Annex C](#) – Provides a detailed description of the primary monitoring and diagnostic techniques that are typically used. Information on the sensors, descriptors plots and the monitoring system requirements for these are also described in this Annex.

NOTE The monitoring techniques that are relevant for a specific condition monitoring strategy vary widely from one application to the next, so these shall be evaluated before implementation. This is described more in [Clause 7.6](#).

Some condition monitoring techniques have been successfully used in the past or are currently being used for detecting and diagnosing certain potential failure modes in reciprocating compressors but are not listed in [Tables 3](#) to [5](#). This is because these techniques are:

- 1) operational process values that are typically monitored by other systems, such as the DCS. Although this data may not necessarily be monitored by the CM system, it should be saved with sufficient resolution in value and time so it can be correlated with the CM monitored data, as described in [Clause 7.4](#);
- 2) not widely used, so there is insufficient knowledge of the techniques;
- 3) relatively new and there is not enough experience to deem the techniques as “tried and proven”;
- 4) very resource intensive, e.g. success with the technique is highly dependent on user expertise that few have;
- 5) relatively old and have since been replaced by newer proven techniques;
- 6) successfully used in other machine types but have a very limited scope of application for reciprocating compressors. Many of these monitoring techniques, however, are amply described in other standards.

Some of the condition monitoring techniques not listed in [Tables 3](#) to [5](#) or explained in [Annex C](#) include:

- i) **Ultrasonic valve monitoring** – Leaking compressor valves can produce ultrasound. More information on this monitoring technique can be found in ISO 29821;
- ii) **Acoustic emission valve monitoring** – Leaking or damaged compressor valves can also produce acoustic emission. More information on this monitoring technique can be found in ISO 22096;
- iii) **Shaft torsion monitoring using strain gauges** – A metal strain gauge is connected to a telemetry device (radio frequency or induction) to monitor shaft torsion. Torsion is not typically monitored on reciprocating compressors, but it is sometimes monitored on the engine driving the compressor;
- iv) **Shaft torsion monitoring using angular encoders** – This system measures angular acceleration as a proxy for dynamic torque. This is particularly applicable for units equipped with variable speed drives which might operate at or near critical speeds due to torsional natural frequencies;

NOTE Operation close to torsional natural frequencies can cause shaft failures without noticeable indication or an obvious increase in the lateral vibrations.

- v) **Leak gas flow in the vent system** – Leak gas flow is proportional to cylinder pressure packing and/or piston rod wear, degradation or deposits, but there are challenges in using a flowmeter for this. This monitoring technique is described in EFRC Report “Inventory of the Emissions of Reciprocating Compressor Systems”. Pressure packing leak gas temperature change, however, can also be monitored for the same purpose, as described in Clause C.3.3. Pressure packing leak detection, in general, is becoming more important due to stricter emission regulations.
- vi) **Thermography** – Valve temperature can be monitored to detect faults. More information on this monitoring technique can be found in ISO 18434-1 and ISO 18434-2
- vii) **Automatic diagnostic decision support** – This is described more in [Clause 7.7](#).

7.3 Primary descriptors and plots

Each monitoring technique for a reciprocating compressor can consist of one or more detection and diagnostic measurements, called descriptors, which can be monitored to alarm limits and viewed in plots.

The descriptors and plots can vary both in name, configuration and function from one monitoring system supplier to another. These can be fixed with regards to the configuration parameters or can be user adjustable so they can be set up to a specific application or fine-tuned as experience is gained.

For this reason, descriptors and plots are not described in detail in this document but are instead listed with a generic name under the relevant monitoring technique in [Tables 3](#) to [5](#). [Table 6](#) lists some of the monitoring techniques and descriptors for the prime mover, which is not covered by this document.

NOTE The monitoring techniques, descriptors and plots presented in this document are considered the most relevant for a wide range of applications and machine types and are based on time-proven experience and best practices. The actual descriptors and plots needed for a specific application have to be determined as described in [Clause 7.6](#).

Table 3 — Partial listing of primary monitoring techniques for cylinder^a portion of the reciprocating compressor

Primary monitoring technique - Cylinder ^a	References Clauses – De- scription/meas. & plots/mon. strategy			Reference standards (referenced in the Bibliogra- phy)
Dynamic pressure – CE, HE, all cylinders and stages				
— Pressure-volume plot (PV)	C.3.1	C.3.1	C.3.1	
— Pressure vs crank angle plot	C.3.3	C.3.3	C.3.3	
— Volumetric efficiency	C.2.2	C.2.2	C.2.2	
— Capacity, flow balance and power/capacity	C.6.1	C.6.1	C.6.1	ISO 1217
— Theoretical discharge gas temperature and Delta discharge gas temperature	C.7.1	C.7.1	C.7.1	
— Indicated power, valve loss, brake power, isentropic efficiency, power/capacity	C.7.3	C.7.3	C.7.3	ISO 1217
— Compression ratio	C.2.2	C.2.2	C.2.2	
— Rod/crosshead pin load (peak load, rod reversal, max., min. tension/compression)	C.10.1	C.10.1	C.10.1	
— Polytropic exponent	C.11.1	C.11.1	C.11.1	
Vibration and displacement – For all cylinders				
— Cylinder vibration (impacts, valve vibration)	C.16.1	C.16.1	C.16.1	API 670
— Rod position and rider band wear – See Table 4 .				
Temperature – For all compressor valves				
^a Includes the cylinder liner, piston, piston rings, rider rings, tail rod, compressor valves, piston nut.				

Table 3 (continued)

Primary monitoring technique - Cylinder ^a	References Clauses – De- scription/meas. & plots/mon. strategy			Reference standards (referenced in the Bibliogra- phy)
— Actual discharge temperature and differential temperature spread of the valves	C.13.1	C.13.1	C.13.1	API 618, API 670
— Pressure packing vent gas – See Table 4 .				
Flow				
— Pressure packing vent gas – See Table 4 .				
Capacity control data for suction valve unloaders and clearance pockets – Machine position signals				
— Standard or stepless unloader, clearance pockets				
— Load step				
^a Includes the cylinder liner, piston, piston rings, rider rings, tail rod, compressor valves, piston nut.				

Table 4 — Partial listing of primary monitoring techniques for the distance piece^a portion (including the crosshead) of the reciprocating compressor

Primary monitoring technique – Distance piece ^a	References Clauses – De- scription/meas. & plots/mon. strategy			Reference standards (referenced in the Bibliogra- phy)
Dynamic pressure – CE, HE, all cylinders and stages				
— Rod/crosshead pin load (peak load, rod reversal, max., min. tension/compression)	C.10.1	C.10.1	C.10.1	API 618
Static pressure, pressure differential				
Buffer gas				
Vibration and displacement				
— Crosshead impact	C.16.1	C.16.1	C.16.1	API 618, API 670
— Rod position and vibration	C.16.4	C.16.4	C.16.4	API 670
— Rider band wear (rod drop, piston drop)	C.15.2	C.15.2	C.15.2	API 670
Temperature				
— Pressure packing leak	C.14.1	C.14.1	C.14.1	API 618
— Vent line gas (pressure packing leak)				API 618
— Crosshead pin				API 618, API 670
— Crosshead guide				API 670
— Inert gas (See also Table 8 for inert gas supply equipment)				API 670
Flow				
— Vent line gas (pressure packing leak)				API 618
— Inert buffer gas (See also Table 8 for buffer gas supply equipment)				API 670
^a Includes the piston rod, pressure packing, crosshead shoe, crosshead pin and bushing.				
NOTE Condition monitoring techniques not completely covered by this document are shown in grey.				

Table 5 — Partial listing of primary monitoring techniques for the frame^a and foundation/skid portion of the reciprocating compressor

Primary monitoring technique - Frame ^a	References Clauses – Description/meas. & plots/ mon. strategy			Reference standards (referenced in the Bibliography)
Vibration and displacement				
— Frame, foundation, crankcase vibration	C.18.1	C.18.1	C.18.1	ISO 20816-8, API 618, API 670
Crank angle reference (typically located on driven end of compressor but applicable for the entire machine)				
Crankshaft, flywheel				API 670
Temperature				
— Main bearing and connecting rod bearing and crank pin				API 618
— Connecting rod bearings				API 618
Oil analysis – Applies to all lubricated components of the compressor, see Table 8 .				
^a Includes the frame, foundation/skid, anchor bolts, connecting rod, crankshaft, main bearings, flywheel and connecting rod bearings (big-end and small-end).				
^b If mounted on the driven end of the prime mover itself, the coupling between the prime mover and compressor must be rigid. If mounted on the non-driven end of the prime mover, the same applies but there must also be a bearing on this end to reduce irregular pulse amplitude.				
NOTE Condition monitoring techniques not completely covered by this document are shown in grey.				

Table 6 — Partial listing of primary monitoring techniques for the prime mover and components (not covered by this document)

Primary monitoring technique – Prime mover ^a	References Clauses – De- scription/meas. & plots/ mon. strategy	Reference stand- ards (referenced in the Bibliography)
Vibration and displacement		
— Main bearings (engine or motor) — Turbocharger (engine) — Frame or casing (motor or engine) — Cooling water pumps and fin-fans — Lubrication pumps		API 670
		API 670
Temperature		
— Main bearings — Motor windings — Engine: Air manifold, fuel header, lube oil inlet and outlet, turbocharger inlet and outlet		API 618
Pressure		
— Engine: Air manifold, lube oil, cooling water		
Torque		
— Motor or engine		
Flow		
— Engine: Fuel flow, fuel gas usage		
Other motor performance parameters		
— Current, active and reactive power, frequency		
^a Includes the engine or motor, gearbox, cooling systems and lubrication systems.		
NOTE Condition monitoring techniques not completely covered by this document are shown in grey.		

Table 6 (continued)

Primary monitoring technique – Prime mover ^a	References Clauses – Description/meas. & plots/mon. strategy	Reference standards (referenced in the Bibliography)
Other engine performance parameters		
— Ignition timing, power		
Oil analysis – See Table 8.		
^a Includes the engine or motor, gearbox, cooling systems and lubrication systems.		
NOTE Condition monitoring techniques not completely covered by this document are shown in grey.		

7.4 Correlation measurements

The primary descriptors and plots for the reciprocating compressor, listed in [Tables 3 to 5](#), are often viewed in plots together with corresponding process values and other descriptors, including those of external systems. This is to better understand the primary descriptor response to specific operating conditions. This also makes it easier to compare similar data when analysing fault symptoms and to define alarm limits with regards to an adaptive monitoring strategy as described in [Clause 7.5](#).

NOTE Because correlated measurements serve as supplementary indicators of failure modes to the primary descriptors, there shall be a sufficiently high sampling rate for these types of measurements for proper correlation.

Typical measurements used for correlation with the primary descriptors can be other descriptors, such as for the prime mover (shown in [Table 6](#)), reciprocating compressor oil and cooling pumps, or those values specifically related to the process. The process values and descriptors that can be used for correlation include but are not limited to those listed in [Tables 7 and 8](#).

Table 7 — Partial listing of process values for the gas properties of the reciprocating compressor (which are important for calculating performance parameters)

Process values – Gas properties	Reference standards (referenced in the Bibliography)
Static pressure – Across the suction and discharge pulsation dampening vessels of all cylinders/stages	
Actual suction and discharge gas	API 618, ISO 13631
— Ambient pressure	ISO 2533
Temperature – All cylinders/stages	
Actual suction	API 618, API 670
— Actual discharge gas	API 618, API 670
— Ambient temperature	ISO 2533
Gas values	
Actual polytropic exponent (n) or isentropic exponent (k)	ISO 1217
Gas composition	API 670, ISO 1217
— Other gas properties (e.g., gas compressibility)	ISO 1217
NOTE Condition monitoring techniques not completely covered by this document are shown in grey.	

Table 8 — Partial listing of process values and monitoring techniques for the reciprocating compressor auxiliary components and external systems (possibly monitored by other systems, but also important for correlation with reciprocating compressor CM systems)

Process values and monitoring techniques for correlation with the primary descriptors for reciprocating compressors	Reference standards (referenced in the Bibliography)
Oil analysis	
— Oil debris, oil colour, oil viscosity, and other parameters	
Static pressure, pressure differential	
— Cylinder lube oil (or mechanical lubricator)	API 618, ISO 13631, ISO 13707
— Frame lube oil filter	API 618, API 670
— Suction filter	API 670
— Nitrogen buffer gas supply equipment	API 670
— Cooling water	API 618, API 670
Flow	
— Cylinder water jacket cooling water	API 618, ISO 13631, ISO 13707, API 670
— Packing cooling water	API 670
— Cylinder lube oil	API 670
— Inert buffer gas supply equipment	API 670
Level	
— Cylinder lube oil, frame lube oil	API 618, API 670
— Knock-out drums	API 618, API 670
— Cooling water	API 618, API 670
Vibration	
— Cooling water pump	
— Lube oil pump	
Temperature	
— Packing	API 618
— Piston rod	API 618
— Cylinder lube oil	API 618
— Frame lube oil	API 618
— Cylinder water jacket supply/inlet	API 618
— Cylinder water jacket return line	API 618
— Packing inlet, outlet cooling water	API 618
— Liquid drop-out temperature for gas (dew point)	
NOTE These process monitoring values are not covered by this document, or only partly so.	

7.5 Adaptive monitoring strategy

Many reciprocating compressors run under several operating conditions, so the signal response of the various descriptors of the monitoring techniques can also greatly vary.

The reciprocating compressor manufacturers typically provide alarm limits that are applicable for all operating conditions. For automatic earlier fault detection, however, the software alarm limits should be individually set for each operating condition, based on experience and/or baselines that apply to the particular machine and application.

Process measurements that are typically used for defining individual operating classes can be any of those listed in [Clause 7.4](#) but are typically speed (especially speed variation), suction/discharge gas temperature and pressure, gas composition and machine binary signals (capacity control signals).

There are two major types of operating regimes for reciprocating compressors;

- steady-state;
- transient.

Most of the operating time is spent in steady-state operating classes, which includes:

- full capacity and fixed speed;
- partial capacity, which can be 25 %, 50 %, 75 % or stepless.

Transient regimes, which includes run-up, transitioning to capacity levels and coast down, are seldom monitored because duration is short. Nevertheless, some maintenance issues are only evident during transient conditions.

NOTE Not all descriptors can be monitored in all machine operating modes. A detailed description of some of the descriptors for each monitoring technique is given in [Annex C](#).

7.6 Monitoring and diagnostic technique selection and evaluation

There are a number of techniques available for the monitoring and diagnostics of reciprocating compressors but the value each one delivers to the user highly depends on the application and the user requirements. A monitoring and diagnostic technique that is useful for one application can be totally unsuitable for other applications with similar machines, or even not useful for a similar application with dissimilar machines.

Initial preparations, such as a cost benefits and risk analysis, are done to define a condition monitoring strategy, as described in [Clause 5](#), but this does not necessarily include selection of individual monitoring techniques, which also have to be evaluated.

The criteria used for evaluating the different techniques can include the following:

- reliability, accuracy and repeatability of the technique;
- detection lead-time to maintenance;
- equipment cost of sensors, signal processing and display;
- ease of installation;
- maintainability and calibration of monitoring equipment;
- diagnostic expertise needed;
- safety with respect to an explosive environment requires expensive intrinsic safe equipment.

There are various ways of evaluating the relevance or value of using the monitoring techniques for a particular application, and one such method is described in the following Annex:

- [Annex D](#) – A simple weighted average method is provided that can be used for evaluating similar monitoring techniques from various suppliers, or for evaluating different monitoring techniques for a specific potential failure mode. An example is given in [Table D.2](#).

NOTE The method described in [Annex D](#) is only intended to supplement the relevant cost benefit and risk analysis processes, not replace them.

7.7 Automatic diagnostic decision support and artificial intelligence (AI)

Traditionally, condition monitoring systems only provided basic anomaly monitoring data to specialists who would interpret this information and forecast when and what type of service has to be done. Today this process has been extended by AI (Artificial Intelligence), digital-twin monitoring and machine learning to assist the task of the specialist for evaluating asset health and planning maintenance services.

There are systems on the market for fine-tuning fault detection and diagnostic descriptors, or for automatic diagnostic decision support and prognostics to predict when service should be done.

These systems, which are outside the scope of this document, can be based on a simple rule-based algorithm, be data-driven based on statistical analytics if a lot of data is available, or based on a physics model if the model and operating load are well understood.

Whichever solution is selected, these systems can save a lot of time for the diagnostic specialists by predicting simple diagnostics, so the specialists can focus on the more complex tasks, and/or enable many more machines to be looked after by a single specialist.

Artificial intelligence and machine learning can be very useful from a machine healthcare point of view, but data science technology is evolving rapidly and therefore cannot be practically covered in this document or other standards. More information on data-driven prognostics can be found in ISO 13381-1.

Regardless of the solution, it is important to understand:

- a) AI algorithms with and without machine learning can support the diagnostic specialist but cannot replace this person. The specialist is still needed for complex diagnostics, e.g. cases of multiple faults, and for configuring and fine-tuning the system.
- b) AI algorithms are based on estimated prediction while condition monitoring is based on actual fault detection.

For this reason, AI cannot replace condition monitoring functionality, but condition monitoring used together with AI can improve the accuracy of determining remaining useful life of components, avoid premature failures and even increase productivity.

8 Implementing, operating and maintaining a monitoring solution

8.1 General

The monitoring techniques selected in [Clause 7](#) require a condition monitoring system to process the incoming signals that are indicative of the condition of the machine, provide diagnostic information on a detected fault, and deliver actionable information to the relevant operators and other systems for display or further processing.

The actionable information is intended to assist making the relevant maintenance and operation decisions in order to minimize the life cycle costs, increase reliability, integrity and safety of the machine and process system, and to maximize production.

8.2 Sensor selection and installation

Reciprocating compressors can have sensors installed as delivered by the manufacturer or packager or can be retrofit with sensors by the CM system supplier or other service provider.

The retrofit sensors that require extensive drilling such as for static and dynamic cylinder pressure (used for PV and rod/crosshead pin load plots), packing temperature and valve temperature can be a challenge to properly install without compromising safety, risk measuring incorrect data or invalidating a warranty.

Pressure sensors represent the single biggest challenge, and it is recommended that their installation be done only by qualified specialists. Any drilling done on the pressurized cylinder walls may require approval from the manufacturer for integrity validation. This is described further in Annex [C.2.1](#).

Even if the compressor cylinder has raised bosses specifically intended for drilling to mount pressure sensors, there is a safety risk if it is not done properly.

Even if the holes are pre-drilled, there is still a risk the sensor will not measure correctly (e.g. acoustic standing wave resonance in a measuring tube).

Other sensors, however, can be retrofit by the condition monitoring system supplier or service providers.

If the user intends to do this task, there are important aspects that shall be considered.

For several monitoring techniques, the proper selection and mounting of sensors is critical for obtaining a signal that is reliably indicative of the incipient potential fault that it is intended to detect during early stages of development.

Incorrect location of the sensor or improper mounting can result in a diminished signal, no signal or even an incorrect signal. Improper wiring and grounding can have the same effect. Similarly, incorrect selection of sensor (e.g. insufficient frequency and/or amplitude range) or incorrect configuration of the sensor signals can also lead to inadequate monitoring results.

It is important to follow the sensor installation recommendations from the sensor supplier, the condition monitoring system supplier or service provider.

The sensors described in this document are shown in [Table 9](#).

Table 9 — Sensors used for reciprocating compressor monitoring techniques as described in this document

Primary component	Monitoring technique	Sensor description Clause
Cylinder	Dynamic pressure sensors in each pressure chamber of each cylinder	C.2.1
	RTD or thermocouples to monitor the Actual discharge temperature and differential temperature spread of the valves	C.12.1
	Accelerometer to monitor cylinder impact and valve vibration	C.16.3
	Displacement sensor on the pressure packing flange to monitor rider band wear	C.17.3
Distance piece, piston rod and crosshead ^a	Displacement sensor(s) on the pressure packing flange to monitor Rod position to detect rod bending and displacement	C.17.3
	Accelerometer to monitor crosshead impact and vibration	C.16.3
	RTD or thermocouples to monitor vent line leak gas	C.12.1
Frame and foundation ^b	Frame vibration accelerometer or velocimeter	C.18.3
	Displacement sensors and temperature to monitor the main bearings	C.18.3
	Foundation, anchor bolts, pedestal, skid	C.18.3
^a Pressure packing case and crosshead guide temperatures are typically provided by the reciprocating compressor manufacturer and are therefore not covered in this document.		
^b Main bearing temperature and connecting rod bearing temperatures (via wireless transmitter) are not covered in this document.		

8.3 Subclause title (first level)

As a matter of definition, a condition monitoring system is intended to detect and diagnose a fault as early in its development as possible so there is maximum lead-time to cost-effectively plan maintenance ahead of time. Production during this time can continue normally and downtime due to a catastrophic failure is avoided.

It is not intended to shut down the machine for machine protection. This is the purpose of a protection system, which:

- For slowly developing faults, it trips the machine as late as possible before a catastrophic failure occurs, in order not to interrupt production until the last possible moment
- For fast developing faults, it trips the machine as early as possible to avoid a catastrophic failure

This protection strategy is intended to minimize downtime for a machine that is still operational and yet still avoid catastrophic damage to the machine, environment or people. In many cases, a protection system includes condition monitoring functionality or can be extended for that purpose.

If there is an existing monitoring system, whether it is a protection system or a legacy condition monitoring system:

- a) It shall be evaluated to determine if it can be extended to include the necessary condition monitoring functionality for the current reciprocating compressor application requirements.
- b) If a new condition monitoring system is needed, there are several solutions from which to select.
- c) A condition monitoring solution can be:
 - 1) an online system (permanently installed);
 - 2) a portable system; or
 - 3) a combination of these.

As an online system, it can be a stand-alone system consisting of a field monitor installed on a single machine or a rack-based system in the control room for several machines.

It can also be a collection of several independent systems including portable units, which can be dedicated to specific reciprocating compressor monitoring tasks.

- d) The system or systems can be independent or integrated together or connected to a process control system, but what is important for many reciprocating compressor applications is that there is at least some remote monitoring capability.

Current trends in Internet of Things (IoT) and digital transformation places new demands and challenges on how data from the condition monitoring system and other systems shall be managed.

Data historians and cloud solutions enable more data to be more easily accessed than was previously achieved by proprietary databases and servers.

Third party service providers can more easily and transparently do analytics on the data.

It is also easier to correlate process data and monitoring data from other systems for more accurate, reliable and faster diagnostics.

- e) Although not all applications fully utilize an automated digitalization form of data management now, consideration shall be given to upgrading of legacy condition monitoring systems already being used to fulfil future requirements.

Although not within the scope of this document, the condition monitoring system selection is ideally based on cost benefits and risk analysis.

- f) In addition to the items mentioned in [Clause 7.6](#), regarding monitoring and diagnostic technique requirements, other requirements shall be considered regarding the monitoring system itself, such as:
 - 1) IT resource requirements — Network, servers, wireless sensor gateways, cyber-security, back-up, personnel;
 - 2) System integration requirements — Data sent to and received from DCS/SCADA, data historian, service provider, cloud, remote control centre and other monitoring systems (via Modbus, TCP/IP and RTU, which are often used in the industry);
 - 3) Alarming and trip strategy — How alarm and trip limits are to be established;
 - 4) Downtime needed for installation — Machines are stopped or disassembled to install sensors and wiring;
 - 5) Specialists needed — To install sensors (if specialists are needed for this), as well as fulfil requirements to operate system and/or provide expertise to interpret diagnostic results from measurements and plots;
 - 6) System training needed — Training requirements to configure, operate and manage the system;

- 7) System services needed — Service provider to operate, maintain and upgrade system;
- 8) Diagnostic services needed — Service provider to perform monitoring, diagnostics and reporting.

8.4 Daily operation of the monitoring system

Most condition monitoring systems provide automatic alarming functionality (detection descriptors that give a warning when alarm limits are exceeded) that allows potential failure modes to be detected at an early stage of development.

Once detected, the faults can be trended and observed over time.

Diagnostic descriptors are additional measurements, together with plots, that are used for analysis purposes, to identify the type and location of the fault, evaluate its severity and determine the lead-time to maintenance.

Routine activities may also include issuing reports at periodic intervals to summarize the general condition of the machines or give notice when a fault is detected.

In special situations, if the necessary monitoring system tools are available, root cause analysis may be performed to avoid experiencing recurring premature faults or prognostics may be implemented to better manage lifetime prediction of components.

The operator workload with the condition monitoring system depends on the type of system selected.

Some systems offer facilities for correlating data together in a historian database to improve reliability of diagnoses.

Other systems offer automated functionality to reduce the user workload, such as an automatic alarm management system (to reduce repetitive or unnecessary alarms), event recording (for event analysis, which includes post-processing of the saved raw signals) and automatic diagnosis functionality (decision support to reduce diagnostic time and expertise needed).

Services are also offered where some or all monitoring, diagnostics and action reports are done by a third party.

Whatever system or services are selected, the common denominator for all is that the condition monitoring solution adds value to the user's business. This means the solution shall be benchmarked, evaluated periodically and refined and updated.

NOTE 1 API 670 gives guidance on installing displacement sensors and accelerometers but very little information on the kind of measurements to be taken. This is left to the OEM, EPC and customer to decide.

NOTE 2 Monitoring deviations are typically due to component normal fatigue and wear or off-design operating conditions. Reciprocating compressor consumables include valves, piston rings, rider bands, packing and bearings.

NOTE 3 Deviations can also be due to defect sensors, improper mounting issues and sensor degradation, such as for the dynamic pressure sensors.

NOTE 4 Implementing a CM strategy is based on both risk and maintenance history. Even if there had been minimal maintenance problems with the reciprocating compressor, there is still a risk, and the risk can change, e.g. due to changing operating conditions and machine age.